

2026 Annual Meeting

Seismological Society of America
Technical Sessions
14–18 April
Pasadena, California

The SSA 2026 Annual Meeting will convene at the Pasadena Convention Center and feature more than 950 technical oral and poster presentations as well as plenary sessions, workshops and field seminars.

The following schedule of events and abstracts are valid until 25 February, 2026 and subject to change.

Where We Are Gathered

We meet this week in a landscape shaped by immense tectonic forces—from the San Gabriel Mountains towering above us to the deep Raymond Basin beneath our feet. This valley has been home to the Hahamongna band of the Tongva people for more than 7,000 years, long before Pasadena was a city.

Acknowledging their ongoing connection to this region is essential to understanding the land we stand on today. For those looking to explore the outdoors, Hahamongna Watershed Park is a space where indigenous roots and geology overlap. Other places to dive into local history include the Southwest Museum of the American Indian, the Autry Museum and the Pasadena Museum of History.

Our science is deeply rooted in a sense of place. We hope you take time this week to appreciate the complex history of this land and the people who remain its stewards.

Annual Meeting Co-Chairs

The Society is grateful to SSA 2026 Co-Chairs Elizabeth Cochran of the U.S. Geological Survey and Kuo-Fong Ma of Institution of Earth Sciences, Academia Sinica for leading the creation of this dynamic week of science.

Contact

abstracts@seismosoc.org

SSA Meetings Code of Conduct

SSA is committed to fostering the exchange of scientific ideas by providing a safe, productive and welcoming environment for all SSA-sponsored meeting participants, including attendees, staff, volunteers and vendors. All participants at SSA meet-

ings are expected to be considerate and collaborative, communicating openly with respect for others and critiquing ideas rather than individuals. Behavior that is acceptable to one person may not be acceptable to another, so use discretion to be sure that respect is communicated. For a detailed description of the ethics and code of conduct policies, please visit the SSA website: seismosoc.org/meetings/code-of-conduct.

Technical Program

Plenary Sessions

Keynote Address: Scaling Up DAS Toward the Next-Generation Seismic Network

Tuesday, 14 April, 6:15–7:15 PM

Zhongwen Zhan, California Institute of Technology

The high-frequency seismic wavefield is the next frontier of observational seismology. It is critical to both our understanding of earthquake physics and to seismic hazard, yet our current seismic networks are not designed to capture this wavefield in detail. Distributed Acoustic Sensing (DAS) changes this by turning optical fibers into dense arrays of tens of thousands of seismic sensors. Over the past decade, DAS deployments in California, across the U.S. and worldwide have generated substantial scientific value and proven that DAS is a practical tool for capturing the high-frequency seismic wavefield. Our bottleneck has shifted from research to operation. There are many challenges, including cost, fiber access, signal saturation and data management and sharing. I will introduce a new initiative, the DAS Hub, as a step toward operating DAS as part of the next-generation seismic network.

Panel Presentation: Building a Resilient Future: What New Research Directions, Technology Developments and Partnerships are Needed?

Wednesday, 15 April, 6–7 PM

Hiroshi Kawase, Kyoto University; Monica Kohler, California Institute of Technology; Albert Kottke, Pacific Gas & Electric Company; Patricia Persaud, University of Arizona; Alba Rodriguez-Padilla, Utah State University

Enhancing the resilience of communities in earthquake-vulnerable regions is a global priority and requires new actionable science and partnerships among scientists, engineers, the public, policymakers and stakeholders. The panel will discuss the highest priority objectives and opportunities among the geosciences and engineering disciplines for building earthquake-ready cities and the importance of growing the communities who are involved in seismic risk assessment and management. Key challenges include identifying what new kinds of observational data – *e.g.*, on fault structures, basins and urban environments – and collective actions are needed to measure and monitor the resilience of a city to earthquakes. The panel will address the main bottlenecks in transferring new knowledge gained from data or models – including strong ground motions (site effects), artificial intel-ligence and machine learning advancements – into practical applications to improve building codes and the resilience of the built environment. A key focus will be how to overcome the current challenges in assessing seismic risk and effectively communicating seismic risk to the public and stakeholders to improve pre-disaster preparedness activities and post-disaster response. The panel will explore new research directions, tech-nology developments and partnerships for improved seismic resilience.

Annual Business and Awards Ceremony

Thursday, 16 April, Noon–12:50 PM
SSA President Zhigang Peng (2026–27) will preside over the awards ceremony and provide an update on the Society. Immediate Past President Susan Bilek (2025–26) will deliver the Presidential Address

- The 2026 Honorees:
- Peter Shearer, Harry Fielding Reid Medal
 - Kevin Milner, Charles F. Richter Early-Career Award
 - Lisa Wald, Frank Press Public Service Award
 - Ruth Harris, Distinguished Service to SSA Award
 - Eduardo Miranda, Bruce Bolt Medal

Joyner Lecture: Seismic Wave Propagation in Complex Geological Domains: From Site Effects in Ground Motion to Diffuse Fields in Passive Seismology

Thursday, 16 April, 6–7 PM
Francisco José Sánchez-Sesma, Universidad Autónoma de Mexico (UNAM)
José Sánchez-Sesma’s Joyner Lecture will reflect on his decades of research aimed at understanding and modeling seismic wave propagation in complex geological media and its manifestations in ground motion, from strong shaking during large earthquakes to weak ambient vibrations such as micro-tremors and seismic noise.

- Special Interest Groups
- SSA 2026 offers seven special interest group meetings (SIGs).
- Advancing Seismology and Societal Benefit via Fiber-Optic Sensing: Opportunities and Challenges of Scaling with Telecommunication Cables
 - AxiSEM/AxiSEM3D Users Group
 - CRESCENT Mid-Stream: Science and Applications in the Cascadia Region Earthquake Science Center
 - Emerging Initiatives and Partnerships in Induced Seismicity Monitoring
 - Rapid Integration of Satellite Imagery for Characterizing Earthquake Surface Displacements and Impacts on Infrastructure
 - Spring 2026 North America SeisComP User Group Meeting
 - Understanding Earthquake Dynamic Strain and its Importance to Lifeline Infrastructure

Workshops

- Advancing Geophysical Research with Cloud Computing
- Tuesday, 14 April, Noon–4 PM
Instructors: Tammy Bravo, Sophia Parafina, Chad Trabant, Robert Weekly and Sarah Wilson of EarthScope Consortium
Cloud computing is a powerful tool for modern geophysical research and education. EarthScope’s cloud-hosted data repositories are adjacent to scalable compute resources, offering new ways to process, analyze and collaborate on scientific data.
This intermediate-level workshop will help participants build on foundational skills by exploring more advanced strategies for using the GeoLab JupyterHub. Through a mix of instruction and hands-on exercises, participants will:

- Compare cloud versus traditional computing workflows
- Explore optimal approaches to accessing and analyzing EarthScope’s cloud-native data
- Work through sample Python notebooks demonstrating data access and processing

This workshop is designed for early to mid-career geophysics researchers, particularly those already working with EarthScope-managed data or interested in migrating workflows to the cloud. Familiarity with basic Python is assumed and familiarity with GeoLab is strongly recommended. The half-day session will include interactive instruction and guided time for exploring cloud workflows relevant to participants’ own research.

- Exploring Careers in Industry: Panel Discussion & Networking Session
- Tuesday, 14 April, 4–5 PM
Moderator: Ross Stein, Temblor, Inc.

Where can seismology take you in the private sector? Ross Stein (Temblor, Inc.) will moderate this panel discus-

sion on exploring careers in industry with representatives from Moody’s, Zanskar, MathWorks, and Lettis Consultants International. You’ll hear about growing sectors and skills in demand from the panelists, then participate in small breakout groups to connect with industry professionals. Admission is free. To save your spot, please RSVP when registering for the meeting.

- Introduction to DAS for Seismology: From Data Acquisition to Analysis
- Tuesday, 14 April, 9 AM–4 PM
Instructors: Ettore Biondi, Stanford University; Jiaxuan Li, University of Houston; Weiqian Zhu, University of California, Berkeley

This one-day workshop is designed for researchers at all levels who are interested in learning how to collect, process and analyze Distributed Acoustic Sensing (DAS) data recorded on telecommunication fiber-optic cables. The session will begin with an overview of DAS technology and include an on-site demonstration showing how to configure a DAS experiment and acquire data. We will cover the unique capabilities of DAS for both temperature and deformation sensing, emphasizing its advantages in seismological and environmental applications.

- Participants will then be introduced to data processing workflows for extracting meaningful seismic information from DAS recordings. This includes techniques for high-precision earthquake travel-time picking using machine learning, and methods for estimating focal mechanisms across a wide range of event magnitudes. In the final segment, we will demonstrate how to compute noise cross-correlations from DAS data and how to combine these with earthquake arrivals to perform high-resolution seismic tomography.
By the end of the workshop, participants will gain a comprehensive understanding of the end-to-end DAS workflow — from field setup to advanced data analysis — empowering them to fully utilize the high spatial and temporal resolution provided by DAS arrays in their research.

- Publishing: How to Review and How to Be Reviewed
- Tuesday, 14 April, 1–4 PM
Instructors: Allison Bent, editor-in-chief, *Seismological Research Letters*; John Ebel, Boston College; Brent Grocholski, chief editor, *Physical Review X* at APS

Peer review is a cornerstone of scientific publishing, and it is a skill that benefits from intentional practice and insight. This interactive workshop will guide participants through the fundamentals of writing fair, constructive and actionable peer reviews. It will also offer strategies for responding thoughtfully and effectively to reviewer feedback on your own submissions. Designed for early-career researchers as well as seasoned scientists looking to refine their editorial skills, this session will

help demystify the publishing process and promote a more productive and collegial scientific community.

Field Seminars

- From Richter to Real Time: Tracking the Evolution of Earthquake Science at Caltech
- Saturday, 18 April, 8 AM–Noon
Trip Leaders: Rayo Bhadha, Southern California Seismic Network; Susan Hough, U.S. Geological Survey; Allen L. Husker, California Institute of Technology; Monica Kohler, California Institute of Technology; Joann Stock, California Institute of Technology; Igor Stubailo, Southern California Seismic Network; Margaret Vinci, Southern California Seismic Network

This field seminar offers a behind-the-scenes tour of Caltech’s world-renowned SeismoLab, where earthquake science has evolved from the pioneering days of Richter, Gutenberg and Benioff to today’s real-time monitoring and innovation. We’ll look back at seismic history, including stories of past Caltech seismologists and enjoy a rare chance to see a slice of the San Andreas Fault with 800 years of history preserved on display.
From there, the focus shifts to today’s cutting-edge research and technology. Participants will step inside the hub of the Southern California Seismic Network, where engineers will demonstrate the instruments and methods used to keep watch over one of the world’s most seismically active regions. We’ll visit the Media Center to discuss how scientists and public officials respond to major earthquakes. We’ll explore lab experiments where fiber optic cables are stretched and measured to quantify DAS response, CO₂ monitoring devices are developed and AI-driven drones are designed for rapid fault mapping after earthquakes. The tour will conclude atop Caltech Hall, where we’ll learn about the experiments that have been done with the building, including a shaker system. Throughout, participants will have the chance to engage with experts, ask questions and experience how earthquake science continues to evolve from Richter’s day to the real-time era.

- Multi-hazards: Earthquakes, Fire and Water Field Seminar
- Saturday, 18 April, 8 AM–6 PM
Trip Leaders: Erica Fischer, Oregon State University; Don Lindsay, California Geological Survey; Scott Lindvall, Lettis Consultants International; Kate Scharer, U.S. Geological Survey

The San Gabriel Mountains rise 3,000 meters above sea level, creating a striking backdrop to the Los Angeles basin and offering a great location for exploring the impacts of large earthquakes on the landscape and the built environment. We will combine stops in this seismotectonic setting with effects of the 2025 Eaton Fire, which burned the wildland-urban

interface along the base of the mountains near Pasadena and provides a compelling setting to consider the interconnected hazards for cities built along the foothills of tectonically active ranges. Participants will visit alluvial fans actively uplifted on the range front and review evidence of large displacement

paleoearthquakes on the Sierra Madre Fault. The group will also traverse debris basins designed to contain post-fire debris flows and engage in discussions about post-earthquake water distribution vulnerabilities revealed by the historic Eaton Fire.

Technical Sessions

Action at a Distance: Understanding Seismic Triggering

A variety of geological/geophysical phenomena may follow shaking or deformation by earthquakes. Examples of triggered phenomena include other earthquakes (aftershocks, foreshocks, swarms, etc.), volcanic eruptions, mud volcanoes, landslides, geysering, seiches and liquefaction. While the underlying physical processes involved may not be universal, triggering can be described as a sudden departure from an equilibrium state followed by a return, often gradual, to a new equilibrium. Triggering only initiates the disequilibrium process, rather than providing the energy that powers it, so the triggered site must be close to disequilibrium or “ripe.” An enhanced understanding of triggering could improve characterizing geohazards, communicating them to stakeholders, understanding cascading events and mapping the state of internal Earth forces and materials. Yet, recognizing and understanding triggering is tricky, in part due to the difficulty of determining if a purportedly triggered event would have taken place had the triggering event not happened. Inferences of triggering, which inherently are probabilistic, are challenged by the fact that Earth processes are slow and recurrence intervals are long relative to the observational record. Moreover, the relevant Earth observations are generally difficult to acquire and imprecise. At a target site, triggering presumably involves both the triggering event’s deformational products (*i.e.*, seismic waves, quasi-static deformation), and the relevant and sometimes altered conditions (often involving fluids). Assessing the ripeness of a triggered site may be particularly challenging. Given this broad topic and the hope of unifying a disparate and difficult subject, we invite contributions related to understanding the elements or observations of triggering. This includes theoretical studies, field observations, laboratory studies and communication to stakeholders of triggering potential in the aftermath of an earthquake.

Conveners: Paul Bodin, University of Washington (bodin@uw.edu); Esteban J. Chaves, Volcanological and Seismological Observatory of Costa Rica (esteban.j.chaves@una.ac.cr); Joan Gomberg, U.S. Geological Survey (gomberg@usgs.gov); Sonia Hajaji, Georgia Institute of Technology (ssalgado30@gatech.edu); Stephanie G. Prejean, U.S. Geological Survey (sprejean@usgs.gov)

Advances and New Challenges in Investigating Seismic Site Response

Site effects represent moderate-to-strong modification of ground shaking caused by the local subsoil structure, geo-

technical and geomorphologic conditions. They can result in a strong amplification of ground motion in site-specific frequency bands and an increase of the shaking duration, as evidenced by seismometric records. Such effects often play a key role in seismic hazard assessment.

Site effects can be affected by 3D conditions; in such cases, they are poorly represented by 2D or, worse, 1D numerical simulations and/or simple approximations commonly used in seismic hazard analyses. 3D conditions are often present in sedimentary basins as well as areas of variable topography; these include amplified rock sites (with fractured/weathered layers), where the use of 3D geophysical imaging approaches may better support realistic modeling.

This session encourages a debate on open questions in the field of site effect research and application, including topics such as numerical modeling for hazard/ground motion, soil nonlinearity, fault zone effects, ambient noise measurements to determine soil and building response, innovative geophysical applications for site characterization along with multidisciplinary and multiscale studies that pull together a variety of datasets to shed light on complex site characterization problems in different geological contexts.

Conveners: Anna Kaiser, Earth Sciences New Zealand (a.kaiser@gns.cri.nz); Elena Manea, Earth Sciences New Zealand (e.manea@gns.cri.nz); Marta Pischiutta, National Institute of Geophysics and Volcanology (marta.pischiutta@ingv.it); Rodolfo Puglia, National Institute of Geophysics and Volcanology (rodolfo.puglia@ingv.it)

Advancing Earthquake Early Warning: Science, Technology and Engagement in the U.S. and Beyond

Earthquake Early Warning (EEW) systems are expanding globally, offering critical seconds of warning to reduce risk and enhance resilience. This session invites contributions highlighting the performance, innovations and future directions of EEW systems and their integration into everyday life, with a focus on the ShakeAlert system in the United States and comparable efforts worldwide. We welcome presentations on algorithmic advancements such as seismic phase identification, finite fault characterization, rapid magnitude/location estimation and ground motion estimation. Submissions exploring the integration of diverse data types, low-cost sensors, fiber-optic technologies and AI/ML approaches are encouraged. We also invite abstracts focused on communication, education and outreach (CEO), including strategies for public messaging, alert delivery, user training and engagement with

technical and institutional users. Additionally, we welcome perspectives on the critical role of governmental emergency management agencies in operationalizing EEW, coordinating response and supporting public readiness. International collaboration is also key, and we encourage contributions from agencies like Natural Resources Canada (NRCan) and others working to advance EEW across borders. Join us to explore how cutting-edge science, technology and partnerships are shaping the future of EEW.

Conveners: Stephen Crane, Natural Resources Canada (stephen.crane@nrcan-rncan.gc.ca); Zoe Krauss, University of Washington (zkrauss@uw.edu); Derek Lambeth, California Office of Emergency Service (derek.lambeth@caloes.ca.gov); Natalia A. Ruppert, U.S. Geological Survey (nruppert@usgs.gov); Jessie Saunders, California Institute of Technology (jsaunder@caltech.edu); Samantha Stanley, University of California, Berkeley (samantha.stanley@berkeley.edu)

Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches

This session brings together a diverse community of researchers and practitioners working across disciplines to tackle the complex challenges of seismic hazard and risk assessment, before and after earthquakes occur. We welcome contributions that enhance understanding of and preparedness for earthquake disasters, with an emphasis on multidisciplinary modeling and assessment approaches. We also encourage submissions that highlight the development and application of community models and databases, including those that integrate post-earthquake observations and datasets, which serve as foundational tools for collaborative research, rapid assessment and decision-making.

We particularly encourage contributions on advanced risk modeling frameworks that trace the complete pathway from earthquake initiation to societal impacts, incorporating innovations such as digital twins, real-time or near-real-time post-earthquake data and rapid hazard and risk assessment systems to support emergency response and recovery. Presentations addressing broader topics — including the evolving built environment, building codes, challenges in hazard mitigation planning and risk communication — are also welcome.

We invite contributions that integrate seismology, geology, geomorphology, and geodesy in earthquake forecasting and hazard–risk frameworks. Topics include forecasting across multiple timescales; fault source characterization; complex and multi-segment rupture modeling; multi-cycle simulators; dynamic rupture processes; and ground-motion modeling with associated uncertainties, including physics-based simulations, non-ergodic models, and site effects. The session also welcomes studies on exposure databases describing populations, buildings, and infrastructure, as well as physical

vulnerability and fragility models based on observations, simulations, and post-earthquake damage data, including time-dependent effects such as aging, deterioration, and cumulative damage. Applications of the International Macroseismic Scale and national annexes are also encouraged.

By convening this diverse community, we aim to share insights from recent earthquakes, compare methodologies and identify pathways to strengthen modeling capabilities, support rapid post-event decision-making and enhance societal resilience.

Conveners: Chung-Han Chan, National Central University, Taiwan (hantijun@googlemail.com); Matthew Gerstenberger, Earth Sciences New Zealand (m.gerstenberger@gns.cri.nz); Tiegan E. Hobbs, Geological Survey of Canada (thobbs@eoas.ubc.ca); Asako Iwaki, National Research Institute for Earth Science and Disaster Prevention (iwaki@bosai.go.jp); Kishor Jaiswal, U.S. Geological Survey (kjaiswal@usgs.gov); Jessie K Saunders, California Institute of Technology (jsaunder@caltech.edu); David J Wald, U.S. Geological Survey (wald@usgs.gov)

Advancing the U.S. Geological Survey National Seismic Hazard Models

The USGS National Seismic Hazard Models (NSHMs) are a bridge between best-available earthquake science and public policy. In this session we will present (1) revisions to the 2023 50-State NSHM; (2) the recently completed 2025 Puerto Rico and the U.S. Virgin Islands NSHM; (3) draft models for the 2026 Guam and the Northern Mariana Islands and American Samoa NSHMs; and (4) planned updates for the 2029 50-State NSHM. We invite additional presentations on topics that will influence future seismic hazard models, via earthquake rupture forecasting, ground-motion characterization and NSHM applications. Topics include, but are not limited to, seismicity catalogs, declustering and smoothed seismicity models, fault models, geologic and geodetic deformation models, fault system inversions and time-dependent forecasts; ground-motion models, including non-ergodic models, incorporation of physics-based 3D simulations, basin effects, site response and directivity; and quantification and propagation of epistemic uncertainty. We also invite presentations on the use of NSHMs for scenario development, building codes, risk assessment for both buildings and infrastructure and risk mitigation within the insurance industry. We are also interested in contributions that highlight potential impacts of hazard modeling uncertainties on downstream applications.

Conveners: Jason M. Altekruise, U.S. Geological Survey (jaltekruise@usgs.gov); Nico Luco, U.S. Geological Survey (nluco@usgs.gov); Peter M. Powers, U.S. Geological Survey (pmpowers@usgs.gov); Emel Seyhan, Moody’s RMS (emel.seyhan@moodys.com); Allison M. Shumway, U.S. Geological Survey (ashumway@usgs.gov)

Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice

Ground-motion models (GMMs) play a vital role in seismic hazard analysis and are essential for earthquake early warning systems, shake maps and rapid response. Over the past two decades, an abundance of instrumental recordings has facilitated advancements in non-ergodic GMMs across multiple regions. However, challenges remain in accurately constraining source-, path- and site-specific effects, particularly in areas with limited data, scaling to large magnitudes and more complex ruptures and 2D/3D site and basin effects.

Recent progress in high-performance, physics-based ground-motion simulations, combined with enhanced source modeling and high-resolution regional 3D velocity models, offers a novel approach to supplement and refine empirical GMMs. This session focuses on the practical integration, validation and application of 2D/3D simulations and/or complementary observational datasets (e.g., macroseismic intensity and low-cost sensor measurements) in the development of GMMs.

This session is targeted at studies focused on integrating simulations and complementary datasets into empirical ground-motion models. It includes regional-scale seismological simulations designed to constrain wave propagation within complex geologic structures, addressing site and path effects as well as source-specific characteristics. The session also covers the treatment of simulation input uncertainties and their propagation into ground motion uncertainty. In addition, topics related to data and metadata formats, along with the information required for combining simulated and observed ground motions in GMM development, are addressed. The integration of complementary datasets to constrain non-ergodic effects is also a key focus of the session.

A central theme is the use of these inputs to constrain regionally varying GMMs, moving from ergodicity toward non-ergodic approaches. The session also welcomes advanced empirical approaches and the use of new datasets (e.g., NGA-W3) to develop GMMs, as well as studies that address epistemic uncertainty and aleatory variability in the application of PSHA.

Conveners: Sanjay Bora, Earth Sciences New Zealand (s.bora@gns.cri.nz); Asako Iwaki, National Research Institute for Earth Science and Disaster Resilience (iwaki@bosai.go.jp); Grigorios Lavrentiadis, University of Buffalo (glavrent@buffalo.edu); Camilo Pinilla-Ramos, GFZ Potsdam (camilo.pinilla@berkeley.edu); Chih-Hsuan Sung, University of California, Berkeley (karensung@berkeley.edu); Paola Traversa, Electricity of France (paola.traversa@edf.fr)

Cryoseismology: Advances in Technology and Scientific Discovery

Polar and glaciated regions have long posed formidable science challenges due to extreme cold, prolonged darkness, difficulty generating and storing power, limited communications infrastructure and logistical remoteness. These conditions, historically, dramatically limited data acquisition. The lack of both long- and short-term geophysical observations strongly contrasts with the critical need for enhanced understanding of ice structure, glacial processes and other cryospheric phenomena that are increasingly relevant for forecasting and mitigating geological hazards in a changing world.

Over the past two decades, technological advances in polar power systems, cold-rated broadband seismometers, distributed acoustic sensing (DAS), novel vehicles, satellite links and ice drilling have transformed cryoseismology. These innovations enable unprecedented access to remote regions and subsurface ice environments, higher-resolution studies and new multidisciplinary collaborations. For example, collaboration with the IceCube Neutrino Observatory has extended Antarctic ice sheet broadband deployment capabilities to 2.4 km depth, while large-N nodes and DAS open new studies in source processes, ice boreholes, firn-ice transition and sub-ice conditions. This session invites contributions that highlight new or emerging cryoseismological research, including conceptual or pilot studies exploring the scientific potential of a deep, three-dimensional seismic and/or DAS observatory at the South Pole or elsewhere. We additionally welcome submissions focused on advances in polar instrumentation as well as in ocean, ice traverse or airborne logistics, ice drilling, remote sensing and other methodologies.

Conveners: Robert E. Anthony, U.S. Geological Survey (reanthony@usgs.gov); Richard C. Aster, Colorado State University (Rick.Aster@colostate.edu); Michael DuVernois, University of Wisconsin, Madison—IceCube Neutrino Observatory (duvernois@icecube.wisc.edu); Katrin Hafner, United States Antarctic Program Antarctic Support Contract (Leidos) (Katrin.Hafner.contractor@usap.gov); Weisen Shen, Stony Brook University (weisen.shen@stonybrook.edu)

Data-Driven Advances in Liquefaction Hazard Analysis

Liquefaction continues to play a major role in earthquake damage worldwide. This session focuses on advances in liquefaction hazard analyses derived from observational and analytical data, with an emphasis on liquefaction-induced ground deformation, lateral spreading and impacts on critical infrastructure and lifelines. Contributions are encouraged that highlight field reconnaissance, geotechnical and seismological analyses, remote sensing of ground failure and discussions of model calibration using both historical and new case histories.

We welcome innovative approaches that apply emerging tools, such as machine learning and other data-driven methods, to earthquake reconnaissance, data integration and hazard assessment. Presentations that explore the implications of these advances for improving liquefaction hazard mapping and resilience are especially encouraged.

Conveners: Adda Athanasopoulos-Zekkos, University of California, Berkeley (adda.zekkos@berkeley.edu); Laurie Baise, Tufts University (laurie.baise@tufts.edu); Brian Olson, California Geological Survey (brian.olson@conservation.ca.gov); Ellen Rathje, University of Texas at Austin (e.rathje@mail.utexas.edu)

Data-Driven and Computational Characterization of Non-Earthquake Seismoacoustic Sources

Non-earthquake seismoacoustic sources, such as landslides, avalanches, volcanoes, glacial calving, utilities and industrial blasts, bolide airburst and their impacts on Earth, are commonly recorded by seismoacoustic monitoring networks. This session focuses on data-driven and computational methods and algorithms that aim to better understand and characterize these non-earthquake sources, and to ultimately better monitor and mitigate their associated hazards. We encourage contributions from studies that include, but are not limited to, seismoacoustic, geodetic and remote sensing techniques at all relevant spatiotemporal scales with emphasis on multisensors Bayesian & Dempster-Shafer statistical data integration and fusion, high-performance deterministic and stochastic computational modeling and simulation, and AI-driven and physics-informed ML techniques. We solicit studies that include, but are not limited to, source detection, location, characterization, modeling, classification, monitoring and hazard mitigation.

Conveners: Souheil M. Ezzedine, Lawrence Livermore National Laboratory (ezzedine1@llnl.gov); Keehoon Kim, Lawrence Livermore National Laboratory (kim84@llnl.gov); Benjamin L. Moyer, University of Maryland (blmoyer@umd.edu)

Detecting, Characterizing and Monitoring Mass Movements

Evolving climate patterns and land-use changes coupled with improved monitoring capabilities have caused a notable increase in geophysical detections of mass movements, such as landslides, debris and snow avalanches, lahars and glacial failures. Recent examples include the Blatten landslide in Switzerland, the Wanrog rock avalanche in Taiwan and the Tracy Arm tsunamigenic landslide in Alaska, USA. Mass movements couple energy into the Earth and atmosphere, making seismic and infrasound analysis useful for detecting, char-

acterizing and monitoring these events. While these sources are not routinely monitored in real-time like earthquakes, recent advancements in seismic and infrasound instrumentation and processing offer opportunities for rapid early warning and post-event detection and analysis. Combining seismic and infrasound methods with auxiliary datasets from remote sensing, ground-based flow monitoring and distributed sensing further improves event characterization. Passive seismic analysis can also provide valuable information about incipient or ongoing slope instabilities.

This session explores innovative research focused on improving our comprehension of various types of mass movements as seismic sources. We invite presentations that investigate the use of seismic and infrasound data as well as interdisciplinary datasets to expand our knowledge of fundamental landslide processes, enhance our ability to characterize and monitor mass movement events and mitigate associated hazards. Topics of interest encompass, but are not limited to, mass movement source detection, location, characterization, modeling and classification, precursory signal analysis, monitoring and hazard mitigation.

Conveners: Paul Bodin, University of Washington (bodin@uw.edu); Pierre Boymond, Volcanological and Seismological Observatory of Costa Rica (pierre.boymond@una.cr); Nahomy Campos, Volcanological and Seismological Observatory of Costa Rica (nahomy.campos.salas@est.una.ac.cr); Esteban J. Chaves, Volcanological and Seismological Observatory of Costa Rica (esteban.j.chaves@una.ac.cr); Avery E. Conner, University of Oregon (aconner2@uoregon.edu); Joan Gomberg, U.S. Geological Survey (gomberg@usgs.gov); Sonia Hajaji, Georgia Institute of Technology (ssalgado30@gatech.edu); Ezgi Karasozen, University of Alaska Fairbanks (ekarasozen@alaska.edu); Cyril Müller, Volcanological and Seismological Observatory of Costa Rica (cyril.muller@una.cr); Evelyn Nuñez, Volcanological and Seismological Observatory of Costa Rica (evelyn.nunez.alpizar@una.cr); Diego Quirós, University of Capetown (diego.quirós@uct.ac.za); Liam Toney, U.S. Geological Survey (ltoney@usgs.gov)

Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science

The rapid rise of artificial intelligence and statistical inference is reshaping earthquake science, enabling breakthroughs in earthquake detection, source characterization, forecasting and earthquake cycle simulations. For example, neural operators have sped up forward modeling and inversion, graph neural networks have successfully tackled a wide range of applications by leveraging the interconnected nature of seismic data and variational inference has effectively connected data to models in high-dimensional parameter spaces. This session highlights new data-driven approaches that improve upon traditional

techniques or introduce new methods entirely. We welcome submissions that bring to light new trends and patterns in old datasets, highlight important signals that are seemingly buried in noise, and speed up scientific analysis when working with large volumes of data. Contributions that demonstrate how AI and statistical methods open fresh pathways for understanding existing problems in earthquake science are of particular interest.

Conveners: Susan E. Hough, U.S. Geological Survey (hough@usgs.gov); Ian McBrearty, Stanford University (imcbrear@stanford.edu); Mostafa Mousavi, Harvard University (mousavim@google.com); Hongyu Sun, University of Texas at El Paso (hsun2@utep.edu); Valeria Villa, California Institute of Technology (vvilla@caltech.edu); Taiyi Wang, California Institute of Technology (taiyi@caltech.edu); Clara Yoon, U.S. Geological Survey (cyoon@usgs.gov); Caifeng Zou, California Institute of Technology (czou@caltech.edu)

Earthquake Ground Motions and Structural Response: Emerging Tools and Applications

Understanding how buildings, bridges, energy infrastructure and the ground beneath them respond to earthquakes is central to both earthquake science and risk reduction. New monitoring approaches — ranging from permanent seismic networks and structural arrays to ambient vibration studies, and the rapid growth of low-cost MEMS and smartphone sensors — are expanding our ability to capture building dynamics and ground motion in unprecedented detail. These observations are providing new insights into structural health, damage processes, and soil-structure interaction and the region-wide distribution of risk for large earthquakes. Newly obtainable data also promises to support applications such as rapid post-event regional damage assessment and long-term seismic resilience.

This session invites contributions from across the seismological, engineering and hazard-modeling communities that address building and ground motion monitoring using traditional networks, emerging low-cost sensors, gradient based sensors such as distributed fiber optic sensing and rotational sensors, novel analytical methods or case studies from recent earthquakes and experiments. We especially encourage interdisciplinary studies that bridge seismology, structural engineering and risk mitigation; provide synergistic applications of unique data and high-performance simulations, as well as applications that highlight the potential for scalable monitoring at the urban or regional level.

Conveners: Richard Allen, University of California, Berkeley (rallen@berkeley.edu); Felix Bernauer, Ludwig Maximilian University of Munich (felix.bernauer@lmu.de); Farid Ghahari, California Geological Survey (ghahari@gmail.com); Monica Kohler, California Institute of Technology (kohler@caltech.edu); Utpal Kumar, University of California,

Berkeley (utpalkumar@berkeley.edu); David McCallen, Lawrence Berkeley National Laboratory (dbmccallen@lbl.gov); Yara Rossi, Ludwig Maximilian University of Munich (yara.rossi@lmu.de)

Earthquake Rupture Hazard and Forecasts from Integration of Paleoseismic Datasets

Earthquake hazard forecasts are often constrained by or evaluated with geologic data on the timing of past large earthquakes. Yet these paleoseismic records have inherent complexities that stem from dating uncertainties, and additional assumptions are required to utilize the site-specific data at a fault system level. This session seeks presentations on paleoseismic datasets and contributions to method development for characterizing or utilizing such data in earthquake forecasting. We welcome investigations of earthquake recurrence statistics derived from paleoseismic or other geologic data, new approaches to improve dating of past events and studies of earthquake recurrence from historic datasets. We strongly encourage presentations on techniques to extrapolate site-level data to fault- or system-level behavior and new approaches to incorporate paleo-rupture models into earthquake rupture forecasts. Work may be local or global in scope, consider time-dependent or time-independent methods or compare physics-based modeling efforts with empirically constrained data.

Conveners: Alex Hatem, U.S. Geological Survey (ahatem@usgs.gov); Mike Oskin, University of California, Davis (meoskin@ucdavis.edu); Katherine Scharer, U.S. Geological Survey (kscharer@usgs.gov)

Earthquake Swarms Across the Earthquake Cycle: Precursors, Transients and Aftereffects

Earthquake swarms occur in diverse tectonic settings and reflect a broad spectrum of physical mechanisms, including fluid diffusion, aseismic slip, fault healing and postseismic relaxation. Rather than representing a single process, swarms can mark multiple stages of the earthquake cycle. They may act as precursors to major ruptures, indicators of transient deformation or aftereffects of stress redistribution.

This session invites contributions that explore the temporal and mechanical roles of earthquake swarms in fault evolution through observations, laboratory experiments, numerical modeling and theoretical analyses. We particularly welcome studies that link swarms with aseismic slip, fluid migration or stress interactions across spatial and temporal scales. By integrating seismic, geodetic and experimental perspectives, this session aims to advance understanding of how earthquake swarms modulate fault loading and release, bridging the gap between slow and fast deformation processes in the litho-

sphere. We encourage interdisciplinary approaches and global case studies that provide new insights into the diverse origins and implications of earthquake swarms.

Conveners: Kate Chen, National Taiwan Normal University (katepili@gmail.com); Aitaro Kato, University of Tokyo (akato@eri.u-tokyo.ac.jp); Kristine Pankow, University of Utah (pankowseis2@gmail.com)

Earth’s Structure from the Crust to the Core

This session will cover all aspects of “structural seismology” and highlight new contributions to research on a wide range of topics, including, but not limited to, core and mantle dynamics, the role of the mantle transition zone in mantle convection, volcanism in different settings around the world, the structure of subducting slabs, lithospheric deformation and processes and lithosphere-asthenosphere interactions and their feedback into geohazards. We encourage submissions that introduce new or new combinations of seismological data types, advances in global and regional-scale seismic tomography, 3D waveform modeling, array-based approaches and the analysis of correlation wavefields.

Conveners: Chuanming Liu, University of Texas (chuanming.liu@jsg.utexas.edu); Maureen Long, Yale University (maureen.long@yale.edu); Carl Tape, University of Alaska Fairbanks (ctape@alaska.edu); Xiaotao Yang, Purdue University (xyang@purdue.edu)

ESC-SSA Joint Session: Advanced Methods for Harnessing Seismic Noise Analysis in Applied Seismology

There is a growing demand for advanced approaches to analyze seismic noise in order to improve the imaging and monitoring of shallow geological structures and to characterize their physical properties as well as study and monitor natural hazards. Such advancements are not only relevant from a scientific perspective but are also essential for practical applications, including land-use planning and risk mitigation in areas exposed to environmental hazards. Seismic noise analysis, when combined with both passive and active seismological methods, provides a reliable and cost-effective tool for subsurface investigations. Recent progress in this field has been driven by the availability of affordable acquisition systems, enhanced computational capacity for solving inverse problems and the development of more sophisticated modeling algorithms. Beyond traditional seismometer-based techniques, novel approaches now exploit large datasets from distributed acoustic sensing, dense nodal arrays and novel fiber sensing methods (e.g., state of polarization, long-range interferometry). Applications of these methods are manifold, ranging from engineering seismology (site effects, site characterization, liquefaction and ground-motion

amplification at various scales) to high-resolution fault imaging, fracture network characterization in reservoirs, volcanic and geothermal environments, landslide hazard assessment etc. Contributions exploring noise-based methods in aquatic environments are also encouraged.

This session will be a joint session between the SSA Annual Meeting 2026 and the 40th General Assembly of the European Seismological Commission (ESC2026).

Conveners: Sean Ahdi, ARUP (sahdi@g.ucla.edu); Ettore Biondi, Stanford University (ettore88@stanford.edu); Cecile Cornou, University of Grenoble Alpes (cecile.cornou@univ-grenoble-alpes.fr); Sebastiano D’Amico, University of Malta (sebastiano.damico@um.edu.mt); Francesco Panzera, University of Catania (francesco.panzera@unict.it); Stefano Parolai, University of Trieste (stefano.parolai@units.it); Matteo Picozzi, National Institute of Oceanography and Applied Geophysics (mpicozzi@ogs.it)

ESC-SSA Joint Session: Interpreting Volcanic Unrest and Eruption Data for Effective Crisis Management

Volcanoes often undergo episodes of unrest that dedicated observatories should monitor, interpret and manage. The mechanisms driving unrests, their timescales and the associated precursory signals are challenging to translate into reliable forecasts of eruption style and intensity. Yet the consequences for nearby populations are potentially profound. Formulating hypotheses about the evolution, or cessation, of unrests requires understanding complex and deep earth processes, a task that is especially challenging when monitoring infrastructure is limited.

Interpreting both the historical and contemporary behavior of volcanic systems is complex but essential. In recent decades, numerous well-documented episodes of unrest have been observed, some of which have culminated in eruptions, while others have not. Notable non-eruptive cases include the Campi Flegrei caldera, Santorini, Dofen and the Chiles-Cerro Negro volcanic complex. By contrast, eruptive examples include Whakaari, Fuego, Kilauea, Sierra Negra, Cumbre Vieja and many others. These events have yielded rich, multidisciplinary datasets that may enhance our understanding of processes driving unrest, eruption and co-eruptive dynamics within volcanic conduits, magmatic systems and flanks.

We invite contributions that investigate the underlying processes of volcanic unrest and focus on the interpretation driven by those global crises. Studies integrating seismic monitoring with complementary approaches, including infrasound, geodesy, gravimetry, geochemistry, petrology, thermal imaging and visual imaging are particularly encouraged.

This session will be a joint session between the SSA Annual Meeting 2026 and the 40th General Assembly of the European Seismological Commission (ESC2026).

Conveners: Luca D’Auria, National Center for Volcanology Canary Islands Volcanological Institute (ldauria@iter.es); Stephen McNutt, University of South Florida (smcnutt@usf.edu); Stephanie G. Prejean, U.S. Geological Survey (sprejean@usgs.gov); Mario C Ruiz, Ecuadoran Geophysical Institute of the National Polytechnic School (mrui@igepn.edu.ec); Margarita Segou, British Geological Survey (msegou@bgs.ac.uk); Anna Tramelli, National Institute of Geophysics and Volcanology (anna.tramelli@ingv.it)

Evolving Frontiers in Explosion Monitoring and Source Physics

Advancing seismological techniques to improve the identification and characterization of anthropogenic activities of interest remains important for national security applications, industry and seismic hazards. This session invites abstracts on recent advancements in geophysical forensic analysis, and seismological tools applied to global security and explosion monitoring efforts. We seek topics involving the analysis of explosions and anthropogenic activity, analysis of seismicity in new sensing environments, event identification and source physics. We welcome submissions incorporating multi-modal observations, machine-learning applications and deployment of innovative instrumentation including distributed acoustic sensing, remote sensing and large-N arrays to improve the observation, modeling and characterization of seismic source signatures. Additionally, we seek to highlight recent advances in controlled source experiments and investigation of signal propagation and Earth structure. This session aims to promote collaboration among institutions and subject-matter experts to share scientific progress.

Conveners: Miles Bodmer, Sandia National Laboratory (mabodme@sandia.gov); Jonas A. Kintner, Los Alamos National Laboratory (jonas.kintner@gmail.com); Colin N. Pennington, Lawrence Livermore National Laboratory (pennington6@llnl.gov); Michelle Scalise, Nevada National Security Sites (scalisme@nv.doe.gov); Daniel Trugman, University of Nevada, Reno (dtrugman@unr.edu)

Fault Networks and Seismic Hazard in the Nevada-California Borderland

Nevada’s fast-growing cities lie within a region of poorly characterized seismic hazard. The tectonic setting in the Walker Lane, at the overlap between extensional and strike-slip provinces, results in a linked network of apparently short faults that are capable of complex quasi-static and dynamic triggering. Related hazards include liquefaction, rock falls and landslides, lake tsunami and vulnerable historic mines and unreinforced masonry buildings across the state.

As a multidisciplinary group, the newly formed Sierra Nevada Earthquake Consortium (SNEC), we invite contribu-

tions from across earthquake science and engineering relevant to: public safety, policy, fault mapping in 2-, 3- and 4D, paleoseismology, seismic swarms and sequences in characteristic Walker Lane style, general studies about transtensional deformation fields, localization or lack thereof, basin characteristics, topographic effects and technological, data and computational advances.

Conveners: Christopher B. DuRoss, U.S. Geological Survey (cduross@usgs.gov); Richard D. Koehler, Nevada Bureau of Mines and Geology (rkoehler@unr.edu); Henry B. Mason, University of Nevada, Reno (hbmason@unr.edu); Ian K. D. Pierce, Pacific Gas & Electric (ipiercegeology@gmail.com); Christie D. Rowe, Nevada Seismological Laboratory (rowec@unr.edu)

Fiber-Optic Sensing Applications in Seismology and Environmental Science

Fiber-optic sensing methods, such as Distributed Acoustic Sensing (DAS), Distributed Temperature Sensing (DTS) and Distributed Strain Sensing (DSS), are transforming seismology by advancing our understanding of seismic sources and Earth’s structure. These innovative technologies convert fiber-optic cables into dense sensor arrays capable of capturing seismic and deformation signals across the solid Earth, oceans and glaciers with unprecedented resolution. We invite contributions on recent developments in fiber-optic seismology applications, including, but not limited to, the detection and characterization of various seismic sources (e.g., earthquakes, icequakes, volcanic activities, ocean processes, atmospheric phenomena, energy extraction and storage activities and anthropogenic signals), Earth’s structure imaging (e.g., urban setting, offshore and cryosphere), environmental monitoring (e.g., the dynamics of oceans, rivers, lakes, critical zones, soil moisture, groundwater, permafrost and glaciers) and natural hazard mitigation (e.g., earthquake, landslides, tsunami and volcanic eruption monitoring and early warning). We also welcome recent engineering advancements in the theoretical, methodological and instrumental aspects of fiber-optic sensing for future Earth and planetary applications, with particular interest in the state-of-the-art use of transmission fibers in operational subsea cables. Contributions from the computational and data science communities focused on exploring fiber-optic data are encouraged, including areas such as machine learning, advanced signal processing techniques, data compression, high-performance computing and cloud computing and storage. We aim to bring together researchers from diverse fields, including Earth science, computational and data science and fiber-optic sensing engineering, to open a discussion on the future opportunities enabled by these new technologies.

Conveners: Mahbubah Ahmed, Virginia Polytechnic Institute and State University (mahbubah@vt.edu); Ettore

Biondi, Stanford University (ettore88@stanford.edu); Xiaowei Chen, Texas A&M University (xiaowei.chen@tamu.edu); Valey Kamalov, International Institute for Ocean Fiber Sensing (vkamalov@gmail.com); Voon Hui Lai, Australian National University(voonhui.lai@anu.edu.au); Jiaxuan Li, University of Houston (jxli@uh.edu); Mikael Mazur, Nokia Bell Labs (Mikael.mazur@nokia-bell-labs.com); Meghan C. Quinn, U.S. Army Engineer Research and Development Center (meghan.c.quinn@usace.army.mil); Qibin Shi, Rice University (qs20@rice.edu); Joseph P. Vantassel, Virginia Polytechnic Institute and State University (jpvantassel@vt.edu); Qiushi Zhai, California Institute of Technology (qzhai@caltech.edu)

From Drilling to Ground Shaking: Mechanisms, Monitoring and Mitigation of Induced Earthquakes

The widespread occurrence of induced earthquakes has generated substantial scientific and societal concerns. These seismic events result from expanded oil and gas extraction — driven by increasing energy demands — as well as geothermal energy production, mining operations and carbon capture and storage activities. The spatiotemporal evolution of induced seismicity is governed by complex interactions among site-specific poroelastic responses, fluid budgets, injection and production histories, reservoir dimension, subsurface hydro-mechanical properties and fault slip behavior under varying drainage conditions. Subsurface stress redistribution depends on fault geometry, hydraulic connectivity and coupled fluid-mechanical processes that are difficult to model.

Understanding these interactions requires integrative and multidisciplinary approaches to illuminate underlying physical mechanisms and guide effective hazard mitigation strategies. We invite submissions that advance induced seismicity research through case studies, novel methodologies and innovative datasets. Topics of interest include, but are not limited to, seismological source studies and machine learning applications for source characterization, enhanced seismic network performance and sensitivity improvements, 3D fault imaging, stress field modeling, numerical simulations of pressure fields and InSAR modeling, ground motion prediction models for induced events and coupled hydrologic and geomechanical modeling informed by operational data.

We particularly encourage contributions leveraging large and integrated datasets, *e.g.* ,seismic, borehole, geodetic and experimental data, to explore the co-evolution of seismicity, stress, reservoir properties and hydro-mechanical processes. This session aims to deepen our understanding of induced seismicity and support the development of comprehensive mitigation strategies.

Conveners: Asiyeh Aziz Zanjani, New Mexico Institute of Mining and Technology (asiye.azizzanjani@nmt.edu); Urbi Basu, New Mexico Institute of Mining and Technology

(urbi.basu@nmt.edu); Yangkang Chen, University of Texas at Austin (yangkang.chen@beg.utexas.edu); Sebastian Hainzl, GFZ Potsdam (hainzl@gfz.de); Thomas H. Goebel, University of Memphis (thgoebel@memphis.edu); Semechah Lui, University of Toronto (semechah.lui@utoronto.ca)

Generating, Calibrating and Validating Multi-Scale Seismic Velocity Models

Accurate multiscale velocity models are essential for estimation of realistic ground motions in seismic hazard, risk analysis and other applications. In many regions, multiple velocity models of different spatial extent and resolution have been developed using different methodologies and datasets (*e.g.*, earthquake tomography, noise cross correlations, receiver functions, well logs, active source data, etc.), with highly variable ground motion prediction efficacy. This session welcomes studies describing new velocity models, as well as efforts to combine (*e.g.*, using machine learning and other methods), calibrate and validate existing velocity models. We also solicit contributions that quantify the importance of various model features on the accuracy of predicted ground motions through physics-based numerical modeling, as well as contributions that aim to model realistic variability of the ground motions. Contributions that quantify and map uncertainty in velocity models into the resulting ground motions are also encouraged.

Conveners: Yehuda Ben-Zion, University of Southern California (benzion@usc.edu); Kim B. Olsen, San Diego State University (kbolsen@mail.sdsu.edu); Patricia Persaud, University of Arizona (ppersaud@arizona.edu); Artie Rodgers, Lawrence Livermore National Laboratory (rodgers7@llnl.gov); Te-Yang Yeh, University of Southern California (tyyeh316@gmail.com)

Geophysical Perspectives on Volcanic Systems: Seismicity, Structure and Dynamics

Over the past few decades, significant advances have been made in understanding the structure and dynamics of volcanic plumbing systems. Our perspective has shifted toward the concept of trans-crustal magmatic system (TCMS), in which magma is distributed across vertically extensive regions throughout the crust rather than only stored within shallow-melt-dominant chambers. However, geophysical imaging may only detect a small portion of the melt in the upper crust beneath many active volcanoes and it struggles to constrain magma storage in the mid- to lower crust. Direct evidence for TCMS beneath modern active volcanoes is lacking, raising a critical question: Do TCMS truly represent the nature of magma storage beneath volcanoes? Furthermore, answering fundamental questions regarding the mechanism and evolu-

tion of magma supply, storage and transportation remains an essential challenge.

This session invites contributions aimed to advance our knowledge of the volcanic plumbing system across various spatial and temporal scales, from mantle magmatic/tectonic processes to surficial hydrothermal/eruptive activities and from decadal to instantaneous activities. We encourage studies presenting recent advancements including, but not limited to, high-resolution and multiparameter (*e.g.*, velocity, anisotropy, attenuation) seismic imaging and monitoring that utilize phases from passive or active sources or full wavefields, analyses of volcanic seismicity such as volcanic-tectonic events, deep long-period earthquakes and tremors. Applications of artificial intelligence and machine learning in this context are encouraged, along with studies integrating multi-physics datasets such as magnetotelluric, geodetic and gravity data. We envision that the session discussion can help to gain new insights into the evolution of magmatic systems and their implications for volcanic hazards.

Conveners: Alysha Armstrong, Lawrence Livermore National Laboratory (armstrong52@llnl.gov); Guanning Pang, University of Science and Technology of China (pgn0707@ustc.edu.cn); Brandon Schmandt, Rice University (Brandon.Schmandt@rice.edu); Sin-Mei Wu, University of Hawaii at Manoa (smwu@hawaii.edu)

International Collaboration to Advance Earthquake Science and Disaster Response

International collaboration and post-earthquake response/reconnaissance activities improve access to data, advance earthquake science and fortify scientific and humanitarian response globally. Nonprofits, governments, private sector partners and universities participate in these international collaboration and response activities, which provide a multitude of opportunities and benefits. This work facilitates opportunities to learn from varied geological contexts and infrequent geophysical events, encourages diverse perspectives on complex seismic and related problems and strengthens relationships that enable scientists to call upon counterparts in other countries for technical and response support. This session will highlight advances in earthquake response capabilities and information products, case studies, benefits, recommendations, ethical considerations and challenges of working in a global, multi-country context to advance earthquake science.

Conveners: Michael L. Blanpied, U.S. Geological Survey (mblanpied@usgs.gov); Lindsay A. Davis, U.S. Geological Survey (ldavis@usgs.gov); Sara K. McBride, Seismic Safety Commission (sara.mcbride@caloes.ca.gov); Jenny Riker, U.S. Geological Survey (jriker@usgs.gov)

The Landscape Record of Earthquakes and Faulting

Recent earthquakes have left vastly different records in the landscape, from coastal uplift in the 2025 Mw8.8 Kamchatka, Russia, earthquake to large lateral surface rupture in the 2025 Mw7.7 Mandalay, Burma (Myanmar), earthquake, and subtle surface displacement in the 2025 Mw7.1 Tingri, China, earthquake. How long the earthquake record remains in the landscape depends on the surface rupture (or lack thereof) and shaking signatures of the earthquake as well as the lithology and climate of the region. Field and remote sensing observations of recent and past ruptures highlight the variable rupture geometries, surface slip distributions, damage zones of distributed or off-fault deformation and ground shaking. The extent to which the complex and heterogenous patterns are consistent or variable between earthquakes is a fundamental question in earthquake science, critical for hazard modeling and remains largely unknown. Meanwhile, advances in numerical and physical models and laboratory experiments expand the ability to study strain accumulation and release and the landscape response and preservation through multiple earthquake cycles. In this session, we encourage abstracts that investigate spatial and temporal patterns in strain accumulation and release spanning coseismic to geologic timescales, including their causes and uncertainties. We welcome contributions from geodesy, earthquake geology, tectonic geomorphology, lacustrine paleoseismology, numerical modeling, analog experiments and especially contributions with novel approaches integrating multiple data sources to further our understanding of how strain accumulation and release are stored in, interpreted from and alter the landscape.

Conveners: Kristen Chياما, Harvard University (kchياما@g.harvard.edu); Catherine Hanagan, U.S. Geological Survey (chanagan@usgs.gov); Jessica A. T. Jobe, U.S. Geological Survey (jjobe@usgs.gov); Emerson Lynch, Colgate University (emerson.lynch@gmail.com); Nadine Reitman, U.S. Geological Survey (nreitman@usgs.gov)

Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cascadia, Chile and Beyond

Subduction zone environments host some of the most dynamic interactions between geological processes and structures, from the deep to the shallow and surface and across timescales from seconds to millennia and beyond. Subduction zone hazards arise from and catalyze the enduring tectonic changes, often involving cascading, interlinked occurrences of earthquakes, tsunamis, volcanic eruptions, landslides and land-level changes that pose significant risks to society. Some of these hazards, such as joint ruptures of the subduction interface along with the upper/lower-plate faults, remain

underobserved but complicate risk assessment. To illuminate the structure, source dynamics and hazard impacts in subduction zones, it is essential to integrate observations and models spanning a wide range of spatial and temporal scales. The deeper insights gained from comparing and contrasting the behaviors of archetypal convergent margins underpin the development of a systems-based framework for improving our predictive understanding of subduction zones.

This session is motivated by SZ4D (www.sz4d.org), a community-driven initiative for a long-term, interdisciplinary research program aimed at understanding how the different components of subduction zone systems interact to produce and magnify geohazards over time. We invite new contributions to studies of subduction zone systems globally, on topics including, but not limited to, sensing technologies, imaging, modeling and interpretation studies for faults and earthquakes (particularly linked ruptures of megathrust and crustal faults), lithosphere and asthenosphere, volcanoes, landscapes and associated geohazards and risk evaluation, across seismology, geodesy, geology, engineering and other related fields. Observational, theoretical, computational and laboratory studies on the SZ4D focus areas of Alaska, Cascadia and Chile, as well as other subduction zones offering relevant insights are particularly welcome.

Conveners: Geoffrey Abers, Cornell University (abers@cornell.edu); Tiegan E. Hobbs, Geological Survey of Canada (thobbs@eoas.ubc.ca); Andrew Howell, University of Canterbury (andrew.howell@canterbury.ac.nz); Junle Jiang, University of Oklahoma (jiang@ou.edu); Duo Li, Earth Sciences New Zealand (d.li@gns.cri.nz); Camilla Penney, University of Canterbury (camilla.penney@canterbury.ac.nz); Chris Rollins, GNS Science (c.rollins@gns.cri.nz); Ignacio Sepulveda, San Diego State University (isepulveda@sdsu.edu); Lingling Ye, Southern University of Science and Technology (yell@sustech.edu.cn); Iris van Zelst, University of Edinburgh (iris.vanzelst@ed.ac.uk)

Mechanisms and Seismogenic Structure for Large Continental Earthquakes

Large continental earthquakes, particularly those near populated areas, have caused significant damage to society, as seen in the recent 2023 M7.7/7.6 Turkey doublet and the 2025 M7.7 Myanmar strike-slip earthquakes. Detailed investigations of the rupture process and high-resolution imaging of the seismogenic structure, utilizing observations from multiple disciplines, is essential for long-term and medium-term probability forecasting, the dynamics of nucleation and rupture, as well as for conducting physics-based ground motion simulations for effective hazard assessment. This session aims to explore

the processes and mechanisms behind large continental earthquakes and their connections to crustal and mantle structures. We invite contributions about techniques in source inversion and seismic imaging and encourage submissions that examine large continental earthquakes from various disciplines, including, but not limited to, seismology, tectonics, geodesy and geodynamics.

Conveners: Qinghui Cui, China Earthquake Administration (qhcu@ief.ac.cn); Yuanyuan Fu, China Earthquake Administration (fuyuanies@163.com); Guohui Li, China Earthquake Administration (lgh@ief.ac.cn); Zhigang Shao, China Earthquake Administration (shaozg@seis.ac.cn); Lingling Ye, Southern University of Science and Technology (yell@sustech.edu.cn)

Network Seismology: Recent Developments, Challenges and Lessons Learned

Seismic monitoring is not only an essential component of earthquake response but also forms the backbone of a substantial amount of research into seismic hazards, the earthquake process and seismotectonics. To ensure networks best serve the public, media, government and academic communities, it is important to continue to develop monitoring networks' abilities to accurately and rapidly catalog earthquakes. Due to the operational environment of seismic monitoring, seismic networks encounter many unique challenges not seen by the research community. In this session, we highlight the unique observations and challenges of monitoring agencies and look to developments that may improve networks' ability to fulfill their missions. Seismic operation centers play a crucial role in collecting seismic data and generating earthquake products, including catalogs, warnings and maps of ground shaking. The purpose of the session is to foster collaboration between network operators, inform the wider seismological community of the interesting and challenging problems within network seismology and look to the future on how to improve monitoring capabilities. This session is not only an opportunity for monitoring agencies to highlight new developments in their capabilities, but we also encourage submissions describing new instrumentation, methods and techniques that would benefit network operations for detecting, locating and characterizing earthquakes, particularly in a near real-time environment.

Conveners: Blaine Bockholt, Idaho National Laboratory (blaine.bockholt@inl.gov); Dara E. Goldberg, U.S. Geological Survey (degoldberg@usgs.gov); Renate Hartog, University of Washington (jrhartog@uw.edu); Kristine Pankow, University of Utah (kris.pankow@utah.edu); Dmitry Storchak, International Seismological Centre (dmitry@isc.ac.uk)

New Developments in Earthquake Rupture Physics For Source Characterization and Ground Motion Modeling

Understanding the physical process of earthquake rupture and slip is central to advancing the applicability of physics-based ground motion modeling to seismic hazard assessment, where 3D regional-scale simulations are increasingly being used to improve empirical ground-motion models. Adequate source characterization, together with well-constrained 3D velocity structures, is critical for producing realistic ground-motion estimates suitable for hazard assessment.

Recent advances in rupture dynamics, kinematic modeling, laboratory friction experiments and theoretical fracture mechanics provide new opportunities to improve our physical representation of earthquake sources. At the same time, important challenges remain in integrating these diverse approaches into a coherent framework for seismic hazard applications.

This session invites contributions from across the spectrum of faulting physics, including dynamic and kinematic rupture modeling and simulations, experimental and theoretical studies of fault friction and fracture and case studies linking observations with source modeling. We particularly encourage submissions that highlight how advances in source characterization can be integrated with broader 3D simulations to improve the accuracy and reliability of physics-based seismic hazard assessment.

Conveners: Ruth Harris, U.S. Geological Survey (harris@usgs.gov); Camilo Pinilla-Ramos, University of Southern California (camilo.pinilla@berkeley.edu); Arben Pitarka, Lawrence Livermore National Laboratory (pitarka1@llnl.gov); David D. Oglesby, University of California, Riverside (david.oglesby@ucr.edu)

New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets

Seismology is rapidly evolving due to vast amounts of data from classical and emerging instrumentation, as well as advances in theory and computation. The new observational tools include distributed acoustic sensing (DAS), dense nodal arrays, satellites and the ubiquitous cell phones, as well as ocean-bottom/underwater sensors and seismic packages deployed on planetary missions, which complement traditional seismometers. We can now both capture ephemeral surface observations and record wavefields with unprecedented spatial and temporal richness across Earth and other planetary bodies. At the same time, high-performance computing and scientific machine learning enable us to simulate, interpret and invert complex

wave phenomena. This session aims to connect these developments by bringing together researchers working on forward and inverse modeling of seismic sources and multi-scale structures, physical interpretation of seismic observations, including unconventional or multi-modal records associated with strong ground motion and human-reported or engineered-environment observations in the near field.

Conveners: Tariq Alkhalifah, King Abdullah University of Science and Technology (tariq.alkhalifah@kaust.edu.sa); Ebru Bozdog, Colorado School of Mines (bozdog@mines.edu); Lori Dengler, California State Polytechnic University, Humboldt (Retired) (lori.dengler@humboldt.edu); Arash Fathi, ExxonMobil Technology and Engineering (arash.fathi@exxonmobil.com); Peggy Hellweg, University of California, Berkeley (Retired) (hellweg@berkeley.edu); Susan E. Hough, U.S. Geological Survey (hough@usgs.gov); Kami Mohammadi, University of Utah (kami.mohammadi@utah.edu); Jack Muir, Fleet Space Technologies (jack.muir@earth.ox.ac.uk); Jeroen Ritsema, University of Michigan (jritsema@umich.edu)

New Possibilities for InSAR in Earthquake Science: the NISAR Mission and OPERA Displacement Maps

In the past year we have seen two milestone advances in Interferometric Synthetic Aperture Radar (InSAR) measurements: the launch of the NASA-ISRO Synthetic Aperture Radar (NISAR) Mission and the release of the Observational Products for End-Users from Remote Sensing Analysis (OPERA) displacement maps over North America. NISAR launched successfully on July 30, 2025, and will begin distributing science data as early as mid-October 2025, ramping up to full science operations – collecting all land and ice-covered surfaces every 12 days from ascending and descending orbit vantage points - in early November 2025. These data will be freely and openly distributed from the NASA Alaska Satellite Facility (ASF) within days of acquisition. The OPERA project collects data from satellite radar and optical instruments to generate a variety of products, among them maps of line-of-sight (LOS) displacement over North America for existing InSAR missions, which will likewise be distributed by ASF. NISAR observations and OPERA displacement products are capable of addressing fundamental and applied research topics in earthquake science, including global tectonics, the impact of anthropogenic processes on active faults and disaster response. This session invites contributions from those who plan to dive into these new datasets, showcasing early results.

Conveners: Eric Fielding, Jet Propulsion Laboratory (eric.j.fielding@jpl.nasa.gov); Kathryn Materna, University of Colorado, Boulder (kathryn.materna@colorado.edu); Ekaterina Tymofyeyeva, Jet Propulsion Laboratory (katia.tymofyeyeva@jpl.nasa.gov)

Observation and Analysis of Topography and Deformation: Relating Earthquakes to Cascading Hazards

Earthquakes may initiate cascading or triggered phenomena such as flooding, landsliding, ground failure, tsunami, urban and wildland fire and post-seismic deformation. Conversely, earthquakes may occur in areas already impacted by hazards such as increased storm activity, drought, sea-level rise, subsidence, societal challenges and other circumstances that increase risk and vulnerability. These combinations of processes and circumstances may affect landscape and damage infrastructure in complex and under-anticipated ways. Understanding these hazards as linked phenomena requires advances in measurement and analysis of deformation and of topography, multidisciplinary research collaborations, scenario development and focused research and planning for new data and observational platforms.

Our aim is to bring together researchers that strive to understand process linkage among diverse hazards, researchers that are advancing remote sensing data acquisition and processing and those that consider the impacts of these processes. Current examples of these efforts include NSF’s CLaSH Center, the newly launched NASA-ISRO SAR mission, NASA’s Surface Topography and Vegetation study and others involving academic researchers, state and federal scientists and others who study hazard and risk associated with critical infrastructure. We are particularly interested in contributions from the geological, geomorphic, geodetic and remote sensing communities that are working to better understand the linkages between surface processes in a cascading hazard framework or have interest in doing so. We welcome novel research results, reports on community efforts to develop research collaborations, remote sensing infrastructure and other planning activities and more generally, presentations that consider how study of earthquakes help us understand other natural hazards and their impacts to society.

Conveners: Stephen B. DeLong, U.S. Geological Survey (sdelong@usgs.gov); Andrea Donnellan, Purdue University (andread@purdue.edu)

On the State of Knowledge/Art/Practice for mHVSr Analyses; A Prelude to the ESG7-COSMOS mHVSr Pre-Event Forum

Several analytical methods have been developed to estimate frequency-dependent site response for seismic hazard assessment. Most spectral analytic methods do not require supplementary data beyond earthquake recordings. However, sufficient earthquake recordings for robust analyses are often unavailable on a site-specific basis. Other site-specific approaches require an a priori prerequisite commonly known

as site characterization. This field data acquisition can be costly and environmentally prohibitive.

To address these challenges, the single-station microtremor horizontal-to-vertical spectral ratio (mHVSr) analysis method is gaining traction as a stop gap when earthquake data is scarce. Given the global adoption of the mHVSr method, there is a need for updated standardized guidelines based on scientific consensus to ensure consistency and reliability in its application. The greatest challenges to an international standardization of mHVSr acquisition and analysis are two-fold: (1) the underlying composition of the microtremor wavefield is site dependent, therefore the appropriate theoretical model for inversion is still strongly debated; and, (2) there are many factors involved in the data acquisition, processing and interpretation stages that remain inconsistently applied so that standardization cannot be implemented.

From the perspective of the historical development of the mHVSr technique — as well as the physical basis of the mHVSr — the international Consortium of Organizations for Strong Motion Observation Systems (COSMOS) invites the seismological and earthquake engineering communities to share their perspectives on the state of knowledge, art and practice on mHVSr analyses. This session is intended as a prelude to the 18 October 2026 7th Effects of Surface Geology (ESG7) special session titled ESG7-COSMOS mHVSr Pre-event Forum (Grenoble, France), where a main topic of interest is to define the roadmap for updating existing guidelines (e.g., SESAME, 2004).

Conveners: Cécile Cornou, University of Grenoble Alpes (cecile.cornou@univ-grenoble-alpes.fr); Shinichi Matsushima, Kyoto University (matsushima@sds.dpri.kyoto-u.ac.jp); Alexandros Savvaidis, Consortium of Organizations for Strong Motion Observation Systems (alexandros.savvaidis@beg.utexas.edu); Alan Yong, U.S. Geological Survey (yong@usgs.gov)

Physical Properties of Fault Zones from the Seismic Source to Earth’s Surface

The physical properties of fault zones — ranging from the frictional behavior of fault interfaces to the (in)elastic and hydrologic properties of surrounding rock — vary in both space and time, influencing deformation throughout the earthquake cycle and ground shaking during earthquakes. Many faults, for example, show spatially variable creep that may reflect heterogeneous frictional rate dependence. Additionally, fault zones generally differ in elastic moduli and permeability from the surrounding crust. These properties also evolve through successive earthquake cycles, reflecting processes like dynamic weakening and off-fault damage during coseismic rupture and healing during postseismic and interseismic periods. Such variations now underpin complex, physics-based models of seismic and aseismic processes enabled by advances

in high-performance computing. Yet, significant challenges remain. Constraining the in-situ properties of fault zones and assessing their importance relative to other controls on fault mechanics, earthquake physics and seismic hazards, such as fault geometry and stress state are critical topics for investigation and discussion.

We welcome contributions that explore the physical properties (e.g., frictional, elastic, inelastic, hydrologic) of fault zones from the seismic source to Earth’s surface using field, laboratory, geodetic, borehole and/or seismic observations. We also invite studies of natural, experimental, or modeled fault slip behavior that evaluate how physical properties and their variability in space and time influence (a) seismic processes and their associated hazards.

Conveners: Alexis Ault, Utah State University (alexis.ault@usu.edu); Curtis Baden, U.S. Geological Survey (cbaden@usgs.gov); Monica Barbery, Brown University (monica_barbery@brown.edu); Betsy Madden, San Jose State University (elizabeth.madden@sjsu.edu); Josie Nevitt, U.S. Geological Survey (jnevitt@usgs.gov); Zachary Smith, University of California, Berkeley (zachary_smith@berkeley.edu); Ashley Streig, Washington Geological Survey (ashley.streig@dnr.wa.gov)

Physics of Earthquakes: Insights from Theory and Observations

Understanding origin and spatio-temporal evolution of seismicity needs a careful quantitative analysis of earthquake source parameters for large sets of earthquakes in studied seismic sequences. Accurate determination of earthquake hypocenters, focal mechanisms, seismic moment tensors, static stress drop, apparent stress and other earthquake source parameters and their uncertainties provides an insight into tectonic stress and crustal strength in the area under study, fault material properties, fault roughness and prevailing fracturing mode (shear/tensile) in the focal zone and allows investigating earthquake source processes in greater details. In addition, studying relations between static and dynamic source parameters and earthquake size is essential for understanding the self-similarity of rupture processes and scaling laws and for improving our knowledge on ground-motion prediction equations.

This session focuses on methodological as well as observational aspects of earthquake source parameters of natural or induced earthquakes in broad range of scales from large natural earthquakes through reservoir-scale microseismicity, to pico- and femto-seismicity from in-situ laboratories and laboratory experiments on rock samples. Presentations of new approaches, methodologies or datasets (e.g., traditional seismic vs. emerging technologies like DAS) for determination of source characteristics as well as case studies related to analysis of earthquake source parameters in the context of earthquake physics are welcome. We also invite contributions related to

scaling of static and dynamic source parameters, to self-similarity of earthquakes and inversions for stress and other physical parameters in the focal zone.

Conveners: Pavla Hrubcova, Czech Academy of Sciences (pavla@ig.cas.cz); Hitoshi Kawakatsu, University of Tokyo (hitosi@eri.u-tokyo.ac.jp); Patricia Martinez Garzon, GFZ Potsdam (patricia@gfz-potsdam.de); Colin N. Pennington, Lawrence Livermore National Laboratory (pennington6@llnl.gov); German Andres Prieto, National University of Colombia (gaprietogo@unal.edu.co); David Shelly, U.S. Geological Survey (dshelly@usgs.gov); Daniel Trugman, University of Nevada, Reno (dtrugman@unr.edu); Nadine Igonin Ushakov, University of Texas at Dallas (nadine.igonin@utdallas.edu); Vaclav Vavrycuk, Czech Academy of Sciences (vv@ig.cas.cz)

Planetary and Gravitational Wave Seismology

Seismology is not anymore the appanage of the Earth, with several past and future planetary missions with deployed seismometers on the Moon (with Apollo and, in near future FSS, LEMS and ChangE-7), on Mars (with Viking and InSight) and other future missions toward Titan (Dragonfly). Seismology is also not only used to search for quakes and other seismic sources, but is also considered for recording planetary vibrations excited by space-time metrics fluctuations associated to gravitational waves. This was the goal of the Apollo 17 gravimeter and will be the goal of several lunar projects aiming to measure strains variations (e.g., LILA) or ground accelerations (e.g., LGWA) generated by gravitational waves emitted by black holes merging, among other astrophysical sources.

The goal of this session is to present the most recent analysis in planetary seismology and in seismic analysis related to gravitational waves detections, including for future projects.

In planetary seismology, we will welcome presentations on recent analysis of the InSight and Apollo seismic data, as well as progress status of selected projects and performances of new instruments or detection concepts in development for future planetary missions. Targets might be terrestrial bodies (e.g., Mars, the Moon, Titan, Venus) but also small bodies. We will also welcome numeral modeling aiming to better understand and model future data and seismic sources on other bodies, including impacts, airburst and atmospheric sources.

In gravitational waves, we will welcome concept and instruments descriptions, as well as modeling of the expected signals and of all sources of noise which might affect detection of GW signals, especially for the Moon which is targeted by several projects. We welcome presentations especially related to the seismic aspects of GW detection, such as estimations of the signals for 1D and 3D realistic lunar models and modeling of the seismic noise and other lunar environmental noises.

Conveners: Karan Jani, Vanderbilt University (karan.jani@Vanderbilt.Edu); Philippe H. Lognonné, Paris Institute

of Earth Physics (lognonne@ipgp.fr); Mark P. Panning, Jet Propulsion Laboratory (mark.p.panning@jpl.nasa.gov); Nicholas C. Schmerr, University of Maryland (nschmerr@umd.edu)

Recent Contributions of Social Science Research to Understanding Earthquakes

Collaborations with social scientists are critical to ensure that the geophysical information developed and produced about earthquakes is effectively used for risk reduction. As applied to real-world issues, including earthquake hazard warnings (*e.g.*, earthquake early warning and operational earthquake forecasting), general and public education regarding earthquake hazards and their societal consequences, establishing institutional trust and credibility and other areas involving communication with various publics, social scientists are increasingly called upon to provide insights based on empirical studies and theoretical orientations. The social and behavioral sciences can provide valuable information on the social and cultural environments in which scientific developments are shared and translated with community residents and various institutional sectors. This session will highlight research from various social sciences that has been used to inform earthquake risk reduction and will provide an opportunity for discussion of new potential directions and collaborations.

Conveners: James Goltz, University of California, Berkeley (jamesgoltz@gmail.com); Anne Wein, U.S. Geological Survey (awein@usgs.gov)

Recent Research on Ground Motion Directionality

Horizontal earthquake ground motion intensity at a site can vary significantly with changes in orientation. However, current ground motion models (GMMs) and regional seismic risk assessments neglect this important characteristic of ground motions, typically using scalar measures of central tendency of the intensity at a site. Older models often provided estimates of the geometric mean of the intensity recorded in two orthogonal horizontal directions, while modern models typically use the orientation-independent median of all horizontal intensities (*i.e.*, RotD50). By doing so, these measures of intensity overlook the fact that the actual intensity affecting structures in specific orientations can be significantly higher or significantly lower than the scalar (*e.g.*, RotD50) predicted by GMMs.

This session aims to present and discuss recent advancements in research on ground motion directionality. Examples of topics that could be addressed in the session include: ground motion directionality models, quantification of component-to-component variability, orientation of maximum ground

motion intensity, effect of style of faulting on the orientation of maximum intensity, spatial distribution of polarization of ground motions, directionality of ground motions recorded at soft soil sites, directionality in the near-fault region, directionality in physics-based ground motion simulations, directionality in recent earthquakes, ground motion directionality using recently proposed alternative measures of intensity, consideration of directionality in design and evaluation of buildings and infrastructure and directionality in seismic risk assessments. Ground motion directionality is an emerging topic that is at the intersection of seismology and earthquake engineering, so we believe it could attract interest from both groups.

Conveners: Pablo Heresi, University of Chile (pheresi@uchile.cl); Eduardo Miranda, Stanford University (emiranda@stanford.edu)

Regional Source, Path and Site Effects in Earthquake Ground Motions

Despite the use of global earthquake ground-motion models (GMMs), ground-motion observations typically show repeatable effects for individual source, path and site locations. Understanding these regional differences and their cause is important for accurate hazard estimates — especially when using global observations to inform local GMMs, or when using GMMs in regions for which they were not developed. We solicit studies focusing on regional aspects of ground motion and its generation from both empirical and numerical simulation perspectives. We are interested in studies of individual earthquakes that focus on source-specific effects on ground motion like directivity or supershear rupture, as well as studies that highlight the influence of regional site conditions on ground motions, such as local geologic variability, sediment thickness and basin structure or kappa. We hope to spark discussion on these types of physical processes, how they control observed regional ground motion variations and in particular how their effects can be predicted or modeled.

Conveners: David Barba Galdamez, North Carolina State University (dfbarbag@ncsu.edu); Evan T. Hirakawa, U.S. Geological Survey (ehirakawa@usgs.gov); Albert Kottke, Pacific Gas & Electric (albert.kottke@pge.com); Shiyong Nie, Tufts University (shiyong.nie@tufts.edu); Grace A. Parker, U.S. Geological Survey (gparker@usgs.gov)

Seismology for All: Expanding STEM Education Through Accessible Tools and Global Collaboration

Seismology is uniquely positioned as a unifying discipline within STEM, combining global impact and a rich history of collaboration across demographics and of open data sharing across political boundaries. Seismology provides an inspiring curriculum to advance education at all stages of the learning

process. This session seeks success stories and innovative practices in STEM engagement that use seismology and associated disciplines to spark curiosity and develop skills. From primary classrooms to community colleges and citizen science initiatives, we welcome examples of how demonstrations, hands-on tools and effective communication can make even advanced topics accessible to new learners. The cost of entry into seismology has never been more affordable with most devices having some form of seismometer and hobby kits, like the Raspberry Shake or Shake App for smart phones that are joining communities across the world. We want to ensure that the seismological community is aware of such tools and encourage discussion of how to improve the impact of seismology in STEM engagement. We encourage discussion on the roadblocks that are hindering progress in STEM. The goal of this session is to strengthen the seismological community’s role in shaping the next generation of scientists and informed global citizens.

Conveners: Jesse Bonner, Lawrence Livermore National Laboratory (bonner21@llnl.gov); Emily McDonald-Williams, Desert Research Institute (emily.mcdonald-williams@dri.edu); Adam Pascale, Seismology Research Centre (adam.pascale@src.com.au); Beatrice “Bibi” Robinson, Oakland University (brobinson2@oakland.edu); Suzan van der Lee, Northwestern University (suzan@northwestern.edu); Aaron Velasco, University of Texas at El Paso (aavelasco@utep.edu); Cleat P. Zeiler, Desert Research Institute (cleat.zeiler@dri.edu)

Seismotectonics of Southern and Baja California

Southern and Baja California offer tectonic flavors for every appetite, including domains of broad extensional basins and stacks of reverse faulted mountains, which are linked by strike-slip systems. Situated adjacent or above these seismic sources are dense urban population centers and critical infrastructure. This session seeks contributions that utilize geological and geophysical observations to improve characterization of earthquake hazard from central California through the Baja Peninsula, spanning from the outer Borderlands across the San Andreas Fault system. Welcome submissions include investigations of fault zones and fault intersections from geological and/or seismological data; insight into basin structure and velocity from seismology or gravity; geomorphic and geologic studies of late Quaternary fault activity; and consequences of the longer geologic history on the present structure and seismicity. We also welcome modeling investigations that illuminate how this geologic framework impacts earthquake hazard locally or regionally for the over 25 million people that inhabit this binational region. Through a diverse assembly of datasets and methods, we aim to connect the tectonic setting and earthquake hazard.

Conveners: John Fletcher, Center for Scientific Research and Higher Education at Ensenada (jfletche@cicese.mx); Devin McPhillips, U.S. Geological Survey (dmcphillips@usgs.gov); Katherine Scharer, U.S. Geological Survey (kscharer@usgs.gov); Drake M. Singleton, U.S. Geological Survey (dsingleton@usgs.gov)

Source Properties of Microearthquakes: Insights from Laboratory, Induced and Natural Events

Microearthquakes provide a unique perspective for exploring earthquake source mechanisms and fault dynamics. Whether recorded under controlled laboratory conditions, induced by industrial activities, or occurring naturally, their source properties, such as estimated energy release and stress drop, provide critical insights to the rupture processes. This session welcomes contributions from seismology, rock mechanics, geophysical monitoring and numerical modeling, particularly studies that integrate multiscale and multi-source data, including high-precision locations, waveform inversion, stress and friction experiments and comparative analyses of induced and natural events. By combining laboratory experiments, field observations and numerical modeling, we aim to deepen our understanding of microearthquake source physics and advance the scientific knowledge base for earthquake hazard forecasting and risk mitigation. We especially encourage submissions that uncover subtle differences in source processes or propose innovative monitoring technologies and data analysis methods.

Conveners: Hilary Chang, Columbia University (hc3627@columbia.edu); Chun-Yu Ke, National Taiwan University (chunyu-ke@ntu.edu.tw); Yen-Yu Lin, National Central University (yenyulin@ncu.edu.tw); Yajing Liu, McGill University (yajing.liu@mcgill.ca); Semechah Lui, University of Toronto, Mississauga (semechah.lui@utoronto.ca)

Southern California Seismicity: Past, Present and Future

Seismic investigation of Southern California began around a century ago to better understand the processes and hazards associated with several major fault zones, such as the San Andreas and numerous other minor and subsidiary faults. The long history of seismic monitoring in the region – with regional/teleseismic instrumental monitoring dating back to ~1900, the local seismic network established in the 1920s and the official earthquake catalog starting in 1932 – has allowed for many ground-breaking studies on earthquakes and their effects. In this session, we welcome all presentations related to Southern California seismicity, from past events preserved in the geologic record to data analysis of recent events to modeling of what we may expect in the future. In order to fully

understand both short-term seismic and long-term tectonic processes, we need contributions from seismology, geology and geodesy as well as from observational, experimental and theoretical work. We hope this session can help spur discussion and collaboration for furthering our understanding of Southern California seismicity and related hazards.

Conveners: Nicolas DeSalvio, University of California, San Diego (ndesalvio@ucsd.edu); Katherine Guns, U.S. Geological Survey (kguns@usgs.gov); Allen Husker, California Institute of Technology (ahusker@caltech.edu); Julian Lozos, California State University, Northridge (julian.lozos@csun.edu); Gabrielle Tepp, California Institute of Technology (gtepp@caltech.edu); Clara Yoon, U.S. Geological Survey (cyoon@usgs.gov)

SSJ-SSOC-SSA Joint Session: From Slow to Fast Earthquakes: Bridging the Spectrum of Fault Slip

Over the past two decades, growing evidence has shown that earthquake faults accommodate a wide spectrum of slip behaviors, ranging from long-lasting slow slip events to unstable, fast ruptures that generate damaging seismic waves within seconds. Between these extremes exist a variety of intermediate phenomena. Together, these slip modes illustrate that fault slip is not a simple binary process, but rather a continuum that plays a fundamental role in nucleation, rupture dynamics and the spatial distribution of slip and energy release.

A central challenge is to understand how these slip behaviors are related, and in particular, how and when a slow earthquake transitions into a fast one. Answering this question requires careful examination of fault structure, stress, fluids and frictional properties and demands contributions from multiple disciplines. Observational seismology and geodesy provide constraints on where and when slow and fast slip occur, while geological and field studies reveal the physical record of past events. Laboratory experiments and rock mechanics shed light on the processes that govern slip modes, and numerical modeling and theoretical approaches offer frameworks for integrating observations and testing physical mechanisms.

This session invites contributions that advance our understanding of slow and fast earthquakes and their potential connections. We welcome geophysical observations, field and laboratory studies, theoretical and numerical investigations and methodological innovations. Submissions that integrate multiple observations and/or perspectives are strongly encouraged. Cutting-edge approaches in data science, machine learning and novel computational methods that enable the detection, analysis and interpretation of diverse slip modes are also particularly welcome. By bringing together these efforts, this session seeks to provide a more comprehensive understanding of the spectrum of fault slip and its role in earthquake generation.

This session is jointly organized by the Seismological Society of Japan, Seismological Society of China and Seismological Society of America.

Conveners: Aitaro Kato, University of Tokyo (akato@eri.u-tokyo.ac.jp); Jiun-Ting Lin, Lawrence Livermore National Laboratory (lin51@llnl.gov); David Shelly, U.S. Geological Survey (dshelly@usgs.gov); Haijiang Zhang, University of Science and Technology of China (zhang11@ustc.edu.cn)

SSJ-SSOC-SSA Joint Session: Lessons from Recent Major Earthquake Sequences Around the World

Over the past few years, the global seismic community has observed a number of major earthquakes, including the 2023 M7.8/M7.6 Turkey doublet, the 2024 M7.5 Noto, Japan, the 2025 M7.1 Dingri, China, the 2025 M7.7 Mandalay, Myanmar, and most recently the M8.8 sequence off the coast of the Kamchatka Peninsula, Russia. Some events produced significant damage and casualties while others occurred in more remote regions with limited societal impact. Regardless of their consequences, each event presents a valuable opportunity to deepen our understanding of earthquake physics — shedding light on detailed rupture processes, foreshocks and precursory signals, aftershock triggering mechanisms and their connections to long-term tectonic loading and deep Earth structure.

This session invites contributions that explore new findings and emerging questions arising from these major earthquakes. We welcome studies utilizing seismic, geodetic, geologic, or remote sensing data to better understand the behaviors before, during and after the mainshocks. Given the diversity of tectonic settings — from continental normal and thrust faulting, strike-slip systems to subduction megathrusts — this session aims to foster cross-regional comparisons and synthesis. We are especially interested in contributions that highlight unexpected rupture behaviors, near-field and remote interactions or cascading hazard behaviors. By bringing together researchers who have studied these significant earthquakes around the world, we hope to identify common themes, highlight unique features and improve our overall understanding of major earthquake behaviors. The session aims to promote dialogue across disciplines and regions, and to support the SSA community’s shared goal of advancing earthquake science for the benefit of society.

This session is jointly organized by the Seismological Society of Japan, Seismological Society of China and Seismological Society of America.

Conveners: Dara E. Goldberg, U.S. Geological Survey (degoldberg@usgs.gov); Ryo Okuwaki, University of Tsukuba (rokuwaki@geol.tsukuba.ac.jp); Zhigang Peng, Georgia Institute of Technology (zpeng@gatech.edu); Dun Wang, China University of Geosciences (wangdun@cug.edu.cn)

Subaqueous Evidence for Earthquakes, Coseismic Landslides, Tsunamis and other Cascading Hazards

Large earthquakes, tsunamis and landslides can have major impacts on populations, infrastructure and habitats across local, regional and transoceanic scales. The destructive impact of these events can be compounded through associated triggering (e.g., shaking induced landsliding and tsunami genesis). Subaqueous environments (i.e., marine and lacustrine) can provide stratigraphic records and quantitative insights to reconstruct these catastrophic events across a range of temporal and spatial scales. High-resolution geophysical imagery combined with detailed geological sampling and geochemical analyses can provide critical context around preconditioning factors as well as the environmental response to these geohazards. We encourage submissions that integrate onshore and offshore geological, geophysical, geochronological and/or geotechnical datasets along active or passive margins to provide constraints on geohazard characterization and/or link fundamental geological processes to geohazards. In addition, we welcome submissions that combine physics-based modeling and geological or geophysical observations from marine, coastal and lacustrine environments to understand and anticipate geohazards.

Conveners: Daniel S. Brothers, U.S. Geological Survey (dbrothers@usgs.gov); Jenna C. Hill, U.S. Geological Survey (jhill@usgs.gov); Jillian Maloney, San Diego State University (jmaloney@sdsu.edu); Drake M. Singleton, U.S. Geological Survey (dsingleton@usgs.gov); Robert Witter, U.S. Geological Survey (rwitter@usgs.gov)

Time-Dependent Seismic Hazard Assessment: Models, Data and Applications

Time-dependent approaches to seismic hazard assessment are increasingly important for understanding and reducing earthquake risk. This session invites contributions that improve the modeling, testing and application of time-dependent seismic hazard frameworks across different scales. We welcome studies on renewal models of earthquake occurrence, physics-based fault system simulations, spatio-temporal patterns of seismicity and probabilistic time-dependent ground motion forecasts.

Submissions that explore the integration of geological, geodetic, seismological and paleoseismological data into time-dependent models are encouraged, as well as case studies that evaluate model performance against past earthquake sequences. Particular interest is given to approaches that quantify and communicate uncertainty, enhance fault interaction modeling, or directly support engineering design, emergency preparedness and policy decisions.

The goal of this session is to showcase the latest advancements in time-dependent hazard analysis and to encourage discussion among seismology, earthquake engineering and risk management communities. By bringing together modelers, observational seismologists and practitioners, we aim to examine both the scientific advances and the practical uses of time-dependent seismic hazard assessment.

Conveners: Aybige Akinci, National Institute of Geophysics and Volcanology (aybige.akinci@ingv.it); Fabian Bonilla, Gustave Eiffel University (luis-fabian.bonilla-hidalgo@univ-eiffel.fr); Pablo Heresi, University of Chile (pheresi@uchile.cl); Felipe Leyton, University of Chile (leyton@csn.uchile.cl); Gonzalo A. Montalva, University of Concepción (gmontalva@udec.cl); Katleen Wils, Ghent University (katleen.wils@ugent.be)

Overview of Technical Program

<i>Tuesday 14 April</i>	<i>Wednesday 15 April</i>	<i>Thursday 16 April</i>	<i>Friday 17 April</i>	<i>Saturday 18 April</i>
9 AM–4 PM Introduction to DAS for Seismology: From Data Acquisition to Analysis Workshop <i>Ballroom Section D</i>	7 AM–5 PM Registration <i>Hall A & B</i>	7 AM–5 PM Registration <i>Hall A & B</i>	7 AM–5 PM Registration <i>Hall A & B</i>	8 AM–Noon From Richter to Real Time: Tracking the Evolution of Earthquake Science at Caltech Field Seminar
Noon–4 PM Advancing Geophysical Research with Cloud Computing Workshop <i>Ballroom Section B</i>	8–9:15 AM Technical Sessions 9:15–10:30 AM Poster Break <i>Hall A & B</i>	8–9:15 AM Technical Sessions 9:15–10:30 AM Poster Break <i>Hall A & B</i>	8–9:15 AM Technical Sessions 9:15–10:30 AM Poster Break <i>Hall A & B</i>	8 AM–6 PM Multi-hazards: Earthquakes, Fire and Water Field Seminar
1–4 PM Publishing: How to Review and How to Be Reviewed Workshop <i>Ballroom Section A</i>	10:30–11:45 AM Technical Sessions 11:45 AM–2 PM Lunch Break 12:30–1:45 PM NEHRP Forum <i>Hall C</i>	10:30–11:45 AM Technical Sessions Noon–12:50 PM Annual Business and Awards Ceremony <i>Hall C</i>	10:30–11:45 AM Technical Sessions 11:45 AM–2 PM Lunch Break 2–3:15 PM Technical Sessions	
3–7:30 PM Registration Opens <i>Hall A & B</i>	2–3:15 PM Technical Sessions 3:15–4:30 PM Poster Break <i>Hall A & B</i>	1–2:15 PM Luncheon <i>Conference Center Lower Level Lobby</i> 2:15–3:30 PM Technical Sessions	3:15–4:30 PM Poster Break <i>Hall A & B</i> 4:30–5:45 PM Technical Sessions	
4–5 PM Exploring Careers in Industry: Panel Discussion & Networking Session Workshop <i>Conference Center Lower Level Lobby</i>	4:30–5:45 PM Technical Sessions 6–7 PM Panel Presentation <i>Hall C</i>	3:30–4:30 PM Poster Break <i>Hall A & B</i> 4:30–5:45 PM Technical Sessions		
5–6 PM Opening Reception <i>Hall A & B</i>	7–8 PM Student/Early-Career Reception* <i>Exhibit Hall</i>	6–7 PM Joyner Lecture <i>Hall C</i> 7–8 PM SSA Honors Reception <i>Hall A & B</i>		
6:15–7:15 PM Keynote Plenary <i>Hall C</i>				

* Invitation only event

Wednesday, 15 April

Oral Sessions

<i>Time</i>	<i>Ballroom A</i>	<i>Ballroom B</i>	<i>Ballroom C</i>	<i>Ballroom D</i>	<i>Time</i>	<i>Ballroom E</i>	<i>Ballroom F</i>	<i>Ballroom G</i>	<i>Ballroom H</i>
8:00–9:15 AM	Regional Source, Path and Site Effects in Earthquake Ground Motions	ESC-SSA Joint Session: Advanced Methods for Harnessing Seismic Noise Analysis in Applied Seismology		Physics of Earthquakes: Insights from Theory and Observations	8:00–9:15 AM	Network Seismology: Recent Developments, Challenges and Lessons Learned	Planetary and Gravitational Wave Seismology	Physical Properties of Fault Zones from the Seismic Source to Earth's Surface	New Possibilities for InSAR in Earthquake Science: the NISAR Mission and OPERA Displacement Maps
9:15–10:30 AM	Poster Break				9:15–10:30 AM	Poster Break			
10:30–11:45 AM	Regional Source, Path and Site Effects in Earthquake Ground Motions	Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches		Physics of Earthquakes: Insights from Theory and Observations	10:30–11:45 AM	Network Seismology: Recent Developments, Challenges and Lessons Learned	Planetary and Gravitational Wave Seismology	Physical Properties of Fault Zones from the Seismic Source to Earth's Surface	Fault Networks and Seismic Hazard in the Nevada-California Borderland
11:45 AM–2:00 PM	Lunch Break				11:45 AM–2:00 PM	Lunch Break			
2:00–3:15 PM	Regional Source, Path and Site Effects in Earthquake Ground Motions	Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches		Physics of Earthquakes: Insights from Theory and Observations	2:00–3:15 PM	Network Seismology: Recent Developments, Challenges and Lessons Learned	Cryoseismology: Advances in Technology and Scientific Discovery	Earth's Structure from the Crust to the Core	Fault Networks and Seismic Hazard in the Nevada-California Borderland
3:15–4:30 PM	Poster Break				3:15–4:30 PM	Poster Break			
4:30–5:45 PM	Seismology for All: Expanding STEM Education Through Accessible Tools and Global Collaboration	Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches	Detecting, Characterizing and Monitoring Mass Movements	Physics of Earthquakes: Insights from Theory and Observations	4:30–5:45 PM	Subaqueous Evidence for Earthquakes, Coseismic Landslides, Tsunamis and other Cascading Hazards	Cryoseismology: Advances in Technology and Scientific Discovery	Earth's Structure from the Crust to the Core	Time-Dependent Seismic Hazard Assessment: Models, Data and Applications
6:00–7:00 PM	Panel Presentation: Building a Resilient Future: What New Research Directions, Technology Developments and Partnerships are Needed?				6:00–7:00 PM	Panel Presentation: Building a Resilient Future: What New Research Directions, Technology Developments and Partnerships are Needed?			
7:00–8:00 PM	Student/Early-Career Reception				7:00–8:00 PM	Student/Early-Career Reception			

Poster Sessions

- Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches
- Cryoseismology: Advances in Technology and Scientific Discovery
- Detecting, Characterizing and Monitoring Mass Movements
- Earth's Structure from the Crust to the Core
- ESC-SSA Joint Session: Advanced Methods for Harnessing Seismic Noise Analysis in Applied Seismology
- Fault Networks and Seismic Hazard in the Nevada-California Borderland
- Network Seismology: Recent Developments, Challenges and Lessons Learned
- New Possibilities for InSAR in Earthquake Science: the NISAR Mission and OPERA Displacement Maps
- Physical Properties of Fault Zones from the Seismic Source to Earth's Surface
- Physics of Earthquakes: Insights from Theory and Observations
- Planetary and Gravitational Wave Seismology
- Regional Source, Path and Site Effects in Earthquake Ground Motions
- Seismology for All: Expanding STEM Education Through Accessible Tools and Global Collaboration
- Subaqueous Evidence for Earthquakes, Coseismic Landslides, Tsunamis and other Cascading Hazards
- Time-Dependent Seismic Hazard Assessment: Models, Data and Applications

Oral Sessions

<i>Time</i>	<i>Ballroom A</i>	<i>Ballroom B</i>	<i>Ballroom C</i>	<i>Ballroom D</i>
8:00–9:15 AM	The Landscape Record of Earthquakes and Faulting	ESC-SSA Joint Session: Interpreting Volcanic Unrest and Eruption Data for Effective Crisis Management	International Col-laboration to Advance Earthquake Science and Disaster Response	Physics of Earthquakes: Insights from Theory and Observations
9:15–10:30 AM	Poster Break			
10:30–11:45 AM	The Landscape Record of Earthquakes and Faulting	Advances and New Chal-lenges in Investigating Seismic Site Response	Earthquake Swarms Across the Earthquake Cycle: Precursors, Tran-sients and Aftereffects	Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science
Noon–12:50 PM	Annual Business and Awards Ceremony			
1:00–2:15 PM	Luncheon			
2:15–3:30 PM	The Landscape Record of Earthquakes and Faulting	Advances and New Chal-lenges in Investigating Seismic Site Response	New Developments in Earthquake Rupture Physics For Source Char-acterization and Ground Motion Modeling	Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science
3:30–4:30 PM	Poster Break			
4:30–5:45 PM	Source Properties of Microearthquakes: Insights from Laboratory, Induced and Natural Events	Recent Contributions of Social Science Research to Understanding Earth- quakes	New Developments in Earthquake Rupture Physics For Source Char-acterization and Ground Motion Modeling	Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science
6:00–7:00 PM	Joyner Lecture: Seismic Wave Propagation in Complex Geological Domains: From Site Effects in Ground Motion to Diffuse Fields in Passive Seismology			
7:00–8:00 PM	SSA Honors Reception			

Poster Sessions

- Advances and New Challenges in Investigating Seismic Site Response
- Advancing Earthquake Early Warning: Science, Technology and Engagement in the U.S. and Beyond
- Data-Driven and Computational Characterization of Non-Earthquake Seismoacoustic Sources
- Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science
- Earthquake Ground Motions and Structural Response: Emerging Tools and Applications
- Earthquake Swarms Across the Earthquake Cycle: Precursors, Transients and Aftereffects
- ESC-SSA Joint Session: Interpreting Volcanic Unrest and Eruption Data for Effective Crisis Management
- Evolving Frontiers in Explosion Monitoring and Source Physics
- International Collaboration to Advance Earthquake Science and Disaster Response
- The Landscape Record of Earthquakes and Faulting
- Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cascadia, Chile and Beyond
- Mechanisms and Seismogenic Structure for Large Continental Earthquakes
- New Developments in Earthquake Rupture Physics For Source Characterization and Ground Motion Modeling
- Recent Contributions of Social Science Research to Understanding Earthquakes
- Seismotectonics of Southern and Baja California
- Source Properties of Microearthquakes: Insights from Laboratory, Induced and Natural Events
- SSJ-SSOC-SSA Joint Session: From Slow to Fast Earthquakes: Bridging the Spectrum of Fault Slip

<i>Time</i>	<i>Ballroom E</i>	<i>Ballroom F</i>	<i>Ballroom G</i>	<i>Ballroom H</i>
8:00–9:15 AM	Advancing Earthquake Early Warning: Science, Technology and Engage-ment in the U.S. and Beyond	Data-Driven and Com-putational Characteriza-tion of Non-Earthquake Seismoacoustic Sources	Earthquake Ground Motions and Structural Response: Emerging Tools and Applications	Mechanisms and Seismo-genic Structure for Large Continental Earthquakes
9:15–10:30 AM	Poster Break			
10:30–11:45 AM	Advancing Earthquake Early Warning: Science, Technology and Engage-ment in the U.S. and Beyond	Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cas-cadia, Chile and Beyond	Earthquake Ground Motions and Structural Response: Emerging Tools and Applications	Evolving Frontiers in Explosion Monitoring and Source Physics
Noon–12:50 PM	Annual Business and Awards Ceremony			
1:00–2:15 PM	Luncheon			
2:15–3:30 PM	Advancing Earthquake Early Warning: Science, Technology and Engage-ment in the U.S. and Beyond	Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cas-cadia, Chile and Beyond	SSJ-SSOC-SSA Joint Ses-sion: From Slow to Fast Earthquakes: Bridging the Spectrum of Fault Slip	Evolving Frontiers in Explosion Monitoring and Source Physics
3:30–4:30 PM	Poster Break			
4:30–5:45 PM	Fiber-Optic Sensing Applications in Seismol-ogy and Environmental Science	Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cas-cadia, Chile and Beyond	SSJ-SSOC-SSA Joint Ses-sion: From Slow to Fast Earthquakes: Bridging the Spectrum of Fault Slip	Seismotectonics of Southern and Baja Cali-fornia
6:00–7:00 PM	Joyner Lecture: Seismic Wave Propagation in Complex Geological Domains: From Site Effects in Ground Motion to Diffuse Fields in Passive Seismology			
7:00–8:00 PM	SSA Honors Reception			

Oral Sessions

<i>Time</i>	<i>Ballroom A</i>	<i>Ballroom B</i>	<i>Ballroom C</i>	<i>Ballroom D</i>	<i>Time</i>	<i>Ballroom E</i>	<i>Ballroom F</i>	<i>Ballroom G</i>	<i>Ballroom H</i>
8:00–9:15 AM	On the State of Knowledge/Art/Practice for mHVSr Analyses; A Prelude to the ESG7-COSMOS mHVSr Pre-Event Forum	From Drilling to Ground Shaking: Mechanisms, Monitoring and Mitigation of Induced Earthquakes	Generating, Calibrating and Validating Multi-Scale Seismic Velocity Models	Advancing the U.S. Geological Survey National Seismic Hazard Models	8:00–9:15 AM	Fiber-Optic Sensing Applications in Seismology and Environmental Science	Geophysical Perspectives on Volcanic Systems: Seismicity, Structure and Dynamics		Observation and Analysis of Topography and Deformation: Relating Earthquakes to Cascading Hazards
9:15–10:30 AM	Poster Break				9:15–10:30 AM	Poster Break			
10:30–11:45 AM	On the State of Knowledge/Art/Practice for mHVSr Analyses; A Prelude to the ESG7-COSMOS mHVSr Pre-Event Forum	From Drilling to Ground Shaking: Mechanisms, Monitoring and Mitigation of Induced Earthquakes	Generating, Calibrating and Validating Multi-Scale Seismic Velocity Models	Advancing the U.S. Geological Survey National Seismic Hazard Models	10:30–11:45 AM	Fiber-Optic Sensing Applications in Seismology and Environmental Science	Geophysical Perspectives on Volcanic Systems: Seismicity, Structure and Dynamics	New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets	Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice
11:45 AM–2:00 PM	Lunch Break				11:45 AM–2:00 PM	Lunch Break			
2:00–3:15 PM		SSJ-SSOC-SSA Joint Session: Lessons from Recent Major Earthquake Sequences Around the World	Earthquake Rupture Hazard and Forecasts from Integration of Paleoseismic Datasets	Advancing the U.S. Geological Survey National Seismic Hazard Models	2:00–3:15 PM	Fiber-Optic Sensing Applications in Seismology and Environmental Science	Action at a Distance: Understanding Seismic Triggering	New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets	Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice
3:15–4:30 PM	Poster Break				3:15–4:30 PM	Poster Break			
4:30–5:45 PM		SSJ-SSOC-SSA Joint Session: Lessons from Recent Major Earthquake Sequences Around the World			4:30–5:45 PM	Fiber-Optic Sensing Applications in Seismology and Environmental Science	Southern California Seismicity: Past, Present and Future	New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets	Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice

Poster Sessions

- Action at a Distance: Understanding Seismic Triggering
- Advancing the U.S. Geological Survey National Seismic Hazard Models
- Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice
- Data-Driven Advances in Liquefaction Hazard Analysis
- Earthquake Rupture Hazard and Forecasts from Integration of Paleoseismic Datasets
- Fiber-Optic Sensing Applications in Seismology and Environmental Science
- From Drilling to Ground Shaking: Mechanisms, Monitoring and Mitigation of Induced Earthquakes
- Generating, Calibrating and Validating Multi-Scale Seismic Velocity Models
- Geophysical Perspectives on Volcanic Systems: Seismicity, Structure and Dynamics
- New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets
- Observation and Analysis of Topography and Deformation: Relating Earthquakes to Cascading Hazards
- On the State of Knowledge/Art/Practice for mHVSr Analyses; A Prelude to the ESG7-COSMOS mHVSr Pre-Event Forum
- Recent Research on Ground Motion Directionality
- Southern California Seismicity: Past, Present and Future
- SSJ-SSOC-SSA Joint Session: Lessons from Recent Major Earthquake Sequences Around the World

Wednesday, 15 April 2026—Oral Sessions

Presenting author is indicated in bold.

<i>Time</i>	<i>Ballroom A</i>	<i>Ballroom B</i>	<i>Ballroom C</i>	<i>Ballroom D</i>	<i>Time</i>	<i>Ballroom E</i>	<i>Ballroom F</i>	<i>Ballroom G</i>	<i>Ballroom H</i>
	Regional Source, Path and Site Effects in Earthquake Ground Motions (see page 1524).	ESC-SSA Joint Session: Advanced Methods for Harnessing Seismic Noise Analysis in Applied Seismology (see page 1403).		Physics of Earthquakes: Insights from Theory and Observations (see page 1506).		Network Seismology: Recent Developments, Challenges and Lessons Learned (see page 1469).	Planetary and Gravitational Wave Seismology (see page 1515).	Physical Properties of Fault Zones from the Seismic Source to Earth's Surface (see page 1500).	New Possibilities for InSAR in Earthquake Science: the NISAR Mission and OPERA Displacement Maps (see page 1491).
8:00 AM	Analysis of Rupture Directivity and Wave Propagation Effects on Simulated Ground Motion for M7 Earthquakes on the Hayward Fault. Nakata, R. , McCallen, D., Pitarka, A., Tang, H., Pinilla Ramos, C.	Performance Assessment of the Hybrid Standard Spectral Ratio Approach in the Norcia Basin, Central Italy. Panzer a, F. , Borzi, A., Amiri Fard, R., Parolai, S.		INVITED: Inference of Absolute Stress From Earthquake-induced Stress Rotations in Subduction Zones. Hardebeck, J.	8:00 AM	Evaluation of Distributed Acoustic Sensing Phase Pick Quality and Performance for Operational Earthquake Monitoring. Tepp, G. , Artiaga, N., Biondi, E.	Seismic Evidence for Widespread Mantle Heterogeneity on Mars. Charalambous, C. , Pike, W. T., Kim, D., Samuel, H., Fernando, B., Bill, C., Lognonné, P. H., Banerdt, B. W.	INVITED: Trigg	A GNSS-based Time-variable Surface Displacement Product for OPERA DISP InSAR Corrections. Hammond, W. C. , Govorcin, M., Blewitt, G., Kreemer, C., Mirzaee, S., Oliver-Cabrera, T., Cinquini, L., Chan, S., Handwerger, A. L.
8:15 AM	On the Scalability of Non-ergodic GMMs From Numerical Simulations: A Case Study Using the SCEC Cybershake Dataset and Southern California Power Network. Zhao, J. , Lavrentiadis, G., Asimaki, D.	Improved Bedrock Mapping in the Upper Mississippi Embayment, Kentucky, Using Ambient Noise HVS		Stress Orientation Around Japan Trench Inferred From Focal Mechanism Solutions of Small Earthquakes. Uchide, T. , Imanishi, K.	8:15 AM	Optimizing Station and Source Graphs for Graph-based Earthquake Phase Association. McBrearty, I. W. , Beroza, G. C.	Insights Into Martian Crustal Formation Through Seismic Anisotropy. Beghein, C. , Li, J.	STUDENT: How Depth-dependent Seismic Properties Control Fault Damage Zone Structure: Insights From 3D Damage-breakage Rheology Model. Zhao, C. , Ben-Zion, Y., Elbanna, A.	New Fringes: Earthquake Monitoring in Vegetated Regions With NISAR. Zebker, M. , Sandwell, D.
8:30 AM	STUDENT: Comprehensive Ground Motion Analysis in the Mendocino Fracture Zone. Rajasekhar, A. , Parker, G. A., Hirakawa, E. T., Baltay, A.	Ambient Seismic Imaging of Subsurface Fractures at the Newberry Volcano Geothermal Field Using the Method of Permeable Fracture Imaging. Malin, P. , Eppink, J., Fleure, T., Mathews, A., Mclain, B., Ontiveros, H., Sicking, C., Stroujkova, A., Valenzuela, S., Vermilye, J.		STUDENT: Coseismic Stress Field Perturbations From the 1999 Chi-Chi and 2024 Hualien Earthquakes, Taiwan. Wang, R. , Houston, H., Hsu, Y.	8:30 AM	Source Type Classification of Non-earthquake Signals Commonly Recorded on Regional Seismic Networks: Implementation and Pipeline Development. Toney, L. , Allstadt, K., Collins, E., Yeck, W. L.	New Magnitude Scaling and Seismic Source Characterization for Marsquakes and Impacts. Song, J. , Kim, D., Tsai, V. C., Kolawole, F.	Influence of Fault Roughness Coupled With Shear-induced Inelastic Dilatancy on Earthquake Sequences. Abdelmeguid, M. , Lapusta, N.	NISAR Urgent Response Products for Earthquakes. Fielding, E. J. , Jones, C. E., Simons, M., Agrawal, R., Borsa, A., Bekaert, D., Chen, J., Fattahi, H., Govorcin, M., Havazli, E., Jasir, M. C. M., Jung, J., Lobos, D. A. L., Lohman, R. B., Meyer, F. J., Pritchard, M. E., Rosen, P. A., Sreejith, K. M., Tymofyeyeva, E., Zebker, H.
8:45 AM	Application of Non-ergodic Site Response Analysis to Seismic Retrofit Projects in Los Angeles. Hudson, K. S. , Stewart, J. P., Hudson, M. B.	Estimation of the Complex Site Response Including Cross-coupling Effects: Toward the Calculation of Virtual Seismograms. Amiri Fard, R., Parolai, S. , Panzera, F., Romanelli, F.		STUDENT: Sensitivity of Co-seismic Displacements to Volumetric Components in Intermediate and Deep Earthquake Sources. Chen, S. , Park, S.	8:45 AM	Phase Picking Beyond Local Distances: Where Waveform Filtering Still Matters. Park, Y. , Alfaro-Diaz, R., Begnaud, M. L.	Updating Venus’ Predicted Seismicity Using New Global Wrinkle Ridge Map Generated Using Machine Learning. Sabbeth, L., Smrekar, S. E., Stock, J. M.	STUDENT: Dilatan	Mapping Creep Along the Central San Andreas Fault Using NISAR and ALOS-2. Tymofyeyeva, E. , Liu, Z., Zinke, R., Rosen, P. A.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
9:00 AM	Regional Source, Path and Site Effects (continued)	ESC-SSA Joint Session (continued)		Physics of Earthquakes: Insights (continued)		Network Seismology (continued)	Planetary and Gravitational Wave Seismology (continued)	Physical Properties of Fault Zones (continued)).	New Possibilities for InSAR (continued)
	STUDENT: Spatial and Azimuthal Variability of Seismic Site Response in the Los Angeles Basin Revealed by a Sub-basin Framework. Shams, R. , Nweke, C. C.	STUDENT: Monitoring Seasonality and Directionality in Ambient Seismic Noise Generated by Africa’s Circumfluent Oceans. Kabanda, A. , van der Lee, S.		Stress Variations and Non-shear Earthquakes Prior to the 2021 Iceland Eruption: Implications for Magmatic Fluid Flow Dynamics. Hrubcova, P. , Vavrycuk, V., Fischer, T. J., Doubravova, J.	9:00 AM	Background Seismicity, Swarms and Fluid-injection Induced Earthquakes in New Mexico: New Constraints from USArray Data. Woo, J. , Chen, T.	From Deep Space to Deep Earth - How the Earth Shapes the Way in Which We Observe the Cosmos. Di Giovanni, M.	INVITED: Rapid Fault Healing From Cementation Controls the Dynamics of Deep Slow Slip and Tremor. Thomas, A. M. , Watkins, J. M., Beeler, N. M., French, M. E., Behr, W. M., Reed, M. H.	Incorporating NISAR to Resolve Three-dimensional Fault and Landslide Deformation. Xu, Y. , Simons, M., Fielding, E. J., Bürgmann, R., Guo, A., Lindsay, D., Handwerger, A. L.
9:15–10:30 AM	Poster Break				9:15–10:30 AM	Poster Break			
	Regional Source, Path and Site Effects in Earthquake Ground Motions (see page 1524).	Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches (see page 1345).		Physics of Earthquakes: Insights from Theory and Observations (see page 1506).		Network Seismology: Recent Developments, Challenges and Lessons Learned (see page 1469).	Planetary and Gravitational Wave Seismology (see page 1515).	Physical Properties of Fault Zones from the Seismic Source to Earth’s Surface (see page 1500).	Fault Networks and Seismic Hazard in the Nevada-California Borderland (see page 1416).
10:30 AM	Understanding the Regional Variability of Ground Motion Across South America for Subduction Earthquakes. Paredes Estacio, J. L. , De Risi, R.	Version 2 of an Integrated Earthquake Catalog for Aotearoa New Zealand and 3D Earthquake-depth Models. Rollins, C. , Manea, E., Thingbaijam, K., Graham, K., Salichon, J., Williams, C., Rampersad, A., Hutchinson, J., Bourguignon, S., Eberhart-Phillips, D., Christophersen, A., Bradley, B. A., Chamberlain, C. J., Gerstenberger, M. C.		INVITED: Accounting for Site Effects Significantly Reduces Uncertainties in Earthquake Stress Parameters. Archuleta, R. J. , Ji, C.	10:30 AM	SCSN Live: A Realtime View of the Network. Acharya, P. , Yu, E., Husker, A.	Geophysical Site Investigation for a Future Einstein Telescope (ET) in Lusatia, Saxony, Germany. Rietbrock, A. , Haberland, C., Ryberg, T., Yao, S., Lindner, M.	STUDENT: Linear Streaks of Seismicity Around California. Shrestha, R. , Bürgmann, R., Ross, Z. E.	STUDENT: Characterizing Walker Lane Aftershock Geometry and Productivity with a Novel High-resolution Catalog of the 2020 Mw 6.5 Monte Cristo Earthquake. Zhang, M. , Trugman, D. T., Scalise, M. E., Eckert, E. E.
10:45 AM	STUDENT: Source Parameters, Attenuation Characteristics and Site Effects Derived From the Non-parametric Generalized Inversion Technique (GIT) for the Mw 8.8 Maule Aftershock Sequence. Flores Allende, R. , Seydoux, L., Bonilla, L. F., Bindi, D., Beauce, E., Gueguen, P.	Should the CEUS SSC Model Be Updated? Arcos, M. , Coppersmith, K., Coppersmith, R., Montaldo Falero, V., Youngs, R.		An Entropic Origin for Gutenberg-Richter Scaling. Page, M. , Field, E. H.	10:45 AM	Webservices of the Italian National Accelerometric Network - RAN. Franke, M. , Filippi, L., Zambonelli, E., Manto, L., Ammirati, A., Radman, S. M.	Fundamental Noise and Gravitational-wave Sensitivity of the Laser Interferometer Lunar Antenna (LILA). Jani, K. , Creighton, T., Quetschke, V., Panning, M. P., Lognonné, P. H., Trippe, J.	Correlation Between Anisotropic Crustal Fabric Strength and Fault Creep. Schulte-Pelkum, V. , Kilb, D., Becker, T. W.	Evaluation of Complex Transtensional Fault Systems Distributed Between Lake Almanor and Madeline, Northeastern California. Koehler, R. D.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	Regional Source, Path and Site Effects (continued)	Advancing Seismic Hazard and Risk Assessment (continued)		Physics of Earthquakes (continued)		Network Seismology (continued)	Planetary and Gravitational Wave Seismology (continued)	Physical Properties of Fault Zones (continued)	Fault Networks and Seismic Hazard (continued)
11:00 AM	Regionalizing NGA-Sub Ground-motion Models for Chile: Source and Path Adjustments. Cáceres, C., Villanueva, F, Contreras, V.	Developing Strong Motion Data Platform for Ground-motion Model Project in Japan. Iwaki, A. , Morikawa, N., Matsumoto, Y., Imai, R., Akiyama, S., Suzuki, W., Kubo, H., Senna, S., Kawai, S., Nakamura, H., Fujiwara, H.		STUDENT: Global Repeating Earthquakes Reveal a Scattered Triangular Recurrence Time–moment Scaling Consistent with Crack Models in a Complex Fault Zone. Wang, B. , Wu, B., Zhou, Y.	11:00 AM	The GRMT Project: Global Real-time Centroid Moment Tensor Analysis for Significant Earthquakes. Lee, S. , Liu, T., Lin, T.	Thermoelastic Perturbations in Lunar Regolith: An Analytical Model for Surface Shielding. Kizhaekke Pakkathillam, S. , Ann Joseph, A., H Lognonné, P.	Exploring (A)seismic Slip and Off-fault Deformation Caused by the 2021 Mw5.3 Calipatria Earthquake, Salton Sea, CA. Guns, K. , Materna, K., Barbour, A. J., McGuire, J. J.	Estimating Long-term Fault Slip Rates Using Geomorphological Evidence. Mason, H. B. , Struble, W. T., McCoy, S. W., Gregory, L. C., Tucker, G. E.
11:15 AM	Nonergodic Ground-motion Models for Subduction Events in Alaska. Sung, C. , Abrahamson, N., Largent, M.	Scenario ShakeMaps for Cascadia Subduction Zone Megathrust Earthquakes Using 3D Ground Motion Simulations. Dunham, A. , Wirth, E. A., Grant, A., Frankel, A. D.		The Time Clustering of Earthquakes. Frank, W. B. , Münchmeyer, J.	11:15 AM	ISC: Collaborating with Seismic Networks Worldwide. Storchak, D. A. , Harris, J., Di Giacomo, D., Garth, T., Gallacher, R.	South Pole Seismic Station (SPSS): An Active and Passive Seismic Deployment for Artemis IV Astronauts. Panning, M. P. , Nunn, C., Lognonné, P. H., Tsuji, T., Abe, S., Cutler, J., Delbo, M., Drilleau, M., Garcia, R., Kawamura, T., Knapmeyer-Endrun, B., Podgornova, O., Tanaka, S., Avdellidou, C., Beucler, É., Jani, K., Mimoun, D. C.	Estimate of Inelastic Strain and Fault Zone Damage Due to Aftershocks. Fialko, Y.	STUDENT: Improving Reno Earthquake Hazard Assessment Through Ground-motion Model Comparisons and a Paleoseismic Study. Dills, C. W. , Trugman, D. T., Koehler, R. D., Rodrigues, K., Wesnousky, S. G.
11:30 AM	Short-distance Attenuation Characteristics of Ground Motions for Induced Earthquakes in South Sichuan, China. Xie, J. , Wu, F., Wang, Y., Zhu, C., Kwak, D.	Development of Stochastic Ground-motion Models for a Reference Rock Condition in South Korea. Park, S. , Noh, M., Min, K., Han, S.		STUDENT: Gutenberg–Richter or Safer? On the Magnitude–frequency Distributions of Induced Seismicity. Li, L. , Avouac, J., Im, K.	11:30 AM	How Not to Be Fooled by Seismicity Depth Distribution: Lessons From the 2023 Kahramanmaraş (Se Türkiye) Aftershock Sequence. Ding, H., Zhou, Y. , Ge, Z.	Lunar DAS: Compact Fiber-optic Sensing to Map the Moon’s Interior. Zhan, Z. , Costa, L., Fu, X., Husker, A., Jackson, J. M., Klesh, A., Kubiak, G., Lefler, C., Steinkraus, J., Stubailo, I., Tamama, Y., Wang, J., Zhai, Q.	Effects of Non-causative Fault Zones on Ground-motion Path Effects: A Simulation Study. Nye, T. , Hirakawa, E. T., Parker, G. A., Baltay, A.	Automated Extraction of Surface Fault Rupture Profiles for Fault Displacement Hazard Analysis. Boggaram, S. , Lavrentiadis, G., Asimaki, D., Reitman, N. G.
11:45 AM–2:00 PM	Lunch Break				11:45 AM–2:00 PM	Lunch Break			

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	Regional Source, Path and Site Effects in Earthquake Ground Motions (see page 1524).	Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches (see page 1345).		Physics of Earthquakes: Insights from Theory and Observations (see page 1506).		Network Seismology: Recent Developments, Challenges and Lessons Learned (see page 1469).	Cryoseismology: Advances in Technology and Scientific Discovery (see page 1367).	Earth’s Structure from the Crust to the Core (see page 1397).	Fault Networks and Seismic Hazard in the Nevada-California Borderland (see page 1416).
2:00 PM	STUDENT: Do 3D Dynamic Rupture Models Capture the Variability in Long-period Velocity Pulses? Insights From the 2023 Mw 7.8 Kahramanmaraş Earthquake. Preca Trapani, R. , Marchandon, M., Palgunadi, K. H., Wu, B., Yen, M., Cotton, F., Gabriel, A.	Seismic Hazard Evaluation Based on Ground-motion Waveforms Using Machine Learning Techniques. Matsumoto, Y. , Yaoyama, T., Lee, S., Iwaki, A., Itoi, T.		Impact of Lithospheric Anisotropy on Moment Tensors: Toward Anisotropic Earthquake Seismology. Kawakatsu, H. , Takeo, A.	2:00 PM	Evidence-based Seismic Impact of Wind Farms and Borehole Sensor Performance at the EKA Array. Hasting, M. A. , Suárez, G.	INVITED: Integrated Seismic and Space Geodetic Remote Sensing of Tidewater Glacier Calving in Greenland. Borsa, A. , Fan, W., Davidson, H.	INVITED: Complex Lithospheric Structure of North America Revealed by a New Sp Receiver Function Stack. Golos, E. , Brunsvik, B., Eilon, Z., Fischer, K. M.	STUDENT: Principal Surface Rupture Hazard: Moving Beyond Aggregate Displacement Metrics. Marmarchinia, S. , Lavrentiadis, G.
2:15 PM	STUDENT: Ground Motion Directionality of Horizontal Response Spectral Ordinates From the 2023 Kahramanmaras, Türkiye Earthquake Sequence. Girmay, N. , Poulos, A., Miranda, E.	Enhancing Reference Ground Motions: Isolating Site Effect-free Time Series via Application of the Complex-valued Generalized Inversion Technique. Pilz, M. , Cotton, F.		Characterization of Seismic Sources in the Middle East Using 3D Velocity Models: Current Capabilities and Frontiers. Rodriguez-Cardozo, F. R. , Braunmiller, J., Sawade, L., Orsvuran, R., Bozdag, E., Ghods, A., Thurin, J., Hu, J., Pham, T., Tkalčić, H., Tape, C.	2:15 PM	Measurements of the Magnetic Sensitivity of Geophysical Instruments. Bloomquist, D. K., Merchant, B. J.	Searching for Glacier-related Seismic Events in Greenland with Waveform Similarity and Machine Learning. Tan, F. , Fan, W., Shearer, P. M.	Seismic Evidence for Slab Breakup Triggering Deep Mantle Upwelling Beneath Central America. Yuan, M., Yu, C. , Jing, Z.	STUDENT: Challenges and Opportunities for Earthquake Early Warning in Nevada. Kinkel, D. , Trugman, D. T.
2:30 PM	Estimating Systematic Source, Site, and Path Effects in Non-ergodic Ground Motion Models: Insights From the Turkish Ground Motion Database. Liu, C. , Macedo, J.	STUDENT: Using “Did You Feel It?” Data to Map Spatially Variable Site Amplification in the Central and Eastern United States. Meyer, E. H. , Baise, L. G., Kaklamanos, J., Pezeshk, S., Roberts, M. E., Nie, S.		Inconsistencies in Moment Magnitude Estimates and How to Fix Them. Trugman, D. T. , Ben-Zion, Y.	2:30 PM	A Frequency Response Model for Passive Seismometers With Complex Impedance Damping. Merchant, B. J. , Bloomquist, D. K.	Seismic Evidence of Widespread Sediments Beneath the Greenland Ice Sheet. Yang, Y. , Fan, W., Behn, M. D., Das, S. B., McGuire, J. J.	STUDENT: Unified Mapping of the African Rift System: Lithospheric Strength and Magmatic Evolution. Maenner, M. E. , Legre, J., Stamps, D. S., Adams, A., Olugboji, T.	Seismic Faults Inside Principal Underground Laboratory for Subcritical Experimentation at the Nevada National Security Site. Li, Y. , Dacayanan, H., Jackson, R., Powers, A., Thangavelu, S.
2:45 PM	Using Earthquake Clustering to Minimize Between-event Ground-motion Residuals for Continental Australia. Allen, T. I.	On Implementing the International Macroseismic Scale (IMS) in the United States and Canada. Wald, D. J. , Hortacsu, A., Porter, K., Hobbs, T. E.		Enigmatic Seismic Excitation of the 1957 Andreanof, Aleutian is., Earthquake. Kanamori, H. , Rivera, L.	2:45 PM	Scoring the Quality of Ground Motion Records. Thompson, E. M. , Steidl, J. H., Aagaard, B. T., Hearne, M., Smith, J. A., Withers, K. B., Moschetti, M. P., Schleicher, L. S.	Monitoring Changes in the Greenland Ice Sheet Using Seismic Waves. Zhu, H. , Zhao, S., Luo, B.	Reflection Seismic Profiling of Mantle Structure Under the Contiguous United States From Ambient Noise Cross-correlation. Shearer, P. M. , Fan, W., Wei, S. S., Rychert, C. A.	Fault Geometry From 12 Years of Relocated Earthquakes (2013-2025) Near Lake Almanor, Northern California, Reveals a Connection at Depth Between Two Mapped Surface Faults. Yoon, C. E. , Skoumal, R. J., Hardebeck, J., Catchings, R. D., Goldman, M., Chan, J., Sickler, R.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
3:00 PM	Regional Source, Path and Site Effects (continued).	Advancing Seismic Hazard and Risk Assessment (continued)		Physics of Earthquakes (continued)
	Preliminary Regionally Adjustable Models for Effective Amplitude Spectra Based on the NGA-West3 Dataset. Parker, G. A. , Atkinson, G. M., Baltay, A., Boore, D. M., Buckreis, T. E., Stewart, J. P.	Probabilistic Seismic Hazard Assessment for Mainland France and the French Lesser Antilles Islands. Beauval, C. , Mariniere, J., López Ordóñez, S., Alloncle, M., Bertil, D., Bonami, T., Corbeau, J., Foix, O., González, O., Jeandet, L., Hoste-Colomer, R., Jomard, H., Reddy Kotha, S., Lemoine, A., Lambotte, S., Laurendeau, A., Masson, F., Maufroy, E., Mazzotti, S., Métois, M., Periollat, A. J., Philippon, M., Roulle, A., Satriano, C., Saurel, J., Shible, H.		Enigmatic Seismic Excitation of the 1957 Andreanof, Aleutian is., Earthquake. Kanamori, H. , Rivera, L. (Continued)
3:15– 4:30 PM	Poster Break			
	Seismology for All: Expanding STEM Education Through Accessible Tools and Global Collaboration (see page 1530).	Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches (see page 1345).	Detecting, Characterizing and Monitoring Mass Movements (see page 1375).	Physics of Earthquakes: Insights from Theory and Observations (see page 1506).
4:30 PM	INVITED: Recruitment by Design: Making Seismology and Scientific Computing Accessible and Engaging Through the Seismology Skill Building Workshop. Hubenthal, M. , Brudzinski, M., Haberli, G., Meyer, E. H., Ventura-Valentin, W., Sultana, N.	STUDENT: Probabilistic Seismic Hazard Assessment in Guatemala Incorporating Geodetic Data for Crustal Faults and Subduction Zone. Arroyo-Solórzano, M., Gamboa-Canté, C. , Maurer, J., Flores, O., Benito, M. B., Cotton, F.	Modeling Tilt From Near-source Broadband Seismic Records of Lahar and Pyroclastic Density Currents at Volcán De Fuego, Guatemala. Waite, G. P. , Bejar-Lopez, G., Krier, J. A.	Are Stress Drops Magnitude-independent? Insights From Seismological Stress-drop Estimates for Earthquake Sources Simulated on Rate-and-state Faults. Lapusta, N. , Lin, Y., Schaal, N.
	Riding Waves for STEM: Earthquake Location for Dummies. Pascale, A.	Ontological Testing of Seismic Hazard Models. Marzocchi, W. , Herrmann, M., Jordan, T. H.	Why Do Some Landslides Give Warning Prior to Failure? Characteristics of Precursory Seismic Sequences in Landslides. Caplan-Auerbach, J. , John, S., Pierce, E., West, M. E., Karasozen, E.	Predicting the Depth Scaling of Stress Drop From a Model of Elastic Loading. Tsai, V. C. , Lee, J., Faulkner, D. R., Hirth, G., Aso, N.

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
3:00 PM	Network Seismology (continued)	Cryoseismology (continued)	Earth’s Structure (continued)	Fault Networks and Seismic Hazard (continued)
	Revolutionizing Borehole/ Posthole Installations: Self-orienting Seismic System. Bainbridge, G. , Somerville, T., Pelyk, N.	Internal Structures and Seasonal Variations in Antarctica and Greenland Revealed by Teleseismic P- and S-wave Autocorrelations. Pham, T. , Sanjayan, A., Tkalčić, H.	STUDENT: Hierarchical Bayesian Joint Inversion of HVSR and Surface Wave Data for Multi-scale Crustal Imaging of the Lower Appalachians & Atlantic Coastal Plain Sediments. Rotimi, B. I. , Russell, J. B.	Rupture Process of the M5.7 December 9, 2024 Parker Butte, Nevada, Earthquake. Pollitz, F. F. , Guns, K., Hammond, W. C., Trugman, D. T.
3:15– 4:30 PM	Poster Break			
	Subaqueous Evidence for Earthquakes, Coseismic Landslides, Tsunamis and other Cascading Hazards (see page 1552).	Cryoseismology: Advances in Technology and Scientific Discovery (see page 1367).	Earth’s Structure from the Crust to the Core (see page 1397).	Time-Dependent Seismic Hazard Assessment: Models, Data and Applications (see page 1557).
4:30 PM	Submarine Faulting and Landslide Deposits in the Outer California Borderland, Southern California. Maloney, J. , Fabbrizzi, A.	Monitoring Glacial Grounding Zone Icequakes With Fiber-optic and Dense Seismic Arrays. Zhang, H. , Zhai, Q., Reid-McLaughlin, A. M., Park, S., Chamberlin, T., Luis, L., Kubiak, G., Leffler, C., Steinkraus, J., Klesh, A., Kaip, G., Zhan, Z.	Imaging the Architecture of the Main Himalayan Thrust in Central Nepal With 3D Local Earthquake Tomography. Douilly, R. , Mendoza, M. M., Ghosh, A., Lee, H.	A Three-dimensional Diffusion Model for Spatiotemporal Aftershock Forecasting Applied to Taiwan Seismicity. Ku, H., Phoa, F.
	Lack of Empirical Links Between Shaking and Turbidity Current Generation in Barkley Canyon, Cascadia Subduction Zone. Sahakian, V. J. , Kilb, D., Ogston, A. S., Chaknova, M., De Leo Cabrera, F., Walczak, M., Hill, J. C.	Single-station Characterization of Tidally Triggered Icequakes Across the Grounding Line of the Ross Ice Shelf at Roosevelt Island, Antarctica. Garza-Giron, R. , Aster, R. C.	Subtle Long-wavelength Topography of the Earth’s Core-mantle Boundary. Chen, Y. , Wu, W., Zhang, B., Ni, S., Chu, R., Mao, W., Zhang, H.	The Modulation of Microseismicity by the Solid Earth Tides Characterizes Fault Zone Physics and May Help With Physics-based, Time-dependent Seismic Hazard Assessment. Beauce, E. , Waldhauser, F., Poli, P.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
	Seismology for All (continued)	Advancing Seismic Hazard (continued)	Detecting (continued)	Physics of Earthquakes (continued)
5:00 PM	Toward Developing Local, Impactful Earthquake Science Projects With Community Engagement. Velasco, A. A. , Garcia, M. A., April, L., Karplus, M.	Assessing Seismic Risk in the United States. Jaiswal, K.	STUDENT: Precursory Earthquakes From the Tracy Arm Landslide. John, S. , West, M. E., Caplan-Auerbach, J., Karasozen, E.	Constraining Earthquake Stress Drop Methods Using Stochastic Simulations. Baltay, A. , Abercrombie, R. E., Shearer, P. M., Bindi, D., Cochran, E. S.
5:15 PM	STUDENT: Expanding Earthquake Science Education With Quakeworx Interactive Web-based Tools. Rekoske, J. M. , Kutschera, F., Yun, J., Oryan, B., Gabriel, A., May, D. A., Chourasia, A., Youn, C., Silva, F., Zhao, C., Tainpakdipat, N., Bhatthal, A., Serafini, F., Ronquillo, J., Winjum, B., Maechling, P. J., Elbanna, A., Ben-Zion, Y.	Financial Recovery Modelling for Earthquake Risk in Canada. Hobbs, T. E.	STUDENT: Landslide Seismicity Records Slip Events on Lateral Shear Margins and on Internal Faults Accommodating Longitudinal Extension. Iwasaki, Y. , Schwartz, S., Finnegan, N.	STUDENT: Breaking the Cubic Dependence: Stabilizing Earthquake Stress Drop Estimates via Asymptotic Spectral Ratios. Knudson, T. , Ellsworth, W. L., Beroza, G. C., Shaw, B. E.
5:30 PM	STUDENT: Student Perspectives on Increasing STEM Engagement and Lowering Barriers to Seismology. Robinson, B.	Urban-scale Seismic Modeling Reshapes Risk Priorities in Basel, Switzerland. Imtiaz, A. , Papadopoulos, A. N., Fäh, D.	Systematic Detection of Glacial Earthquakes in Thwaites Glacier, West Antarctica, by Regional Surface Waves. Pham, T.	Focal Mechanisms in the Southeastern South Island of Aotearoa New Zealand Indicate Scale-dependent Partitioning of Transpressional Strain. Williams, J. N. , Eberhart-Phillips, D., Bourguignon, S., Stirling, M. W., Reyners, M., Upton, P.
6:00–7:00 PM	Panel Presentation: Building a Resilient Future: What New Research Directions, Technology Developments and Partnerships are Needed?			

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	Subaqueous Evidence for Earthquakes (continued)	Cryoseismology (continued)	Earth's Structure (continued)	Time-Dependent Seismic (continued)
5:00 PM	INVITED: STUDENT: Distinguishing Earthquakes From Flood Deposits in a Submarine Canyon Head: Implications for the Marine Paleoseismic Record. Lahr, E. , Hill, J. C., Ogston, A. S., Moore, G.	INVITED: STUDENT: Strength and Seismic Properties of Ross Ice Shelf Ice Rifts Constrained through Joint Seismic and Geodetic Deployments. Udell-Lopez, K. , Huang, M., Schmerr, N., Lekíc, V., Dapré, K., Schlossnagle, Z., Harkleroad, E., Eisl, S., Hurford, T.	Rank-reduction Based Uncertainty Quantification for FWI. Keating, S. , Zunino, A., Fichtner, A.	Time-dependent Ground-motion Scenarios for Large Megathrust Earthquakes and Mature Seismic Gaps Along the Chilean Margin. Ojeda, J. , Montalva, G. A., Osses-Valenzuela, M., Bastías, N., Leyton Flórez, F., Heresi, P., Jünemann, R., Calderón, S.
5:15 PM	Lacustrine Record of Paleoseismicity in the Patagonian Andes South of the Chile Triple Junction: Evidence of Seismic Activity From a Silent Subduction Zone. Magnani, M. , Villalobos Claramunt, A., Ito, E.	STUDENT: Large-N Seismic Nodes and Broadband Observations at the South Pole: Enabling High-resolution Cryoseismology in Extreme Polar Environments. Wu, H. , Shen, W.	Constraining Slab Geometry and Seismic Velocity Structure From Tillamook to Portland, Oregon. Wirth, E. A. , Trehu, A. M., Stone, I., Hooft, E. E. E., Ward, K.	Assessing Temporal Variations of H/V Spectral Ratio From Long-term Seismic Noise Records. Leyton Flórez, F. , Pasten, C., Montalva, G. A., Heresi, P.
5:30 PM	Post-glacial Seismoturbidite Deposits in Ozette Lake, Washington, Reveal Clustering and Bi-modal Recurrence of Strong Shaking During the Last 14,000 Years. Brothers, D. S. , Padgett, J., Singleton, D. M., Sherrod, B., Kluesner, J., Derosier, B., Hill, J. C., LeSelle, S.	Development and Deployment of the Deep (2.46 Km) Ice Seismometer at South Pole, Antarctica. Anthony, R. E. , DuVernois, M., Grulke, S., Weber, J., Stoup, V., Sandstrom, P., Bainbridge, G., Braun, J., Cherwinka, J., Kelley, J., Chan, J., Griffin, S. C., Auer, R., Bastien, P., Karle, A., Kromer, E., Ng, C., Quiros, F., Tanner, G. C., Telesha, T., Tosi, D., Trerice, N., Patton, J. V., Wilson, D. C.	Modelling 3D Teleseismic Waveforms Above 1 Hz Using a SEM–DSM Hybrid Method. Wu, W.	STUDENT: Non-Poisson Probabilistic Seismic Hazard Analysis. Largent, M. , Abrahamson, N.
6:00–7:00 PM	Panel Presentation: Building a Resilient Future: What New Research Directions, Technology Developments and Partnerships are Needed?			

Poster Sessions

Cryoseismology: Advances in Technology and Scientific Discovery (see page 1370).

1. Source Study of Ice-quakes in a Ross Ice Shelf Rift. **Aziz Zanjani, F.**, Wiens, D. A., Wysession, M. E.
2. STUDENT: Basal Icequake Detection at Eastern Shear Margin of Thwaites Glacier, Antarctica. **Fleenor, D.**, Walter, J., Smith, E. C., Karplus, M., Gonzalez, L., Longhauser, W., Miller, N.
3. STUDENT: Wind-wave Scaling in Antarctic Coastal Polynyas From Microseism Observations. **Yang, M.**, Williams, E. F.
4. Seismic Full-wavefield Imaging of the West Antarctica Ice Sheet. **Zhang, Z.**, Nakata, N., Wei, S., Liu, Y.
5. Using Ambient Seismic Noise to Characterize the Polar Environment Near Baffin Bay. **Gong, J.**

Network Seismology: Recent Developments, Challenges and Lessons Learned (see page 1472).

6. Earthquake Detection, Classification and Location in the Wabash Valley Seismic Zone. **Gong, J.**
7. ANSS Station Information System: A Centralized Station Metadata Repository for Populating, Managing and Distributing Seismic and GNSS Station Metadata. **Acharya, P.**, Yu, E., Kientz, S., Alvarez, M., Husker, A.
8. Using Version Control to Manage Seismic Software Configurations. **Antolik, L.**, Friberg, P. A., Lisowski, S. W.
9. Combining Strong and Weak Motion Data, with Amplitude Ratio as a New State of Health Metric. **Bainbridge, G.**, Perlin, M., Somerville, T., Pelyk, N.
10. Earthquake Source Depth Refinement in France and Nearby Regions. **Barkat, A.**, Zhang, M., Li, W., Arroucau, P.
11. Building a Stronger Seismic Network for Statewide Earthquake Monitoring in New Mexico. **Basu, U.**, Record, A., Ochoa, E.
12. Incorporating Machine Learning to Improve Monitoring at the Southern California Seismic Network (SCSN). **Bhadha, R.**, Black, M. L., Jones, A., Good, A. D., Tam, R. W., Yu, E., Tepp, G., Husker, A.
13. Recent Innovations and Improvements for Real-time Operations at the Southern California Seismic Network (SCSN). **Bhadha, R.**, Watkins, M., Black, M. L., Stubailo, I., Hoggro, C., Jones, A., Husker, A.
14. Architecture and Infrastructure of the Southern California Earthquake Data Center (SCEDC). **Chen, S. E.**, Yu, E., Bhaskaran, A., Dungan, S., Pinkston, D., Husker, A.
15. Phase Associator Comparison for Small Scale Seismic Networks. **Friberg, P. A.**, Dzubay, A. J., Stachnik, J., John, S.

16. Ultra Low Power, High Resolution Standalone Seismic Digitizer. Germenis, N. G., **Friberg, P. A.**
17. Ultra Low Power, Standalone Wide-band Miniature Seismometer. Germenis, N. G., **Friberg, P. A.**
18. A New Local Magnitude Scale for Alaska. **Gossett, D.**, Karasozen, E., Holland, A. A., McFarlin, H., West, M. E.
19. Architecture of Generation 3 Real-time System at the Alaska Earthquake Center. **Holland, A. A.**, West, M. E., Murphy, N. W., McFarlin, H., Gossett, D., Karasozen, E.
20. Monitoring Network and Station State of Health with Grafana. **Kessinger, J.**, Acharya, P., Stubailo, I., Bhadha, R., Watkins, M., Yu, E., Ramsay, J., Husker, A.
21. Shaking Intensity Parameters Computed at Seismic Sensor Sites for Real-time Monitoring: Application to the Community Seismic Network. **Kohler, M.**, Banda, E., Guy, R., Clayton, R. W., Yu, E.
22. Multidisciplinary Stations: A Next Generation Tool Kit for Geoscience. **Laporte, M.**, Somerville, T., Perlin, M., Easton, D., Pelyk, N., Jusko, M.
23. Practical Digitizer Testing: The Albuquerque Seismological Laboratory Digitizer Test Suite. **Litherland, M.**, Bastien, P., Beutel, C., Holcomb, A., Holland, J., Kearns, A., Kromer, E., Podmore, I., Ringler, A.
24. A Seismic Network Assessment for Prioritizing Analog Upgrades Based on Pick-ability and Location Performance. **Morton, E. A.**, Trow, A. J., Wilson, D. C., Pankow, K.
25. STUDENT: Training and Performance of Machine Learning Pickers With Alaska-specific Data. **Noel, S. K.**, West, M. E.
26. STUDENT: The RAII-UABC Urban Accelerometric Network: Real-time Seismic Monitoring and Ground-shaking Products for Emergency Response. **Nuñez, A.**, Ramírez, E., Arregui, S., Arce, R., Rosado, R. S.
27. Human-centered AI for Seismic Phase Picking in Operational Monitoring. **Park, Y.**
28. Güralp Data Centre: Cloud-based Data Acquisition and State-of-health Monitoring for Seismic Networks. Calver, J. M., **Restelli, F.**
29. Generalized, Automated Mapping of High-impact Regions for Seismic Station Deployment. **Siervo Plata, D.**, Savvaidis, A., Breton, C., Huang, G.
30. Comparing Verizon and AT&T FirstNet Latency During the 2026 Rose Parade. **Stubailo, I.**, Watkins, M., Jones, A., Black, M. L., Wright, D., Chen, S. E., Yoon, C. E., Bhadha, R., Husker, A.
31. Do You See What I See? Comparing Operational Shakemap Products in Northern California. **Terra, F.**, Schleicher, L. S.
32. Integration of MEMS Accelerometers in Regional Seismological Networks: Piloting A Low-cost Edge Computing Approach. **Walter, J.**, Xiao, H., Ogwari, P. O., Thiel, A., Gregg, N., Woelfel, I., Mace, B., Muñoz-Santos, L. F., Fleenor, D.

33. Variability in Seismic Sensor Calibrations. **Wilson, D. C.**, Bastien, P., Litherland, M., Ringler, A.
34. Seismology as a Service: Portable Product Generation at the Southern California Seismic Network (SCSN) Using Service-oriented Architecture and Cloud Computing. **Yu, E.**, Tepp, G., Tam, R. W., Bhaskaran, A., Baker, B., Chen, S. E., Askari, A., Choi, J., Husker, A.
35. STATION: A Scalable Platform for Cross-regional Seismic Station and Site Characterization. Tarchini, G., Scafidi, D., **Parolai, S.**, Picozzi, M., Bindi, D., Spallarossa, D.

Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches (see page 1349).

36. A High-frequency Magnitude Scale (M3HZ): From Instrumental Ground Motions to Historical Earthquake Catalogs. **Parolai, S.**, Spallarossa, D., Picozzi, M., Amiri Fard, R., Oth, A., Bindi, D., Rovida, A.
37. A Partially Nonergodic Seismic Hazard Framework Using Earthquake-cycle Simulations. **Aspiotis, T.**, Zielke, O., Aquib, T., Mai, P.
38. Modeling Multi-hazard Assessment in the Western Corinthian Gulf, Central Greece, Using Machine Learning and Gis. **Bathrellos, G.**, Andriopoulou-Mounteanou, S., Paliou, Z., Skilodimou, H. D., Zymvragakis, A., Spingos, I., Kaviris, G.
39. Regional Seismic Risk Assessment in Taiwan Using Optimized Exposure and Fragility Models: Insights From the 2016 Meinong and 2024 Hualien Earthquakes. **Chan, C.**, Hung, J.
40. Updated Mmax Distributions for Seismic Hazard Analyses of Nuclear Facilities in the Central and Eastern US. **Chandrasekhar, S.**, Montaldo Falero, V., Youngs, R.
41. Looking for the Possible Epicenters and Magnitudes of Strong Prehistoric Earthquakes Near Boston, Massachusetts. **Ebel, J. E.**, Monecke, K., Hubeny, J., McCarthy, F. M. G., Theis, L., Alderson, A.
42. STUDENT: Linked Earthquake and Tsunami Hazard Modeling on Puget Sound’s Crustal Faults. **Grossman, J. B.**, Wirth, E. A., Dunham, A., Stone, I., LeVeque, R. J., Adams, L. M., Wei, Y., Moore, C.
43. STUDENT: Development of an Empirical Ground Motion Model for Spectral Displacement Using High Rate GNSS. **Hensley, B.**, Sahakian, V. J., DeGrande, J., Crowell, B. W.
44. Seismic Hazard Studies in West Africa Using Integrated Techniques for Planning and Development of Critical Facilities. **Kadiri, U. A.**, Kijko, A.
45. STUDENT: Applying Selena for Seismic Risk Analysis in Kenya. **Kuria, K. K.**, Brassai, O. K.
46. STUDENT: Region-specific Empirical Models for Arias Intensity, Cumulative Absolute Velocity, and Significant Duration in the Alborz Region. **Pakniat, S.**, Davatgari-Tafreshi, M., Pezeshk, S.

47. On the Development of Multi-hazard Map at the Lefkada Island (Western Greece) by Combining Seismic and Landslide Hazard Maps. **Skilodimou, H. D.**, Andriopoulou-Mounteanou, S., Paliou, Z., Bathrellos, G., Zymvragakis, A., Spingos, I., Kaviris, G.
48. Simulation-based Scenario Shakemaps for Earthquakes on the Seattle, Tacoma, and Southern Whidbey Island Faults, Washington, U.S.A. **Stone, I.**, Wirth, E. A., Grant, A., Grossman, J. B., Frankel, A. D.
49. Advancing Seismic Hazard and Risk Inputs for Tbilisi. **Tsereteli, N.**, Kharanauli, D., Silva, V., Varazanashvili, O.
50. STUDENT: Gulfnet: Large-scale Nodal Seismic Deployment Along the Texas-Louisiana Coast. **Villagomez, J.**, McNease, J., Zhang, Z., Murphy, M., Suppe, J., Zheng, Y.
51. Ball Lightnings in Earthquakes and Seismic Damage. **Zimin, M.**, Zimin, M.
52. Stochastic Analysis of Avalanches and Slushflows Triggered by Earthquakes. **Zimin, M.**, Gavrilenko, T., Zimin, M., Kulikova, O., Kumukova, O.
53. Complex Monitoring of Potential Earthquake Localities. **Zimin, M.**, Zimina, S.
54. Open Scientific Data: A Case Study on the Phoenix Drainage Basin (Greece) for Seismic and Flood Hazard Assessment. **Kaviris, G.**, Zymvragakis, A., Spingos, I., Andriopoulou-Mounteanou, S., Paliou, Z., Skilodimou, H. D., Bathrellos, G.

Time-Dependent Seismic Hazard Assessment: Models, Data and Applications (see page 1558).

55. Smoothing Kernel-based Versus Uncertainty-driven Seismicity Models: Performance Comparison in the Gulf of Corinth (Greece). **Kaviris, G.**, Bonatis, P., Karakostas, V., Kourouklas, C., Papadimitriou, E.
56. STUDENT: Toward the Incorporation of Anelastic Path Attenuation in Non-ergodic Ground-Motion Models (GMMs): A 3D Perspective for the Chilean Subduction Zone. **Bastías, N.**, Montalva, G. A., Ojeda, J., Leyton Flórez, F.
57. New Seismic Hazard Research Capabilities in OpenSHA v26.1. **Bhatthal, A.**, Maechling, P. J., Milner, K. R., Callaghan, S. A., Elbanna, A.
58. STUDENT: Seismic Hazard Assessment for the Levant Fault System Using the MCQsim Earthquake Simulator. **Bilal Peralta Nemr, B.**, Beauval, C., Brax, M., Zielke, O., Klinger, Y.
59. Time-dependent Seismic Hazard Assessment of the San Ramón Fault in Santiago, Chile. **Heresi, P.**, Fernández, M., Montalva, G. A., Leyton Flórez, F.
60. Utilizing the RSQSim Long-term Earthquake Simulator to Generate a Synthetic Earthquake Catalog for the Eastern California Bay Area. **Marschall, E.**, Gabriel, A., Shaw, B. E., Yun, J., Kottke, A. R., Donahue, J.

61. On the Temporal Stationarity of Systematic Effects in Non-ergodic Ground-motion Models: Evidence From Chilean Megathrust Sequences. **Montalva, G. A.**, Bastías, N., Heresi, P., Leyton Flórez, F., Cabello, C.

62. STUDENT: Physics-based Seismic Hazard Assessment Using RSQSim Synthetic Catalogs: Validation Against USGS Nshm 2023 for Los Angeles. **Olawoyin, V. T.**, Ebel, J. E.

63. Unrecoverable Crust Destructions Incurred by Low-permeability Heterogeneity—Based on Time-dependent Continuous Leakage Detecting Models. **Zhang, Y.**, Fu, L., Qi, S., Zhang, H., Manga, M.

64. Innovations in Time-dependent Methodologies for Earthquake Loss Modeling. **Neely, J. S.**, Apel, T., Safiey, A., Gupta, N.

Physics of Earthquakes: Insights from Theory and Observations (see page 1511).

65. What’s Real and What’s Not? Assessing Spectral Stress Drop Observations With Synthetic Earthquakes. **Neely, J. S.**, Park, S., Abercrombie, R. E.

66. STUDENT: Fault Zone Structure and Earthquake Generation Mechanisms at the Xinfengjiang Reservoir, China, From the Earthquake Catalog (2013-2014). **Hu, Y.**, Ye, L., Xu, S.

67. STUDENT: A Seismically Active Shear Zone in the Uppermost Mantle Beneath the Canadian Rockies. **Hutchings, S. J.**, Koper, K. D., Pang, G.

68. Rupture Properties Diversities Across Taiwan Area Revealed by Back-projection Method. **Jian, P.**

69. The 10 September 2025 Mw 4.1 Earthquake in Northeastern Utah, USA: An Archetypal Continental Mantle Event. **Koper, K. D.**, Hutchings, S. J., Burlacu, R., Whidden, K., Tibi, R., Pang, G., Springer, V.

70. Is Stress-drop Depth Dependent?—Insights From Observations, and the Roles of Normal-stress and Attenuation. **Kurzon, I.**, Lyakhovsky, V., Sagy, A.

71. Large Repeating Gorda Intraplate Earthquakes Occurring Along an Inherited Weak Zone Near the Mendocino Triple Junction. **McPherson, R. C.**, Patton, J. R., Hellweg, M., Smith, S. W., Dengler, L., Lomax, A., Dreger, D. S.

72. A Geometric Explanation for Faulting-style-dependent Non-double-couple Components in Global Moment Tensors. **Rösler, B.**

73. West Texas Earthquake Catalog Using a 3D Earth Model. **Savvaidis, A.**, Lomax, A., Parastatidis, E., Salles, V., Huang, G.

74. STUDENT: Physics-bounded Maximum Magnitude of Production-induced Earthquakes in the Groningen Gas Field. **Shi, Q.**

75. Applications of MTUQ: A Framework for Estimating Moment Tensors, Point Forces, and Their Uncertainties. **Thurin, J.**, Modrak, R., McPherson, A., Tape, C., Rodriguez-Cardozo, F. R., Braunmiller, J., Hu, J., Tkalčić, H.

76. STUDENT: The Spatio-temporal Scales of a Self-sustaining Stress Transfer Mechanism Responsible for Intermediate-Depth Earthquakes Within the Bucaramanga Nest, Colombia. **Tsuchiyama, A.**, Frank, W. B., Prieto, G. A.

77. Coda-derived Source Parameters of Shallow Earthquakes in Mainland Alaska. **West, M. E.**, Al-Kaabi, M., Mayeda, K., Roman-Nieves, J., Barno, J.

78. STUDENT: Earthquake Focal Depths and Tectonic Implications of the Shanxi Rift Based on a Depth-phase Scanning Algorithm. **Wu, Y.**, Yu, H., Zhang, S., Wang, Y., Li, L.

79. The Connected Nucleation Spectrum of an M5.6 Earthquake. **Zi, J.**, Yang, H.

Detecting, Characterizing and Monitoring Mass Movements (see page 1377).

80. Adapting a Granular Flow Model to the U.S. Geological Survey Experimental Debris-flow Flume. **Biegel, K.**, Conner, A., Thomas, A. M., Allstadt, K., Obryk, M., Farin, M.

81. Linking Landslide Dynamics to Seismic Detection at Barry Arm Landslide, Alaska. **Karasozen, E.**, Allstadt, K., Barnhart, K.

82. Advances in Seismic Monitoring of Landslides in Alaska. **Karasozen, E.**, West, M. E.

83. Triggering of Slow-moving Landslides in New Zealand and Northern California: Insights From InSAR Time Series Analysis of the 2016 Kaikōura and 2022 Ferndale Earthquakes. **Lindsay, D.**, Burgmann, R., Massey, C., Hamling, I.

84. STUDENT: Seismic Monitoring of Flooding, Debris Flows, and Landslide Dynamics After the 2025 Palisades Fire, California. **Ma, Y.**, Tan, B., Fiorillo, E., Mills-Terry, I., Akin, I., West, A., Paige, D. A., Moon, S., Meng, L.

85. Seismic Monitoring of Mass Movements and Cascading Surface Hazards in Mountain Regions. **Zhang, Z.**, Walter, F., He, S., Tan, Y.

ESC-SSA Joint Session: Advanced Methods for Harnessing Seismic Noise Analysis in Applied Seismology (see page 1404).

86. STUDENT: Toward Monitoring Groundwater-induced Seismic Velocity Changes Using Ambient Noise Correlation in the Upper Mississippi Embayment. **Araji, A.**, Carpenter, S., Rodriguez-Cardozo, F. R., Beck, G., Schmidt, J. P., Braunmiller, J., Woolery, E. W.

87. Beyond Source Homogeneity: High-frequency Control for Empirical Green’s Function Retrieval. **Chen, Y.**

88. STUDENT: Traveltime Tomography Using Ambient Noise P Body-waves From Distant Typhoons. **Du, M.**, Gao, J., Zhang, H.

89. STUDENT: Characterizing Fundamental Frequencies Across Geologies Using Ambient-noise HVSR. **Mansfield, R.**, K C, S., Nweke, C. C.

90. STUDENT: Capturing Subsurface Impacts of Recent Rainstorms in the San Joaquin Valley Using Coda Wave Interferometry. **Moussissa, N.**, Taira, T., Allen, R.

91. Preliminary Shallow Subsoil Velocity Imaging of the Contursi Terme Hydrothermal System (Southern Italy). **Serlenga, V.**, Cabrera-Perez, I., D’Auria, L., Napolitano, F., Panebianco, S., Stabile, T., Giampaolo, V., Amoroso, O.

92. Shear-wave Velocities in the Bellingham and Everett Basins, Washington State: Insights From Multimethod Characterization With krSPAC and Active-source Linear Arrays. **Stephenson, W. J.**, Lindberg, N. S., Leeds, A. L., Odum, J. K.

93. Artius: A Revolutionary Broadband Node to Enable Passive Seismology. **Watkiss, N. M.**, Spark, R. M.

Fault Networks and Seismic Hazard in the Nevada-California Borderland [Poster] (see page 1418).

94. Quaternary Geologic and Fault Mapping to Inform Future Paleoseismic Characterization at Yucca Mountain, Nevada. **Koehler, R. D.**, Gross, M., Rutherford, R.

95. STUDENT: Active Faulting in the Klamath Mountains Revealed by Lidar Data. **Lynch, R. M. C.**, Oskin, M. E.

96. STUDENT: Earthquake Hazard and Geomorphic Mapping in the Reno Urban Area. **Marino, D.**, Rowe, C. D., Koehler, R. D., Bogolub, K. R., Cashman, P. H., Pretell, R., Wesnousky, S. G.

97. STUDENT: Right-oblique Slip Rate of the Round Valley Fault, Eastern California. Alatorre-Acevado, E., Franck, S., Lynch, R. M. C., Papin, L., **Perkins, E.**, Yepishin, E., Oskin, M. E.

98. STUDENT: ELVIS: A Seismic Array for Hazard and Structure in the Las Vegas Basin. **Samuel, D.**, Ford, H. A., Byrnes, J., Barth, N., Catchings, R. D., Doreme, G., Douilly, R., Gaherty, J. B., Garcia, J., Marschall, E., Parida, B., Perzan, Z., Porter, R. C., Shallon, B., Shillington, D. J., Stroup, A.

Earth’s Structure from the Crust to the Core (see page 1400).

99. STUDENT: Constraining Depths of Basin and Crustal Discontinuities Across the Powder River Basin, Wyoming, and Black Hills South Dakota. **Samuel, D.**, Ford, H. A., Bezeda, M. J., Byrnes, J.

100. Inherited Lithospheric Structure Controls Cenozoic Intraplate Basaltic Volcanism in Central Mongolia Due to Mantle Upwelling. **Bao, X.**, Jiang, M.

101. STUDENT: Joint Body and Surface Wave Inversion for the Structure of the Northern Los Angeles Basins. **Bird, E.**, Biondi, E., Clayton, R. W., Zhan, Z.

102. Possible Layered Crustal Seismic Anisotropy in the NE Tibetan Plateau. **Gao, Y.**, Li, S., Xia, X.

103. Imaging the Crust and Upper Mantle of Georgia Using Receiver Functions TRANSECT and SNECCA Seismic Arrays. **Godoladze, T.**, Nabelek, J., Ratiani, L., Kakhoberashvili, S., Sandvol, E., Grigalashvili, R., Javakhishvili, Z.

104. STUDENT: Mantle Transition Zone Imaging Beneath the East Sea (Sea of Japan) Using Teleseismic Receiver Functions. **Hwang, J.**, Chang, S.

105. Resolving the Deep Structure of the Yellowstone Mantle Plume. **Kumar, U.**, Romanowicz, B., Wolf, J., Lyu, C., Munch, F.

106. Layered Seismic Anisotropy and Tectonics of the Anatolian Plate. **Liu, C.**, Schulte-Pelkum, V., Becker, T. W., Link, F.

107. STUDENT: Rayleigh-wave Attenuation in the Southern Korean Peninsula From Helmholtz Tomography. **Park, S.**, Chang, S.

108. STUDENT: Mantle Transition Zone Thickness Variation Across Tibet Using P-wave Receiver Functions. **Singh, A.**, Sandvol, E., Liu, C.

109. STUDENT: Deep Learning for Deep Earth: Global D’’ Reflections in Massive Seismic Dataset. **Wang, H.**, Wolf, J., Zhu, W.

110. A Comprehensive Crustal Coda Attenuation Map of Continental China. **Wang, W. W. W.**

111. STUDENT: A Machine Learning Enhanced Catalogue for New Zealand: Observations From Two Decades of Seismicity. **Williams, C.**, Chamberlain, C. J., Townend, J.

112. Upper Crustal Structural Heterogeneity and Its Role in Intracontinental Seismogenesis in the Western United States. **Yang, X.**, Levandowski, W., Cao, Z.

113. STUDENT: The Shallow Moho Below the Los Angeles Basin. **Villa, V.**, Clayton, R. W.

Physical Properties of Fault Zones from the Seismic Source to Earth’s Surface (see page 1503).

114. STUDENT: Hydraulic Tomography of Faults Near Cahuilla, Southern California. **Villa, V.**, Ross, Z. E., Cochran, E. S.

115. STUDENT: The Effects of Plasticity on Vertical Off-fault Deformation Percentages for the 1971 San Fernando Earthquake. **Bravo, G.**, Oglesby, D. D., Gaudreau, É., Funning, G. J., Nissen, E., Hollingsworth, J.

116. STUDENT: Space-time Variations of In-situ Vp/Vs Ratios in the San Jacinto Fault Zone. **Huang, S.**, Ben-Zion, Y.

117. STUDENT: Integrated Geophysical Investigation of Quaternary Paleo-earthquake Evidence in Soft Soil Deposits Using GPR, ERT, MASW, and HVSR Surveys. **Jeon, Y.**, Kim, B., Kim, S., Choi, J., Lee, H.

118. STUDENT: Investigating the Geometric Origin of Slip Asperities. **Lee, J.**, Tsai, V. C., Hirth, G., Trugman, D. T.

119. Fault Damage Zone Structure at Depth Extracted by FZTWs and Receiver Functions From Teleseismograms. **Li, Y.**

120. Monitoring Temporal Variations in Dtp/Dts Ratio Owing to Water-saturation Within the Fault Zone - a Plausible Earthquake Precursor. **Li, Y.**

121. Comparing Fault Zones that Host Induced and Tectonic Earthquakes in Oklahoma and California. **Neo, J.,** Huang, Y.

122. Depth-dependent Frictional Stability and Rupture Arrest on the Pütürge Segment of the East Anatolian Fault Zone, Turkey (Türkiye). **Nevitt, J. M.,** Jeppson, T. N., Bilham, R., Moore, D. E., Lockner, D. A., Barnhart, W. D., Çakır, Z., Ayruk, E. T., Brooks, B. A., Ruth, D. C. S., Ekhtari, N., Gomez, F. G., Weiss, J. R., Minson, S. E., Ergintav, S., Doğan, U., Özarpacı, S., Reitman, N. G., Harris, R. A.

123. STUDENT: Influence of Fault Zone Overstrengthening on Future Earthquake Processes. **Smith, Z. D.,** Bürgmann, R., Waligora, F., Griffith, A., Nevitt, J. M., Materna, K., Gleeson, M., Yan, R., Idzakovich, M.

124. STUDENT: Depth Dependence of Seismic Velocity Recovery Following the 2009 L'Aquila and 2016 Amatrice Earthquakes. **Van Linn, J.,** Tarantino, S., Poli, P., McLaskey, G. C.

125. Multiparametric Geophysical Monitoring Reveals Fluid-driven Precursors to Seismic and Volcanic Events: Rgunal Network Design and Preliminary Results. **Vargas, C. A.,** Caneva, A., Monsalve, G., Duque, E., Duque, S., Perez, J., Angulo, V., Osorio, J. D., Duque, G., Barbosa, A., Gulisano, A., Delgado-Toala, D.

126. Speeds, Modes and Directionality of the 2025 Mw 7.8 Madalay Earthquake Explained by the Fault Core Structure. **Xia, K.,** Wang, C., Zhu, S., Rosakis, A.

127. Fault Zone Structure of the Alpine Fault in New Zealand Imaged by Seismic Receiver Functions. **Zhang, P.,** Miller, M. S., Wang, X., Townend, J., Michailos, K.

New Possibilities for InSAR in Earthquake Science: the NISAR Mission and OPERA Displacement Maps (see page 1492).

128. Identification of Potential Slow-moving Landslides Using ICA on InSAR Time Series and Terrain Analysis. Chaves Fitzgerald, G., **Huang, M.**

129. Leveraging Multitemporal InSAR Products for Geohazards and Geomechanics Research: Characterizing Data Quality and Lessons Learned. **Jiang, J.,** Bodunde, S., Kang, Z., Shodunke, G., Thapa, M., Zhao, X.

130. Mapping Surface Deformation at Scale: A Look at the Opera Displacement Products for Earthquake Science and Hazards Applications. **Sangha, S. S.,** Bato, G., Handwerger, A. L., Mirzaee, S., Staniewicz, S., Fattahi,

H., Govorcin, M., Oliver-Cabrera, T., Yoon, P., Agram, P., Chan, S., Cinquini, L., Fielding, E. J., Bekaert, D.

131. STUDENT: Triggered Aseismic Creep Following the 2023 Ocotillo Swarm Constrained by 3D InSAR Observations. **Tan, M.,** Materna, K.

Planetary and Gravitational Wave Seismology (see page 1517).

132. Seismo-acoustic Characterization of Lunar Rocket Plume Hazards Using Distributed Acoustic Sensing. **Donahue, C. M.,** Lanza, N. L.

133. STUDENT: Using Inertial Measurement Units as Seismometers for Planetary Missions. **Gansler, K. R.,** Schmerr, N., Wang, J., Lewis, K. W., Fernando, B.

134. Seismological Characterization of the Sardinia (Italy) Candidate Site for the Einstein Telescope. **Giunchi, C.,** Cianetti, S., Diaferia, G., Molinari, I., Olivieri, M.

135. Detection of a Martian Long Range Thermospheric Acoustic Wave by SEIS/InSight. **Lognonné, P. H.,** Froment, M., Charalambous, C., Kim, D., Xu, Z., Panning, M. P.

136. Determining Lunar Interior Structure through LILA, a Lunar Gravitational Wave Observatory Concept. Panning, M. P., **Lognonné, P. H.,** Creighton, T., Jani, K., Trippe, J., Quetschke, V., Majstorović, J.

137. STUDENT: Probing Small-scale Lunar Mantle Heterogeneities Using High-frequency P-wave Scattering from Shallow Moonquakes. **Margarit, R.,** Lognonné, P. H., Drilleau, M., Kawamura, T., Menina, S.

138. STUDENT: Benchmarking Single-station Focal Mechanism Inversion to Characterize Martian Crustal Anisotropy. **Mohanna, S.,** Singh, N., Meng, L., Li, J.

139. A Microseismometer for Venus. **Pike, W. T.,** Funk, N. W., Hunter, G. W., Chen, L., Adams, C. M., Krasowski, M. J.

140. Seismic Evidence of Active Deep Crustal Deformation Beneath Valles Marineris, Mars. **Song, J.,** Kim, D., Kolawole, F., Tsai, V. C., Davis, J.

141. STUDENT: High-resolution Characterization of Seismic Scattering in the Lunar Near-surface From Observations and Synthetic Records. **Tamama, Y.,** Civilini, F., Husker, A., Jackson, J. M., Biondi, E., Wang, J., Zhai, Q., Zhan, Z.

142. Early Earthquake Detection With Elasto-gravitational Waves. **Wang, S.,** Chua, S. S. Y., Fichtner, A., Cummins, P. R., Ward, R. L., Slagmolen, B. J. J.

Regional Source, Path and Site Effects in Earthquake Ground Motions (see page 1527).

143. Extraordinarily Large Site Amplification Factors in Noto, Japan, Possibly Due to 3D Resonance. **Ito, E.,** Kawase, H.

144. Path-dependent Topographic Site Effects Revealed by 3D Ground Motion Simulations and Ambient Noise. **Kizhaekke Pakkathillam, S.,** Oral, E., Larmat, C., Asimaki, D.

145. Modeling Non-ergodic Path Effects Using Conditional Generative Model for Fourier Amplitude Spectra. **Lacour, M.,** Ren, P., Nakata, R., Nakata, N., Mahoney, M.

146. STUDENT: Effect of Subsurface Variability on Surface Ground Motion: Uncertainty Quantification in Equivalent-linear Analysis. **Muratoglu, G.,** Askan, A.

147. Multi-scale Geospatial Site Terms for Fourier Amplitude Spectrum Modeling in NGA-West 3. **Nie, S.,** Baise, L. G., Kottke, A. R., Kuehn, N., Bozorgnia, Y., Campbell, K. W.

148. The Soft Soil Effect of Marine Soil on Ground Motion Parameters. **Peng, Y.,** Lv, Y., Fang, Y.

149. Developing a Dataset for Non-ergodic Subduction Ground-motion Models in Alaska. **Smith, J. A.,** Thompson, E. M., Kottke, A. R., Sung, C., Abrahamson, N.

150. Slip Kinematics, Radiation Pattern, and Rupture Directivity Effects on the Peak Ground Velocity (PGV) of the 2024 Mw4.8 Tewksbury, New Jersey, Earthquake. **Wu, B.,** Kolawole, F., Gabriel, A.

151. Evaluating Ground Motion Models for the Chilean Subduction Zone. **Wu, Q.,** Wong, I. G.

Seismology for All: Expanding STEM Education Through Accessible Tools and Global Collaboration (see page 1531).

152. Lowering Barriers to Seismology Education Through Open-access Computing Tools and Shared Educational Infrastructure. **Bravo, T.,** Haberli, G., Weber, M., Hubenthal, M., Brudzinski, M.

153. STUDENT: Seismic Monitoring of Tapir Ground Interactions in Costa Rica: Nodal Arrays as Opportunistic Biologgers for Quantifying Wildlife Visits, and Impulse. **Campos, N. A.,** Vargas Hernández, C., Monge Velazquez, M., Hajaji, S., Nuñez Alpizar, E., Porras Murillo, L., Chaves, E. J.

154. STUDENT: A Community-deployed Raspberry Shake Network for Seismic Monitoring in El Paso, Texas. **Garcia, M. A.,** Macias, M., Velasco, A. A., Karplus, M.

155. The InSAR Lookbook: A Visual Guide to Understanding Earthquake Deformation Interferograms. **Sethanant, I.,** Nissen, E.

156. Seismology 4 All. **Zeiler, C. P.,** Russell, J., Anderson, D., Parker, B.

Subaqueous Evidence for Earthquakes, Coseismic Landslides, Tsunamis and other Cascading Hazards (see page 1554).

157. Submarine Deformation by the Intra-arc Strike-slip System in Southern Chile: Faulting, Sedimentation, and Seismicity Processes on the Lliquiñe-Ofqui Fault Zone. **Cortés Rivas, V.,** González, J., Morales-Yáñez, C., Díaz-Naveas, J.

158. Lacustrine Paleoseismic Proxies from Lake Whatcom, Washington, USA: Decoding Megathrust and Crustal Shaking Using 14 m Sediment Cores. **Derosier, B.,** Brothers, D. S., Singleton, D. M., Hill, J. C., Sherrod, B., Ponton, C.

159. Characterizing Earthquake-triggered Sedimentation in an Intraplate Setting: Delta Collapse and Turbidite Deposition From the 2020 Mw 6.5 Stanley Earthquake (Idaho, USA). **DuRoss, C. B.,** Nicovich, S. R., Jobe, J. A. T., Briggs, R. W., Powell, J. H., Shapley, M., Finney, B. P., Thackray, G.

160. Detailed Marine Paleoseismic Records From Earthquake Triggered Submarine Landslides in Outer Prince William Sound, Alaska. **Hill, J. C.,** Kluesner, J., Brothers, D. S., Singleton, D. M., Witter, R., Haeussler, P. J., Watt, J., Derosier, B., Balster-Gee, A.

161. STUDENT: Offshore Site Effects in Alaska: Geologic Factors and Pervasive Small-strain Nonlinearity. **Huang, L.,** Williams, E. F.

162. Using Lake Records to Investigate Earthquakes in Stable Continental Interiors: Case Study of the 1638 M6.5 New Hampshire, USA, Earthquake. **Jobe, J. A. T.,** Nicovich, S. R., Rodysill, J., DuRoss, C. B.

163. Evidence of Widespread and Historical Earthquake-triggered Deformation, Slope Failure, and Associated Deposits Within Lake Washington and Lake Sammamish. **Kluesner, J.,** Hill, J. C., Brothers, D. S., Sherrod, B., Takesue, R., Conrad, J., Dartnell, P.

164. Potential Effects of the 1983 M6.9 Borah Peak Earthquake on Nearby Lakes. **Nicovich, S. R.,** DuRoss, C. B., Shapley, M., Finney, B. P., Jobe, J. A. T., Thackray, G.

165. Fingerprinting of Mass Transport Deposits Using High-resolution XRF Core Scanning. **Prouty, N.,** Singleton, D. M., Derosier, B., Moy, C., Brothers, D. S.

166. Evidence of Seismic, Climatic, and Volcanic Events in the Sedimentary Record at Chelatna Lake, Alaska Over the Past 11,000 Yrs. **Singleton, D. M.,** Witter, R., Kaufman, D., Allen, H., Haeussler, P. J., Brothers, D. S., Jensen, B.

167. Shaking Evidence Near the Epicenter of the 1964 Great Alaska Earthquake at Allison Lake, Alaska USA. **Witter, R.,** Singleton, D. M., Haeussler, P. J., Kaufman, D., Allen, H., Derosier, B., Brothers, D. S.

Thursday, 16 April 2026—Oral Sessions

Presenting author is indicated in bold.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	The Landscape Record of Earthquakes and Faulting (see page 1450).	ESC-SSA Joint Session: Interpreting Volcanic Unrest and Eruption Data for Effective Crisis Management (see page 1406).	International Collaboration to Advance Earthquake Science and Disaster Response (see page 1447).	Physics of Earthquakes: Insights from Theory and Observations (see page 1506).		Advancing Earthquake Early Warning: Science, Technology and Engagement in the U.S. and Beyond (see page 1337).	Data-Driven and Computational Characterization of Non-Earthquake Seismoacoustic Sources (see page 1372).	Earthquake Ground Motions and Structural Response: Emerging Tools and Applications (see page 1386).	Mechanisms and Seismogenic Structure for Large Continental Earthquakes (see page 1464).
8:00 AM	INVITED: STUDENT: Climate Oscillations and Slip Rate Control Channel and Hillslope Responses to Slow Strike-slip Faulting in the Hyper-arid Atacama Desert. Aranguiz-Rago, T. E. , Duvall, A. R., Crowell, B. W.	Detection and Monitoring of Volcano-seismic Processes During an Eruption Cycle at Axial Seamount. Waldhauser, F. , Wang, K., Colet, M., Wilcock, W. S. D., Zhang, M., Tolstoy, M., Tan, Y., Wang, P.	INVITED: Global Collaborations for Seismic Resilience: Advancing Seismic Hazard and Risk Modeling Through GEM’s Projects Worldwide. Johnson, K., Styron, R. H. , Pagani, M., Rao, A., Silva, V., Yepes-Estrada, C., Calderón, A., Crowley, H., Bayliss, K., Todorovic, L., Brooks, C., Villani, M.	Borehole Seismic Attenuation Measurements and Strong-motion Kappa_0 Estimates Imply More High-frequency Radiation From Earthquakes Than Simple ω^2 Model Predictions. Shearer, P. M. , Abercrombie, R. E.	8:00 AM	ShakeAlert Earthquake Early Warning Testing Developments Review. Smith, D. E. , Crummey, J., McGuire, J. J., Sumant, J., Bunn, J.	Seismoacoustic Source Localization: Case Study from AES Tennessee Explosion. Koch, C.	An Overview of NGA-West3 Research Program. Bozorgnia, Y. , Donahue, J., Abrahamson, N., Al Atik, L., Atkinson, G. M., Bahrampouri, M., Baise, L. G., Bayless, J., Boore, D. M., Bradley, B. A., Buckreis, T. E., Campbell, K. W., Chiou, B., Idriss, I. M., Kishida, T., Kottke, A. R., Kuehn, N., Lavrentiadis, G., Nie, S., Parker, G. A., Pinilla Ramos, C., Rodriguez-Marek, A., Stafford, P., Stewart, J. P., Sung, C., Youngs, R.	Progressive Eastward Rupture of the Main Marmara Fault Toward Istanbul. Bohnhoff, M. , Martinez-Garzon, P., Chen, X., Becker, D., Nunez-Jara, S., Kartal, R., Turker, E., Dresen, G., Ben-Zion, Y., Jara, J., Cotton, F., Kadirioglu, F., Kilic, T.
8:15 AM	Reconciling the Paradox of Offshore Fault Slip in the 1906 San Andreas Earthquake. Herman, M. W. , Furlong, K. P., McKenzie, K. A., Kummerfeldt, S. R.	INVITED: STUDENT: Rapid Seismicity Migration in the 2025 Santorini-Amorgos sequence. Tan, X. , Beroza, G. C., Ellsworth, W. L., Prejean, S. G., Pesicek, J. D.	Pager 2.0: Next Generation Forecasts to Inform Rapid Global Earthquake Response. Jaiswal, K. , Wald, D. J., Earle, P. S., Marano, K. D., Hearne, M., Schmitt, R.	S/P Amplitude Ratios with Distributed Acoustic Sensing and Application to Earthquake Focal Mechanisms. Skoumal, R. J. , Atterholt, J. W., Barbour, A. J., Hardebeck, J.	8:15 AM	Station Expected Contribution Metric for the ShakeAlert EEW System. Biasi, G. , Bunn, J., Stubailo, I., Alvarez, M.	Seismoacoustic Monitoring of Explosive Sources on the Korean Peninsula. Park, J. , Hayward, C., Che, I., Arrowsmith, S., Kim, K., Kim, B., Lee, H.	STUDENT: Testing Data-driven Techniques for Separating Free-field Ground-motion From Building Response in Smartphone Data. Marcou, S. , Allen, R.	Hierarchical Architecture of the 2025 Mw7.1 Dingri, Southern Tibet Normal Earthquake. Yao, D. , Wang, D., Wang, M., Chen, F., Liao, J., Yao, J.
8:30 AM	Surface Ruptures and Near-fault Deformation of the 2025 Mw 7.7 Myanmar Earthquake. Min, S., Aung, T., Chen, C., Reitman, N. G., Tsutsumi, H., Htun, W., Mon, C., Aung, L., Win, K., Min, S., Myo, E., Htay, K., Khaing, S., Thant, M., Tun, S., Wang, Y.	Bulk Locations and Mechanisms of Repetitive Long-period Seismicity at Mount St. Helens in July 2005. Matoza, R. S. , Chouet, B. A., Dawson, P. B.	From Source to Impacts: Advances in Real-time Analysis of NZ’s Big Quakes Through the RCET Programme. Kaiser, A. , Fry, B., Andrews, J., Caballero, E., Horspool, N., Warren-Smith, E., Aden, F., Chamberlain, C. J., D’Anastasio, E., Goded, T., Jamelot, A., Zweck, C., Behr, Y., Bernardi, F., Liao, W., Solares, M., Crowell, B. W., Melgar, D., Böse, M., Massin, F., Moseley, A., Lukovic, B., Massey, C.	STUDENT: Multi-episode Rupture Kinematics of a Microearthquake in Weak Crust Revealed by Dense DAS Observations. Han, S. , Kim, Y., Kim, J., Nayak, A., Yin, F., Ajo-Franklin, J.	8:30 AM	Exploring the Use of Existing Offshore Cabled Infrastructure for Earthquake Early Warning in the Pacific Northwest. Krauss, Z. , Thompson, M., Dunham, A., Dybing, S. N., Hartog, J.	Exploring Seismo-acoustic Sources From an Underground Fully Decoupled Chemical Explosion. Ezzedine, S. M.	State-of-the-art Use of Simulated Ground Motions to Enhance Urban Seismic Resilience in Turkey. Askan, A. , Erberik, M.	Seismic Reflection Imaging of the Source Zone of the 2024 Mw4.8 Tewksbury, New Jersey, Earthquake, and the Relation of Eastern U.S. Seismicity to Crustal Structure. Pratt, T. L. , Chapman, M.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
	The Landscape Record (continued)	ESC-SSA Joint Session (continued)	International Collaboration (continued)	Physics of Earthquakes (continued)
8:45 AM	Post-glacial Surface Faulting Along the East Gallatin-Reese Creek Fault System, Yellowstone National Park. Mauch, J. , Gavillot, Y.	Interpreting Campi Flegrei Unrest Through Integrated Seismic Tomography and Earthquake Analysis: Implications for Fault Reactivation and Hazard. De Landro, G. , Nazeri, S., Scotto di Uccio, F., Zollo, A., Vanorio, T., Lomax, A., Muzellec, T., Virieux, J., Natale, J., Russo, G., Festa, G., Di Toro, G., Convertito, V., Strumia, C., Bobbio, A., Antonio, I. G., Longobardi, V., Palo, M., Sollai, A.	Post-earthquake Response Activities and Planning at the Statewide California Earthquake Center (SCEC). Elbanna, A.	Source Characterizations of Northern California Earthquakes Through Moment Rate Function Properties and Finite-fault Modeling. Taira, T. , Dreger, D. S.
9:00 AM	How Has the Landscape Affected by the Ridgecrest CA Earthquake Sequence Changed Since 2019? A View From Repeat Lidar and Field Observations. DeLong, S. B. , Hammer, M., DuRoss, C. B., Scharer, K., Vermeer, J., Philibosian, B., Hanagan, C. E., Zimmerman, J., Jobe, J. A. T.	Recurrent Hydrothermal Pressurization at Campi Flegrei Revealed by Seismic Tomography and Laboratory Rock Physics. Vanorio, T. , Guo, T., De Landro, G., Williams, S. A., Virieux, J., Zollo, A., Russo, G.	INVITED: The Global Collaboratory for the Study of Earthquake Predictability (CSEP): International Standards, Software, and Benchmarks for Prospective Testing of Earthquake Forecast Models. Serafini, F. , Iturrieta, P., Bayona, J. A., Savran, W. H., Silva, F., Herrmann, M., Maechling, P. J., Graham, K., Gerstenberger, M. C., Marzocchi, W., Mizrahi, L., Schorlemmer, D., Jordan, T. H., Zhang, Y., Werner, M. J.	Fracture Energy of Earthquakes May Scale Linearly with Slip Across Ten Orders of Magnitude. Kaneko, Y. , Watanabe, S.
9:15–10:30 AM	Poster Break			

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	Advancing Earthquake Early Warning (continued)	Data-Driven and Computational (continued)	Earthquake Ground Motions (continued)	Mechanisms and Seismogenic Structure (continued)
	Improving the Reliability of High-rate Global Positioning System Data for Earthquake Early Warning Using Long Short-term Memory-based Anomaly Detection. Manaster, A. E. , Murray, J. R., Murray, M. H., Santillan, M., Scrivner, C., Melbourne, T.	Source Model for Non-steady Flow Within Fractures. Maier, N. , Donahue, C. M., Woo, J., Frash, L.	Quantification of Ground Shaking Effects on Buried Gas Transmission Pipelines. Peng, Y. , Guan, X., Bozorgnia, Y., Honegger, D., Seylabi, E., McCallen, D.	Why Do Large Earthquakes Occur in the New Madrid Seismic Zone, Central United States? Langston, C.
	Mitigating the Effect of Spurious Displacements on Magnitudes Estimated From Peak Ground Displacement Measured With Real-time Global Positioning System Data. Murray, J. R. , Manaster, A. E.	STUDENT: On the Feasibility of Single-station Scalar Moment Estimation for Earthquake and Non-earthquake Sources. Moyer, B. L. , Lekic, V.	Towards the Development of Static Ground Displacement and Transient Ground Strain Shakemaps. Wald, D. J. , Atterholt, J. W., Barbour, A. J., Burgi, P., Graves, R. W., Yin, H. Z., Davis, C. A.	INVITED: A Tale of Three Events: Systematic Comparison of Mainshock Rupture Properties, Sequence Behaviors and Fault Zone Structures for Recent Major Continental Earthquake Sequences. Peng, Z. , Mach, P., Si, X., Lei, X., Deng, Y., Sandvol, E., Kato, A.
9:15–10:30 AM	Poster Break			

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	The Landscape Record of Earthquakes and Faulting (see page 1450).	Advances and New Challenges in Investigating Seismic Site Response (see page 1331).	Earthquake Swarms Across the Earthquake Cycle: Precursors, Transients and Aftereffects (see page 1394).	Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science (see page 1378).		Advancing Earthquake Early Warning: Science, Technology and Engagement in the U.S. and Beyond (see page 1337).	Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cascadia, Chile and Beyond (see page 1456).	Earthquake Ground Motions and Structural Response: Emerging Tools and Applications (see page 1386).	Evolving Frontiers in Explosion Monitoring and Source Physics (see page 1409).
10:30 AM	Two Surface-rupturing Earthquakes on the Great Southern Puerto Rico Fault Zone Since ~19 Ka. Lynch, E. M. , Jobe, J. A. T., Briggs, R. W., DuRoss, C. B., Nicovich, S. R., Hanagan, C. E., López Venegas, A., Tan, M., Gray, H., Strickland, L. E.	STUDENT: Seismic Site Characterization Using Ambient Noise and Earthquake Data in the Mexicali Valley, Northern Baja California, Mexico. Aregawi, A. B. , Huerta-López, C. I., Vidal-Villegas, J.	STUDENT: Examining Swarm and Foreshock Behavior in Tiny Earthquakes Resolved by Nodal Arrays around the San Jacinto Fault in Southern California. Morioka, T. , Brenguier, F., Cochran, E. S., Fan, W., Higueret, Q., Hollis, D., Shearer, P. M., Vernon, F., Vidale, J., Wang, R., Zhang, H.	INVITED: Random Splitting and the Risk of Information Leakage in Seismic AI. Park, Y. , Delbridge, B. G.		The M5.9 Dayton, NV ShakeAlert False Alert: Lessons Learned. Lux, A. I. , Terra, F., Akimov, A., Henson, I., Crummey, J.	Constraining the Shallow Structure of Cook Inlet Basin, Alaska Using P-wave Autocorrelations: Insights Into Subduction Zone and Forearc Structure. Dey, S. , Golos, E.	Automated Operational Modal Analysis of High-rise Buildings Using Crowdsourced Smartphone Data. Kumar, U. , Allen, R., Hutchinson, T. C., (Charlie) Zhang, J., Sorosh, S.	Posterior Source-type Classification for Explosion Monitoring Using Moment Tensors. Alvizuri, C. R.
10:45 AM	STUDENT: Holocene Fault Activity Near the Oak Grove Fork Clackamas River: Kinematic Linkage of the Clackamas River and Mount Hood Fault Zones. Schwarzbart, S. , Streig, A., Bennett, S. E. K., Madin, I., Amos, C. B., Briseno, D., Vazquez, R. A., Sullivan, J. K.	STUDENT: High-resolution Mapping of Site Response Variability in the Los Angeles Basin Using Dense Community Seismic Network Data. Shams, R. , Nweke, C. C., Kohler, M.	STUDENT: Fault-zone Evolution During the Preparatory Stage of the 2024 Noto Peninsula Earthquake in Japan. DeSalvio, N. D. , Fan, W., Okuwaki, R., Morzfeld, M., Huang, Y.	Robust Moment Tensor Inversion on Irregular Arrays With Physics-structured Sim-to-teal Training. Jia, Z. , Zhang, J., Li, J.		Operating EEW in Eastern Canada Part I: Reducing False Alerts in Testing. Crane, S. , Adams, J., Seywerd, H., McCormack, D., Perry, C., Ackerley, N., Bird, A., Nykolaishen, L.	Razor Sharp Edge – the Yakutat Slab Dissecting South-central Alaska. Miller, M. S. , Zhang, P., Pickle, R. C., Waldien, T., Roeske, S. M.	Assessment of Building Risk Based on an Affordable Structural Health Monitoring System Developed in Taiwan. Liang, W. , Chang, G. T., Kumar, U., Ma, K.	Identifying Sensor Types and Models Using a Deep Learning Model. Quinones, L. A. , Davenport, K.
11:00 AM	STUDENT: Assessing Active Faults in the Cascade Arc: A Case Study of the Blue Ridge Fault, Mount Hood, Oregon. Carlson, M. L. , Streig, A., Madin, I., Bennett, S. E. K.	INVITED: Experimental and Numerical Analysis of the Effects of 3D Velocity Structures on HVSR. González, J. G., Baena-Rivera, M., Spurlin, J. H., Ramos-Pérez, E., Jaramillo-Rivera, A. H., Iturrarán, U., López-Sugahara, O. I., Cruz-Jiménez, H., Sánchez-Sesma, F. J.	INVITED: Spatio-temporal Migration Patterns of Micro-seismicity Driven by Fluid Injections and Induced Aseismic Slip. Sáez, A. , Sarma, A., Avouac, J., Lecampion, B.	STUDENT: Machine-learned Acceleration of Earthquake Sequence Simulations. Yanagi, R. , Kim, T., Bhattacharya, K., Lapusta, N.		Expansion of the Metro Vancouver Network-based EEWS: Challenges and Opportunities. Zaicenco, A. G. , Weir-Jones, I.	Control of Slab Tearing on Deep-focus Earthquakes and Volcanoes. Zhang, H.	Measuring Structural Motion Without Permission. Castellaro, S.	Seismo-acoustic Analysis of the 22 September 2023 Pingtung, Taiwan Chemical Explosion From Near Source Records. Huang, B. , Ho, M., Ku, C., Lin, C.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	The Landscape Record (continued)	Advances and New Challenges (continued)	Earthquake Swarms (continued)	Developing Data-Driven Methods (continued)		Advancing Earthquake Early Warning (continued)	Linking Subduction Zone Processes (continued)	Earthquake Ground Motions (continued)	Evolving Frontiers in Explosion (continued)
11:15 AM	STUDENT: First Paleoseismic Evidence of Late Quaternary Surface Rupture in the Fraser Canyon of British Columbia, Canada. Mendoza, R. , Hobbs, T. E., Nissen, E., Leonard, L. J., Bennett, S. E. K., Woor, S., Salomon, G., Podhorodeski, A., Menounos, B., Yakuden, L., Lian, O., D’Arcy, M.	Three-dimensional Numerical Analyses of Local Seismic Response in Complex Geological Settings: Applications to the Norcia Sedimentary Basin and the Introdacqua Rock Site (Central Italy). Linsalata, F. , Puglia, R., Costanzo, A., Massa, M., Lovati, S., Smerzini, C., Pischietta, M., Vanini, M., Parolai, S., D’Onofrio, A., Silvestri, F., Raggiunti, M.	Seismic Moment Release Patterns in a Swarm-dominated Fault System. Fischer, T. J. , Vlček, J., Káldy, E.	Development of an Enhanced Seismicity Catalog for the Cascadia Subduction Zone. Hirao, B. W. , Thomas, A. M., Ni, Y., Denolle, M. A., Bachelot, L., Trugman, D. T., Marfo, W., Hartog, J., Tobin, H. J.		Testing Earthquake Early Warning for New Zealand: Performance and Adaptation of the Finite Fault Rupture Detector (Finder) Algorithm. Andrews, J. , Behr, Y., Böse, M., Kaiser, A., Fry, B., Planès, T.	Pick Aggregator: A Multi-model Ensemble of Machine Learning Pickers to Detect Offshore Seismic Swarms North of Puerto Rico and the Virgin Islands. Aziz Zanjani, A. , DeShon, H. R.	Bridging Numerical Simulation, Cost-effective Condition Monitoring and Experimental Testing for Post-earthquake Resilience. Gunay, S., Mosalam, K. M.	STUDENT: Aircraft Detection with Surface-draped Fiber Optic Cable. McGhee, E. A. , Viens, L., Donahue, C. M., Boschelli, J. D., Carr, C. G., Aster, R. C.
11:30 AM	INVITED: Restraining Bend Topography Records Long-term Fault Slip and Fault Strength. Baden, C. W. , Nevitt, J. M., Hilley, G. E.	Limits of 1D Site Response in Basel’s Urban 3D Geological Environment. Imtiaz, A. , Hallo, M., Dresmann, H., Steiner, B., Panzera, F., Fäh, D.	Low-activity, Steady-state Earthquake Clustering in SW Australia: Evidence for Significant Prehistoric Activity? Pickle, R. C. , Allen, T. I., Miller, M. S.	STUDENT: Automated Labeling to Build Deep Learning Models for OBS Phase Picking. Qi, Q. , Du, K., Liu, X., Nakanishi, A., Tonegawa, T., Fujie, G.		Towards Public Earthquake Early Warning in Switzerland, Greece, Romania and Croatia. Planès, T. , Clinton, J., Boese, M., Massin, F., Burgoa Rosso, B. E., Marmureanu, A., Anghel, M., Neagoe, C., Ene, D., Manea, E., Evangelidis, C. P., Boukouras, K., Zailac, K., Sećanj, M., Stipčević, J., Dasović, I.	Low-frequency Earthquakes Track the Motion of a Captured Slab Fragment at the Mendocino Triple Junction. Shelly, D. R. , Thomas, A. M., Materna, K., Skoumal, R. J.	Urban-scale Assessment of Soil–building Resonance Effects Using Ambient Noise Measurements in Matera, Southern Italy. Gallipoli, M. , Calamita, G., Tragni, N., Mucciarelli, M., Stabile, T., Perrone, A., Amato, L.	Sparse Seismo-acoustic Data Reveals the Timing and Size of the Accurate Energetic Systems Explosion. Carmichael, J. D. , Kintner, J. A., Bishop, J. W., Alfaro-Diaz, R., Blom, P. S.
Noon–12:50 PM	Annual Business and Awards Ceremony				Noon–12:50 PM	Annual Business and Awards Ceremony			
1:00–2:15 PM	Luncheon				1:00–2:15 PM	Luncheon			
	The Landscape Record of Earthquakes and Faulting (see page 1450).	Advances and New Challenges in Investigating Seismic Site Response (see page 1331).	New Developments in Earthquake Rupture Physics For Source Characterization and Ground Motion Modeling (see page 1479).	Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science (see page 1378).		Advancing Earthquake Early Warning: Science, Technology and Engagement in the U.S. and Beyond (see page 1337).	Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cascadia, Chile and Beyond (see page 1456).	SSJ-SSOC-SSA Joint Session: From Slow to Fast Earthquakes: Bridging the Spectrum of Fault Slip (see page 1541).	Evolving Frontiers in Explosion Monitoring and Source Physics (see page 1409).
2:15 PM	Geology and Geomorphology of the Creeping Central Calaveras Fault. Martin, H. R., Rowe, C. D. , Koehler, R. D., Duncan, M., Travers, A.	INVITED: OpenAmp: An Open-source Site Amplification Database to Unlock the Potential of Machine Learning. Zhu, C. , Kwak, D., Pilz, M., Haendel, A., Xie, J., Kawase, H., Cotton, F.	Dynamic Branching and Surface Rupture in the Signal Hill Stepover on the Newport-Inglewood Fault, Southern California. Oglesby, D. D. , Toghramadjian, N., Plesch, A., Shaw, J. H., Zhang, W.	Data-driven Seismology for Nonstationary Wavefields and Hydromechanics. Denolle, M. A. , Ni, Y., Sanger, M., Stone, I., Bao, Y., Maurer, B. W., Kutz, J.		Beyond Earthquakes: The Role of Emergency Management in Seismic Events. Lambeth, D. J., Gudel, J.	STUDENT: Reconstructing Spatial and Temporal Megathrust Rupture History Using Stratigraphy and Microfossils at Sitkinak Island, Alaska. Nowak, T. , Dura, T., Engelhart, S., Briggs, R. W., Witter, R., Koehler, R. D., Haeussler, P. J.	Temperature Controls the Episodic Dynamics of Deep Slow Slip. El Yousfi, Z., Rousset, B., Radiguet, M., Frank, W. B.	STUDENT: Characterizing Anthropogenic Signals at Rellis Campus Explosion Site Using Nodal Arrays. Metzler, E. , Chen, X., Arthur, L., Asirifi, R.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
	The Landscape Record (continued)	Advances and New Challenges (continued)	New Developments in Earthquake (continued)	Developing Data-Driven Methods (continued)
2:30 PM	STUDENT: Spatiotemporal Trends in Slip Rate and Earthquake Recurrence on the Sierra Madre-Cucamonga Fault Zone, Southern California. Kindred Weigandt, C. , Dolan, J. F., Rodrigues, K., Jordan, F. F	Dense Array Experiment on Mt. Plaia (Central Italy), to Improve Understanding of Site Amplification on Topography. Raggiunti, M. , Pischiutta, M., Pastori, M., Roselli, P., Cammarano, F., Speciale, S., Scudero, S., Cabrera-Perez, I., Savard, G., Lisi, A., Linsalata, F.	Complex Rupture Behavior of the 2023 Mw 7.8 Kahramanmaraş, Türkiye Earthquake Revealed by Broadband Ground-motion Simulations. Akinci, A. , Pitarka, A., Artale Harris, P., Graves, R. W., Tsuda, K., Cuius, A.	STUDENT: Large-scale 3D Ground-motion Synthesis With Physics-inspired Latent Operator Flow Matching. Shi, Y. , Lavrentiadis, G., Ross, Z. E., Asimaki, D.
2:45 PM	STUDENT: Deep Earthquakes Can Generate Larger and Far-reaching Co-seismic Displacements Than Shallow Events. Chen, S. , Park, S.	Integration of Non-ergodic Site Response Into NEHRP Provisions & ASCE-7. Stewart, J. P. , Teague, D. P., Crouse, C. B., Kasali, G., Mazzoni, S., Murphy, D., Pezeshk, S., Walling, M., Williams, T., Zafir, Z.	INVITED: A Physics-informed Probabilistic Approach to Forecast Large Earthquake Ruptures. Ampuero, J. , Michel, S., Molina-Ormazabal, D., Jolivet, R., Tassara, A.	STUDENT: The Digital Archivist: Automating Legacy Macroseismic Data Processing Mining Using Large Language Models. Agrawal, A., Hough, S. E. , Mousavi, S., Yoon, C. E., Blanco, S. E., Hellweg, M.
3:00 PM	Gold Deposits as a Proxy to Identify Paleoseismic Cycles: A Numerical Investigation. Walker, R. L. , Hood, S.	Effects of Damping Contrasts at Soil and Soil-rock Boundaries on the Response of Layered Soil Deposits. Borcherdt, R. D.	When and Where Does Aseismic Creep Stop Rupture Propagation? Lozos, J.	Scalable Earthquake Phase Association Based on Wadati and Voronoi Diagrams. Song, J. , Zhu, W., Wang, H., Kumar, U., Taira, T., Allen, R.
3:15 PM	Validating Physics-engine Simulations of Precariously Balanced Rocks for Hazards Applications. McPhillips, D. , Chen, Z., Klabie, K.	STUDENT: Development of Non-linear Site Response Model Based on 1D Simulations. Anbazhagan, B. , Kottke, A. R., Stafford, P., Rodriguez-Marek, A., Bradley, B. A., Bahrapouri, M.	INVITED: The “Finite Volume” Effects of Faults in Dynamic Earthquake Rupture and Sequence Simulations. Huang, Y.	STUDENT: Optimizing Seismic Phase Picking in West Indonesia Using Transfer-learned Phasenet Models. Febriarta, B. , Sahara, D. P., Widiyantoro, S., Rosalia, S., Nugraha, A. D., Triyoso, W., Wibowo, A., Pratama, C., Wibisono, A., Krisnadhi, A. A., Putra, A. S., Muttaqy, F., Kusumawati, D., Faturrochman, I.

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	Advancing Earthquake Early Warning (continued)	Linking Subduction Zone Processes (continued)	SSJ-SSOC-SSA Joint Session (continued)	Evolving Frontiers in Explosion (continued)
	How to Learn an Industry in 10 Days! Utilizing Qualitative Methods to Build Industry-specific Expertise Within the ShakeAlert Earthquake Early Warning Technical Engagement Team. Stanley, S. M., Vinci, M. , Lotto, G., Reusch, M.	Impact of Rough Topography and Seamount Subduction on Near-trench Deformation in the Taltal Seismic Gap, Northern Chile. Cortés Rivas, V. , Moreno, M., Contreras-Reyes, E., Melnick, D., Lange, D.	INVITED: Slow Earthquake Activity and the Role of Seamount Subduction in the Guerrero Seismic Gap, Mexico. Ito, Y. , Flores-Ibara, K., Chen, Y., Hernández Díaz de León, S. A., Banales, I. M. R., Plata-Martínez, R., Cruz-Atienza, V. M.	The Source Physics Experiment on Seismic Waves Generated by Explosions: Results So Far and Future Plans. Walter, W. R. , Snelson, C. M., Abbott, R. E., Scalise, M. E., Pyle, M. L., Carr, C. G., Bodmer, M., Miller, A., Alger, E., Kintner, J. A., Berg, E., Turley, R. S., Pennington, C. N., Alfaro-Diaz, R., Stanciu, A., Smith, K., Bonner, J., Laintz, K., Luckie, T. W., Dietel, M., Price, A., Wilson, J., Gochenour, J. A., Harding, J., Aerts, J.
	Caution! Dangerous Intersections Ahead: Understanding Human Behavior, Traffic Patterns, Protective Actions and Accidents. McBride, S. K., Baldwin, D., Young, J., Fox, E. J. , McGuire, J. J., de Groot, R. M., Chupp, W.	Stress, Strain, the Seismic Cycle and Long-Term Forearc Deformation in Northern Chile. Schurr, B. D. , Dielforder, A., Lehmann, L., Sippl, C.	Seamount-controlled Tremor Distribution at Hyuga-nada Revealed by High-Resolution Vp and Vs Imaging. Nakata, R. , Ma, Y., Mochizuki, K., Kinoshita, M., Nakata, N., Hashimoto, Y., Hamada, Y., Miura, S., Nakamura, Y., Arai, R.	Physical Mechanisms of Underground Explosion-generated Shear Waves. Lei, Z. , Euser, B., Rougier, E., Knight, E., Larmat, C.
	Deaf, Deafblind and Hard of Hearing University Student Experiences With Earthquake Early Warning in the United States: Evaluating Language Planning and Technology Access. Cooper, A. C., Takayama, K., Cooke, M. L., Drakes, O., Sumy, D. F., McBride, S. K.	Do Coupled Megathrusts Rupture? Oryan, B., Gabriel, A.	Coupling Heterogeneity in the Cascadia Slow-slip Zone From GNSS Inversions and Physics-based Modeling. Magen, Y. , Gabriel, A., May, D. A.	Simulation of P/S Amplitude Ratio Discriminant at the Rock Valley, Nevada. Pitarka, A. , Walter, W. R., Pyle, M. L.
	Implementing Public EEW in Guatemala: From Seismic Detection to Public Action. Orihuela Gonzales, B., Yani, R., Castro, D., Marroquin, T., Planès, T. , Burgoa Rosso, B. E., Clinton, J.	The 2017 Mw 8.2 Mexican Earthquake Jumped From a Normal Outer-rise Fault Onto the Megathrust Interface. Husker, A. , Garcia, M. A., Velasco, A. A.	Spatiotemporal Modulation of Episodic Tremor and Slow Slip Behavior by Tectonic and Environmental Stresses in Cascadia. Meng, Q. , Liu, Z., Adhikari, S., Luo, Y.	Effects of Lateral Heterogeneity, Shallow Scattering, and Variable Crustal Thickness on High-frequency Explosion Waveforms. Modrak, R. , Gao, K., Creasy, N., Kintner, J. A., Nelson, P., Zhou, R., Saikia, C.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
3:30– 4:30 PM	Poster Break			
	Source Properties of Microearthquakes: Insights from Laboratory, Induced and Natural Events (see page 1536).	Recent Contributions of Social Science Research to Understanding Earthquakes (see page 1520).	New Developments in Earthquake Rupture Physics For Source Characterization and Ground Motion Modeling (see page 1479).	Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science (see page 1378).
4:30 PM	INVITED: Towards Improving Estimates of Small Earthquake Source Properties and Their Interpretation. Abercrombie, R. E. , Chen, X.	INVITED: 50 Years of the California Seismic Safety Commission: Where Social Science, Public Policy, Seismology, Geology, and Engineering Collide. McBride, S. K.	Constraining Rupture-generator Scaling Using Measured Surface Offsets, Near-fault Ground Motions and Rupture Dynamic Simulations. Pinilla Ramos, C. , Abrahamson, N.	STUDENT: A Machine-learning-enhanced Catalog of California Statewide Seismicity Over Two Decades. Rong, B. , Zhu, W., McBrearty, I. W., Beroza, G. C.
4:45 PM	Induced Earthquake With 200-to-800 Hz, Bell-shaped Source Spectra From 6 Kms Deep Injection in Igneous Basement Rock Near Helsinki, Finland. Malin, P. , Heikkinen, P., Leary, P., Blumle, F.	INVITED: Prototyping User-centered Graphics and Maps for Aftershock Forecasts. Schneider, M. , Wein, A., Artigas, B., McBride, S. K., van der Elst, N., Becker, J., Castro, R. R., Gonzalez-Huizar, H., Diaz, M., Hardebeck, J., Michael, A. J., Mixco, L., Page, M.	Realistic Representation of the Complex Dynamic Rupture Process to Simultaneously Account for Asperity Pulses and High-frequency Radiation: Syncro-shock Hypothesis. Kawase, H.	Performance of the Deep-learning Phase Picker Phasenet on Magnitude 3+ Earthquakes in Southern California. Tepp, G. , Shimota, B., Biondi, E., Zhu, W., Husker, A.
5:00 PM	INVITED: The Energy Budget of Laboratory Failure Experiments. Ortega-Arroyo, D. , Ghaffari, H., Peč, M., Gong, Z., Fu, R., Ohl, M., Cattania, C., Plümper, O.	Used and Useful: Usability Research on Earthquake Event Pages. Macías, M. , McBride, S. K., Davis, A., Palermo, L., Hunter, E., Pope, I. E.	Characterizing Rupture Speed Through Near-fault Particle Motions in Large Strike-slip Earthquakes. Yang, H. , Yao, S., Bhat, H., Aochi, H.	A Systematic Comparison of Foundation Models for Earthquake Detection. Si, X. , Peng, Z., Wu, X., Li, J., Cui, X., Li, Z.
5:15 PM	STUDENT: Ubiquitous Interactions and Subcritical Patches Explain the Irregularity of Repeating Earthquakes. Li, L. , Lapusta, N.	STUDENT: Real-time Public Reactions to Earthquakes via an Earthquake Early Warning Platform in Japan: Implications for Risk Perception. Fukurai, M. , Yong, A., Grant Ludwig, L., Bocekli, B., Wang, P., Matsushima, S., Hudson, K. S., Stanley, S. M.	Neural Operator Augmented Earthquake Sequence Simulations with Elastic Heterogeneities. Wang, T. , Abdelmeguid, M., Im, K., Ross, Z. E., Cattania, C.	STUDENT: AkiNet: A Physics-informed AI for Wave Extraction From Noise. Xue, S., Olugboji, T.

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
3:30– 4:30 PM	Poster Break			
	Fiber-Optic Sensing Applications in Seismology and Environmental Science (see page 1419).	Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cascadia, Chile and Beyond (see page 1456).	SSJ-SSOC-SSA Joint Session: From Slow to Fast Earthquakes: Bridging the Spectrum of Fault Slip (see page 1541).	Seismotectonics of Southern and Baja California (see page 1532).
	Unveiling Stick-slip Dynamics in Deep-seated Landslides Using Borehole Distributed Acoustic Sensing. Huang, H. , Huang, Y., Chen, H., Wang, K., Hsu, Y., Chen, C., Ku, C.	2025 Mw 7.0 Hubbard Glacier Earthquake: Seismic Hazard in Fault Corridor. Parameswaran, R. M. , Karasozen, E., Thurin, J., West, M. E., Grapenthin, R., Holland, A. A., Tape, C.	INVITED: Supershear Rupture Enabled by Bimaterial Effect and Favorable Energy Ratio Enablein the 2025 Myanmar-Mandalay Earthquake. Meng, L. , Xu, L., Yunjun, Z., Weng, H., Su, E., Ji, C.	INVITED: Urban Sedimentary Basins of Southern California: A Plate Boundary View of Seismic Hazard. Persaud, P. , Nardoni, C., Villa, V., Contreras, J., Clayton, R. W.
	INVITED: Ultra-broadband Fiber-optic Strain Sensing: Development and Applications to Plate Boundary Processes. Araki, E. , Yokobiki, T., Shuhei, N., Zumberge, M., Tsuji, S., Matsumoto, H.	STUDENT: Constraining the Coseismic Slip Distribution of a Megathrust Earthquake by Stress-driven Afterslip. Zhuo, Z. , Jeffrey, J., Fukuda, J., Xiao, Z., Elliott, J., Grapenthin, R.	A New Fault Slip Mode Unveiled in the Regional Dynamic Triggering of the 2023 Turkey Kahramanmaraş Earthquake Sequence. Luo, H., Zhou, Y. , Zhao, Z., Wang, T., Yue, H., Song, X., Bürgmann, R.	Shifting Patterns of Faulting in the Big Bend Domain of the Pacific-north America Plate Margin. Fletcher, J. M. , Rockwell, T. K.
	Illuminating Ruptures of Moderate Earthquakes With Multi-fibre Networks. Zhang, H. , Zhan, Z.	The Duality of Doublets: Unusually Large Aftershocks or Unusually Strong Fault Interactions? Jiang, Y. , Stein, R. S., Trugman, D. T.	STUDENT: Stress Interactions Among Strong-weak Fault Patches Govern Earthquake Cycle. Jiang, L., Zhang, S., Zhang, H.	INVITED: STUDENT: How Does the Cumulative Interaction of Diverse Faulting Mechanisms Shape the Long-term Tectonic Evolution of the Gulf of California? The Yuha Desert Case of Study. Jasso Lara, A. D. , Fletcher, J. M., Rockwell, T. K., Pascal, C., González Fernández, A., Inguaggiato, C.
	Investigating the Feasibility of Incorporating DAS Into Ground Motion Modeling. Meng, X. , Zhai, Q., Kottke, A. R., Atterholt, J. W., Pinilla Ramos, C., Ben-Zion, Y.	STUDENT: Tectonic Pump Closes the Evolutionary Loop for Long-buried Subseafloor Microbes. Li, Z. , Barbot, S., Lloyd, K.	Characterization of Focal Mechanisms for Small Earthquakes Preceding the Mw 7.5 Noto Peninsula Earthquake. Zhang, M. , Kato, A.	Complications in Characterizing Seismic Hazards in the Blind Fault System of the Santa Maria Basin, California. McGregor, I. S. , Onderdonk, N. W.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
	Source Properties of Microearthquakes (continued)	Recent Contributions of Social Science Research (continued)	New Developments in Earthquake Rupture Physics (continued)	Developing Data-Driven Methods (continued)
5:30 PM	STUDENT: Comparing Earthquake Interaction on Creeping Faults in California with Induced Earthquakes in the Central US. Ries, R. , Beroza, G. C., Ellsworth, W. L.	Assessing Behavioral Response to Earthquake Early Warnings: What We Know and Would Like to Know About Response. Goltz, J. D.	Unified Nucleation Mode and Mechanics Model for All Earthquake Rupture Speeds. Xia, K. , Dong, P.	Qseek: Scalable Data-driven Earthquake Detection and Localization. Isken, M. P. , Peter, N., Münchmeyer, J., Büyükkapinar, P., Torsten, D.
6:00–7:00 PM	Joyner Lecture: Seismic Wave Propagation in Complex Geological Domains: From Site Effects in Ground Motion to Diffuse Fields in Passive Seismology			
7:00–8:00 PM	SSA Honors Reception			

Poster Sessions

Advances and New Challenges in Investigating Seismic Site Response (see page 1333).

- STUDENT: Subsurface Velocity Structure at Eureka, NV, for Inferring Acoustic-to-seismic Conversion From the OSIRIS-REx Capsule Re-entry Sonic Boom. **Bazargan, S.**, Langston, C. A.
- STUDENT: Global Annual Long Period Seismic Background Variability. **Becker, J.**, Rapoport, Y., Aster, R. C., Lee, T. A., Simons, F. J., Ringler, A., Anthony, R. E.
- Generic Nonlinear Amplification Functions for Taiwan. Wang, Y., **Chang, Y.**, Hsu, S., Wang, S.
- Near Surface S-wave Velocity Measurement and Site Classification at 46 Sites in the East Bay and Delta. **Craig, M.**, Romero, M., Hayashi, K.
- Predictions of Ground Motions and Wave Radiation Patterns From a Chemical Explosion in Highly Faulted Testbed: Applications to the Nevada Rock Valley Source Physics Experiment. **Ezzedine, S. M.**
- Reconnaissance Noise Survey for Seismic Network Expansion in Ukraine Under Wartime and Infrastructure Constraints. **Farfuliak, L.**, Amashukeli, T., Mackey, K., Chiang, A., Stachnik, J., Daniel, B., Aderhold, K., Petrenko, K., Haniiev, O., Kuplovskiy, B.
- Application of Machine Learning in Ground Motion Prediction: A Case Study From West Java, Indonesia. **Kaka, S.**, Rachmdn, A.

- Assessment of Site Amplification Factors From the Non-reference Site Approach – a Case Study of the Taipei Basin. **Kuo, C.**, Chen, Y.
- STUDENT: Predictive Models for Depth to Rock Using Horizontal-to-Vertical Spectral Ratio Method and Geospatial Parameters in Southeastern Korea. **Lee, J.**, Ahn, S., Seo, H., Kim, B.
- STUDENT: HVSR Site Response in the Willamette Valley, Oregon. **Mann, C. A.**, Sahakian, V. J.
- Site-specific Hazard Analysis of a Liquefied Natural Gas Tank Located in South-central Virginia. **Pezeshk, S.**, Zandieh, A., Wong, I. G., Wu, Q.
- A Systematic Analysis of Directional Site Amplification Effects at Stations of the Seismic Network (Nz), to Test the Relation With Local Geological and Morphological Proxies. **Pischiutta, M.**, Kaiser, A., Puglia, R., Manea, E.
- Ground Velocity and Ground Tilt From Seismometers: Two for the Price of One. Guralp, C., **Rademacher, H.**
- Engineering Site Response Validation of Method Using Random Vibration Theory. **Thornley, J.**, Dutta, U.
- Site-response Characterization in Tbilisi Using Integrated Geophysical Data. **Tsereteli, N.**, Dvali, L., Kvirkhkhalia, T.
- STUDENT: Behind the Curtain: Developing Methods and Toolkits Supporting Practical Assessment of Discharge and Bedload of the Nisqually River Within Mount Rainier National Park. **Zawol, Z.**
- An Additive Approach for Developing Hybrid VS30 Models: Incorporating Geological Information Into a Geospatial Model for an Updated VS30 Map of Chinese Mainland. **Zhou, J.**, Rong, Y., Li, L., Ren, Y., Tian, X.

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	Fiber-Optic Sensing Applications (continued)	Linking Subduction Zone Processes (continued)	SSJ-SSOC-SSA Joint Session (continued)	Seismotectonics of Southern and Baja California (continued)
	Acoustic Coda–based Yield Estimation of Surface Explosions With Distributed Acoustic Sensing. Delbridge, B. G. , Viens, L.	Patterns of Coseismic Landslides in Subduction Zones: Observations From the 2025 M8.8 Kamchatka Peninsula Earthquake and Beyond. Grant, A. , Allstadt, K., Collins, E., Dunham, A.	Supercritical Fluid Flow, Phase Transitions, and Seismicity at the Brittle–ductile Transition Imaged by Integrated Active and Passive Seismology. Tsuji, T.	Structure, Seismicity, Earthquake and Tsunami Potential of the San Clemente Fault System. Legg, M. , Kamerling, M.
6:00–7:00 PM	Joyner Lecture: Seismic Wave Propagation in Complex Geological Domains: From Site Effects in Ground Motion to Diffuse Fields in Passive Seismology			
7:00–8:00 PM	SSA Honors Reception			

Advancing Earthquake Early Warning: Science, Technology and Engagement in the U.S. and Beyond (see page 1341).

- The Testsuite and the Baseline Performance for Canada’s National Earthquake Early Warning System. **Crane, S.**, Saravanamutto, P., Seywerd, H.
- Operating EEW in Eastern Canada Part II: Seismological Parameters. **Crane, S.**, Perry, C., Kolaj, M., Adams, J., Seywerd, H.
- Outreach and Engagement to Ensure the Success of Canada’s Earthquake Early Warning System. Bird, A., Seywerd, H., Boucher, C., **Crane, S.**, Blais, C.
- Evaluating GFAST-PGD’s Contributions to ShakeAlert® System Performance for Simulated Cascadia Subduction Zone Earthquakes. **Dybing, S. N.**, Ulberg, C. W., Dunham, A., Murray, J. R., Thompson, M., Krauss, Z., Hartog, J.
- Testing Cloud-based Resiliency Options for the U.S. ShakeAlert Earthquake Early Warning System. **Felizardo, C.**, Saunders, J. K., Bhadha, R., Husker, A.
- Continued Testing of FinDer Templates for Earthquake Early Warning and Implementation of a Dash Application for Visualizing and Analyzing Performance. Thompson, M., **Hartog, J.**, Böse, M., Saunders, J. K., Felizardo, C., Andrews, J., Ceylan, S., Good, A. D.
- Earthquake Early Warning Instrumentation and System Considerations. **Laporte, M.**, Somerville, T., Perlin, M., Easton, D., Jusko, M., Pelyk, N.
- STUDENT: Designing Seismic Arrays for Offshore Earthquake Early Warning Applications: Insights From Coastal Deployments in Alaska. **Quigley, C.**, West, M. E.

- Stress Testing ShakeAlert® Using the 2023 M7.7 Kahramanmaraş Earthquake Sequence, Türkiye. **Saunders, J. K.**, Boese, M., Ulberg, C. W., Bunn, J., Lux, A. I., Dybing, S. N., Ceylan, S., Murray, J. R., McGuire, J. J., Felizardo, C., Jha, S., Crowell, B. W.
- Field Test of Deep Learning-based, Real-time, False-pick Filter for EEW: 1-second Time-window Approach. **Seo, J.**, Lee, J.
- System Monitoring, Telemetry Quality Control and DAS Testing at SCSN. **Stubailo, I.**, Zhai, Q., Wang, J., Biasi, G., Alvarez, M., Watkins, M., Bhadha, R., Husker, A.
- Sparse Rupture Inversion Using Moment Tensor Interpolation – Synthetic Benchmark and Application to the 2025 Mw 7.6 Aomori Prefecture Earthquake, Japan. **Thurin, J.**, Maubant, L., Itoh, Y.
- Optimizing the Epic Algorithm’s Performance to Detect and Characterize Recent Moderate Sized Earthquakes in Alaska. **Williamson, A. L.**, Lux, A. I., Henson, I., Akimov, A., Allen, R.
- Calibrating Per-station Magnitude Corrections in Epic Using a Large Dataset of Past Detections. **Williamson, A. L.**, Lux, A. I., Henson, I., Akimov, A., Allen, R.
- Earthquake Early Warning and Real-time Shakemap Development Using Low-cost Sensors in Taiwan. **Wu, Y.**

Data-Driven and Computational Characterization of Non-Earthquake Seismoacoustic Sources (see page 1373).

- STUDENT: Catalog of Clustered Strombolian Eruptions Using Waveform Cross-correlation and Matched Filtering - Erebus Volcano, Ross Island, Antarctica. **Burton, S.**,

Aster, R. C., Chaput, J., Garza-Giron, R., Emerson, T., Grapenthin, R.

35. Observed and Simulated Seismic Ground Motions From a 13-story Building Implosion-collapse in Hayward, California. **Hirakawa, E. T.**, Nye, T., Poulos, A., Catchings, R. D., Goldman, M., Parker, G. A., Baltay, A.

36. Explosion Yield Estimation and Impacts of Small-scale Atmospheric Perturbation on Infrasound Propagation. **Kim, K.**

37. STUDENT: Interpretable Spectral Representations of Planetary Signals in Vector Spaces (Spec2VEC). Swar, S. K., Mittal, T., **Olugboji, T.**

38. STUDENT: Cryospheric Clutter. **Sivam, S.**, Matoza, R. S.

39. STUDENT: Broadband Seismic and Infrasonic Signals From Two Recent Tornadoes. **Thompson, S. C.**, Carpenter, S., Soni, Y., Wang, Z., Woolery, E. W.

40. Component-dependent Seismic Ambient Noise Amplification During Hurricane Milton (2024) in South Florida. **Yang, X.**, Lin, G., Wang, Y.

41. Radiosonde-to-space (R2S) Atmospheric Specifications: Bridging Observations and Models for Infrasound Propagation. Schaible, L. P., Silber, E. A., **Albert, S. A.**

42. A Multi-year Regional Infrasound Array Network in Utah, USA. **Albert, S. A.**, Pankow, K., Forbes, N., Kelley, S.

Evolving Frontiers in Explosion Monitoring and Source Physics (see page 1411).

43. DL-G2S: A Deep Learning Ground-to-space Uncertainty Model for Infrasound Propagation. **Albert, S. A.**, Silber, E. A., Sakamoto, J., Cho, M.

44. Source-type Discrimination of Local-distance Seismic Events in the Utah Region Using Machine Learning Differential Seismic Phase Detection Probabilities. **Beskardes, G. D.**, Tibi, R., Young, C. J., Heck, S., Koper, K. D.

45. Uncertainty Quantification of Two Recent Chemical Explosion Experiments Using Time Variable Moment Tensor Seismic Source Inversions. **Darrh, A.**, Preston, L., Stanciu, A.

46. Signatures of the Damage Zone of Underground Explosions. **Delorey, A. A.**

47. Monitoring Ongoing Seismicity in the Southern Nevada National Security Site: Toward Understanding the Shallow Structure of the Rock Valley Fault Zone. **Gochenour, J. A.**, Smith, K., Scalise, M. E., Eckert, E. E., Turley, R. S.

48. Decoding Underground Explosions with Time-domain Seismic Source Functions. **Kintner, J. A.**, Alfaro-Diaz, R., Lei, Z., Euser, B., Vitali, E., Pippin, J. E.

49. Source Characterization of Nuclear Tests From Reloaded Tunnels in Degelen Mountain From Digitalized Regional Short-period Seismic Data. **Likhovod, M.**, Berezina, A., Mackey, K., Burk, D.

50. Recovery and Digitalization of Legacy Semipalatinsk Test Site Nuclear Explosion Seismograms From Kazakhstan and the Kyrgyz Republic. **Mackey, K.**, Burk, D., Berezina, A., Shiman, D., Yeginbekova, N., Abdrakhmatov, K.

51. Low-magnitude Seismic Source Inversions for the Rock Valley, Nevada. **Modrak, R.**, Kintner, J. A., Scalise, M. E., Larmat, C., Eckert, E. E., Pitarka, A.

52. Modelling Observed Backazimuth and Slowness Deviations From Local Earthquakes at a Small Aperture Broadband Seismic Array. **Nippress, S. E. J.**, Green, D. N.

53. Detection Capability Analysis for the RV/DC Experiment Design. **Pennington, C. N.**, Pyle, M. L., Walter, W. R.

54. STUDENT: Discriminating Between Natural Earthquakes, Induced Events, and Explosions in West Texas. **Pippin, J. E.**, Alfaro-Diaz, R., Kintner, J. A., Chen, T., Velasco, A. A.

55. Quantifying Uncertainty in Regional-scale Seismic Moment Tensors. **Preston, L.**, Darrh, A.

56. Reevaluating the 1993 Rock Valley Sequence: How Can New Information Help Constrain Historic Event Locations? **Pyle, M. L.**, Chen, T., Gao, K., Gochenour, J. A., Luckie, T. W., Park, Y., Preston, L., Rowe, C., Scalise, M. E., Smith, K., Syracuse, E., Trugman, D. T.

57. Waveform Tomography for Improved 3D Wavespeed Models and Moment Tensors for Nuclear Explosion Monitoring. **Rodgers, A. J.**, Doody, C.

58. Simulating Locally Recorded Earthquakes to Evaluate the Rock Valley Geologic Framework Model. **Scalise, M. E.**, Eckert, E. E., Pitarka, A., Modrak, R., Larmat, C.

59. Signal Separation and Enhancement in the Stockwell Transform Domain and Application to Local and Regional Seismic Data. **Tibi, R.**

60. Waveform-based Machine Learning Detection and Characterization of Small Events. **Tibi, R.**, Quinones, L. A.

Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science (see page 1382).

61. STUDENT: A Graph-based Generative Framework for Modeling Spatial Correlation of Within-event Ground-motion Residuals. **Aquib, T.**, Mai, P.

62. Chatting With the Earth: LLMs for Seismic Data Processing. **Blanco, S. E.**, Mousavi, S., Liu, J.

63. Seismicity of the Western Idaho Suture Zone Illuminated by Machine Learning. **Bockholt, B.**, Lifton, Z.

64. Cautions for Applying Automated Earthquake Cataloging Workflow to Local Nodal Arrays. **Chen, X.**, Asirifi, R., Woo, J., Chen, T., Fan, W., Abercrombie, R. E.

65. Which is Better: Deep-learning or Manual Seismic Arrival-time Picking? **Cianetti, S.**, Lomax, A., Michelini, A., Giunchi, C.

66. ESM25: A Machine-learning Ready Snapshot of the European Engineering Strong-motion Database. **Cianetti,**

S., Mascandola, C., Faenza, L., Felicetta, C., Russo, E., Jozinović, D., Münchmeyer, J., Luzi, L., Michelini, A.

67. Transfer Learning with Self-normalizing Neural Network-based Ground Motion Models: From NGA-West to CEUS. **Fallahpour Mojavery, S.**, Pezeshk, S.

68. A Critical Assessment of Domain Adaptation Methods for NGA-West2-to-CEUS Transfer. **Fallahpour Mojavery, S.**, Pezeshk, S.

69. STUDENT: Conditional Ground Motion Generation using Diffusion Transformer (DiT). **Feng, Y.**, Zhu, W., Lu, X.

70. Space-time Completeness of Seismic Ground Motions via Non-intrusive Model Order Reduction. May, D. A., **Gabriel, A.**, Trugman, D. T., Krämer, B.

71. STUDENT: Earthquake Forecasting With Single-station Waveform Detection Without Relying on Event Catalogs. **Iwasaki, Y.**, Brodsky, E., Dascher-Cousineau, K.

72. STUDENT: Constraining Parameters of Earthquake Cycle Models With Uncertainty Quantification Using Paleoseismic Records: A Synthetic Study. **Kaveh, H.**, Dunbar, O., Avouac, J., Stuart, A.

73. Machine Learning-based Ground Motion Models for Shallow Crustal Earthquakes in California Using NGA-West3 Database. **Kim, S.**, Seyhan, E., Cao, Y.

74. STUDENT: Constraining Fault Geometry of the Marlborough Fault System in Aotearoa New Zealand, Using Machine Learning. **Montalvo-Lara, C. E.**, Townend, J., Chamberlain, C. J., Warren-Smith, E., Jacobs, K., Okada, T., Iio, Y., Matsumoto, S.

75. STUDENT: Interpretable Gradient Boosting Machines for Post-earthquake Building Damage Assessment: Data from the 2015 Nepal Gorkha Earthquake. **Niu, Y.**, Foroughi, H.

76. From Redundancy to Coverage: Compact Benchmarks for Seismic Artificial Intelligence Models. **Parikh, N.**, Myren, S., Rael, R., Alfaro-Diaz, R., Gopalan, G., Casleton, E.

78. STUDENT: Graph-regularized Receiver-function Interpretation Using Gravity Constraints. **Villa, V.**, Clayton, R. W., Persaud, P.

79. STUDENT: I-Hades: A Seismic Event Locator Combining Deep Learning With Distance Geometry Methods. **Vullo, G.**, Grigoli, F.

80. A Regional Multi-station Deep Learning Model for Earthquake South Depth Determination in Southern California. Li, W., **Zhang, M.**

81. STUDENT: Deep Image Prior-based Framework for Simultaneous Regularization and Denoising of Teleseismic Receiver Functions. **Zuo, P.**, Chen, Y., Li, C., Chen, Y.

Earthquake Ground Motions and Structural Response: Emerging Tools and Applications (see page 1389).

82. STUDENT: Identifying Reference Stations for SSR-based Site-effect Studies Near the Mississippi. **Abbasi Hafshejani, Z.**, Pezeshk, S., Cramer, C.

83. Damage Detection Across California: Using the Myshake Smartphone App to Measure Building Modal Frequencies. **Allen, R.**, Kumar, U.

84. STUDENT: Seismological Overview of the Toppling of Easter Island Moai Statues Using Real and Synthetic Ground Motion Records. **Bhandari, A.**, Sharma, J., DeShon, H. R., Aghagholidzadeh, M., McCoy, M.

85. Ambient Noise Deconvolution Seismic Interferometry as a Complementary Tool for Structural Characterization of Civil Infrastructures. **Gallipoli, M.**, Tragni, N., Serlenga, V., Petrovic, B., Parolai, S.

86. Monitoring Multimodal Frequency Variations in a 10-story Cold-formed Steel (CFS10) Building for Damage Assessment. **Guo, H.**, Zhang, S., Kohler, M., Sorosh, S., Zhang, J., Hutchinson, T. C., Guy, R.

87. Only Very Strong Shaking Can Break a Tree. **Hough, S. E.**

88. The Güralp Stratis: A Commercial Six-degree-of-freedom Seismometer for Ground Motion and Structural Monitoring. **Lindsey, J.**, Restelli, F.

89. Integrating Distributed On-premises Linux Back-ends With Scalable Azure Web Infrastructure for Real-time Seismic Data Distribution. **Lisowski, S. W.**, Haddadi, H., Branum, D., Antolik, L., Mertl, S., Cooke, A.

90. Assessing the Role of Low-cost MEMS Sensors in Strong-motion Networks Through Industry’s Lens. **Saifullah, M.**, Skolnik, D. A.

91. STUDENT: 1D Velocity Profiles and Site Characteristic Assessment, Using Bayesian SPAC Analysis, in Puerto Rico. **Toro Acosta, C.**, Vanacore, E., Pacchai, S.

92. Seismic Strain Demand Prediction of Natural Gas Pipelines via Active Learning With a Query-by-committee Approach. **Zengin, E.**, Peng, Y., Ayello, F., Hyun, G., Honegger, D., Bozorgnia, Y.

Earthquake Swarms Across the Earthquake Cycle: Precursors, Transients and Aftereffects (see page 1395).

93. Depth-dependent Interaction of Tectonic Tremors, Repeating Earthquakes, and Earthquake Swarms in a Collision Zone of Taiwan. **Chen, K.**, Peng, W.

94. Aseismic Slip and Seismic Swarms Leading Up to the 2024 M7.3 Hualien Earthquake. Peng, W., **Chen, K.**, Bürgmann, R., Hsu, Y., Chen, Y.

95. Automated Workflow for Earthquake Cluster Detection, Classification, and Migration Analysis: Application to California Seismicity. **Cui, X.**, Li, Z., De Barros, L., Ampuero, J.

96. Comparison of Swarm Activity in Natural and Induced Intraplate Tectonic Settings. **DeShon, H. R.**, Seldon, Y., Neupane, P., Aziz Zanjani, A., Walter, J.

97. STUDENT: Stress Heterogeneity of Seismogenic Structures Revealed by Waveform Similarity: Before and After the

2024 Mw 7.4 Hualien Earthquake, Taiwan. **Hung, H.**, Ma, K., Tseng, T.

98. Characterizing Aseismic Stress Transients During Earthquake Swarms in California and Nevada From Seismicity Rate Observations. **Jiang, Y.**, Trugman, D. T.

99. Burst-like Rapid Earthquake Migrations During the 2025 Tokara Islands Seismic Swarm, Japan. **Kato, A.**, Yakiwara, H., Hirano, S., Nakao, S., Sakai, S.

100. STUDENT: Physically Scaled Nearest-neighbor Clustering for Identifying Swarm and Aftershock Regimes in Tectonic and Volcanic Environments. **Montazeri, S.**, Chen, X.

101. Study of Seismic Stresses and Foreshock Patterns Before the 1978 Magnitude 7.8 Oaxaca Earthquake. **Nunez-Cornu, F. J.**

ESC-SSA Joint Session: Interpreting Volcanic Unrest and Eruption Data for Effective Crisis Management (see page 1408).

102. Source Modelling of Surface Deformation and Seismicity at the Campi Flegrei. **Cheng, J.**, Li, Z., Acosta, M., Lecampion, B., Ayouac, J.

103. Surface-wave Relocation and Characterization of the 2024-2025 Dyking Episode Along the Fentale-Dofen Segment of the Ethiopian Rift. **Deane, C. A.**, Pesicek, J. D., Bagnardi, M. D., Shelly, D. R., Prejean, S. G., Yeck, W. L., Earle, P. S.

104. STUDENT: Spectral Energy Distribution and Multiplet Analysis of Seismicity at Nevado del Ruiz Volcano Near Eruptive Events. **Rave-Bonilla, Y. P.**, Rodgers, M., Rodriguez-Cardozo, F. R., Braunmiller, J., Londono, J. M., Thompson, G.

105. Challenges and Opportunities for Seismic and Infrasound Monitoring at Ecuadorian Volcanoes. **Ruiz, M. C.**, Mothes, P., Hernandez, S.

106. STUDENT: Exploring Automated P-wave Polarity Picking for Focal Mechanism Determination for Seismicity on the Island of Hawai`i. **San Ramon, G. Z.**, Matoza, R. S., Uchide, T., Chang, J. C., Flinders, A. F., Ji, C.

107. Volcanic Tsunami and Its Prediction for Early Warning. **Song, Y.**

108. Interpretation of Shallow Hybrid Earthquakes at Campi Flegrei. **Tramelli, A.**, Petrosino, S., Dalla Via, G., Tan, X., Aquino, I., Beroza, G. C., Bianco, F., D'Auria, L., Ellsworth, W. L., Manzo, R., Orazi, M., Marzocchi, W., Ricciolino, P., Ricco, C.

International Collaboration to Advance Earthquake Science and Disaster Response (see page 1449).

109. The NEHRP Post-earthquake Investigations Program. **Blanpied, M. L.**

110. The U.S. Geological Survey's PAGER System at 15: A Performance Evaluation and Lessons Learned. **Marano, K. D.**, Wald, D. J., Jaiswal, K., Hearne, M.

111. International Aftershock Forecasting and Products at the U.S. Geological Survey. **Schneider, M.**, van der Elst, N., McBride, S. K., Page, M., Michael, A. J., Hardebeck, J., Davis, L., Blanpied, M. L., Hayes, G.

112. Improving Seismic Monitoring in the Southwest Pacific. **Shiro, B.**, Yeck, W. L., Benz, H. M., Wilson, D. C., Mooney, W. D.

The Landscape Record of Earthquakes and Faulting (see page 1454).

113. STUDENT: Preliminary Characterization of the Multorpor Mountain Fault: Evidence for Repeated Late Quaternary Faulting on the Mount Hood Fault Zone, North-central Oregon. **Briseno, D.**, Streig, A., Bennett, S. E. K.

115. Middle to Late Pleistocene Faulting on the Puyé Fault Zone, Española Basin, New Mexico. **Jobe, J. A. T.**, Cline, M., Reitman, N. G., Briggs, R. W., Sion, B., Mahan, S., Gray, H., Ellett, N., Gold, R., Tan, M., Nicovich, S. R.

116. STUDENT: Can Sackungen in Arthur's Pass Record Past Large Earthquakes? **Parker, M. O.**, Howell, A., Nicol, A., Coffey, G., O'Kane, A.

117. No Apparent Coseismic Surface Rupture in Trench Exposures of the Creeping San Andreas Fault at Topo Creek. **Philibosian, B.**, Vermeer, J., Usher, E., Trexler, C. C., Alongi, T., Elliott, A., Hammer, M., Hanagan, C. E., DeLong, S. B.

118. Paleoseismic Investigation of Quaternary Faulting in the Southwest Montezuma Hills, Sacramento – San Joaquin Delta Region, California. **Trexler, C. C.**, Philibosian, B., Vermeer, J., Gray, H., Elliott, A., Alongi, T., Cunetta, N.

119. Comparison of Lidar-differencing Fault Displacement Maps With Geomorphic Fault Mapping on the Central San Andreas Fault. **Vermeer, J.**, Hanagan, C. E., DeLong, S. B., Hammer, M., Powell, J. H., Philibosian, B., Arrowsmith, R.

120. Late Quaternary Fault Scarps in the Saratoga Valley, Wyoming: A Potential Source for 1882 Colorado Earthquake? **Zellman, M.**, Hartleb, R., Lindvall, S. C., Unruh, J. R., Rockwell, T. K., Chase, R. E.

Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cascadia, Chile and Beyond (see page 1459).

121. STUDENT: Machine Learning-based High-resolution Earthquake Catalog for the Middle America Trench Using Ocean Bottom and Land Seismometers. **Asgarvand, O.**, DeShon, H. R., Aziz Zanjani, A.

122. Evaluating Seismic Hazards for Carbon Storage on the Scotian Shelf Offshore Nova Scotia. **Barkat, A.**, Zhang, M., Nedimović, M., Niksejel, A., Wach, G., Cairns, G., Bosman, K., Thibodeau, J.

123. PACSAFE LEG2: Investigating Seismicity in the Northern Segment of the Queen Charlotte Triple Junction Using a Year-long OBS Deployment. **Barkat, A.**, Zhang, M., Nedimović, M., Plourde, A., Schaeffer, A. J., Hobbs, T. E., Sun, T., Cairns, G., Bosman, K., Thibodeau, J., Bostock, M. G., Nissen, E., Peacock, S., Kao, H., Wang, K., Rohr, K., Lintern, G.

124. Investigating Interseismic Vertical Land Motion Along the Cascadia Subduction Zone Using High-resolution Diatom-based Paleogeodesy and Radiocarbon Chronologies. **Bruce, D.**, Dura, T., Hawkes, A. D.

125. STUDENT: Machine Learning Detection of Offshore Tremor in the Cascadia Subduction Zone Using Multi-year Continuous Offshore and Onshore Seismic Data. **Dong, B.**, Byrnes, J., Janiszewski, H. A.

126. A 2D and 3D Community Fault Model for the Cascadia Subduction Zone: Release of CRESCENT CFM Version 1.0. **Fildes, R. A.**, Amos, C. B., Roland, E., Streig, A., Bennett, S. E. K., Hatem, A. E., Ledeczi, A., Meigs, A., Styron, R. H., Tobin, H. J.

127. Dynamic Rupture Modeling of the 2010 Mw 7.8 Mentawai Tsunami Earthquake With Self- Similar Stress Drop and Wedge Inelasticity. **Hung, R.**, Ma, S.

128. STUDENT: Comparison of Seismicity Along the Northern and Southern Central Andes and Its Relationship With Along-strike Variations in Andean Deformation. **Mahanti, S.**, Kiser, E., Bradford, J. M., Beck, S. L., Fernandez, M., Tauber, S., Porter, R. C., Leon-Rios, S., Reyes-Wagner, V., Trad, S., Ortiz, G. F., Saez, M., Roecker, S., Comte, D., Orosco, L.

129. A Surface-in-cell Approach to Including Evolving Faults in Geodynamic Models. **Moresi, L.**, Gollapalli, T.

130. STUDENT: Low Frequency Earthquakes in the Alaska Subduction Zone. **Perez Estay, N. A.**, Bostock, M. G., Sammis, C.

131. STUDENT: Forearc Seismic Structure at the Alaska Peninsula Revealed From AACSE Receiver Functions. **Rojas Churkovic, I. P.**, Janiszewski, H. A., Wei, S. S., Kim, H.

132. STUDENT: Revisiting the Tectonic Geomorphology of the Nicaragua Segment of the Middle America Trench Using Newly Collected High-resolution Bathymetry and Reprocessed Marine Seismic Reflection Data. **Rysanek, S.**, Lindsey, E., Worthington, L., Xie, S., Zumberge, M., Dixon, T.

133. Crustal Stress and Faulting in the Pacific Northwest: Insights From an Updated Focal Mechanism Catalog. **Stone, I.**, Wirth, E. A., Pollitz, F. F.

134. The Cascadia Offshore Subduction Zone Observatory Infrastructure Project. **Thompson, M.**, Wilcock, W. S. D., Harrington, M. J., Schmidt, D. A., Kelley, D. S., Tobin, H. J., Denolle, M. A., Cram, G. S., Khoo, M., Labrado, A. L., Manalang, D. A., McGuire, C., Smith, K., Tilley, J. W., Zumberge, M., Sasagawa, G.

135. Monitoring Seafloor Deformation in Taiwan via Ocean-bottom Geodetic Instrumentation. **Tung, H.**, Hsu, Y., Chen, H., Tang, C.

136. Using Seafloor Geodesy to Constrain Gorda Plate Kinematics and Shallow Megathrust Locking in Southern Cascadia. **Watt, J.**, Ericksen, T., DeSanto, J., Brooks, B. A., Parsons, T., Zumberge, M., Sasagawa, G., Phillips, E., Marcuson, R., Chadwell, D.

137. STUDENT: Subduction, Faulting and Earthquake Interaction Across the Cook Strait of New Zealand. **Williams, C.**, Chamberlain, C. J., Townend, J.

138. STUDENT: Seismic Patterns of the Luzon Arc South of Taiwan. **Wiyono, S. H.**, Chi, W., Kuo, B., Liang, W., Lin, C., Lin, P. P.

139. Ensemble Analysis of Large Megathrust Earthquakes: From Rupture Heterogeneity to Stress Changes and Ground Motion. **Jiang, J.**, Viteri Lopez, J., Zhao, X.

SSJ-SSOC-SSA Joint Session: From Slow to Fast Earthquakes: Bridging the Spectrum of Fault Slip (see page 1544).

140. Resolving Spatiotemporal Variabilities of Fast and Slow Slip on California Crustal Faults. **Jiang, J.**, Zhao, X., Kang, Z.

141. STUDENT: Post-seismic Deformation Associated With the 2020 Mw7.0 Samos (Eastern Aegean Sea) Earthquake. **Bonatis, P.**, Karakostas, V., Papadimitriou, E., Kaviris, G., Foumelis, M., Kaplon, J., Pikridas, C.

142. STUDENT: Classifying Missing Seismic Sources Offshore of Southeast Japan. **Burnett, H. J.**, Fan, W., Okuwaki, R., Matsuzawa, T.

143. STUDENT: Use of Repeating Earthquakes to Discriminate Slow Earthquakes in the Central Pacific Subduction Zone of Costa Rica. **Campos, N. A.**, Chaves Sibaja, E. E.

144. LFEs and Slow Slip Beneath the Aguas Zarcas Landslide: Evidence for Coupled Gravitational and Strike-slip Deformation in Northern Costa Rica. Campos, N. A., **Chaves, E. J.**, Hajaji, S., Nuñez Alpizar, E., Sequeira Arguedas, J.

145. STUDENT: How Do Stick-slip Events Initiate on a Rough Fault? **Chen, H.**, McLaskey, G. C.

146. STUDENT: Detection of Repeating Microearthquakes in Southeastern Costa Rica. **Hajaji, S.**, Chaves, E. J., Peng, Z.

147. STUDENT: When Strike-slip Is Not Enough: The Full Kinematics of the Central San Andreas Fault. **Lin, L.**, Funning, G. J.

148. STUDENT: Observational Evidence of a Very-low-frequency Earthquake (Mw 3.8) Leading to an Earthquake (Mw 4.2): Minto Flats Strike-slip Fault Zone, Central Alaska. **McPherson, A.**, Tape, C., Kaneko, Y.

149. STUDENT: Constraining Slow Slip in Cascadia Using a Joint Tremor-GNSS Inversion. **Papin, L.**, Thomas, A. M.

150. How Does Slow Slip Reshape Megathrust Locking? **Periollat, A. J.**, Costantino, G., Funning, G. J.

151. Arias Intensity as an Indicator of Rupture Kinematics in Tsunami Earthquakes. **Riquelme, S.**, Crempien, J.

152. Interaction Between Seismic and Aseismic Slip Along the Mendocino Oceanic Transform Fault Offshore Northern California. Liu, M., Liu, H., **Tan, Y.**

153. STUDENT: Cyclic Sealing and Drainage on an Oceanic Transform Fault. **Yang, H.**, Ye, L., Zhang, H.

Mechanisms and Seismogenic Structure for Large Continental Earthquakes (see page 1466).

154. An Evaluation of Factors that Influence Earthquake Event Magnitudes. **Bent, A. L.**

155. The Stagnant Pacific Slab in the Lower Mantle Transition Zone Beneath Northeast Asia Continental Margin and Large Deep Outboard Earthquakes. **Cui, Q.**, Zhou, Y., Gao, Y., Chu, R., Liu, L., Su, H.

156. Slab Morphology Change and Subduction-zone Dynamics Beneath the Kuril-Kamchatka From Topographies of the 410-Km and 660-Km Discontinuities. **Cui, Q.**, Zhou, Y., Gao, Y., Liu, L.

157. Earthquake Nucleation Along Paleotectonic Weak Zones in Stable Intraplate Regions. **Hong, T.**, Lee, J., Kim, B., Lee, J., Kim, D.

158. STUDENT: Unveiling the Pre-rupture Seismicity of the 2022 Ferndale Fault: A 15-year Template Matching Analysis. **Islam, M.**, Gong, J.

159. STUDENT: Corrosion of Rupture Barriers Through Rock Damage Induced by Aftershocks. **Ju, F.**, Ben-Zion, Y.

160. Microseismicity and Upper-crustal Anisotropy in the Southern Sichuan-Yunnan Block, SE Tibetan Plateau. **Li, Y.**, Gao, Y.

161. STUDENT: Advancing Earthquake Catalog Completeness and Slab Imaging in Hispaniola Using Deep-learning Phase Pickers and Fine-Tuned Machine-learning Workflows. **Muñoz-Santos, L. F.**, Walter, J., Pulliam, J., Xiao, H., Polanco, E., Leonel, J., Rodríguez, J.

162. STUDENT: Assessing the Sensitivity of Recurrence Parameters to Completeness Choices. **Ocrospoma Valverde, J.**, Aguinda Navarro, C., Maldonado Pariona, J.

163. Exploring New Statistical Metrics to Evaluate the Magnitude Distribution of Earthquake Forecasting Models. **Serafini, F.**, Mizrahi, L., Han, M., Bayliss, K., Iturrieta, P., Bayona, J. A., Naylor, M., Werner, M. J.

164. Fault Branching, Slip Partitioning, and Tectonic Implications of the 2021 Mw 7.4 Maduo Earthquake, Northern Tibet. **Su, Z.**

165. Pulse-like Ground Motion Observed During the 6 February 2023 Mw 7.8 Pazarcık Earthquake, Türkiye. Wu, F., **Xie, J.**, Taymaz, T., Li, X.

166. An Intraplate Long-lasting Earthquake Sequence Near Feidong County, Hefei, East China (2024-2025). **Ye, L.**, Zeng, L., Yao, H., Xu, S., Chen, X.

New Developments in Earthquake Rupture Physics For Source Characterization and Ground Motion Modeling (see page 1482).

167. Improving Parallel Scalability and Solver Performance in the PyLith Crustal Deformation Modeling Software. **Aagaard, B. T.**, Knepley, M. G., Williams, C. A.

168. STUDENT: Identify Transient Supershear Rupture Through Deciphering Near-fault data. **Deng, D.**, Yao, S., Yang, H.

169. STUDENT: Analysis of Energy Budgets as a Means of Comparing Modeled Earthquakes Along the Cascadia and Sumatra Subduction Zones. **Hsieh, S.**, Gross, L., Lisemby, C., Madden, E.

170. STUDENT: Mitigating Geometry-induced Stress Singularities in Three-dimensional Boundary Element Method Simulations of Rough Faults. **Huang, X.**, Cattania, C.

171. STUDENT: Rich Rupture Dynamics of the 2025 Mw 7.7 Mandalay Earthquake Revealed by Unprecedented Near-fault and High-resolution Observations. **Zheng, F.**, Gao, J., Liu, Z., Meng, H., Hou, Y., Wang, L., Xu, S., Peng, Z., Wang, C., Zhou, M., Yue, H., Sun, J., Wang, Z., Ben-Zion, Y.

Recent Contributions of Social Science Research to Understanding Earthquakes (see page 1521).

172. STUDENT: The Ethics of Infrastructure Resilience to Earthquakes: Philosophy Meets Seismic Policy. **Leung, G.**

173. Operationalizing Equity: Assessing the Usability of Near-real-time Earthquake Information for Supporting Impacted Communities. **Macías, M.**, Loos, S., Reddy, E., Knodel, E., McGowan, S.

174. STUDENT: Does the Rainbow Palette Negatively Impact the Use of Shakemap? **Pope, I. E.**, Worden, C. B., Wald, D. J.

Seismotectonics of Southern and Baja California (see page 1534).

175. STUDENT: Insights into a Transform Fault Bounded Pull-apart Basin, Cerro Prieto, Northern Baja California, México. **Aladro, Y.**

176. A New Approach for Estimating Inbuilt Age Effects on Paleoseismic Event Dates. **Biasi, G.**, Scharer, K., McPhillips, D.

177. Vertical Offset and Recurrence of Large Earthquakes on the Cañada David Detachment, Baja California, Mexico. Cambrón-Rosas, J. F., **Fletcher, J. M.**, Rockwell, T. K., Spelz, R. M., Hinojosa-Corona, A., Helenes-Escamilla, J., González-Ortega, A., Gudiño-Elizondo, N., Lacan, P., Rösler, B., Peña-Villa, I. A., Guerrero-Murcia, L. A., Garcia Meza, I. F.

178. STUDENT: An Updated San Andreas Fault Geometry in Parkfield, California. **Margolis, A.**, Oglesby, D. D., Periollat, A. J., Funning, G. J., Lin, L.

179. STUDENT: Testing Uplift Rates of the Palos Verdes Peninsula Using Luminescence Dating on Marine Terraces. **Martin, A.**

180. High Resolution Holocene Slip Rate for the Southern San Andreas Fault in the Salton Trough, California. **Rockwell, T. K.**, Scharer, K., Buckley, W., Figueiredo, P. M., Brown, N., Williams, P.

181. STUDENT: Paleoseismology of the Southern Segment of the Compton Blind Thrust Fault: Defining the Potential for Multi-segment, Large-magnitude Earthquakes Beneath Metropolitan Los Angeles. **Salinas, M. P.**, Leon, L. A., Dolan, J. F., Shaw, J. H., Pratt, T. L., Anthonissen, C. J.

182. New Mapping and Subsurface Data on the Southernmost Extent of the San Jacinto Fault. **Scharer, K.**, Rockwell, T. K., Blair, L., Figueiredo, P. M.

Source Properties of Microearthquakes: Insights from Laboratory, Induced and Natural Events (see page 1537).

183. Investigating Source Properties of Ultra-shallow Nanoearthquakes Using the Midas Borehole Seismic Monitoring System in Taiwan. **Chan, J.**, Lin, Y.

184. Using Borehole Distributed Acoustic Sensing to Investigate Microearthquake Source Parameter Variability in an Enhanced Geothermal System. **Chang, H.**, Nakata, N., Abercrombie, R. E., Dadi, S., Titov, A.

185. Rupture Directivity—Insights From Theoretical Studies Applied to Observations. **Kurzon, I.**, Grinberg, L., Lior, I.

186. STUDENT: Spatiotemporal Evolution of the Dapu Earthquake Sequence in the Frontal Western Foothills, Taiwan: Insights from a Dense Near-source Seismic Array. **Lai, C.**, Chen, Y., Wen, S., Lin, Y.

187. Lightning-induced Implosive Microseismic Events at Depth Detected by Downhole Distributed Acoustic Sensing in Taiwan. **Lin, Y.**, Huang, H., Hsieh, M., Kuo, L., Chen, C., Chang, M., Chen, T., Chen, H., Brown, D.

188. Reconciling Seismological and Numerical Source Parameters of Repeating Earthquakes Near Parkfield. **Lui, S. K. Y.**, Lin, Y., Pun, H.

189. The Impact of Wastewater Injection Enhanced In-situ Stress on Hydraulic Fracturing Induced Seismicity Near Kingsher, Oklahoma. **Ogwari, P. O.**, Walter, J., Xiao, H., Thiel, A., Gregg, N., Woelfel, I., Mace, B.

190. Small Earthquake Monitoring for Structural Potential Characterization and Source Parameter Analysis in Northern Hualien, Taiwan, by a Borehole Seismometer Array. **Tsai, R.**, Lin, Y., Yen, Y., Chen, C.

191. Normal-faulting Earthquakes Under a Compressional Stress Regime, Insights from the Weiyuan Shale Gas Field, China. **Yang, H.**, Jiang, Y., Zi, J.

Friday, 17 April 2025—Oral Sessions

Presenting author is indicated in bold.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	On the State of Knowledge/Art/Practice for mHVSr Analyses; A Prelude to the ESG7-COSMOS mHVSr Pre-Event Forum (see page 1496).	From Drilling to Ground Shaking: Mechanisms, Monitoring and Mitigation of Induced Earthquakes (see page 1432).	Generating, Calibrating and Validating Multi-Scale Seismic Velocity Models (see page 1436).	Advancing the U.S. Geological Survey National Seismic Hazard Models (see page 1354).		Fiber-Optic Sensing Applications in Seismology and Environmental Science (see page 1419).	Geophysical Perspectives on Volcanic Systems: Seismicity, Structure and Dynamics (see page 1441).		Observation and Analysis of Topography and Deformation: Relating Earthquakes to Cascading Hazards (see page 1493).
8:00 AM	Perspectives on the State of Knowledge and Practice About Single-station Microtremor Horizontal-to-vertical Spectral Ratio (mHVSr) Analysis for Evaluating Seismic Site Response. Yong, A.	Probabilistic Induced Seismic Hazard Analysis in the Western Canada Sedimentary Basin. Mahani, A. , Kao, H., Assatourians, K.	Multi-scale Statewide California Seismic Velocity Models: Version 1. Yeh, T. , Ben-Zion, Y., Olsen, K. B.	Nonergodic Ground Motion Model for the Central and Eastern United States. Davatgari-Tafreshi, M. , Pezeshk, S., Campbell, K. W.	8:00 AM	STUDENT: A Contribution to the Assessment of DAS Performance With Surface Waves: A Case-study From Northern Italy. Beretta, S. , Castellaro, S.	STUDENT: Arc Magma Migration Inferred at Laguna Del Maule, Chile Using Well Constrained Seismicity and Receiver Function Imaging. Bradford, J. M. , Mahanti, S., Kiser, E., Beck, S. L., Fernandez, M., Trad, S., Porter, R. C., Maharaj, A., Howe, H. E., Ortiz, G. F., Saez, M.		INVITED: The Center for Land Surface Hazards (Clash): A Community Effort to Understand Cascading Land Surface Hazards. West, A. , Clark, M., Roering, J., Yanites, B., Zekkos, D.
8:15 AM	H/V Processing of Seismic Noise Recordings: A Retrospective and Roadmap for Updating the SESAME Guidelines. Cornou, C. , Bard, P.	Characteristics of Fracture Networks Regularly Activated by Geothermal Production at the Coso Geothermal Field. Holmgren, J. M. , Kaven, J., Oye, V.	Multi-scale Velocity Model Integration for the Los Angeles Basin: A Framework for Continuous Neural Representation. Jia, Z. , Clayton, R. W.	Efficient Non-ergodic Predictions of Path Effects and Applications to National Seismic Hazard Maps. Lacour, M. , Abrahamson, N., Sung, C.	8:15 AM	Coda Wave Interferometry with DAS for Continuous Relative Velocity Change Monitoring of a Tailings Dam in British Columbia. Savard, G. , Ouellet, S., Dettmer, J., Mikesell, T., Forbes, B., Sangha, A.	INVITED: Dynamic Evolution of the Magmatic-hydrothermal System at Uturuncu Volcano, Bolivia. Liu, Y. , Zhang, H., Kendall, M., Blundy, J., Wang, X., Xu, X.		Gravity Modulates Earthquake-triggered Sliding During the 2025 Dingri Normal-fault Earthquake on the Tibetan Plateau. Li, Z. , Wang, T., Yue, H.
8:30 AM	Characteristics of Microtremor Horizontal-to-Vertical Spectral Ratios and Resulting Subsurface Structures in Japan and Taiwan. Matsushima, S. , Chou, Y., Nagashima, F., Kaigara, T.	STUDENT: Mapping Fracture Growth During the Utah Forge 2024 Extended Circulation. Spraker, G. M. , Niemz, P., Pankow, K.	Constructing Basin Seismic Velocity Structure Constrained by Chronostratigraphy - a Case Study in the Los Angeles Basin. Olsen, K. B. , Yeh, T., Kohler, M.	INVITED: Overview of the NGA-West3 Project Database. Buckreis, T. E. , Bozorgnia, Y., Donahue, J., Abrahamson, N., Al Atik, L., Atkinson, G. M., Bahrampouri, M., Bayless, J., Baise, L. G., Boore, D. M., Bradley, B. A., Brandenburg, S. J., Campbell, K. W., Chiou, B., Gulerce, Z., Idriss, I. M., Kishida, T., Kottke, A. R., Kuehn, N., Lavrentiadis, G., Nie, S., Nweke, C. C., Parker, G. A., Pinilla Ramos, C., Rodriguez-Marek, A., Stafford, P., Stewart, J. P., Sung, C., Youngs, R.	8:30 AM	Subsurface Characterization Along Rail Lines - Distributed Acoustic Sensing in the Swiss Alps. Bowden, D. , Bajad, S. N., Fern, E. J., Fichtner, A., Bharadwaj, P., Edme, P.	Deep-learning-based Monitoring of Volcano-tectonic and Long-period Earthquakes. Zhong, Y., Tan, Y.		Active Stress Pattern Investigations and Earthquake Probabilities in North Pakistan: Implications for Seismic Hazard. Shah, S.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
8:45 AM	On the State of Knowledge (continued)	From Drilling to Ground Shaking (continued)	Generating, Calibrating (continued)	Advancing the U.S. Geological (continued)		Fiber-Optic Sensing Applications (continued)	Geophysical Perspectives on Volcanic (continued)		Observation and Analysis (continued)
	The New Sesame Criteria: Why Not Ai? Castellaro, S.	INVITED: The Bound Growth of Induced Earthquakes Could De-risk Hydraulic Fracturing. Schultz, R. , Lanza, F., Dyer, B., Karvounis, D., Fiori, R., Shi, P., Ritz, V., Linus, V., Meier, P., Wiemer, S.	Ambient Noise Tomography Across the 2022 Los Angeles Basin Nodal Array. Gkogkas, K., Lin, F. , Clayton, R. W.	Suitability of Ground-motion Models for Seismic Hazard Assessments in Guam, the Northern Mariana Islands and American Samoa. Aagaard, B. T. , Moschetti, M. P., Withers, K. B.		STUDENT: Distributed Acoustic Sensing-based Joint Inversion for the Structure of the Reykjanes Peninsula, Iceland. Bird, E. , Biondi, E., Hjörleifsdóttir, V., Zhan, Z.	STUDENT: Event Classification Using Seismic Arrays in Volcanic Environments. Rinty, S. , Goebel, T.		A GNSS-derived Strain Rate Map of North America and Implications for Continental Deformation. Zeng, Y.
9:00 AM	Estimating Regional Shallow 3D S-Wave Velocity Model From Active and Passive Surface Wave Methods and Horizontal-to-Vertical Spectral Ratios Based on Neural Networks. Hayashi, K. , Suzuki, T., Inazaki, T., Konishi, C., Suzuki, H., Matsuyama, H.	Tremor and Slow Slip in Sedimentary Basins. Ushakov, N. , Byrnes, J., Bochen, D.	STUDENT: Calibration of the Near-surface Seismic Structure in the San Francisco Community Velocity Model (SFCVM). Patel, A. , Olsen, K. B.	Forecasting Gridded Seismicity Rates for the USGS National Seismic Hazard Models for U.S. Pacific Territories. Llenos, A. , Haynie, K. L., Michael, A. J., Shelly, D. R., Shumway, A. M.		DAS Surface-wave Observations of Deep-crustal Structure in Western Nevada From a 56 Km Infrastructure Fiber. Louie, J. N. , Barnes, D., Watson, P., Sayyadi, S., Kratt, C.	Interconnected Magma Reservoirs at Santorini and Kolumbo: Insights From the Recent Magmatic Crisis. Isken, M. P. , Karstens, J., Nomikou, P., Parks, M. M., Hooft, E. E. E., Anastasiou, D., Shapiro, N. M., Walter, T. R., Rivalta, E., Kopp, H., Torsten, D., Berndt, C.		INVITED: Coseismic Landslides and Their Cascading Hazards: Improving Modeling, Assessment and Communication. Allstadt, K. , Thompson, E. M., Grant, A., Burgi, P., Wald, D. J., Collins, E., Jensen, E., Eiden, E.
9:15–10:30 AM	Poster Break				9:15–10:30 AM	Poster Break			
10:30 AM	On the State of Knowledge/Art/Practice for mHVSr Analyses; A Prelude to the ESG7-COSMOS mHVSr Pre-Event Forum (see page 1496).	From Drilling to Ground Shaking: Mechanisms, Monitoring and Mitigation of Induced Earthquakes (see page 1432).	Generating, Calibrating and Validating Multi-Scale Seismic Velocity Models (see page 1436).	Advancing the U.S. Geological Survey National Seismic Hazard Models (see page 1354).		Fiber-Optic Sensing Applications in Seismology and Environmental Science (see page 1419).	Geophysical Perspectives on Volcanic Systems: Seismicity, Structure and Dynamics (see page 1441).	New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets (see page 1483).	Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice (see page 1362).
	The Physical Basis for the Modeling of HVSr Under the Diffuse Fields Assumption. Sánchez-Sesma, F. J. , Weaver, R. L., Campillo, M., Perton, M., Baena-Rivera, M., González, J. G., Piña-Flores, J., Iturrarán, U., Luzón, F., García-Jerez, A., Lontsi, A. M., Matsushima, S., Kawase, H.	INVITED: Localized Transfer Learning for Detection of Induced Seismicity Across Diverse Monitoring Systems. Xiao, H. , Walter, J., Ogwari, P. O., Ho, L., Thiel, A., Gregg, N., Mace, B., Woelfel, I.	Full Waveform Inversion Tomography for Improved Earthquake Ground Motion Simulations in California and Japan. Rodgers, A. J.	Insights From Fault System Inversions for Rupture Modeling in the New Madrid Seismic Zone. Velasquez, J. , Milliner, C. W. D., Papadopoulos, A. N., Crume, H. R.		STUDENT: Fiber-optic Seismic Sensing of River-amplified Permafrost Warming. Sun, H. , Cheng, F., Xia, J.	STUDENT: New Focal Mechanism Constraints on the Caldera Ring Fault System at Axial Seamount from an Expanded OBS Network. Zhang, M. , Wilcock, W. S. D., Waldhauser, F., Wang, K., Colet, M., Tolstoy, M., Tan, Y.	Widespread Urban Seismic Quietening During the 2024 Total Solar Eclipse. Fernando, B.	INVITED: Implementing Physics-based Ground-motion Simulations in Probabilistic Seismic Hazard Analysis Practice. Abrahamson, N.

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
	On the State of Knowledge (continued)	From Drilling to Ground Shaking (continued)	Generating, Calibrating (continued)	Advancing the U.S. Geological (continued)
10:45 AM	Basics of Double-correction Method for mHVSr Based on the Diffuse-field Concept as a Replacement for “Nakamura Method”. Kawase, H. , Ito, E., Nakano, K., Nagashima, F.	A Comprehensive Machine Learning-based Catalog for Effective Monitoring of Induced Seismicity in Southeastern New Mexico. Aziz Zanjani, A. , Basu, U.	A New 3D Crustal Velocity Model for Northern Israel: Tomography and Validation. Ben Dor, G., Tape, C., Kurzon, I., Tsesarsky, M.	STUDENT: Geophysical Studies Provide New Insights of the Tectonic Evolution of the Lajas Valley, Southwestern Puerto Rico. Justiniano, C. , Vanacore, E., López Venegas, A.
11:00 AM	3D Numerical Modeling of Ambient Seismic Noise: Assessing the Impact of Noise Source Directivity and 3D Basin Structure on Ambient Seismic mHVSr Ratios. Gregor, D. , Chaljub, E., Wathelet, M., Hollender, F., Perron, V., de Martin, F.	Modulation of Injection Induced Seismicity in Complex Fault Network. Elbanna, A. , Mia, M., Abdelmeguid, M.	STUDENT: Seismic Interferometry as a Cost-effective Tool for Seismic Velocity-model Validation in Geothermal Fields. Naranjo, D. , Draganov, D.	Stress and Fault Slip Potential of Alaskan Crustal Faults Included in the USGS National Seismic Hazard Model. Levandowski, W. , Yang, X.
11:15 AM	Review of Site Response Modeling Conditional on HVSr. Stewart, J. P.	Complex Fault Slip Behavior Modulated by Injection Rate With Implications to Hazard Mitigation of Induced Seismicity. Wang, C. , Wang, P., Xu, Y., Bhat, H., Bhattacharya, P., Xie, Y., Xia, K., Schubnel, A.	Combining Multiple Data Types to Improve or Merge Models in Arrival Time Tomography: Virtual VSP’s. Thurber, C.	STUDENT: Characterizing Differences in Seismicity Clustering and Background Rates Between Hawaii and California. Rinty, S. , Goebel, T.
11:30 AM	Examples of Microtremor Horizontal-to-Vertical Spectral Ratios as a Useful Tool for Geotechnical Site Characterization. Hudson, K. S.	STUDENT: Understanding Rupture and Source Properties of Induced Microearthquakes in the Western Canadian Sedimentary Basin. Hasnain, M. S. , Lui, S. K. Y., Ushakov, N.	STUDENT: Velocity and Attenuation Models of Mississippi Embayment Sediments Derived From Refraction Wavefields. Islam, S. , Langston, C. A.	Progress on a USGS Nationwide Long-term Time-dependent Earthquake Rupture Forecast. Field, E. H. , Hatem, A. E., Milner, K. R., Neely, J. S., Briggs, R. W.
11:45 AM–2:00 PM	Lunch Break			

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	Fiber-Optic Sensing Applications (continued)	Geophysical Perspectives on Volcanic (continued)	New Frontiers in Seismic Observations (continued)	Constraining GMMs (continued)
	INVITED: STUDENT: Illuminating Tidally Modulated Grounding Zone Migration at Constellation Inlet: A Seismic Motion Picture With Distributed Acoustic Sensing. Reid-McLaughlin, A. M. , Park, S., Chamberlin, T., Steinkraus, J., Klesh, A., Lefler, C., Kubiak, G., Costa, L., Kaip, G., Zhang, H., Zhai, Q., Zhan, Z.	Transcrustal Anisotropic Imaging of Magmatic Structures Along the Alaska-Aleutian Arc Using Receiver Functions. Schulte-Pelkum, V. , Gandhi, A., Haney, M. M.	Seafloor Topography Controls Primary Microseism Generation: New Insights From Cyclone-forced Seismic Observations in Northeastern Australia. Pandey, A., Pham, T. , Tkalčić, H.	Validation for Cybershake in Northern California. Callaghan, S. A. , Meng, X., Graves, R. W., Olsen, K. B., Su, M., Moschetti, M. P., Kottke, A. R., Pinilla Ramos, C., Milner, K. R., Silva, F., Maechling, P. J., Abrahamson, N., Ben-Zion, Y., Elbanna, A.
	Direct Ice Density Constraints from Multimode Surface Waves using DAS. Lanteri, A., Fichtner, A. , Keating, S., Gebraad, L., Klaasen, S., Pienkowska-Cote, M., Eisen, O., Zunino, A., Jonsdottir, K., Hofstede, C., Zigone, D.	Seismic Constraints on the Magmatic System Beneath the San Francisco Volcanic Field in Northern Arizona. Kiser, E. , Porter, R. C., Bradford, J. M., Mahanti, S., Moitra, P.	Earthquake Observations From Moored Vertical Hydrophone Array in Arctic Ocean. Pipatprathanporn, S. , Dzieciuch, M. A., Shearer, P. M.	Performance Evaluation Metrics for Velocity Models Used for Numerical Simulations of Ground Motions for Seismic Hazard Applications. Pinilla Ramos, C. , Abrahamson, N., Liou, I. Y.
	STUDENT: Chasing Storms with Distributed Acoustic Sensing (DAS) in Fiordland, South Island, New Zealand. Smart, A. F. J. , Miller, M. S., Sun, T., Michailos, K., Hui Lai, V., Townend, J., Osborne, N.	Probing the Wairakei-Tauhara Geothermal System, Taupō Volcanic Zone, With a Dense Nodal Seismic Array. Jiang, C. , Miller, M. S., Illsley-Kemp, F., Mestel, E. R. H., Hughes, B., Townend, J., Ayling, B.	Tremor-like Signals Along the San Jacinto Fault: Observations From a Long-term Dense Seismic Array (Faultscan). Higueret, Q. , Vignon-Livache, M., Brenguier, F., Mordret, A., Sheng, Y., Lavoue, F., Vernon, F., Hollis, D., Aubert, C., Ben-Zion, Y.	Toward the 2028 Short-term Time-dependent Revision of New Zealand National Seismic Hazard Model: A Framework for Ground-motion Characterization Modelling Update. Bora, S. , Li, D., Gerstenberger, M. C.
	STUDENT: Distributed Acoustic Sensing for Environmental and Weather Monitoring Using Existing Fiber-optic Infrastructure. Rading, R. , Hoffman, M., Isleif, K., Gerberding, O., Hadziioannou, C., Schlarb, H.	Magmatic Volatile Flux Drives Non-eruptive Volcano-tectonic Seismicity at Mount St. Helens, USA From 2008–2024. Hirao, B. W. , Thomas, A. M., Shelly, D. R., Thelen, W. A.	Extremely Shallow Semi-repeating Tremor Caused by Water Hammers in a Sewer Pipe in Social Circle, Georgia. Si, X., Peng, Z.	Practical Approaches to Physics-based PSHA. Liou, I. Y. , Weatherill, G., Cotton, F., Abrahamson, N.
11:45 AM–2:00 PM	Lunch Break			

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D	Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
2:00 PM		SSJ-SSOC-SSA Joint Session: Lessons from Recent Major Earthquake Sequences Around the World (see page 1547).	Earthquake Rupture Hazard and Forecasts from Integration of Paleoseismic Datasets (see page 1392).	Advancing the U.S. Geological Survey National Seismic Hazard Models (see page 1354).		Fiber-Optic Sensing Applications in Seismology and Environmental Science (see page 1419).	Action at a Distance: Understanding Seismic Triggering (see page 1328).	New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets (see page 1483).	Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice (see page 1362).
		Tectonic Significance and Observations of Ground Failure From the 6 December 2025 Mw 7.0 Earthquake in Yukon, Canada. Biegel, K. , Finley, T., Gosselin, J., Lipovsky, P., Cronmiller, D., Schaeffer, A. J., Dettmer, J.	Earthquake-cycle Modality Revealed by Paleoseismic Inter-event Time Distributions. Oskin, M. E. , Scharer, K., Lau, W.	Taming the Logic Tree: Combinatorics and Correlations of Epistemic Uncertainties in National Hazard Models. Milner, K. R.		STUDENT: Integrated Fiber-optic Sensing for Multi-environment Monitoring: Earthquakes, Ocean Waves, and Vehicle Signals. Wang, Y. , Fichtner, A., Bogris, A., Simos, C., Simos, I., Melis, N. S., Deligiannidis, S.	STUDENT: Evaluation of Mainshock-induced Strength–stiffness Reduction Thresholds for Aftershock-triggered Slope Failures. Kim, J. , Kim, B.	INVITED: Railroad Buckling in Earthquakes. Bilham, R. , Hough, S. E.	Analytical Approximations for Hazard Calculations for Areal Sources Modeled by Virtual Faults. Lacour, M. , Abrahamson, N., Largent, M.
	2:15 PM	STUDENT: Complex Multi-segment Rupture of the 2025 M 6.0 Afghanistan Earthquake From Sentinel-1 InSAR Data. Rivera, K. M. , Funning, G. J.	On the Behavior of Faults and Fault Systems: Geological Insights Into Patterns and Controls on Earthquake Occurrence in Time and Space. Dolan, J. F. , Gauriau, J., Cawood, T. K., Rhodes, E. J., Van Dissen, R. J., Zinke, R., Hatem, A. E., Fougere, D. M., McGill, S. F., Gordon, L.	Why are Site-specific Seismic Hazard Analyses and the National Seismic Hazard Model Different? Wong, I. G.		High-resolution Directionality of Ocean Swell With the SWOT Mission and Fiber Sensing. Zhang, S. , Ardhuin, F., Liu, M., Collard, F., Callies, J., Zhan, Z.	Dynamically Initiated Seismic Sequences in Eastern North America Following the Large 2025 Kamchatka Earthquakes. Beauce, E. , Waldhauser, F., Kolawole, F., Kim, W.	Potential Abiotic Methane Hydrate in Earth’s Deepest Subduction Zone. Wei, S. , Feng, M., Yan, T., Wang, Y., Zhang, Z., Wang, X., Chen, L., Hao, T., Tong, P.	Evaluating Random Vibration Theory Assumptions for Non-ergodic Ground-motion Modeling. Lavrentiadis, G.
	2:30 PM	INVITED: SWOT Satellite Altimetry Observations and Source Model for the Tsunami From the 2025 M 8.8 Kamchatka Earthquake. Melgar, D. , Ruiz-Angulo, A., de Marez, C., Deniau, A., Nencioli, F., Hjörleifsdóttir, V.	Spatiotemporal Clustering of Paleo-earthquakes Along the Central Altyn Tagh Fault: Rupture Termination and Near Geometric Complexities. Han, L., Liu, J. , Oskin, M. E., Hu, G., Klinger, Y., Wang, W., Yao, W., Wang, H., Zhang, B., Xu, J., Shao, Y.	Risk Assessment of the 2023 National Seismic Hazard Model for Alaska: Impact of Subduction Zone Implementation Decisions on Losses. Polun, S. G., Ruhl, C. J. , Fadugba, O. I., Shen-Tu, B.		What Is the Upper Frequency Limit of Secondary Microseisms? Titova, A. , Bakulin, A.	Fluid Pressure Surge of a Hydrofracture Due to Seismic Wave Stimulation. Zheng, Y.	The Martian Crust Outside Elysium Planitia From Joint Probabilistic Inversion of PP/SS Precursors and Rayleigh Waves. Zhang, Z., Kim, D., Olugboji, T. , Lekić, V.	Resolving Site Effects in Modified Mercalli Intensity Data to Better Constrain Non-ergodic Path Terms. Sung, C. , Abrahamson, N.
2:45 PM		The 2025 and 1952 Kamchatka Earthquakes Viewed From Tsunami Waveforms Recorded Around the Pacific Ocean. Satake, K. , Fujii, Y.	ILLuminating Earthquake Histories: Using Luminescence Dating to Decode Fault Slip and Magnitude Variability of Earthquake Ruptures in the Carrizo Plain, CA. Akçiz, S. , Brown, N.	INVITED: Updated Shaking Potential and Ground Motion Hazard Maps for California. Chen, R. , Kang, M., Wurgler, R., Dawson, T., Thomas, K., Bohon, W.		STUDENT: Denoising Distributed Acoustic Sensing (DAS) Data for Shallow-water Observations. Huang, X. , Wu, W., Lin, Y.	High Frequency Vibroseis Triggering of Microseismicity in the New Madrid Seismic Zone? Langston, C. A.	Earth Balloons Sensors as Precursors of Venus Seismology Missions. Mimoun, D. C. , Garcia, R., Gerier, S.	STUDENT: Components of Variability in Ground-motion Model Derived from Distributed Acoustic Sensing. Lin, C. , von Specht, S., Cotton, F.

Friday, 17 April (continued)

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
3:00 PM		SSJ-SSOC-SSA Joint Session (continued)	Earthquake Rupture Hazard (continued)	Advancing the U.S. Geological (continued)
		Rapid Characterization of the 2025 M8.8 Kamchatka, Russia Earthquake. Yin, H. Z. , Allstadt, K., Barnhart, W. D., Clapp, S. A., Earle, P. S., Goldberg, D. E., Grant, A., Herman, M. W., Jaiswal, K., McBride, S. K., Ringler, A., Schneider, M., Thompson, E. M., van der Elst, N., Wald, D. J., Wang, D., Worden, C. B.	Mapping Maximum Post-glacial Earthquake Magnitudes in the Northeastern U.S. From Precariously Balanced Erratics. Pratt, T. L. , Stirling, M. W., McPhillips, D., Figueiredo, P. M.	Fully Probabilistic Ground Motions Replace Deterministic Capping in 2026 Update of NEHRP Recommended Seismic Provisions for New Buildings and Other Structures. Luco, N. , Murphy, D., Mazzoni, S.
3:15– 4:30 PM	Poster Break			
4:30 PM		SSJ-SSOC-SSA Joint Session: Lessons from Recent Major Earthquake Sequences Around the World (see page 1547).		
		INVITED: Rupture Propagation and Arrest in Global Strike-slip Earthquakes Constrained by CCTV Video, and Near-fault Seismic Observations. Kearse, J. , Kaneko, Y.		
4:45 PM		STUDENT: Along-fault Slip-rate Heterogeneity as a Control on Rupture Segmentation: Insights From Recent Major Strike-slip Earthquakes in Turkey and Myanmar. Wang, B. , Barbot, S., Liu, M., Guvercin, S. E., Li, Z., Wang, T., Liu, C., Ji, L.		

Friday, 17 April (continued)

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
3:15– 4:30 PM	Fiber-Optic Sensing Applications (continued)	Action at a Distance (continued)	New Frontiers in Seismic (continued)	Constraining GMMs (continued)
	Improving Travel-time Estimation in Distributed Acoustic Sensing Data Through Denoising. Lin, J. , Ichinose, G., Aguiar, A. C.	STUDENT: Lack of Strong Dynamically Triggered Tectonic Tremor in Costa Rica. Hajaji, S. , Peng, Z., Chaves, E. J., Ding, C.	Distributed Acoustic Sensing Without Burial: Implications for Seismic Studies of the Moon and Earth. Donahue, C. M. , Probst, S., Robertsson, J. O. A., Zandanel, A., Gao, K.	Physical Calibration of Ground Motion Models for Induced Seismicity: Application to the Prinos Co ₂ Storage Site. Pilz, M. , Kiratzi, A., Vavlas, N., Anterriotis-Kalpakidis, N.
3:15– 4:30 PM	Poster Break			
	Fiber-Optic Sensing Applications in Seismology and Environmental Science (see page 1419).	Southern California Seismicity: Past, Present and Future (see page 1539).	New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets (see page 1483).	Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice (see page 1362).
	INVITED: Observation of Submarine Earthquake Swarm Activity in the Tokara Islands Region Using Distributed Fiber-optic Sensing on a Submarine Telecommunication Cable. Araki, E. , Yokobiki, T., Wakisaka, Y., Toge, K., Iida, D., Mori, A., Takahashi, H., Kito, C.	Do-it-yourself (DIY) Method to Forecast Local Earthquakes: Application to Southern California. Rundle, J. B. , Donnellan, A., Grant Ludwig, L.	The Distributional Finite Difference Method: An Efficient Approach for High-resolution Global Wavefield Simulations. Tian, Y. , Awan, M. G., Soergel, D., Wu, W., Romanowicz, B.	STUDENT: Using Dynamic Rupture Simulations to Improve Ground Motion Models for Normal Faulting Earthquakes. Franco, Y. , Trugman, D. T.
	INVITED: Volcanic Crisis Unraveled Using Fiber Optic Sensing of a Sub-haul Cable on the Reykjanes Peninsula, SW Iceland. Jonsdottir, K. , Cubuk-Sabuncu, Y., Erlendsson, P., Li, J., Hjörleifsdóttir, V., Biondi, E., Kristinsson, I., Roberts, M., Vogfjord, K., Gestsson, E. B., Morten, J. P., Zhongwen, Z.	STUDENT: The Q-score: A Magnitude-weighted Model Evaluation Score for Earthquake Forecasting. Jansson Valter, J., Arjon, A. , Serafini, F., Schoenberg, F.	Building Local sP and PmP Phase Datasets for Precise Earthquake Location and Whole-crust Imaging Using AI-assisted Methods. Tong, P. , Li, T., Chen, J., Yang, X.	Physics-based Simulations of the Dead-Sea Fault System – How Unique Geological Features Affect Ground Motion Variability. Kamai, R. , Shachrur, N., Porat Dekel, C., Roda, G. K., Tsesarsky, M.

Friday, 17 April (continued)

Time	Ballroom A	Ballroom B	Ballroom C	Ballroom D
5:00 PM		SSJ-SSOC-SSA Joint Session (continued)		
		Complex Initial Rupture of the Narli Fault Triggered the 2023 Mw 7.8 Kahramanmaraş Earthquake. Ellsworth, W. L. , Bulut, F.		
5:15 PM		Complex Fault Structures in Southeastern Türkiye Revealed by High-resolution Aftershock Location and Focal Mechanism Catalog of the 2023 Kahramanmaraş, Türkiye, Earthquake Sequence. Si, X. , Peng, Z., Mach, P., Oluwaseyifunmi, A., Gao, H., Sandvol, E., Zor, E., Ergin, M., Ding, C.		
5:30 PM		Tibetan Plateau Kinematics Revealed in a Single Event: The Mw 7.1 January 7, 2025 Tingri Earthquake. Hanagan, C. E. , Jobe, J. A. T., Yin, H. Z., Hatem, A. E., Reitman, N. G., Briggs, R. W., Lynch, E. M.		

Friday, 17 April (continued)

Time	Ballroom E	Ballroom F	Ballroom G	Ballroom H
	Fiber-Optic Sensing Applications (continued)	Southern California Seismicity (continued)	New Frontiers in Seismic (continued).	Constraining GMMs (continued)
	Ocean Bottom Boundary Layer Turbulence Scaling From the Vibrations of a Subsea Cable With Long-range Fiber-optic Sensing. Williams, E. F. , Kamalov, V., Karrenbach, M., Ruiz-Angulo, A., Hjörleifsdóttir, V., Jonsson, O., Fontaine, N. K., Ryf, R., Mazur, M.	A Decade-long Pseudo-prospective Evaluation of UCERF3-ETAS Next-day Seismicity Forecasts. Serafini, F. , Bayona, J. A., Silva, F., Werner, M. J., Milner, K. R., Field, E. H.	STUDENT: Full Waveform Inversion of the Los Angeles Basin Using Neural Operators. Zou, C. , Shi, Y., Ross, Z. E., Clayton, R. W., Azizzadenesheli, K.	Modeling Hanging Wall Effects for Ground Motion Fourier Amplitude Spectra. Bayless, J. , Abrahamson, N., Pinilla Ramos, C., Sung, C.
	Analysis of Seismic Body-waves Observed on Multiple Spans of the Iris Subsea Fiber-optic Cable Connecting Iceland and Ireland. Hjörleifsdóttir, V. , Lepere, A., Gunnarsson, A. I. G., Mazur, M., Kamalov, V., Karrenbach, M., Williams, E. F., Jonsson, O., Fontaine, N. K., Ryf, R., Dallachiesa, L., Ruiz-Angulo, A., Neilson, D.	STUDENT: Non-interacting Seismicity in the San Jacinto Fault Zone: Insights From Earthquake Cycle Simulations. Villa, V. , Ross, Z. E., Lapusta, N.	From Physics to Scale: Building Foundation Models for Seismic Full-waveform Inversion. Lin, Y. , Feng, Y., Jin, P., Chen, Y.	STUDENT: QuakeF2G: A Transformer-based Ground Motion Prediction Model Considering Fault Segments Modeling. Feng, Y. , Zhu, W., Lu, X.
	DAS Beyond Repeaters: Multi-span Monitoring Using Submarine Cables in the Pacific Ocean. Krauss, Z. , Mazur, M., Wilcock, W. S. D., Fontaine, N. K., Ryf, R., Rose, A., Dientsfrey, W., Abadi, S., Denolle, M. A., Lipovsky, B., Hartog, J.	Dynamic Rupture Simulations on the Rose Canyon, Spanish Bight, and Descanso Faults, San Diego, Southern California. Lozos, J. , Fabbrizzi, A., Maloney, J.	Red-Diffeq: Regularization by Denoising Diffusion Models for Solving Inverse PDE Problems With Application to Full Waveform Inversion. Lu, L. , Shan, S.	STUDENT: Semi-empirical Ground Motion Prediction Equations for the Central Gulf of California, Mexico, Using Stochastic Finite-fault Simulations. Azua Flores, J. M. , Castro, R. R.

Poster Sessions

Action at a Distance: Understanding Seismic Triggering (see page 1329).

1. Do Earthquake Deformation and Shaking Trigger Eruptions? Gomberg, J., Prejean, S. G., **Bodin, P.**, Pesicek, J. D., Taveras, O.
2. A New Agent, Pycorelator, Advances the Starring Role of Triggering in Paleoseismology. **Gomberg, J.**, Lai, L., Sylvester, Z., Covault, J., Nieminski, N.
3. False Positives in the Identification of Dynamic Earthquake Triggering. **Hardebeck, J.**, DeSalvio, N. D., Fan, W., Barbour, A. J.
4. STUDENT: Dynamic Earthquake Triggering Regions in Texas and the Role of Fluid Injection. **Hosain, A.**, Alfaro-Diaz, R., Chen, T.
5. Hard-linking and the Hikurangi: Controls on Fault Co-rupture From Synthetic Earthquake Catalogues. **Penney, C.**, Howell, A., McLennan, T., Nicol, A., Fry, B.
6. Larger Earthquakes Happen Sooner: Non-separability of Magnitude and Time Distributions of Aftershocks. **van der Elst, N.**
7. STUDENT: Complex Faulting and Stress Transfer During the July 25, 2023 Mw 5.5 Earthquake Sequence in Kozan, Southeastern Türkiye. **Mach, P.**, Peng, Z., Si, X., Adeboboye, O., Zor, E., Ergin, M., Sandvol, E.

SSJ-SSOC-SSA Joint Session: Lessons from Recent Major Earthquake Sequences Around the World (see page 1550).

8. STUDENT: Preliminary Results on Foreshock Behaviors and Mainshock Rupture Processes of the 2025 Mw 8.8 Kamchatka Earthquake Sequence. **Mach, P.**, Si, X., Wang, D., Shcherbakov, R., He, P., Taymaz, T., Ding, C., Peng, Z.
9. STUDENT: Controls of Along-strike Dip Variations on Multi-Section Ruptures: 3D Dynamic Earthquake-cycle Simulations of the Sagaing Fault. **Bordbar, H.**, Duan, B., Liu, M., Tang, Z.
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145. Evaluation of Ambient Noise HVSR Measurements for Urban Site Characterization in Anchorage, Alaska. **Densham, C.**, Zhu, Y., Zhao, Y., Thornley, J., Dutta, U.

146. Preliminary Results From Two Months of Continuous Recording of Ambient Vibration on a Dense Array of Smartsolo 3C Seismic Instruments Deployed in the Metropolitan Area of San Juan, Puerto Rico. **Huerta-López, C. I.**, Martínez-Cruzado, J. A.

147. Horizontal-to-Vertical Spectral Ratio and Surface Wave Dispersion Inversions to Determine the 1D Velocity Structure Beneath Foulness Island, UK. **Nippres, S. E. J.**, Green, D. N., Read, E.

148. A Framework for Quantifying the Time-dependent Evolution of HVSR Features for Basin Site Response Modeling. **Nweke, C. C.**

149. STUDENT: Site Response Characterization of California's Geomorphic Basin Categories Using Microtremor-based HVSR. **Ornelas, F. G.**, Nweke, C. C., Buckreis, T. E., de la Torre, C. A., Brandenburg, S. J., Stewart, J. P.

150. Analysis of the Azimuthal Dependency of the HVSR Spectra in Complex 3D Velocity Structures Using Numerical Modeling. **Pinilla Ramos, C.**, Dreger, D. S., Pitarka, A., Abrahamson, N., Kayen, R. E., Castellanos-Nash, P.

Southern California Seismicity: Past, Present and Future (see page 1540).

151. What's New at the SCEDC & SCSN: Data Products, Services, and Tools for Seismic Data in Southern California. **Bhaskaran, A.**, Chen, S. E., Yu, E., Tepp, G., Tam, R. W., Askari, A., Husker, A.

152. S-wave Attenuation Preceding the 2010 El Mayor-Cucapah, Baja California, Mexico Earthquake (Mw7.2). **Castro, R. R.**, Reinoza, C. E., Cruz-Hernández, F.

153. Illuminating Hidden Seismicity Patterns Along the San Jacinto Fault Using a Dense, Long-term Array of 300 Seismic Sensors. **Higueret, Q.**, Brenguier, F., Mordret, A., Sheng, Y., Vernon, F., Hollis, D., Aubert, C., Lavoue, F., Ben-Zion, Y.

154. STUDENT: Evaluating Stress Transfer on the Puente Hills Fault Due to Earthquakes on Nearby Source Faults in Southern California. **Olesh, A.**, Alam, M., Anyiam, U.

155. STUDENT: Rapid-response Seismic Imaging of the Aftershock Sequence of the 14 April 2025 Mw 5.2 Julian Earthquake. **Parida, B.**, Ghosh, A., Niyogi, S., Ford, H. A., Bravo, G., Leung, R., Margolis, A., Nakaya, S., Periollat, A. J., Stroup, A.

Abstracts of the Annual Meeting

Action at a Distance: Understanding Seismic Triggering

Oral Session • Friday 17 April • 2:00 PM Local

Conveners: Paul Bodin, University of Washington (bodin@uw.edu); Esteban J Chaves, Volcanological and Seismological Observatory of Costa Rica (esteban.j.chaves@una.ac.cr); Joan Gomberg, U.S. Geological Survey (gomberg@usgs.gov); Sonia Hajaji, Georgia Institute of Technology (ssalgado30@gatech.edu); Stephanie G. Prejean, U.S. Geological Survey (sprejean@usgs.gov)

Evaluation of Mainshock-induced Strength–stiffness Reduction Thresholds for Aftershock-triggered Slope Failures

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The 2001 El Salvador earthquake sequence, consisting of a M_w 7.7 mainshock and a M_w 6.6 aftershock one month later, produced numerous slope failures. Notably, several slopes that remained stable during the larger mainshock PGA (PGA^{MS}) failed during the smaller aftershock PGA (PGA^{AS}), suggesting that mainshock-induced weakening increased slope susceptibility. This study quantifies the critical strength–stiffness reduction thresholds required for aftershock-induced failure and evaluates thresholds as a function of PGA^{MS} .

We selected 15 slope failure cases documented by the U.S. Geological Survey (USGS) in which PGA^{AS} was smaller than PGA^{MS} and below 0.2 g. Five rock-site mainshock and one rock-site aftershock records were obtained from the Consortium of Organizations for Strong-Motion Observation Systems, and four additional aftershock motions were generated by spectrum matching to GMPEs. All ground motions were scaled to estimated PGA^{MS} and PGA^{AS} for each slope.

We performed numerical analyses using FLAC^{2D} with a 5 m soil layer over rigid bedrock, consistent with the shallow failures observed during the aftershock. Prior to analysis, we compared FLAC^{2D} displacements with Newmark displacements because standard Newmark criteria cannot be directly applied to numerical outputs. As a result, the mean displacement of nodes exceeding 5% of the maximum displacement matched Newmark estimates, confirming that the Newmark-based 2 cm threshold of disrupted slides could be used as the failure criterion.

To identify minimum strength–stiffness reduction thresholds, soil properties were adjusted so that mainshock-induced displacement approached 2 cm, representing the most vulnerable non-failing condition. We then uniformly reduced shear-wave velocity, friction angle, and cohesion until aftershock-induced displacement reached 2 cm.

Results indicate that smaller PGA^{AS} require larger strength–stiffness reductions to cause failure, while larger PGA^{MS} correspond to greater reductions. For a PGA^{MS} of about 0.6 g, slope strength–stiffness decreases by approximately 45%, indicating substantial pre–aftershock weakening.

Dynamically Initiated Seismic Sequences in Eastern North America Following the Large 2025 Kamchatka Earthquakes

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Eastern North America (ENA) is characterized by the absence of measurable tectonic deformation, and thus constitutes a stable continental region (SCR). Yet, earthquakes do occur throughout ENA, although at a much lower rate than at active plate boundaries. Given the lack of tectonic deformation, crustal stresses in ENA vary primarily due to long- and short-term environmental factors (e.g., hydrology, tides), perturbations from local and distant earthquakes, and anthropogenic activity. Understanding earthquake occurrence in ENA and other SCRs is intrinsically related to understanding seismic triggering. Using a new, comprehensive, machine-learning- and template-matching-

based earthquake catalog for ENA for 2025, we observe an increase in seismic activity in multiple areas across ENA following the series of major ($M > 7$) earthquakes that struck the region of Kamchatka, Russia, in 2025, culminating in a M_w 8.8 event on July 29, 2025. The areas of increased seismicity in ENA are located in previously quiescent regions, suggesting that they initiated due to dynamic stresses produced by the Kamchatka earthquakes. The duration and temporal evolution of these sequences vary from hours-long bursts to months-long swarms, underlining the complex interplay between “direct” dynamic triggering and dynamically initiated local processes like pore-fluid pressure reorganization or self-sustained seismicity. We use the nearest seismic stations to estimate the dynamic strain and stress perturbations in the areas of increased seismicity to quantify the triggering thresholds. Our study helps elucidate the effects of dynamic stresses on earthquake occurrence and the behavior of active faults in low strain rate regions such as ENA and other SCRs and may improve seismic hazard assessment.

Fluid Pressure Surge of a Hydrofracture Due to Seismic Wave Stimulation

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Triggering of earthquakes in geothermal and volcanic fluid regions by weak-amplitude (1 kPa ~ tens of kPa) vibrational forcing, such as a passing seismic wave, is a well-established phenomenon. However, the cause of triggering remains unresolved. Here, we propose a new mechanism, called the pressure surge (PS) effect. It was first discovered in numerical modeling (Zheng, 2018) and later verified in the lab (Jin, Zheng, Dyaour, 2021). PS demonstrates that the fluid pressure in a fluid-filled fracture can be amplified by two orders of magnitude relative to the incident seismic-wave pressure and is frequency-dependent. In this presentation, the scope of work will be expanded from the previous single-planar fracture to multi-branched fractures. The pressure amplification factor and resonance frequency of each fracture branch, as well as the duration of the incident wave, will be investigated. This study will shed light on why low-frequency incident waves have higher potential in triggered occurrences and the role of long-duration stimulations.

High Frequency Vibroseis Triggering of Microseismicity in the New Madrid Seismic Zone?

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Intriguing microseismic activity was observed in 100 out of 162 raw shot gathers taken during a joint USGS/CERI vibroseis reflection profile in November 2006. The observations of high apparent velocity, high frequency (8-15 Hz) impulsive arrivals across the reflection spread suggested sources that were deeper than 5 km and associated with the Reelfoot fault plane directly under the reflection experiment. These observations motivated a subsequent broad band, passive array experiment that was deployed in the area from November 2009 to September 2011, the New Madrid Nonvolcanic Tremor Array. Analysis of the passive array data uncovered thousands of similar signals with many occurring to the west of the array, as seen in the reflection data, and many to the northeast. The rate of occurrence of these small events ($M \sim 1$) seen in the array data was consistent with that inferred from the Gutenberg-Richter rate inferred from New Madrid Cooperative Network seismicity suggesting the sensible result that there are many low-magnitude events occurring in the seismic zone that are missed by the regional network. However, the passive array did not record any swarm-like behavior as seen in the reflection experiment; the seismicity rate was one to two orders of magnitude greater than the Gutenberg-Richter rate for events seen in 2006. Low frequency stress changes induced by barometric pressure change, river loading, and from great earthquake surface wave trains were not seen to obviously trigger local seismicity in the passive array experiment. Accepting the possibility that the high seismicity rate seen in the 2006 observations may be a unique natural occurrence, we examine the remaining hypothesis that the high frequency vibroseis source itself triggered deep swarms of events similar to reported observations of induced acoustic emissions from Russian oil fields.

Lack of Strong Dynamically Triggered Tectonic Tremor in Costa Rica

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Tectonic tremor is one of the seismic expressions of slow earthquakes mainly along major plate boundary faults. Tremor is highly stress sensitive and can be modulated by solid Earth tides and dynamically triggered by the passage of teleseismic surface waves. In many fault systems, the triggering threshold for tremor can be only a few kPa, which has been interpreted as evidence for very low effective stress at the tremor source region. Dynamic triggering is therefore a useful stress test for comparing fault conditions across regions. Systematic global searches have documented triggered tremor in many tectonic settings, yet in Costa Rica no clear dynamically triggered tremor has yet been identified. Costa Rica is highly seismic and tectonically diverse, shaped by interactions among four tectonic plates, including a triple junction and a segmented subduction zone. In this study we investigate why Costa Rica—despite having slow slip events and ambient tremor—shows no strong evidence of dynamically triggered tectonic tremor. We systematically searched for triggered tremor during large-amplitude surface waves of 25 teleseismic mainshocks from 2010 to February 2023, mostly from the American continent, using OVSICORI’s broadband seismic stations across the country. Except for some weak tremor near Volcan Turrialba during the surface waves of the 2017 $M_{8.1}$ Chiapas, Mexico earthquake, we find no clear evidence for dynamically triggered tectonic tremor in Costa Rica. This largely null result either reflect observational limitations that mask weak tremor during the teleseismic surface waves, or it may indicate that key physical conditions that favor triggered tremor generation are not sufficiently established in this region. Costa Rica is therefore an important member for understanding why dynamic triggering is common in some tremor zones but absent in others, and it motivates future work for testing how subduction zones and fault systems characteristics control tremor susceptibility to external stress perturbations.

Action at a Distance: Understanding Seismic Triggering

[Poster]

Poster Session • Friday 17 April

Conveners: Paul Bodin, University of Washington (bodin@uw.edu); Esteban J Chaves, Volcanological and Seismological Observatory of Costa Rica (esteban.j.chaves@una.ac.cr); Joan Gomberg, U.S. Geological Survey (gomberg@usgs.gov); Sonia Hajaji, Georgia Institute of Technology (ssalgado30@gatech.edu); Stephanie G. Prejean, U.S. Geological Survey (sprejean@usgs.gov)

Do Earthquake Deformation and Shaking Trigger Eruptions?

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We present a new approach to evaluate the potential triggering of volcanic unrest by deformations and shaking induced by earthquakes. We posit that earthquake-generated perturbations at a single volcano may be cumulative, and we tally all these deformations, quasi-static and dynamic, as they develop over time. This deformation time series is then compared to the history of unrest at the volcano. By focusing on this cumulative deformation history, our “volcano-centric” method inverts the more common “earthquake-centric” approach of looking for unrest at multiple volcanoes in the aftermath of a particular earthquake. Our approach also accounts for finite durations of earthquake-generated deformation and volcanic relaxation. We use deformation proxies provided by equations describing earthquake ground motions and epidemic-type aftershock sequences (ETAS), together with the most complete and longest seismicity catalogs. We exclude earthquakes <50 km from a volcano since they may be caused by the unrest. We test this approach for four volcanoes in different tectonic settings. We use a simple, effectively binary, measure of unrest defined as $VEI > 2$ eruptions at the Redoubt USA, Turrialba Costa Rica, and Krasheninnikov Russia Volcanoes, and also the onset of geodetically-observed deformation at Taupō Volcano New Zealand. A convincing

case of large earthquake-induced deformations triggering eruptions cannot be made for these volcanoes, except perhaps the 2025 Krasheninnikov Volcano that erupted a few days after the $M_{8.8}$ Kamchatka Russia earthquake, after 500 years of dormancy. However, even this case highlights the challenge of forecasting such triggering scenarios without confident knowledge of how poised a volcano is to erupt, noting that no eruption at Krasheninnikov followed larger deformations from a closer $M_{7.8}$ earthquake in 1997. Currently such confidence requires onsite monitoring. We also find that in all cases, summed dynamic deformations from smaller closer earthquakes may exceed those from larger more distant events, implying most previous earthquake-centric studies use incomplete datasets.

A New Agent, Pycorelator, Advances the Starring Role of Triggering in Paleoseismology

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Knowledge of pre-historic earthquakes relies on observations of the phenomena they trigger, particularly mass transport events (e.g., landslides, sediment flows) and tsunamis observed in characteristic deposits. These fingerprints are preserved within stratigraphic sequences in cores taken at sites across an area likely affected by the posited earthquake, with high correlations between fingerprints assumed to indicate synchronous triggering by the same earthquake. The spatial distribution of correlative pairs is assumed to provide an estimate of the earthquake’s size. Correlations often are assessed subjectively, allowing for input of sedimentologists’ expertise and independent constraints. However, these may be challenging to reproduce, non-unique, and often do not amply consider variations in depositional environments and triggering earthquake source and shaking characteristics. We introduce a new Python tool, pyCoreRelator, designed to systematically and objectively identify all feasible correlations between core pairs, honor age dates or other tie points, account for varying bed thickness, include multiple log and image data types, allow for sedimentologists’ input, and enable evaluation of correlation quality and uniqueness. PyCoreRelator may be applied to many paleoseismic studies involving stratigraphic correlation. Our initial application uses marine sediment cores from Cascadia that were previously interpreted as synchronous, earthquake-triggered turbidite deposits. Initial results highlight the need to consider depositional environment differences, evident as a decrease in correlation quality and significance metrics as the distance between cores increases. Cases in which these metrics degrade when age constraints are included further suggest that depositional environment differences may overwhelm any source-related fingerprints and thus that correlation analyses may not be appropriate. Results also provide guidance for future analyses and data collection, particularly that correlation-based inferences should rely on core pairs from where sediments may pond (e.g., abyssal plains and confined basins).

False Positives in the Identification of Dynamic Earthquake Triggering

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Triggering phenomena, such as dynamic triggering of distant earthquakes, are commonly identified through temporal correlation between the apparently triggered events and the presumed triggering earthquake. However, correlation does not imply causation. False positives may occur when unrelated processes coincidentally occur at around the times of large earthquakes. We investigate the false positive rate for dynamic earthquake triggering by finding the rate of apparent triggering in synthetic earthquake catalogs with no true triggering. In our example, we apply the statistical tests of DeSalvio and Fan (2023) to identify seismicity rate increases coincident with global $M \geq 6$ earthquakes in synthetic seismicity catalogs for Southern California. We find a false positive rate of ~3.5-8.5% of tested global earthquake-spatial location pairs when realistic seismicity clustering is present, consistent with the 95% confidence typically used in seismology. However, when this false positive rate is applied to the tens of thousands of spatial-temporal windows in Southern California tested in DeSalvio and Fan (2023), thousands of false positives are expected. The expected false positive rate is large enough to explain the

observed apparent triggering following 70% of large global earthquakes during 2008-2017 (DeSalvio & Fan, 2023), without requiring any true dynamic triggering. Aside from the known triggering from the nearby El Mayor-Cucapah, Mexico, earthquake, the spatial and temporal characteristics of the reported triggering are indistinguishable from random false positives. This implies that best practice for dynamic triggering studies that depend on temporal correlation is to estimate the false positive rate and investigate whether the observed apparent triggering is distinguishable from the correlations that may occur by chance. Other methods to avoid false positives in dynamic earthquake triggering studies include stacking observations to enhance any signals and reduce the effect of random correlations or requiring a seismicity rate change over a large area, which is less likely to occur by chance.

POSTER 4
Dynamic Earthquake Triggering Regions in Texas and the Role of Fluid Injection
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Large magnitude teleseismic earthquakes ($M_w \gtrsim 7$) can trigger smaller earthquakes by dynamically altering stress conditions at remote locations. Earthquake triggered by these dynamic stress changes can be useful to identify critically stressed faults near failure which could inform seismic hazard assessments. We investigate the greater Texas region and identify the sub-regions with statistically significant occurrences of dynamically triggered local seismicity between 2017 and 2024. Statistical analysis (beta and Z) for triggered seismicity (changes after compared to before teleseismic wave arrival) reveal 18% teleseismic events triggers 97 local events in 9 distinct regions and minimum dynamic stress for triggering is 0.0001 MPa. Among the triggered events the dominance in delayed triggering (83%) and instantaneous Rayleigh wave triggering (14%) indicates a fluid pressure driven nucleation mechanism. The depth, magnitude, distance, azimuthal direction of teleseismic source to Texas couldn't differentiate between triggering and non-triggering teleseismic events. In addition, the fluid injection volume with injection well location positively correlates with triggered region. However, Peak Dynamic Stress (PDS), which is calculated from waveform's Peak Ground Velocity (PGV) shows a lack of direct positive correlation with triggering teleseismic event. This study suggests any subsurface activity (fluid injection/production wells, geothermal or hydrofracking activities) in triggered regions needs extra precautions and could nucleate damaging future earthquake.

POSTER 5
Hard-linking and the Hikurangi: Controls on Fault Co-rupture From Synthetic Earthquake Catalogues
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Recent earthquakes involving multiple faults, such as the 2010 El Mayor-Cucapah and 2016 Kaikōura earthquakes demonstrate the potentially complex interactions of faults in single earthquakes (or triggered sub-events). Physics-based earthquake simulators offer one approach for exploring the occurrence of, and controls on, such multi-fault earthquakes and the stress interactions between the faults involved. Here we use the physics-based earthquake simulator RSQsim to generate synthetic earthquake catalogues for central Aotearoa New Zealand in the region of the 2016 Kaikōura earthquake. We generate two 450 kyr synthetic catalogues, one with and one without the Hikurangi subduction interface. We improve on previous synthetic earthquake catalogues for Aotearoa New Zealand by implementing a new 3D fault modelling methodology, which is better able to account for along-fault and down-dip variations in fault geometry. We investigate the occurrence of multi-fault earthquakes in our synthetic catalogues with a particular emphasis on the role of the southern part of the Hikurangi subduction interface in these earthquakes. The synthetic catalogues show an increasing proportion of multi-fault earthquakes at higher magnitudes. We find that the subduction interface exerts a significant control on the aspect ratios, rates of occurrence, and faults involved in synthetic multi-fault earthquakes. Whilst our catalogues contain >100 complex multi-fault events broadly similar to the 2016 Kaikōura earthquake, none rupture exactly the same combination of faults, suggesting that either this fault com-

bination is rare or that key aspects of the controlling physics or fault network are not captured by the earthquake simulator.

POSTER 6
Larger Earthquakes Happen Sooner: Non-separability of Magnitude and Time Distributions of Aftershocks
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Recent work in statistical seismology has revealed frequent non-stationary behavior in aftershock sequences. This can be obvious with swarms and foreshocks, but may appear more subtly in conventional aftershock sequences. Non-stationarity is most interesting when it involves the magnitude-frequency distribution, which determines the instantaneous chance of a large aftershock. While magnitude non-stationarity can be captured by statistics, e.g. through the changing parameters of an exponential distribution, visual techniques may also prove valuable. I here visualize magnitude non-stationarity via a rank-time map (copula plot). Under stationarity, the copula plot should be uniform; deviations from uniform point to non-stationarity. Unfortunately for statistical seismology, the marginal of the magnitude distribution is already strongly non-stationary due to incompleteness at early times, making such plots useless for most seismological applications. By instead focusing on positive successive magnitude differences, I rehabilitate the rank-time map and obtain an unbiased look into the magnitude distribution of the entire aftershock sequence. Recent sequences with prominent foreshocks (2019-2020 Puerto Rico; 2019 Ridgecrest, CA) show substantial clustering of large aftershocks toward the start of the aftershock sequence, and smaller earthquakes later. I interpret the clustering of large aftershocks as evidence of correlation between the stress-dependent nucleation rate (as evidenced by the Omori c -value) and growth rate (as evidenced by the b -value) of triggered earthquakes. We know that these parameters correlate between tectonic regimes in a way that is consistent with their stress dependencies in the lab; if high stress drives both faster nucleation and faster growth, then we should expect larger earthquakes to happen sooner. This implies that the sites of the earliest aftershocks may soon host the largest.

POSTER 7
Complex Faulting and Stress Transfer During the July 25, 2023 Mw 5.5 Earthquake Sequence in Kozan, Southeastern Türkiye
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The 2023 Mw 7.8 and 7.5 Kahramanmaraş doublet earthquakes in southeastern Türkiye triggered prolonged and spatially complex aftershock activity along the East Anatolian Fault system. To better characterize the evolving seismicity and underlying fault structures, we deployed over 200 SmartSolo nodal stations across both aftershock zones, with continuous 500-Hz waveforms for more than 100 days starting in May 2023. During this deployment, we recorded an independent sequence on July 25, 2023, centered near Kozan in northern Adana, Türkiye, and characterized by a Mw 5.5 mainshock and numerous aftershocks. Analysis of near-source nodal and broadband recordings reveals that the Mw 5.5 mainshock was followed within tens of seconds by another local event of comparable magnitude. The waveforms of both events were overlapped at larger distances, making it challenging to separate the two events apart using conventional approaches. To resolve the spatiotemporal evolution of this sequence, we combine deep learning phase picking with matched-filter detection and high precision relative relocation to construct a high-resolution aftershock catalog. The resulting seismicity delineates a complex faulting pattern in the Kozan region involving multiple activated fault segments striking at high angles to the nearby Kozan fault. Additionally, we quantify Coulomb stress changes from the February 2023 Kahramanmaraş doublet earthquakes and examine their spatial correspondence with the Mw 5.5 Kozan sequence and its complex faulting geometry to explore whether static or dynamic stress transfer may have facilitated delayed triggering of the July 25, 2023 Mw 5.5 events. Our observations provide new insights into how complex faulting interactions and stress transfer can jointly influence the timing and rupture behavior of moderate magnitude earthquakes in southeastern Türkiye. Improved understanding of such localized sequences contributes to

better seismic hazard assessments in the Kozan region and broader southeastern Türkiye.

Advances and New Challenges in Investigating Seismic Site Response

Oral Session • Thursday 16 April • 10:30 AM Local

Conveners: Anna Kaiser, Earth Sciences New Zealand (a.kaiser@gns.cri.nz); Elena Manea, Earth Sciences New Zealand (e.manea@gns.cri.nz); Marta Pischiutta, National Institute of Geophysics and Volcanology (marta.pischiutta@ingv.it); Rodolfo Puglia, National Institute of Geophysics and Volcanology (rodolfo.puglia@ingv.it)

Seismic Site Characterization Using Ambient Noise and Earthquake Data in the Mexicali Valley, Northern Baja California, Mexico

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This study applies an integrated spectral ratio to characterize seismic site response in the Mexicali Valley, Northern Baja California, Mexico. Ambient noise and earthquake recordings 3 earthquakes including the the November 11, 2022, M6.1 earthquake occurred at coordinates 30.721° -116.479° were processed, using data from eight stations. Using both types of data, two spectral-ratio methods were employed: the HVSR technique proposed in 1989 by Nakamura and the cross-power/auto-power spectral-ratio method proposed in 2023 by Huerta López & Vidal Villegas. Custom Python routines were developed to compute fundamental resonance frequencies and peak amplitudes from the datasets.

Preliminary HVSR analyses using Nakamura's method indicate that most of the sites have low fundamental frequencies (0.39–1.22 Hz) and moderate-to-high peak amplitude values (2.54–7.78), whereas the Cerro Prieto station, on a high elevation (110m) on the volcano, shows a high fundamental frequency (2.05 Hz) and high amplitude value (13.10). Similarly, the cross/auto power spectral ratio method yields consistent trends for these sites (frequencies from 0.44 – 1.22 Hz and peak amplitude values from 2.25 – 6.68) and confirms the Cerro Prieto station's distinct signature (2.05 Hz; 11.56). Concerning the earthquake data analysis, the results further reinforce the reliability of both methods, showing closely matching frequency estimates (0.54 – 3.63 Hz from HVSR vs. 0.73 – 3.63 Hz from SR-XPBV/APVV) and comparable amplifications (3.97 – 9.03 vs. 3.50 – 8.11) across multiple stations. The markedly higher amplification at Cerro Prieto is interpreted as a topographic effect, consistent with the results reported by Vidal Villegas et al. in 2022.

The results validate the combined use of HVSR and SR-XPBV/APVV methods for site characterization in the Mexicali Valley, demonstrating that both ambient noise and earthquake data yield consistent site-response estimates in this complex geological setting.

High-resolution Mapping of Site Response Variability in the Los Angeles Basin Using Dense Community Seismic Network Data

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Understanding spatial variability in seismic site response is essential for accurate ground-motion prediction and multiscale seismic hazard assessment in large sedimentary basins. The Los Angeles Basin (LAB) exhibits complex amplification behaviour driven by a variety of physical mechanisms including basin-edge effects, impedance contrasts, and fault-controlled structural variability, amongst others. These mechanisms, and their impacts on site response, are difficult to resolve using sparsely spaced traditional seismic networks, but this study addresses these limitations by leveraging a densely instrumented region of the LAB with recordings from the Advanced National Seismic System (ANSS) and the Community Seismic Network (CSN). We estimate 5%-damped RotD50 pseudo-spectral acceleration site residuals using mixed-effects regression relative to the Boore et al. (2014) ground-motion model,

and we compare spectral characteristics, total residuals, and spatial patterns across stations.

Comparison of CSN and ANSS site residuals indicate strong consistency at short periods ($T < 0.3$ s), with a small systematic bias of ~5% across short-to-intermediate periods and increased divergence beyond approximately 1 s due to reduced long-period signal-to-noise ratios for the CSN records. Despite these limitations, we observe coherency in the spectral shapes and spatial trends of CSN and ANSS stations, including localized amplification near basin edges, cross-fault transitions in site residuals, and small pockets of de-amplification. The dense CSN deployment substantially enhances spatial sampling, yielding smoother and more stable residual fields that improve characterization of intra-basin variability relevant to non-ergodic ground-motion modelling. These findings demonstrate the efficacy of combining CSN recordings with observations from ANSS for high-resolution site-response studies when modest period-dependent bias is accounted for. The results further highlight the value of dense urban sensor networks for advancing basin-focused seismic hazard assessment in Southern California.

Experimental and Numerical Analysis of the Effects of 3D Velocity Structures on HVSR

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The horizontal-to-vertical spectral ratio (HVSR) is a widely used measure for estimating the dominant ground period (T_g) at a site, a key parameter in seismic microzonation studies. Under the diffuse field assumption (DFA), that is to say that the ambient seismic noise (ASN) is diffuse, the HVSR allows to retrieve the subsurface velocity structure of flat layers. For significant lateral variations, the velocity structures are 3D and their effects on HVSR are yet a research problem. The easiest thing to do is interpolation of diverse 1D interpretations at a given site but this is clearly misleading because lateral inhomogeneities introduces spatial and directional variations in HVSR. The challenge is to account for this directional character by improving the modeling and the ensuing interpretation of HVSR. In order to gain understanding of directional HVSR features, we rely on the diffuse field assumption and compute the HVSR through the imaginary part of Green's function, at the source point, of the irregular system – a layer over a half-space with irregular interface-, which reveals direction and space dependent behaviors that include the effects of interface morphology.

We performed relatively dense measurements at sites of Mexico City and detect these spatial and directional HVSR variations and give preliminary interpretations of the effects of lateral irregularity. To model laterally irregular layers, we use the indirect Boundary Element Method (IBEM), which, formulated in the frequency domain, allows for an efficient computation of the imaginary part of the system's Green's function. We implemented adaptative physics informed meshes which sizes and spatial distributions are determined using Fresnel volumes. We computed directional-HVSR. Preliminary results are encouraging. This research is partially supported by DGAPA-UNAM under grants IN105523 and IG100626. J. G. González is supported by the UNAM Postdoctoral Program (POSDOC).

Three-dimensional Numerical Analyses of Local Seismic Response in Complex Geological Settings: Applications to the Norcia Sedimentary Basin and the Introdacqua Rock Site (Central Italy)

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Understanding seismic site effects in complex geological and morphological settings requires numerical approaches capable of describing 3D seismic wave propagation. In the framework of the INGV-MUR project Pianeta Dinamico GEMME, 3D numerical simulations were performed to investigate local seismic response in two high-hazard areas of Central Italy: the Norcia sedimentary basin and Introdacqua topography site. The Norcia basin, located in the central Apennines, is a Quaternary intermontane depression that has been repeatedly impacted by major seismic events, including the Mw 6.5 earthquake of 30 October 2016. Its complex geological framework, characterized by lacustrine, palustrine, alluvial and conglomeratic deposits overlying a carbonate bedrock, makes it an ideal natural laboratory for investigating 3D seismic site amplification effects and basin-related phenomena. The basin has been characterized by combining new field data, such as MASW profiles, passive seismic arrays, and stratigraphic boreholes, with information from previous investigations and seismic microzonation studies. This allowed us to reconstruct the 3D geometry of the basin and the spatial variability of its sedimentary infill and bedrock properties. For Introdacqua, ongoing 3D modeling focuses on the influence of topography, geological structure, and rock fracturing on seismic response and directional effects.

The resulting models have been implemented in two physics-based numerical frameworks: SPEED, which employs the spectral element method, and FLAC3D, based on the finite difference approach. Although both numerical codes are capable of simulating non-linear soil behaviour, model validation is performed in the linear domain using, in the case of Norcia, weak-motion recordings from the temporary seismic network 3H-2009, while, in the case of Introdacqua, recordings from nodal-arrays performed during the project. The study confirms the need for 3D modeling to reliably interpret site effects and provides a solid basis for future extensions to nonlinear conditions, aimed at improving seismic hazard assessment in structurally complex areas.

Limits of 1D Site Response in Basel’s Urban 3D Geological Environment

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One-dimensional (1D) site response models assume horizontally layered media and vertically propagating shear waves. This approximation becomes limited where lateral velocity contrasts are comparable to vertical gradients. Owing to its pronounced geological contrasts and dense observational coverage, the Basel region in Switzerland provides a suitable test case for examining these limits. Located near the southeastern margin of the Upper Rhine Graben, Basel has experienced strong site effects during past earthquakes. The city straddles the Rhine Graben Fault, separating two contrasting geological domains over horizontal distances of 100–300 m. West of the fault, Quaternary sediments overlie thick Tertiary deposits above Mesozoic bedrock, whereas east of the fault Mesozoic limestone occurs at shallow depth beneath thin Quaternary cover. This juxtaposition generates sharp lateral shear-wave velocity (Vs) contrasts.

To characterize this subsurface complexity, we integrate borehole data, active and passive seismic measurements, and a 3D geological model resolved at 25 m over ~130 km². Analysis of 2,200 horizontal-to-vertical spectral ratios reveals variations strongly correlated with geological boundaries. Fundamental resonance frequencies range from 0.3 to 1 Hz within the basin and shift by up to 0.8 Hz over distances <50 m near the fault zone, before increasing above 2 Hz beyond it. Broad peaks with multiple sub-peaks indicate lateral wave propagation and basin-edge effects. Bayesian Multizonal Transdimensional Inversion applied to 35 ambient vibration arrays yields Vs profiles with quantified uncertainty. Comparisons with empirical amplification show that satisfactory 1D fits occur primarily at sites distant from major velocity discontinuities. Combined analysis of the profiles further reveals systematic depth-dependent variations within individual geological formations. These results demonstrate that deviations from 1D predictions are controlled

by site complexity, requiring method selection guided by geological structure rather than uniform application of simplified models.

OpenAmp: An Open-source Site Amplification Database to Unlock the Potential of Machine Learning

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OpenAmp is an open-source, consistently curated, high-quality database of earthquake site amplification functions derived from instrumental recordings, accompanied by a comprehensive suite of site metadata, for 1,742 K-NET and KiK-net strong-motion recording sites in Japan. The site metadata builds upon the site database of Zhu et al. (2021) and introduces several new parameters, including the site-specific spectral decay parameter (κ_0), the standard deviation of the horizontal-to-vertical spectral ratio of earthquake recordings (σ_{HV}), and site dimensionality index (I1D3D). A distinctive feature of OpenAmp is the inclusion, for the first time, of a diverse set of vector-based parameters and proxies, including quarter-wavelength velocity (V_s , qwl), and frequency- and scale-dependent topographic metrics. The (linear) site amplification functions are derived from weak-motion recordings using a generalized inversion technique in the Fourier domain, and their correlations with various site data are also presented. OpenAmp is unparalleled in its quality, scale, and completeness by any existing databases. It enables a wide range of applications, including optimal site parameterization, development and benchmarking of site-specific or geospatial amplification models, and testing novel ideas. Ultimately, OpenAmp has the potential to significantly advance data-driven approaches for modeling near-surface effects in seismic hazard assessments. The database and associated resources can be freely accessed via: <https://doi.org/10.25398/rd.northumbria.29649008>.

Dense Array Experiment on Mt. Plaia (Central Italy), to Improve Understanding of Site Amplification on Topography

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A dense array experiment was carried out on Mt. Plaia, a carbonate relief located in the central Apennines, and across the historic Middle-Ages village of Introdacqua. The site hosts the permanent seismic station IV.INTR of the Italian National Seismic Network (RSN), operated by INGV, which records higher-than-average amplitude levels and positive residuals in magnitude estimations. Recent studies have confirmed the occurrence of a directional amplification effect in the 1–3 Hz frequency band, with maximum amplification along N160° azimuth. The observed amplification pattern cannot be explained by stratigraphic amplification, nor by a simple resonant topography model. A detailed structural geological survey highlighted the local presence of intensely fractured rocks, possibly associated with an E–W fault zone located approximately 2 km to the south, which may be responsible for the observed effect rather than topographic irregularities.

Therefore, within the framework of the INGV–MUR Pianeta Dinamico GEMME project, and in order to improve the understanding of site amplification effects by imaging the local velocity structure, we deployed a dense nodal array composed of 48, 4.5-Hz geophones, equipped with GSB data recorders. The instruments continuously recorded data for approximately 30 days.

To characterize the ambient noise wavefield, we performed beamforming analyses on daily time windows using the entire array. The resulting polar plots reveal a consistent noise source arriving from the NNW.

We also performed ambient noise tomography (ANT) to reconstruct the velocity structure of the relief. The recorded dataset exhibits high quality, yielding stable cross-correlation functions (CCFs) between station pairs with high signal-to-noise ratios. This allowed the extraction of clear and coherent Rayleigh-wave dispersion curves, which are currently being inverted to retrieve the shear-wave velocity (VS) structure of the relief.

These results highlight the complexity of the site response and demonstrate the effectiveness of dense array deployments in characterizing carbon-ate reliefs.

Integration of Non-ergodic Site Response Into NEHRP Provisions & ASCE-7

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Site response effects are accounted for in the development of risk-targeted maximum considered earthquake (MCE_R) ground motions in two ways: (1) as site factors incorporated within ground-motion models, as implemented in the National Seismic Hazard Model, and (2) from the use of site response analyses that model wave propagation through a geotechnical model of the project site. Site response analyses are the subject of Section 21.1 in the NEHRP Provisions and the ASCE-7 Standard.

As part of a provisions update cycle that will conclude in 2026 for the NEHRP Provisions and 2028 for ASCE-7, Section 21.1 was rewritten to permit the use of probabilistic methods for combining site response with reference site ground motions, as well as to incorporate significant improvements related to parameter selection, uncertainty evaluation, and analytical approaches. These revisions to Section 21.1 are approved for the 2026 NEHRP Provisions and are in the final stages of review for ASCE-7.

The updates to Section 21.1 permit use of *site-specific* (partially non-ergodic) site-response methods that incorporate aleatory variability reduction in hazard calculations. The updates also allow for continued use of traditional methods in which MCE_R spectra for a reference site condition are adjusted through simple multiplication by ground motion amplification factors derived from ground response analyses. However, some adjustments to the traditional procedure are provided that mitigate different sources of bias that can lead to under-prediction of ground motions. Those traditional methods, with adjustments, are referred to as providing *hybrid ground motions* in the updated Section 21.1. Separate requirements are provided for the two general methods of analysis (site-specific and hybrid).

The revised Section 21.1 promotes improved practice in ground response analyses by avoiding commonly encountered problems, including consideration of shear strength in the development of nonlinear soil properties, phase transformation behavior of liquefiable soils, and site response effects at long periods.

Effects of Damping Contrasts at Soil and Soil-rock Boundaries on the Response of Layered Soil Deposits

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Recent advances in the general theory of viscoelastic waves and rays in layered media provide a rigorous mathematical framework for site-specific soil-response models used in earthquake-resistant design. These advances predict newly discovered effects of damping contrasts at soil and soil-rock boundaries, which cause variations in the amplitude and spatial distribution of ground-motion amplification within alluvial basins. Such variations, and their engineering significance, depend on damping levels, damping-contrast ratios, and layer geometry. For site-specific projects, the significance of these effects can be readily estimated using recently published closed-form anelastic ray-tracing algorithms. This study provides estimates of the effects of damping-contrasts for typical layered soil deposits in the San Francisco Bay region.

Development of Non-linear Site Response Model Based on 1D Simulations

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Site effects form an important part of ground motion prediction. Linear site effects can be empirically constrained with data; however, nonlinear site effects are difficult to constrain empirically as there is a lack of strong ground motion observations that induce non-linearity. Nevertheless, modelling nonlinearity in site response is essential for ground motion models. In this research, four nonlinear site response models are developed based on 1-D site response analyses using two sets of shear wave velocity (V_s) profiles and two different approaches for analytically modeling non-linearity of the soil. The first set of profiles, which represents realistic V_s variation with depth, were obtained by combining the near-surface velocity profiles sampled from Shi and Asimaki (2017) model and the crustal profile from the USGS National Crustal Model. The second set of profiles, which are smooth and generic, were empirically constrained using quarter wavelength amplification to fit the linear site terms obtained by inverting the NGA West -3 data. Nonlinear site response analyses were performed for both sets of profiles using two different approaches– traditional equivalent linear (EQL) analyses where the induced strains in the layers are assumed independent of frequency and frequency-dependent moduli (FDM) approach where the strains are a function of frequency. While the traditional EQL approach predicts excessive damping of high frequencies, the FDM approach predicts almost linear response at high frequencies. The models developed in this study provide median non-linear transfer functions for effective amplitude spectra along with their uncertainty, conditioned on the time-averaged shear wave velocity in the top-30m (V_{s30}) and the Arias intensity of the input motion (I_a) at the base of the deep profiles. The differences in the multiple models not only provide a source of epistemic uncertainty consideration, but also highlight the need for further research to address this important aspect of strong ground motion prediction that has been historically under-appreciated.

Advances and New Challenges in Investigating Seismic Site Response [Poster]

Poster Session • Thursday 16 April

Conveners: Anna Kaiser, Earth Sciences New Zealand (a.kaiser@gns.cri.nz); Elena Manea, Earth Sciences New Zealand (e.manea@gns.cri.nz); Marta Pischiutta, National Institute of Geophysics and Volcanology (marta.pischiutta@ingv.it); Rodolfo Puglia, National Institute of Geophysics and Volcanology (rodolfo.puglia@ingv.it)

POSTER 1

Subsurface Velocity Structure at Eureka, NV, for Inferring Acoustic-to-seismic Conversion From the OSIRIS-REx Capsule Re-entry Sonic Boom

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In collaboration with Sandia National Laboratory, we deployed a 1 km aperture seismic array and two small acoustic subarrays at the Eureka County airport, Nevada, to record the sonic boom generated by the capsule re-entry of NASA's OSIRIS-REx mission on September 24, 2023. The experiment aimed to understand the wave propagation mechanisms important in the conversion of the incident acoustic pressure field into three-component ground motions. We also performed two 96-meter-long refraction surveys to map the near-surface P- and S-wave velocity structures near each infrasound array. Rather than rely on simple refraction models based on first arrival times, our goal is to use body and surface wave amplitudes to constrain velocity and attenuation structure of the upper 30 m of the Diamond Valley lake beds at the site, since it is well known in Acoustics that near-surface materials have very low Poisson's

ratios that strongly affect conversion. The body wave refraction data and local water well logs suggest that the near surface contains one or more significant low velocity zones giving rise to shadow zones. Surface wave dispersion gives very low shear wave velocities of 0.35 km/s, and a first approximation to the P wave velocity structure gives a near-surface velocity of 0.75 km/s. Our method for determining the best vertically inhomogeneous Earth model is to progressively model body wave travel times using tau-p tomographic inversion coupled with fundamental mode surface wave phase velocity inversion. Amplitudes of the refraction body and surface waves are modeled using wave-number synthetic seismograms and are expected to constrain near-surface anelasticity. The existence of the low velocity zones complicates the body wave tomography, which necessitates considering separate generalized rays for different distances along the profile.

POSTER 2

Global Annual Long Period Seismic Background Variability
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Earth’s microseism wave field determines global background noise levels between approximately 4–20 s and contains geographically integrated information regarding periodic and secular changes in ocean gravity wave energy spanning many decades. The surface wave-dominated microseism spectrum results from two ocean-wave seismic source processes that can be isolated in primary (PM; 14–20 s) and secondary (SM; 4–10 s) microseism bands and have ocean wave sensitivity kernels that generally increase in geographic scale with seismic period. We examine data from the Global Seismographic and GEOSCOPE networks for 73 stations with continuous data exceeding 20 years to characterize global annual PM and SM variations. PM and SM vertical-component accelerations display characteristic site-specific annual amplitude variations that can exceed 30 dB between quiet summer to noisy winter conditions due to annually periodic high-latitude storm intensity. Characterizing these annual variations with annually periodic harmonic functions reveals distinctive regional PM and SM amplitude and phase variations. These parameters thus quantify the ranges and predictability of seasonal long-period background noise levels relevant to earthquake and other signal detection thresholds.

Most sites, primarily in the Northern Hemisphere, show a high degree of annual PM to SM amplitude correlation with maxima during hemispheric winter and minima during hemispheric summers. Many sites, however, have significantly less correlated PM and SM amplitudes and have annualized amplitude histories that depart from the hemispheric winter-summer cycle. Notable examples include station clusters in Antarctica and East Asia, and some ocean islands. Overall, annual SM amplitudes tend to be more predictable than PM amplitudes, and Southern Hemisphere SM and PM amplitudes are much less annually predictable and less correlated with each other than in the Northern Hemisphere.

POSTER 3

Generic Nonlinear Amplification Functions for Taiwan
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The response spectrum amplification factor (F_{ζ}) is commonly represented as the sum of an intensity-independent linear amplification component (F_{lin}) and a nonlinear site amplification component (F_{nl}). The linear component is typically derived from empirical data, whereas the nonlinear component is generally evaluated using site response analysis. In this study, measured seismic velocity profiles and geophysical inversion results from Taiwan are compiled to develop a suite of generic velocity profiles extending to the geological bedrock. The amplification characteristics of the complete shear-wave velocity profiles are also investigated. Conversion between surface conditions and the reference condition of $V_S = 760$ m/s is applied to the input peak ground acceleration (PGA) at rock outcrop for various oscillator periods, based on linear amplification simulations. The input ground motions are assumed to follow point-source theory.

Considering appropriate nonlinear curves for soils and rocks additionally, the site effects for various sites under different seismic motions are further evaluated. The analysis reveals that the soil nonlinearity significantly affects the sites with soft soil ($V_{S30} < 360$ m/s) when under strong ground motions ($PGA > 0.1$ g). Furthermore, the amplification and the response of short-period and long-period signals are distinct. Moreover, the amplification behavior and response characteristics differ markedly between short-period and long-period signals. The nonlinear model developed in this study is compared with the nonlinear site amplification models proposed by Harmon et al. (2019) and Ilhan et al. (202X) in the NGA-West3 framework. The actions of soil noniaroty are short-period similar, but long-period and minute differences exist.

POSTER 4

Near Surface S-wave Velocity Measurement and Site Classification at 46 Sites in the East Bay and Delta
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Seismic surface wave surveys were conducted to measure near-surface V_S at 46 sites in the San Francisco Bay-Delta; 26 in the East Bay and 20 in the Delta. Both regions are prone to strong shaking due to earthquakes. The Delta contains extensive levees and is also prone to flooding. Site conditions included alluvial sediments, estuarine mud, peat, and fill over mud or peat. Surveys provided 1D velocity (V_{ζ}) models of the upper ~30 m and V_{S30} for site classification. Surveys used combined active and passive methods; multichannel analysis of surface waves (MASW) and microtremor array method (MAM). Most surveys (40) were recorded at estuarine soft-sediment sites using a linear array of 48 vertical geophones (4.5 Hz) with 2 m spacing. Vertical resolution was 1-2 m near the surface. At sites in open fields, velocity increases with depth, and dispersion curves are predominantly fundamental mode. At sites with fill over mud or on top of levees, however, velocity decreases with depth, and dispersion curves are dominated by higher modes. Higher modes were included in dispersion curve modeling when needed.

Among the 40 sites, V_{S30} ranged from 61 m/s to 251 m/s. Data were binned in ASCE 7-22 site classes. All sites fell into the three lowest-velocity classes (E, DE, and D). Thirteen sites had V_{S30} of 61-150 m/s (E), 17 sites had V_{S30} of 150–200 m/s (DE), and 10 sites had V_{S30} of 200-251 m/s (D). Additional surveys were recorded at six sites using 2D (areal) arrays with 2 Hz geophones, some at the same locations of surveys performed using linear arrays. V_{S30} from two soft-sediment sites where surveys where performed using both 2D and linear arrays were within 5% agreement. V_{S30} from our surveys were compared with values from the statewide V_{S30} map, which has categories associated with mapped geologic units. Agreement between our measurements and the state V_{S30} map was within 5% at low-velocity sites near the shoreline and within about 30% for sites in an inland alluvial valley (Tri Valley).

POSTER 5

Predictions of Ground Motions and Wave Radiation Patterns From a Chemical Explosion in Highly Faulted Testbed: Applications to the Nevada Rock Valley Source Physics Experiment
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Rock Valley Source Physics Experiment is Phase III of the Source Physics Experiment (SPE) to be conducted at the Nevada National Security Site. The experiment includes two chemical explosion experiments. The first, RVDC-1, is a 1-ton equivalent TNT located at 1.8km depth, while the second, RVDC-2, is a 10-ton equivalent TNT located at 1.7km depth. The local geology of the site is complex and encompasses a deep hard-rock, dolomite starting at 1km depth, and the shallow 1km is a mixture of tuff and sedimentary layers, deposited under a rugged topography. The water table is located 500m deep. The layered beds are crosscut by a series of faults. The source package is sized to be 3.5 to 4.5 feet diameter emplaced in a 4 to 5 feet diameter ground-zero (GZ) borehole. The characterization of the geology is limited and includes one straight continuous core-hole (CH), and two directional observation boreholes (OB) cored as needed sporadically. Based on this complex geological conceptual setting, we have conducted 3-dimensional non-linear numerical simulations of the ground motions generated from both explosions. First, we used deterministic geophysical properties of the layered model and assessed the response of the system with and without the faults to assess their effect on the anisotropic radiation of the ground motions. Second, we have included

stochastic variations in the geological layers. We adopted a scheme of including stochastic discrete fractures in the deep dolomite layer, while a continuous stochastic variation of lenses in the shallow geological layers. Assessing the effect of those stochastic parametrizations on the overall response of the system were obtained using a sophisticated interval Monte Carlo method. Material models have been calibrated to laboratory experiments and assessed under variably saturation conditions. Differentials of ground motion under different conditions of physical and structural uncertainties are then derived for both RVDC-1, RVDC-2, and a hypothetical earthquake.

POSTER 6

Reconnaissance Noise Survey for Seismic Network Expansion in Ukraine Under Wartime and Infrastructure Constraints
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The current stage of expansion and modernization of the Ukrainian national seismic network is being carried out under wartime conditions, limited access to infrastructure, and complex permitting procedures, requiring a systematic approach to site selection for new seismic stations and avoidance of unfavorable conditions for long-term operation. Within this stage, a reconnaissance ambient noise survey was conducted to assess the suitability of potential sites. Prior to noise analysis, topographic and geological–tectonic conditions were evaluated, while the primary selection criterion was based on ambient noise characteristics derived from Power Spectral Density (PSD) and Probabilistic Power Spectral Density (PPSD) analyses in the 0.02–20 Hz frequency range, using the Peterson New Low Noise Model (NLNM) and New High Noise Model (NHNM) as reference models.

In total, 18 potential sites were analyzed during the current modernization phase, of which 9 sites (50%) were rejected due to elevated noise levels exceeding the NLNM by 10–30 dB. The largest deviations were observed in the microseismic band (0.1–0.3 Hz) and at frequencies above 1 Hz, dominated by local anthropogenic and environmental noise sources. This pattern reflects the high degree of urbanization across Ukraine and ongoing military activity. The unsuitable sites include KANV, MYRO, SHEP, PLTV, KHRY, SUDI, BOKA, GOLU, and TUZL. In contrast, nine sites (SUGL, LOMU, VOVU, GRAU, STPH, ISKA, AKTA, BOKA1, and FURM) exhibit low noise levels, with PSD curves close to or below the NLNM in the 0.1–1 Hz range, meeting requirements for broadband seismic stations.

Data acquisition and archiving have been implemented using the SeisComP system. Despite non-technical constraints, several stations (LUBU, GOSU, SKVR, TURU) are already operational, their data integrated into EarthScope, and the network recorded a series of earthquakes in Crimea during 12–14 December 2025.

POSTER 7

Application of Machine Learning in Ground Motion Prediction: A Case Study From West Java, Indonesia
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Accurate prediction of ground motions is essential for reliable seismic hazard assessment, the design of earthquake-resistant structures, and the development of effective earthquake early warning (EEW) systems. Traditional Ground Motion Prediction Equations (GMPEs), constrained by predefined mathematical forms, often fail to capture the complex nonlinear relationships among source, path, and site parameters. This study employs machine learning (ML) techniques to develop data-driven attenuation models for West Java, Indonesia, aimed at predicting Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and 5% damped pseudo-spectral acceleration (PSA) at periods of 0.3, 1.0, and 3.0 seconds. The models incorporate

moment magnitude, epicentral distance, focal depth, and site conditions as predictive variables. A dataset comprising 3,561 strong-motion records from 383 earthquakes (Mw 2.4–7.0; 5.5–867 km) recorded by the Meteorological, Cimatological, and Geophysical Agency (BMKG) network between 2010–2024 was used for model training and validation. Three ML algorithms, Random Forest (RF), Extreme Gradient Boosting (XGB), and Artificial Neural Network (ANN), were evaluated using the coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE), and residual analyses. All ML models outperformed traditional regression-based approaches, with the RF model achieving the highest accuracy and stability. The optimized model accurately reproduced ground motions observed during 2024 event. This demonstrates its potential to improve regional seismic hazard assessments and enhance EEW capabilities in Indonesia.

POSTER 8

Assessment of Site Amplification Factors From the Non-reference Site Approach – a Case Study of the Taipei Basin
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The non-reference site approach (NSA) has emerged as a flexible framework for evaluating frequency-dependent site amplification without requiring a nearby reference rock station. We apply the NSA in northern Taiwan to assess linear site amplification functions (SAFs) in and around the Taipei Basin. The median within-event residual at each site relative to a generic rock condition ($V_{S30} = 760$ m/s) is then interpreted as a linear, frequency-dependent SAF, from which the dominant frequency (f_0) and amplification factor (A_0) of stations can be derived. The results reveal that stations inside the basin generally exhibit low dominant frequencies (approximately 0.4–1.5 Hz) and significant amplifications (about 3–6), whereas stations along the basin edge and outside the basin show higher dominant frequencies and smaller amplifications. These patterns align with previous results obtained from single-station microtremor observations (mHVSr). The NSA-derived results offer a non-ergodic SAF, which more accurately captures site-specific amplification behavior than a SAF predicted by a GMM using only V_{S30} and $Z_{1.0}/Z_{2.5}$. Our results show comparable spectral shape between NSA-derived SAFs and earthquake horizontal-to-vertical spectral ratios (eHVSr), indicating that the NSA reasonably captures the linear component of site response. Furthermore, the strong agreement between the two independent approaches supports eHVSr’s approach to a SAF and provides an opportunity to further understand the physical characteristics of eHVSr. Spatial distributions of dominant frequency and amplification factor within the Taipei Basin, corresponding to a uniform engineering bedrock, are then derived using the NSA method. The result confirms significant long-period amplification, especially in the western sector, where a thick sediment layer was deposited, suggesting that the current seismic design spectra may underestimate the effects of basin amplification at longer periods.

POSTER 9

Predictive Models for Depth to Rock Using Horizontal-to-Vertical Spectral Ratio Method and Geospatial Parameters in Southeastern Korea
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Depth to rock (D^{rock}) is a critical parameter for site classification, ground motion amplification, and evaluation of earthquake-induced liquefaction. While previous studies developed empirical models for D^{rock} using resonance frequency (f_0), this study aims to improve prediction accuracy in Southeastern Korea. We compile 113 borehole logs from the region and obtain f_0 at these sites using the horizontal-to-vertical spectral ratio (HVSr) method. The collected dataset covers a broad range of site conditions, with D^{rock} ranging from 2.2 to 95.1 m and f_0 from 0.76 to 22.45 Hz. Initially, we develop an empirical model to predict D^{rock} based solely on f_0 derived from the HVSr surveys. This simple model demonstrates better performance compared to existing models, achieving a 19.12% reduction in the root mean square error (RMSE). To further improve prediction accuracy, we incorporate geospatial parameters from 113 sites without additional field investigations. The best model, which integrates f_0 , the HVSr amplitude at f_0 ($A(f_0)$), and seven geospatial parameters, outperforms the simple model, resulting in a further 16.48% reduction in the RMSE.

HVSR Site Response in the Willamette Valley, Oregon
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Understanding site response and its relationship to subsurface structure are a key component of improving ground motion estimations and seismic hazard, yet this structure is poorly constrained in the Willamette Valley, where Oregon's population density is most concentrated. This project focuses on site-specific characterization of ground motion and inferences for subsurface structure within the Willamette Valley, using a comparison of horizontal-to-vertical spectral ratio (HVSR) methods – earthquake (eHVSR) and microtremor (mHVSR) to identify fundamental site frequencies of peak ground motion amplification to help better constrain local subsurface geology and velocity structures that may impact future earthquake ground motions.

We computed eHVSR and mHVSR for 30 sites in the Willamette Valley region, predominately located near the basin edges, with approximately 235 earthquakes > M3 and 60-minute microtremor recordings. We performed comparison of eHVSR to mHVSR methods for the same site locations, which indicated both methods could be used reliably, though mHVSR may require more subjective observations to identify peaks, as amplitude is often diminished compared to eHVSR. Lower frequency peaks < 3Hz were observed nearest basin and sub-basin edges, while frequencies approaching 10Hz were observed nearest the center of the basin. Additionally, at some locations, most notably in the western side of the basin, more than one peak frequency was occasionally observed, suggesting multiple layers of stratification, where each peak represents an individual strong velocity contrast. In the case of additional peaks at higher frequencies, basin resonance effects are suspected to be the source. Next steps include inferring subsurface structure with limited existing seismic velocity data and other available geophysical and geologic datasets. These results can be incorporated into future velocity models, as well as inform site characterization studies.

Site-specific Hazard Analysis of a Liquefied Natural Gas Tank Located in South-central Virginia
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A site-specific seismic hazard evaluation was performed for a liquefied natural gas (LNG) site in south-central Virginia. The site is located in the Appalachian Highlands, near the Coastal Plain, in a region characterized by low to moderate historical seismicity. However, the site was impacted by the 1886 moment magnitude (M) 7.1 Charleston, South Carolina, and the 2011 M 5.8 Mineral, Virginia, earthquakes. A probabilistic seismic hazard analysis (PSHA) for hard rock was performed using an updated Central and Eastern U.S. (CEUS) Seismic Source Characterization (SSC) model (EPRI/DOE/NRC, 2012) and the NGA-East ground motion models adjusted for an observed bias in the models (Ramos-Sepulveda et al., 2024). Revisions were made to the CEUS SSC model using post-2012 data and information, with particular attention to the Charleston seismic zone. The major contributor to the hazard over short periods was the Extended Continental Crust–Atlantic Margin seismotectonic zone, in which the site is located. Over long periods (>1 sec), the Charleston seismic zone governs the hazard. The hard rock hazard was adjusted to the ground surface using a fully probabilistic site-response analysis. Amplification factors (AFs) were derived from equivalent-linear site-response analyses using random vibration theory. The surface ground motions were computed by convolving the hard-rock hazard with the probabilistic distribution of amplification functions. MASW surveys were conducted to develop shallow shear-wave velocity (Vs) profiles for use in site response analysis. The epistemic uncertainty between the base case and the profile was accounted for by calculating and inputting lower- and upper-range base-case profiles. Aleatory variability was addressed by using 30 randomized profiles for each of the three base-case vs. profiles.

Seismic analysis of LNG tanks is particularly challenging because it requires consideration of a broad frequency range, including fundamental structural frequencies of approximately 2–10 Hz and low-frequency sloshing modes near 0.1 Hz.

A Systematic Analysis of Directional Site Amplification Effects at Stations of the Seismic Network (Nz), to Test the Relation With Local Geological and Morphological Proxies
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We conducted a systematic study of site amplification at 279 New Zealand seismic stations, including 203 permanent broadband stations of the GeoNet network and 76 temporary weak motion stations from regional networks. The amplification characteristics at each station are retrieved through calculating the horizontal-to-vertical spectral ratios (HVSR) based on ambient vibrations. We find that a high portion of the stations sampled (66%) are affected by significant amplification, with HVSR amplitudes exceeding a factor of 2. This is a crucial issue considering that these stations are employed for seismic surveillance and magnitude estimation of regional seismicity.

We define the amplification characteristics at each station by using a quantitative criterion finding that almost half of the amplified stations (43%) are affected by amplification in a broad frequency band or, rather with a multi-peak pattern, increasing complexity in further interpretations.

We have tried to establish a relation between the amplification pattern and geological and morphometric proxies, without retrieving satisfactory correlations.

Therefore, this study highlights: (i) the unexpected wide occurrence of site amplification effects at locations chosen for permanent seismic network; (ii) the importance of considering the local geological pattern as well as site-specific characteristics to interpret the site response.

Ground Velocity and Ground Tilt From Seismometers: Two for the Price of One
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At many sites the measurement of tilt is of equal interest to that of seismic signals. Modern, feedback-controlled, three-component, broadband seismometers of classic, orthogonal topography can serve both these needs, delivering timeseries of both types. The typical seismometer output is velocity-proportional seismic data for the three sensors, the vertical, and two perpendicular horizontals. Less well known is that the mass position output for the horizontal sensors is proportional to tilt. These data describe the actual position of the inertial mass within the transducer used to provide the feedback. They are typically digitized with low sensitivity and low sampling rates and used to monitor the general health of the sensor, i.e. the symmetry of its dynamic range. The often observed long term drift in these values may be due to temperature fluctuations and other environmental influences, and when the drift has become too large, recentering the sensors may be necessary.

The changes of the mass positions of the two horizontal components of a feedback seismometer, recorded with high dynamic range and at suitable sampling rates, may also directly reflect tilting of the surface on which the seismometer is deployed. We first lay out the theoretical foundation describing the relationship between the mass positions of the horizontal sensors and tilt. We next demonstrate their calibration using a tilt table. Finally, we compare measurements of ground tilt in real world applications from other instruments with those from the mass positions. Please note that such tilt measurements can only be derived from feedback systems designed in the classic orthogonal topology and are not possible for Galperin type seismic sensors. Hence, a modern broadband seismometer with well-designed feedback is a measuring device for ground tilt as well as elastic waves.

Engineering Site Response Validation of Method Using Random Vibration Theory
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Earthquake records collected at dense arrays of strong-motion stations are often utilized in microzonation studies to evaluate the changes in site response due to variability in site conditions across a region. These studies typically begin with calculating Fourier spectral amplifications and then transition to performing engineering site response analyses. It has proven difficult to utilize

Fourier spectral amplifications to define the appropriate elastic response spectra for a site or sites. A past study utilized a database of 95 events to calculate Fourier spectral amplifications at 35 strong-motion stations in Anchorage, Alaska using the generalized inversion technique (GIT). Estimated response spectra have been evaluated at each site by applying those Fourier spectral amplifications to a response spectrum of a reference station through random vibration theory (RVT). Correction factors are also applied within the approach to account for nonlinear site effects. The method provided a coherent and straightforward way to use GIT-derived Fourier spectral amplifications to directly estimate site-specific response spectra, accounting for nonlinear site effects and without requiring engineering characterization of subsurface soil conditions. The authors have evaluated the use of this method to estimate site response from another dense array of strong-motion stations in Italy, where moderate to large earthquake ground motions have been recorded for several years. The results from this study indicate that the method of using GIT-derived Fourier spectral amplifications provides an effective method of estimating site response across a network of stations provided that rock site motions are utilized to develop spectral amplifications. One of the major benefits of this method is that the site response is directly measured utilizing moderate earthquakes to predict site amplifications for future large earthquakes and allows the opportunity to avoid the standard challenges and limitations of one-dimensional site response analysis.

Site-response Characterization in Tbilisi Using Integrated Geophysical Data
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This study presents a multi-scale site-response investigation for the city of Tbilisi, combining ambient noise measurements, surface wave methods, and geotechnical information. A city-wide HVSR survey was carried out across spatially distributed locations throughout the urban area. The resulting H/V curves show pronounced spatial variability in resonance frequencies, reflecting heterogeneous near-surface conditions. Site characterization was further supported by several active-source methods, including seismic refraction and MASW, as well as joint acquisition of MASW and ambient-noise measurements at selected sites to constrain near-surface velocity profiles. Active-source MASW surveys were conducted using Tromino instruments operated in triggered mode, a configuration particularly suitable for dense urban environments with limited space and high noise levels. At the same locations, passive MASW surveys using L-shaped array geometries were applied to enhance sensitivity to lateral heterogeneity. These acquisition strategies represent the first systematic application of triggered Tromino MASW and passive L-shaped MASW arrays in Georgia. The derived 1D shear-wave velocity profiles and Vs30 estimates provide key constraints on site conditions. Limited borehole information, a 1:25,000-scale engineering–geological map, and high-resolution topographic data were used as supporting constraints for subsurface interpretation and for examining relationships between Vs30 and topography. For representative sites, 1D site-response analyses using STRATA were performed to explore general amplification tendencies. Although the dataset highlights areas where lateral stiffness contrasts, basin edges, or topographic effects may influence ground motion, the current acquisition geometry does not allow construction of robust 2D or 3D velocity models. The integrated dataset documents significant lateral variability in Tbilisi’s site conditions and provides a solid basis for future microzonation, hazard, and risk assessments.

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Behind the Curtain: Developing Methods and Toolkits Supporting Practical Assessment of Discharge and Bedload of the Nisqually River Within Mount Rainier National Park
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Impacts from a changing climate continue to drive changes in the hydrology, geomorphology, and inherent variability of the world’s rivers. Upland watersheds with strongly coupled fluvial/hillslope dynamics are especially vulnerable to these effects, leaving mountainous watersheds in a precarious position. Classic methods for hydrologic monitoring are almost exclusively developed for rivers with slopes of <0.001 m/m, leaving steep mountain rivers com-

paratively unstudied, and slow to advance by comparison. This work seeks to continue efforts from the Mount Rainier National Park (MORA) Imminent Threats Program to address research gaps pertaining to the continuous measurement of discharge and sediment transport in mountain rivers with a slope ≥0.02 m/m, furthering our understanding of impacts to morphodynamic processes advancing into downstream communities.

Containing widely distributed low-resilience infrastructure, significant increases to precipitation intensities, and glacial recession rates greater than 0.1 m/day, the Nisqually River of MORA exemplifies the nexus of modern land management issues driven by climate stressors of the Pacific Northwest. With this study, we seek to further characterize observable surface processes in the Nisqually watershed within MORA and consider new frameworks enabling reliable monitoring of steep mountain rivers.

Here, we continue the efforts to refine the use of seismic analysis focused on pristine mountain rivers by creating tools to package analyses, and testing combinations of field practices for calibrating model frameworks. We combine visualization and data selection tools to aid large data management of our repository (>10TB), targeting analysis for time periods of interest. We also attempt to use experimental schema of active-source calibration testing for stations within a remote monitoring network to determine Green’s function parameters, moving from relative monitoring toward quantifying discharge and bedload. If successful, MORA will finally begin collecting a record of river discharge after 127 years of management.

An Additive Approach for Developing Hybrid VS30 Models: Incorporating Geological Information Into a Geospatial Model for an Updated VS30 Map of Chinese Mainland
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Mapping seismic site conditions provides a systematic approach to characterize site effects in earthquake ground-motions. VS30, a widely adopted metric, enables quantitative assessment of regional variations in site conditions, particularly for large-scale applications. Proxy variables such as topographic slope, terrain classes, and geological attributes are widely used to estimate VS30. However, conventional workflows often require rebuilding an existing model when introducing additional variables, which can be time-consuming and complex.

In this study, we propose an additive approach based on Bayesian updating to incorporate geological information into an existing geospatial VS30 model by updating prior estimates rather than reconstructing the model from scratch. This framework enables flexible integration of new variables to develop a hybrid VS30 model that preserves the strengths of the original model while explicitly reflecting the contribution of the newly introduced information. We apply the approach to update a VS30 map for Chinese mainland previously produced using a cokriging-based VS30 model (SCK), in which topographic slope serves as a secondary parameter and 7,939 V_{s30} measurements provide constraints. The geology-enhanced SCK model is referred to as the GeoSCK. Surface geological age and sedimentary environment, extracted from a 1:1,500,000 geology map, are used as geological variables.

To accurately establish the geology- V_{s30} relationship for Chinese mainland, we address the issue of preferential sampling bias, which often results from over-sampling in flat terrains and under-sampling in steep terrains. This adjustment yields more reliable representative V_{s30} values for different geological classes and reveals patterns that were previously obscured. Compared to the original map, the updated map exhibits reduced estimation uncertainty through the incorporation of geological information. Comparative validation using local V_{s30} measurements confirms that the new map outperforms existing national and regional V_{s30} and site classification maps in terms of predictive accuracy.

Advancing Earthquake Early Warning: Science, Technology and Engagement in the U.S. and Beyond
Oral Session • Thursday 16 April • 8:00 AM Local
Conveners: Stephen Crane, Natural Resources Canada (stephen.crane@nrcan-rncan.gc.ca); Zoe Krauss, University of Washington (zkrauss@uw.edu); Derek Lambeth, California Office of Emergency Service (derek.lambeth@caloes.ca.gov);

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ShakeAlert Earthquake Early Warning Testing Developments Review

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The West Coast ShakeAlert Earthquake Early warning system has been sending public alerts since October 17, 2019, and has been successfully generating real-time earthquake messages. In order to assess continuing algorithm development and proposed improvements, ShakeAlert has a System Testing and Performance (STP) platform. The overarching principle is that proposed changes should improve either the warning time and/or accuracy location and magnitude estimates while minimizing additional complexity to the system and alerting. Performance analysis must balance these competing goals. To properly assess the value of proposed software changes, STP replays a suite of waveforms (recordings of moderate to large earthquakes plus a few synthetic earthquakes) through 4-8 instances of the algorithm stack and assesses with metrics from Cochran et al. (2017). These metrics are focused on point source parameters such as magnitude, location, and origin time. In addition, proposed software is run on a set of test machines that are configured like the production system to process real-time data for a minimum period of 2-4 weeks.

Since the Cochran et al. (2017) paper there have also been a number of improvements to the testing system itself. This includes significant modernization and updates to the Python code base, development of new figures and metrics in terms of ground motion estimates, and migration of the testing platform including the use of the ansible automation tool and updating of essential analysis scripts.

The ShakeAlert tests that have been performed during this time period also showcase the significant improvements that have been made to the system since mid 2019. This includes: 1) updates to FinDer (line source algorithm), Solution Aggregator and EqInfo2GM (algorithm to convert point/line source parameters to ground motion) post-Ridgecrest, 2) contour alerting, 3) alert pause introduction, 4) addition of a geodetic algorithm, and 5) inclusion of a new Bayesian EPIC (point source algorithm) to improve edge of network performance.

Station Expected Contribution Metric for the ShakeAlert EEW System

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We present a new metric for estimated station expected contribution (SEC) for individual seismic stations in an early warning network. The SEC metric has been developed to inform decisions such as station operation and maintenance and applies principally to established networks. SEC combines the likelihood of a station contributing to earthquake detection, the detection time improvement because the station is “on duty”, and the number of people near enough to benefit from the EEW detection. We extract an annualized rate of station utilization from USGS fault hazard curves. Stations near active faults will contribute, on average, more often than stations in a low hazard area. A model magnitude distribution is used to relate ground motion of the hazard curve to conditional ground shaking. The marginal number of people at each magnitude who could benefit from EEW depends on the population within a given shaking intensity (MMI) radius. The station alert-time metric comes from network geometry - the time lost due to more distant stations being needed to complete the 4-station detection quorum. The combined SEC metric is the product of alert-time metric and annualized population exposure, in people-seconds/year. Physically, an SEC of 1000 provides the annualized equivalent of 1000 people being given one extra second of time for protective action.

We apply the SEC metric to stations of the Southern California Seismic Network (SCSN) contributing to the USGS ShakeAlert® EEW system. We find that the annualized number of people exposed at a shaking level of MMI 4.5+varies among stations by four orders of magnitude, from 6 to ~60,000.

Alert-time advantage varies from 0.2 s or less for stations in dense urban coverage to ~2.4 s in the remote desert. SEC, which combines exposure and alert-time advantage, and varies by over 2 orders of magnitude in annualized benefit, from under 100 to 10,000 people-seconds/yr. Highest scoring stations are concentrated near urban areas where the station covers a relatively larger open area in the network.

Exploring the Use of Existing Offshore Cabled Infrastructure for Earthquake Early Warning in the Pacific Northwest

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A Cascadia subduction zone M8-9 megathrust earthquake will generate extensive offshore fault rupture that will widely impact the Pacific Northwest of North America. However, the existing ShakeAlert earthquake early warning system uses no seafloor sensors, hindering rapid and accurate warnings for such an event. We explore the incorporation of existing offshore cabled infrastructure into the ShakeAlert system. There are two scientific submarine cable networks in Cascadia: the Ocean Observatories Initiative (OOI) Regional Cabled Network offshore Oregon, which currently supports two existing ocean bottom seismometers (OBSs), with four additional OBS deployments planned in the near future, and the Ocean Networks Canada NEPTUNE cable offshore Vancouver Island, which supports five existing OBSs. These submarine cables themselves, alongside other private telecommunication cables, could be converted into dense seismic arrays via distributed acoustic sensing (DAS). Using existing data, we show that the cabled OBSs pass ShakeAlert requirements and are comparable to land stations in terms of data quality and triggering performance. We show that pilot DAS experiments also exhibit consistent noise characteristics across various candidate cables offshore Cascadia with sufficient sensitivity for early warning. Forward modeling suggests that incorporation of existing OBSs could improve the detection time of nearby hypocenters by 5-9 s. Further, if DAS were deployed on the first segments of the OOI cables, detection times of nearby hypocenters could improve by up to ~10 s. If DAS were deployed on the full extent of all 18 known offshore cables, nearly 50% of all theoretical offshore hypocenters could be detected more rapidly, by up to ~18s in some locations. Full ShakeAlert replays using new 3-D ground motion simulations of M8.7-9.2 Cascadia megathrust events show that offshore sensors could also improve ShakeAlert magnitude and location estimates. Assuming the distribution of existing OBSs, this could translate to ~40 s of additional warning time beyond improved detection time for nearby offshore hypocenters.

Improving the Reliability of High-rate Global Positioning System Data for Earthquake Early Warning Using Long Short-term Memory-based Anomaly Detection

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The ShakeAlert® earthquake early warning (EEW) system integrates seismic and geodetic observations to characterize large earthquakes (> M7) without magnitude saturation. More than 1000 Global Positioning System (GPS) stations in the ShakeAlert network process real-time, high-rate (1 Hz) position data to provide direct measurements of peak ground displacements during an earthquake. A significant challenge in using these data for EEW is separating true ground motion from noise. GPS position time series exhibit colored noise (drift) and transient artifacts arising from cycle slips, atmospheric delays, multipath effects, and receiver instabilities. This noise can obscure coseismic signals, complicating data quality control and reducing confidence in geodetic magnitude estimates.

We investigate the use of Long Short-Term Memory (LSTM) models for anomaly detection in high-rate GPS position time series. Trained on quiescent windows of historical data from GPS stations in the ShakeAlert region (i.e., time periods devoid of earthquakes with displacements detectable by real-time GPS), the model learns the expected short-term structure/behavior of 3-D position components, allowing residuals between observed and predicted

positions to serve as an adaptive anomaly metric. The model predicts the position at a given epoch using the previous N samples (e.g., N ≈ 120) for a single GPS station, with prediction residuals (minimized during training) used as anomaly scores that can support downstream quality control and diagnostic workflows. By capturing temporal dependencies and non-stationary noise characteristics across a wide range of stations during training, this approach enables the robust identification of spurious jumps/spikes and transient artifacts in GPS position time series without suppressing sensitivity to coseismic signals. We discuss strategies for training a network-wide model, defining anomaly thresholds, and ensuring long-term generalization. This will highlight the potential of LSTM-based anomaly detection to improve the reliability of geodetic inputs in EEW systems.

Mitigating the Effect of Spurious Displacements on Magnitudes Estimated From Peak Ground Displacement Measured With Real-time Global Positioning System Data

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ShakeAlert® includes an algorithm, GFAST-PGD, that estimates magnitude from real-time, 1 Hz Global Positioning System (GPS) data. When triggered by ShakeAlert’s seismic algorithms, GFAST-PGD uses the current origin time (OT) and hypocenter estimates to select GPS stations and computes each station’s displacement relative to its position at the OT. It repeats this over a 120 sec window as new position, OT, and location estimates arrive. At any point in this window, a station’s peak ground displacement (PGD) is the maximum displacement since OT. GFAST-PGD estimates magnitude (M_{PGD}) from PGD (in cm) via a scaling relationship (Crowell et al., 2016):

$$\log_{10}(PGD) = A + BM_{PGD} + CM_{PGD}\log_{10}(R_{hyp})$$

where R_{hyp} is the station’s hypocentral distance; and A (-6.687), B (1.5), and C (-0.214) are regression constants.

ShakeAlert applies two empirically derived criteria to mitigate the effect of characteristic colored noise in GPS time series that leads to position drift and, in turn, overestimated M_{PGD} . One criterion requires M_{PGD} uncertainty ≤ 0.5 ; the other requires ≥ 3 stations with PGD exceeding predefined thresholds. These criteria may not eliminate overestimated M_{PGD} when anomalously large displacements arise simultaneously at multiple stations due to unpredictable problems with real-time positioning. However, the scaling relationship indicates that in an earthquake the slope and intercept of a line fit to $\log_{10}(PGD)$ vs. $\log_{10}(R_{hyp})$ depend on magnitude and fall within a defined range of values. If stations at a variety of R_{hyp} simultaneously report similar PGDs in error, the slope would be close to zero. Slope and intercept values outside the expected earthquake range or a slope that is not significantly different from zero could indicate unreliable M_{PGD} . We test this hypothesis using PGD computed in real-time when GFAST-PGD was triggered by ShakeAlert (760 events, June - November, 2025). Compared to the PGD threshold criterion, the new approach eliminates more M_{PGD} estimates due to noise, and in retrospective analysis of the 2019 M7.1 Ridgecrest event it would eliminate fewer reliable M_{PGD} estimates unnecessarily.

The M5.9 Dayton, NV ShakeAlert False Alert: Lessons Learned

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On December 4, 2025, at 16:07:09.9 UTC (08:07:09.9 local time) an alert was published by the ShakeAlert system for a M5.9 earthquake near Dayton, NV. The alert was quickly determined to be erroneous, as waveforms from seismic stations in that area clearly showed no seismicity near that region at that time. The alert was created by the EPIC earthquake warning algorithm, one of three algorithms that comprise the ShakeAlert system.

EPIC requires triggers from at least four stations to create an alert. Triggers from two stations were determined to be spurious triggers - one was a large step function, and one was very low amplitude noise. Waveforms from the three other triggers that were associated with this event showed no activity that should have triggered EPIC’s STA/LTA algorithm. Analysis of all components of the ShakeAlert system determined that the cause of the triggers and corresponding false alert was frequent gaps in the data coming from a group of stations near the false alert’s estimated epicenter.

Here we present a detailed analysis of the cause of the M5.9 false alert, lessons learned, and modifications to both the EPIC code and the ShakeAlert system that have been made to prevent future false alerts.

Operating EEW in Eastern Canada Part I: Reducing False Alerts in Testing

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During testing of the National Earthquake Early Warning System for eastern Canada a high number of moderate-magnitude false alerts was observed, raising the concern that a false alert large enough to exceed distribution thresholds might occur once the system was operational. Several factors contributed to the generation of these false alerts: 26 of the 190 eastern EEW stations were excessively noisy, with very frequent triggers attributed to anthropogenic sources within or close to the station sites. This high frequency of triggers coupled with the proximity of stations to each other, led to false events, in some cases exceeding Mw 4. During the early stages of testing, stations had been validated based on the Probabilistic Power Spectral Density (PPSD) falling within acceptable limits. It was found, however, that PPSD statistics did not correlate well with actual triggering rates. To mitigate this issue, over-triggering stations are being relocated to be further from cultural noise sources. In addition, the required number of triggered stations to produce an alert is increased from four to six. This change significantly reduced the likelihood of temporally-correlated spurious triggers forming a false alert, at the expense of a small increase in alert times. As more, better quality, stations are deployed, we will revisit the number of triggered stations required.

A further concern arose following a teleseismic earthquake off the California coast (the December 5th, 2024, M7 offshore Cape Mendocino), which was falsely registered by the eastern EEW system as a regional earthquake. It was determined that the teleseismic filter was not working as expected, allowing an alert to be sent when none of the triggers are considered by this filter. A change to the filter’s logic was applied, ensuring at least one trigger contributes to this filter before an alert is sent. Our experience highlights the need for a more conservative approach (possibly resulting in a temporary reduction in alert timeliness) in regions of relatively low seismicity and attenuation compared to areas where earthquakes are more frequent.

Expansion of the Metro Vancouver Network-based EEWs: Challenges and Opportunities

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The Greater Vancouver Water District operates a network-based EEW system which was designed, built, and commissioned in 2021-2022. Currently, the system is being expanded to include additional stations, improve operational reliability, new dashboards, and alert message distribution system.

The main algorithmic challenge of the system is to reduce the uncertainty in the estimates of the magnitude and epicenter location, as well as uncertainties in the predicted peak parameters of the strong ground motion. The magnitude estimation is based on the assumption of determinism in the earthquake rupture and relies mostly on the dominant frequency of the truncated P wave. The accuracy of the epicenter location is strongly affected by the limited geographical spread of the sensor network, when almost all seismic events occur outside the network. Therefore, we employ multiple methods to locate and characterize the events. These methods are being tested against small-magnitude regional events recorded by the network, as well as KiK-net strong motion seismograph network in Japan. In addition to the sensor network configuration constraints, the accuracy of the derived solutions is affected by the heterogeneous conditions of the medium and considerable variability in the local site conditions in the Metro Vancouver region.

We analyze the EEW system performance using the records of M4.0 event which occurred on 09/26/ 2024, with the epicentral distance to the closest station 79km. Availability of the data from the instrumented structure next to one of the EEW sensors demonstrated SSI effects and allowed us to conduct baseline measurements of the structural health parameters. Structural health

monitoring (SHM) is the second component of the network-based EEW system. We employ ambient vibration techniques and rely on the SVD analysis of the Hankel matrix constructed from the records to solve the system identification problem. The expansion of the SHM component of the network is currently underway. It includes scaling up the number of instrumented facilities, creation of dashboards, and upgrade of the back-end engine.

Testing Earthquake Early Warning for New Zealand: Performance and Adaptation of the Finite Fault Rupture Detector (Finder) Algorithm

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New Zealand (NZ) has significant earthquake shaking and tsunami hazard from the subduction zones and crustal fault systems that form a complex boundary zone between the Pacific and Australian plates. Recent and historic sequences (e.g. 2010-2011 M7.1 and M6.2 Canterbury, 2016 M7.8 Kaikōura) caused significant societal and economic impact. Despite the high seismic hazard NZ currently has no national earthquake early warning (EEW) system, though Google’s Android Earthquake Alerts are issued in the country. NZ’s tectonic setting and monitoring network present challenges for any EEW system, including: strong path and site effects; the occurrence of deep slab earthquakes; multi-fault ruptures; significant offshore seismicity; high network noise; low and heterogeneous station spacing; and short instrumental period.

The FinDer algorithm is designed to rapidly characterise earthquake rupture using template matching for the observed spatial pattern of high frequency, high amplitude ground motions, and is implemented globally in several EEW systems. FinDer has been operational in NZ since 2023 for rapid characterisation of rupture and ground shaking. Real-time and historic playback systems have allowed us to monitor and test source characterisation performance, and also potential EEW behaviour, for hundreds of real and synthetic earthquakes in the magnitude range 2.9 – 8+. For onshore crustal sources FinDer demonstrates reliable source characterisation, and with the current GeoNet monitoring network would have the ability to provide actionable EEW alerts for M7+ earthquakes. Here we present testing, performance and adaptation of FinDer in NZ towards its potential use in a national EEW system.

Towards Public Earthquake Early Warning in Switzerland, Greece, Romania and Croatia

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EEW is in operation in many places around the globe, but no country in Europe currently offers a public alert system despite significant seismic risk. Recently, the Swiss Seismological Service (SED) at ETH Zurich, in collaboration with local agencies, has rolled out public EEW systems across Central America using their internally developed algorithms and mobile phone application. The ETH-SED SeisComP EEW (ESE) system consists of two algorithms - the point source Virtual Seismologist (VS) and the Finite fault rupture detector (Finder). The mobile phone application relies on Firecloud messaging and Apple Push Notifications and is available for Android and iOS users. It has proven reliable to send low-latency alerts to several hundred of thousand users.

We are currently installing and testing the ESE system in Europe in countries where the earthquake hazard ranges from moderate (Switzerland-

SED) to high (Greece-NOA, Romania-NIEP, Croatia-UniZG). Here, we present the developments undertaken over the last year in those countries and report on the algorithm performance and alert distribution for recent events. We discuss the remaining challenges and communication strategies towards public release.

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Beyond Earthquakes: The Role of Emergency Management in Seismic Events

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This presentation will review the important role of emergency management before, during, and after a seismic event. A key focus will be on how the California Governor’s Office of Emergency Services (Cal OES) coordinates closely with the State Operations Center and the California Integrated Seismic Network, including partners such as the California Geological Survey (CGS), United States Geological Survey (USGS), the California Institute of Technology (Caltech), and the University of California, Berkeley Seismology Lab (BSL).

The role of emergency managers is to prepare for, respond to, and recover from disasters in ways that support the protection and resilience of communities. Having the best information is key to those efforts. This presentation will explore how the integration of earthquake science with emergency management provides real-time data for decision making and socially relevant and expedient messaging for the public.

Additionally, discussion of the California Earthquake Early Warning System (CEEWS), powered by ShakeAlert, will show it to be a public safety tool aimed at providing life-saving seconds of notification before shaking occurs, enabling protective actions such as Drop, Cover, and Hold On. Real-world case studies will show how CEEWS has successfully notified millions of devices/people in recent years.

The MyShake app, developed by BSL with funding from Cal OES, serves as a primary earthquake early warning delivery method for the West Coast and has more than 4.3 million downloads in California, Oregon, and Washington. This presentation will also examine the expansion of the app over the last year, including its recent availability on Chromebooks and PCs, and the potential for system integration into all sectors and critical infrastructure throughout California.

Advancements in technology and public education are both crucial to California’s earthquake preparedness. California’s emergency managers and their science partners are leveraging both to mitigate seismic risk, thus reducing the impact of seismic events to save lives and property.

How to Learn an Industry in 10 Days! Utilizing Qualitative Methods to Build Industry-specific Expertise Within the ShakeAlert Earthquake Early Warning Technical Engagement Team

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Since 2016, ShakeAlert Earthquake Early Warning (EEW) has been promoted to organizations, businesses, and institutions that could make use of seconds of warning prior to potentially strong earthquake shaking. The ShakeAlert Technical Engagement team is tasked with communication, education, and outreach activities that raise awareness, adoption, and impact of EEW. Prioritization of EEW implementation has been centered around industries and sectors that are the most vital for safety and resilience: schools, emergency response operations, healthcare facilities, and utilities are just a few. The Technical Engagement team has embarked upon a series of research projects that utilize qualitative research methods to reveal key information about critical industries. As a result, in-depth knowledge about each industry is collected and contained as a resource for anyone in the ShakeAlert Technical Engagement community.

In this presentation, we will review the Critical Sector Implementation Project (CSIP), designed as a collaborative research project to give the Technical Engagement team expertise in the industries where ShakeAlert can be most effective. We will discuss the conceptualization of the project, its goals and activities, and the research methods employed for each indus-

try. Attendees of this session will have a stronger understanding of how CSIP utilizes established methodologies and academic rigor in its understanding of critical industries and pursuit of EEW implementations. They will also learn key findings about industries such as live entertainment venues, industrialized communications, and water / wastewater facilities, and how this knowledge will inform the practice of ShakeAlert technical engagement going forward. Finally, the presentation will demonstrate how this in-depth research project elevates the knowledge base of the Technical Engagement team.

Caution! Dangerous Intersections Ahead: Understanding Human Behavior, Traffic Patterns, Protective Actions and Accidents

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While earthquake early warning systems are technologically advanced, there is a gap in empirical evidence regarding how vehicle operators physically react to sudden shaking and to Earthquake Early Warning (EEW) alerts prior to the onset of shaking. The U.S. Geological Survey ShakeAlert Project, in partnership with the U.S. Department of Transportation Volpe Center and the University of Oregon, developed a collaboration to answer critical questions about individual human driving behavior in relation to protective actions. The project included an analysis of traffic conducted in a shaking environment where EEW alerts were distributed to drivers. Understanding driver reactions to EEW alerts and earthquake shaking is critical for reducing secondary accidents during and immediately following an earthquake. The project used a collection of videos collected from publicly available social media platforms depicting earthquake-related human behavior. Several hundred real-world videos were captured during an active earthquake, with the majority being from the April 3, 2024, M7.4 Hualien, Taiwan, earthquake. A subset of these video recordings provides rare, firsthand visual evidence of operator behaviors during earthquakes and EEW alerts.

The research team then analyzed and classified driver behavior during seismic events by using an object-detection algorithm to efficiently review hours of footage and identify “transportation-related activities,” focusing specifically on vehicle cabins, road-facing views, and operator interactions. Another round of manual review was conducted to categorize specific reactions:

- o Response to physical shaking.
- o Response to audible/text alerts via mobile devices (EEW).
- o Latency between alert/shaking and defensive driving maneuvers (braking, pulling over, etc.).

Findings from this study aim to determine whether in-vehicle cellphone alerts trigger immediate safety actions or cause temporary distraction, as well as develop recommendations for the timing and “voice” of audible alerts to optimize driver compliance and safety in relation to earthquake events.

Deaf, Deafblind and Hard of Hearing University Student Experiences With Earthquake Early Warning in the United States: Evaluating Language Planning and Technology Access

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Growing literature on deaf and hard of hearing (DHH+) populations and disasters demonstrates that emergency communication (including alerts) is not reaching global DHH+ communities with dangerous impacts for morbidity and mortality. This is the first research study in the U.S. to explore the experiences of DHH+ persons with earthquake early warning (EEW) through qualitative analysis of group-based dialogue sessions. The study investigates eight DHH+ university students’ past earthquake experiences, access to EEW alerts, and perceptions of ShakeAlert*, an EEW system for detecting

earthquakes and alerting residents of California, Oregon, and Washington. Findings highlight key gaps in accessibility of disaster alerts within four thematic areas: lack of messaging in participants’ language(s), unclear alert messaging, inaccessible message delivery for deafblind persons, and insufficient access to earthquake information and training that leads to dependence on informal information networks. Weaknesses identified in these four themes reduces the trust of DHH+ in EEW systems and compromises the capacity of alert recipients either to take swift protective action or to mentally prepare before shaking starts. The study also underscores structural factors, such as insufficient linguistic representation in disaster language planning and technology design, which marginalizes DHH+ individuals by excluding their linguistic and sensory access needs. Building on disaster language planning frameworks, we recommend co-development of inclusive EEW alerts with DHH+ communities. By centering DHH+ perspectives and linguistic expertise, this research contributes to ongoing efforts to ensure that EEW systems reach all populations at increased risk due to information deprivation.

Implementing Public EEW in Guatemala: From Seismic Detection to Public Action

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Public Earthquake Early Warning (EEW) in Guatemala was launched via a mobile application in February 2024. Emerging seismic events are characterized using the SeisComP-based ESE system, using seismic data collected by the national seismic network and foreign partners. Alerts are delivered through critical push notifications using Firebase Cloud Messaging and Apple Push Notifications for Android and iPhone devices respectively. The deployment of this system marks an important step for risk reduction in a seismically active country with a highly vulnerable building stock. This study presents the Guate-EW initiative, which seeks to enhance the effectiveness of EEW by linking technological developments with institutional response tools and community-focused preparedness strategies.

In July 2025, a sequence of damaging earthquakes that were strongly felt in the capital Guatemala City were well characterised by the EEW system and the number of users increased temporarily to over 1 million, over 5% of the population. As the user base grew rapidly, our system struggled to provide low latency alerts to all users. In this presentation, we summarize the performance of the EEW system so far, focusing on alert dissemination and user experience during recent widely felt earthquakes in Guatemala. System performance metrics including detection and alert latencies, available warning times, and spatial dissemination are analyzed for selected events and linked to post-event survey data collected via social media, capturing alert reception, perceived shaking, and protective actions. Results confirmed variability in warning times and exposed wide diversity in behavioral responses, underscoring the importance of clear guidance and repeated exposure to alerts. Building on these findings, the EEW app is now being integrated into preparedness activities, including national earthquake drills led by civil protection authorities and the Red Cross. This integration represents a step toward connecting early warning with humanitarian response and public training, supporting the transition from EEW demonstration to effective operational use.

Advancing Earthquake Early Warning: Science, Technology and Engagement in the U.S. and Beyond [Poster]

Poster Session • Thursday 16 April

Conveners: Stephen Crane, Natural Resources Canada

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The Testsuite and the Baseline Performance for Canada’s National Earthquake Early Warning System
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The Canadian Earthquake Early Warning (EEW) System began operating in western Canada in May 2024 and in eastern Canada in November 2025. Previously Natural Resources Canada (NRCan) collected the data from earthquakes in both regions to test the software and provide a baseline for any future updates of the software. The variety of earthquakes in the testsuite was selected to ensure a thorough test of the EEW system. The earthquake selection process considered the historical significance of the earthquake and how many nearby recordings were available. The testsuite contains 15 magnitude 4.3 to 7.8 earthquakes in western Canada and 22 magnitude 3.0 to 5.0 earthquakes in eastern Canada.

Using a point-source assessment method, the mean value for the overall assessment scores of the initial earthquake solutions are 78.8% for western and 94.0% for eastern Canada. Both values increase slightly to 85.4 and 94.7%, respectively, for the mean overall assessment score of the final earthquake solution. Western Canada had 1 missed event, the 2012 M7.8 Haida Gwaii earthquake, which was poorly recorded for EEW purposes, but kept in the testsuite because of its historical significance. Similarly, eastern Canada also had one missed event, the 2005 M4.5 Rivière-du-Loup earthquake, which was well recorded by nearby stations but had a poor azimuthal coverage. The scores are better in eastern Canada due to all the earthquakes being well recorded with good azimuthal coverage, whereas several of the earthquakes in western Canada are offshore events with poor azimuthal coverage. Alert timeliness is determined based on the difference of the alert time from the model time, as replays lack a real-time latency component. Most earthquakes generated EEW solutions within 3 seconds of the expected alert time; anomalously slow alert times (two earthquakes in western Canada, one in eastern Canada) are generally due to one of the closest stations not triggering. Overall, the testsuite can be used to test EEW in Canada, and future improvements to the algorithms or configurations can be compared to this baseline performance.

POSTER 19
Operating EEW in Eastern Canada Part II: Seismological Parameters
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Earthquake Early Warning (EEW) systems rapidly analyze seismic data from nearby stations to determine an earthquake’s source parameters and the expected intensity of ground shaking. For an EEW system to be effective and reliable, the magnitude, epicentre location, and predicted shaking intensity must be accurate. Canada’s EEW system has been operational in western Canada since 2024 and was then adapted for the seismic characteristics of eastern Canada, where it became operational in November 2025. The substantial differences in source, path and site parameters between western and eastern North America required changes to some of the seismological parameters from those appropriate for the US West Coast EEW system software to render it suitable for operation in eastern Canada. A large dataset of strong and weak motion recordings for many moderate-to-large earthquakes in eastern North America were collected and processed to obtain a revised magnitude relationship based on time-domain measured peak displacement amplitude of the first four seconds of the P-wave and hypocentral distance. The Ground Motion Models and Ground Motion to Intensity Conversion Equations were also modified to reflect the low attenuation in eastern Canada. These adjustments have resulted in better initial point-source assessment scores for the earthquakes in the EEW testsuite.

POSTER 20
Outreach and Engagement to Ensure the Success of Canada’s Earthquake Early Warning System
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Natural Resources Canada (NRCan) operates a national Earthquake Early Warning (EEW) system, focussed on regions with moderate to high seismic hazard: western British Columbia, eastern Ontario, and southern Quebec. EEW mitigates earthquake impacts by allowing for timely response actions by the public, emergency measures organizations, Critical Infrastructure (CI) operators, and other industrial facilities. For the system to be effective, however, a culture of awareness is valuable in ensuring appropriate protective actions are taken when alerts are received. A coordinated public education campaign is helping to achieve this, with a pre-launch survey conducted to establish the baseline knowledge of people within EEW regions. Social science research by collaborators has also guided the education of vulnerable populations. The efficacy of such efforts was examined in the wake of two EEWs disseminated in British Columbia within a year of the EEW system’s initiation in the region.

NRCan has hosted workshops and other outreach activities with CI operators to ensure they have the opportunity to incorporate technologies that automatically translate EEW alerts into protective actions, such as halting trains, opening doors, closing valves, and issuing warnings. Over the past year, NRCan has been integrating Technical Partners (TPs) from the Transportation, Emergency Management, and Energy sectors. Simultaneously, NRCan is encouraging EEW technology providers in Canada to develop such automated systems. To ensure broad reach of these efforts, NRCan is collaborating with federal and provincial public safety organizations, private and international partners, and Non-Governmental Organizations, to ensure authoritative, consistent, accessible EEW messaging for the public, TPs and other technical users. By making it possible to take protective actions before the arrival of potentially harmful shaking, the national EEW system will contribute to the reduction of earthquake risk in Canada, as recommended within the United Nations Sendai Framework for Disaster Risk Reduction.

POSTER 21
Evaluating GFAST-PGD’s Contributions to ShakeAlert® System Performance for Simulated Cascadia Subduction Zone Earthquakes
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Since 2024, Global Navigation Satellite Systems (GNSS) data have been able to contribute to alerts issued by the ShakeAlert® earthquake early warning system through the GFAST-PGD algorithm, which uses the peak ground displacement (PGD) from GNSS stations and their hypocentral distances to invert for earthquake magnitude (M_{PGD}). GFAST-PGD improves the system’s ability to handle very large magnitude (>M8) earthquakes, such as Cascadia Subduction Zone (CSZ) events. However, the production ShakeAlert® system (with or without GFAST-PGD) has not yet been tested on real North American events of this size due to their rarity. Simulations of CSZ earthquakes offer an opportunity to evaluate how ShakeAlert® may perform in these scenarios, as synthetic waveforms can be run through the system as if they were real-time streaming data. We utilize 3D broadband ground motion simulations for 36 CSZ full-margin rupture scenarios (~M8.7-9.2) from Dunham et al. (2025), an expansion of the M9 Project (Frankel et al., 2018; Wirth et al., 2018), and focus our analysis on the performance and contributions of the GFAST-PGD algorithm, as well as how it interplays with the seismic algorithms (FinDer and EPIC). We identify scenarios for which GFAST-PGD has more accurate M_{PGD} estimates and those for which it performs poorly, and examine the causes of these variations. For example, GFAST-PGD incorporates epicentral distance weighting in the M_{PGD} inversion scheme, in which stations closer to the epicenter are weighted more strongly in the inversion. This can sometimes result in erroneously low M_{PGD} estimates for scenarios in which the amount

of slip on the megathrust is lower near the hypocenter than at farther distances, as GNSS stations at those distances would only weakly contribute to the M_{PGD} estimate. We explore potential options for improving GFAST-PGD performance in scenarios like this, such as removal of the epicentral distance weighting scheme. We also investigate how the differences in the performance of GFAST-PGD for the varying scenarios affect the accuracy of the alerts issued by the full ShakeAlert® system.

POSTER 22
Testing Cloud-based Resiliency Options for the U.S. ShakeAlert Earthquake Early Warning System
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The ShakeAlert Earthquake Early Warning (EEW) System for the West Coast of the United States has multiple layers of redundant processing to maintain consistent alert performance, including four processing centers with two processing servers at each center at the production level. Whereas the source-parameter estimation algorithms are running on all eight machines, station data is processed only on the servers associated with their region. This creates a vulnerability within ShakeAlert – for example, if something were to happen to the ShakeAlert processing servers at the Southern California Seismic Network (SCSN), the system would be unable to receive any data from Southern California stations. In recent years, SCSN has improved its internal resiliency and data robustness for its regular earthquake monitoring operations by utilizing cloud processing instances and establishing a redundant cloud-based station feed for the majority of SCSN stations that is streamed alongside the regular terrestrial station telemetry (called the dual feed). Here, we investigate if similar cloud-based options can improve the resiliency of ShakeAlert.

In 2024, we established two internal cloud instances of the ShakeAlert system with different station availability: one uses the station dual-feed setup, and the other uses the cloud-only station feed. We assess whether the cloud instances introduce significant processing delays compared to the terrestrial servers, as well as evaluate how station availability issues could impact the system, by comparing the ShakeAlert detections and source parameter estimates on these machines with those from the terrestrial production machines. We specifically highlight EEW performance for significant Southern California earthquakes during this period, including the 2024 M5.2 Lamont and 2025 M5.2 Julian earthquakes.

POSTER 23
Continued Testing of FinDer Templates for Earthquake Early Warning and Implementation of a Dash Application for Visualizing and Analyzing Performance
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FinDer is a finite-source characterization algorithm used by the U.S. Geological Survey ShakeAlert system to estimate rupture area, magnitude, and centroid location during an ongoing earthquake by matching interpolated images of observed peak ground acceleration (PGA) to precalculated PGA distribution templates. It is also under consideration by other seismic monitoring agencies worldwide. We evaluate FinDer’s performance using fault-specific templates and introduce code modifications that tailor the matching process for this approach. Because fault-specific template sets can contain up to tens of thousands of templates, FinDer limits its search to those within a specified magnitude range and distance range from the estimated event epicenter. Our modified code instead selects templates based on proximity to the evolving earthquake centroid, which can shift significantly during large ruptures, and refines the logic for selecting the initial PGA threshold for matching. Our test suite includes real waveforms from the December 5, 2024 M7 Cape Mendocino earthquake, the March 11, 2011 M9 Tohoku earthquake and other Japan events, and the February 6, 2023 M7.7 Pazarcik and M7.6 Elbistan earthquakes. It also incorporates synthetic seismograms from three M7.8 San Andreas Fault earthquake scenarios with different hypocenters and

thirty simulated M9 Cascadia Subduction Zone earthquake scenarios with varying hypocenters, down-dip rupture extents, slip distributions, and locations of high-stress drop subevents. Preliminary results indicate improved agreement between fault-specific templates and observed ground motions for the M9 scenarios. Finally, we present a dash application that uses parsed log files from individual ShakeAlert algorithms for visualizing and analyzing earthquake early warning performance.

POSTER 24
Earthquake Early Warning Instrumentation and System Considerations
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Earthquake early warning (EEW) systems depend on the prompt, reliable arrival of seismic data at network data centers. Network operators invest significant resources into the design, installation and operation of real-time acquisition systems to ensure maximum data completeness and minimum data latency, to allow EEW processing modules to detect events and issue warnings as quickly as possible. These mission critical acquisition systems must perform before, during and after earthquakes, as main shocks are frequently preceded by foreshocks and followed by aftershocks, which are often just as dangerous.

To optimize earthquake early warning systems, much can be learned from existing and industry proven EEW solutions and how they can be efficiently deployed with high quality ground motion seismic stations capable of delivering the highest fidelity and low latency data sets to the processing data centers’ detection algorithms. Specifically, public safety EEW systems require strict service level agreements (SLA) with regards to overall uptime, prompt arrival of high quality data, and issuance of accurate and timely warnings. This can only be achieved via the proper definition and selection of sensors, data-loggers, power systems, and communication systems. Also, when planning EEW Networks, it is important to consider the end-to-end workflow, from system definition and roll-out, through to network operation, maintenance and ongoing validation to ensure the system continues to satisfy its mandate.

Deployment of an EEW system can represent a significant challenge to monitoring agencies, but leveraging proven implementations and technology partners can greatly reduce the associated risk and implementation timeline. This presentation covers these key considerations and challenges for EEW systems, as well as fielded solutions that address them.

POSTER 26
Designing Seismic Arrays for Offshore Earthquake Early Warning Applications: Insights From Coastal Deployments in Alaska
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The last few years has seen an increased interest in utilizing seismic arrays in earthquake early warning (EEW) systems and general network monitoring of earthquakes. Compared to individual stations, arrays of seismometers are well-suited for accurately determining a slowness vector (backazimuth and trace velocity) from an incoming seismic wave. A further application of small-aperture seismic arrays is the ability to track earthquake ruptures as they evolve over time. This can be especially useful for very large earthquakes (>M7), where the magnitude estimation from the p-arrival alone saturates and further information about the rupture extent is needed for accurately estimating the magnitude.

This renewed interest in using seismic arrays for offshore EEW has led to multiple array deployments on Vancouver Island (NRCan) and the Olympic peninsula of Washington (UW). In addition, the USGS ShakeAlert Technical Implementation Plan for Alaska includes plans and budget for twelve small-aperture seismic arrays spaced along the Alaska coast. However, questions remain on how to design these arrays (number of stations, station spacing, array aperture) with the intention of high quality performance while minimizing operational costs. Here, we utilize two nodal seismic arrays that were deployed in Homer, AK and Kodiak, AK during the fall of 2025. Each of these arrays contained 26 three component Fairfield ZLand nodes spread over a 2 kilometer aperture. During the deployment, both arrays recorded >180 M2.5+ earthquakes within 500 km of the arrays. The dense spacing of seismometers

in each array allows us to create a multitude of smaller subarrays with a variety of geometries and number of elements. We use array processing methods for each subarray on the earthquake dataset to identify the optimal array geometry. This work will provide necessary insight to designing purpose-built seismic arrays for the unique challenges of coastal, subduction zone settings.

POSTER 27

Stress Testing ShakeAlert® Using the 2023 M7.7 Kahramanmaraş Earthquake Sequence, Türkiye
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The occurrence of multiple earthquakes in rapid succession increases uncertainty in event detection, location, and source characterization due to overlapping seismic signals, challenging Earthquake Early Warning (EEW) systems. We evaluate the ShakeAlert EEW system, which integrates EPIC, FinDer, and GFAST, using seismic and geodetic waveform playbacks from the first three days of the 2023 Kahramanmaraş earthquake sequence in Türkiye. Our analysis examines detections, source characterizations, ground-motion forecasts, and warning times for the Mw 7.7 Pazarcık and Mw 7.6 Elbistan mainshocks, and includes tests of candidate algorithms such as APPLES, bEPIC, and FinDer with fault-specific templates.

ShakeAlert performs largely as designed: EPIC provides the fastest detections, while FinDer and GFAST are most effective for large events. The system generates 114 detections with peak magnitudes exceeding 4.5, including 38 exceeding magnitude 5.0 that would trigger Wireless Emergency Alerts (WEA) in the United States. Median detection time is 8 s after origin, with median location and magnitude errors of 5.6 km and ± 0.4 units, respectively. The Pazarcık and Elbistan mainshocks are detected within 5–11 s, with peak magnitude estimates of M 7.7 and M 7.3. Using MMI III–IV ShakeAlert contour products, the majority of sites experiencing damaging shaking could have received 8–10 s of warning, neglecting alert distribution delays. The sequence also reveals key limitations: overlapping events during intense seismicity, degraded station coverage, and early GNSS station dropouts that bias magnitude estimates. These results highlight the need for improved event association, magnitude averaging, GNSS robustness, alerting strategies, and candidate algorithm integration. As a real-world stress test, the sequence demonstrates both the resilience and current operational constraints of ShakeAlert, underscoring opportunities for future system enhancements.

POSTER 28

Field Test of Deep Learning-based, Real-time, False-pick Filter for EEW: 1-second Time-window Approach
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The CNN-based ‘EEWNet Part 1 False-Pick Filter’ has demonstrated robust performance in distinguishing P-waves from noise and is scheduled for deployment in South Korea’s public Earthquake Early Warning (EEW) service in 2026. This study presents an optimized version of this model, designed to enhance the rapidity of onsite EEW systems. While the previous model utilized a time window from 2 seconds before to 2 seconds after the P-wave arrival, this research proposes a reduced window approach, limiting the input vector to 1 second after arrival (i.e., -2s to +1s). This modification advances the classification timing by one second and mitigates the risk of S-wave contamination in the input data. To validate this approach, a field test was conducted in Hualien, Taiwan, from August to September 2025. The improved model was implemented as an On-Device AI module embedded within a Smart Seismic Sensor, allowing for immediate analysis without data transmission latency. The field test results confirmed that classification was completed within an average of 1.2 seconds after P-wave arrival. During the testing period, the system successfully detected and verified 98.57% of P-waves for seven local events occurring within an epicentral distance of 15 km. These results suggest that the 1-second time-window approach significantly improves the speed and reliability of onsite EEW systems in active seismic zones.

POSTER 29

System Monitoring, Telemetry Quality Control and DAS Testing at SCSN
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The Caltech/USGS Southern California Seismic Network (SCSN) is an advanced digital seismic network that records ground motion throughout Southern California. The network designs, operates, and maintains robust data acquisition and delivery systems that support the rapid generation of earthquake information products, including event locations, magnitudes, ShakeMap, and Earthquake Early Warning through ShakeAlert.

A suite of tools has been developed to evaluate the system’s state of health using multiple performance metrics. This study presents results from measurements of data transport latency and telemetry bandwidth between field dataloggers and the data center, as well as analyses of seismic noise over time, across varying site conditions, and during selected seismic events.

In addition, a quantitative framework has been introduced to assess station locations within the ShakeAlert mission. This framework estimates each station’s expected contribution to earthquake detection and its benefit to nearby populations.

SCSN has also begun integrating Distributed Acoustic Sensing (DAS) technology into its operations. A DAS instrument is currently deployed in the Ridgecrest, California, area, converting a 100-km telecommunications fiber into a 10,000-channel seismic array analyzed using PhaseNet-DAS. Selected waveforms and phase picks from 18 DAS channels are incorporated into existing earthquake monitoring workflows, demonstrating the potential of DAS to enhance seismic monitoring capabilities.

To further evaluate this emerging technology, a laboratory-scale experiment was conducted to assess DAS response, the effects of cable properties, and fiber–ground coupling. A bi-axial shake table was used to impose controlled deformations on a fiber-optic cable, with displacement amplitudes as small as 20 microns. The results show that, when strained within their operational limits, fiber-optic cables produce responses comparable to those of conventional seismic sensors.

POSTER 30

Sparse Rupture Inversion Using Moment Tensor Interpolation – Synthetic Benchmark and Application to the 2025 Mw 7.6 Aomori Prefecture Earthquake, Japan
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Accurate characterization of large earthquake sources is crucial for understanding rupture processes and informing seismic hazard assessments and crisis response. While conventional finite-fault inversion approaches can represent a wide range of complex slip behavior in space and time, they often suffer from overparameterization and require strong regularization. Conversely, approaches that represent the slip distribution as a sum of singular point sources across space and time are inherently sparse, but struggle to accurately model near-field static displacements and are known to underestimate total moment release. Here, we bridge these methods using a sparse parameterization that represents rupture as a continuous moment-tensor field controlled by a small set of “key” tensors. This method reconstructs the slip distribution via source-type preserving interpolation, producing smooth, geometrically coherent variations in orientation along the fault plane.

We explore the feasibility of this hybrid representation for large earthquake source characterization, which is formulated as an optimization problem in which the model parameters are: (1) key-tensor locations along a predefined fault plane, (2) orientations, (3) scalar moments, (4) origin times, and (5) a spatial support function. Using precomputed Green’s functions in a 1D Earth structure, we evaluate long-period waveforms and near-field static displacements, enabling the combined use of seismic and geodetic observations. We validate the approach using synthetic benchmarks and apply it to the 2025 Mw 7.6 Aomori Prefecture, Japan earthquake, comparing data fit and predicted deformation with published finite-fault solutions while tracking how model complexity trades off against misfit. This first inversion effort

provides a baseline test of how much rupture complexity can be captured with a sparse, moment-tensor-based parameterization, and helps clarify the trade-offs between model complexity and data fit. The same framework is designed to extend to 3D Earth models and will enable joint evaluation of slip and geometry.

POSTER 31

Optimizing the Epic Algorithm’s Performance to Detect and Characterize Recent Moderate Sized Earthquakes in Alaska
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As one of three operational earthquake detection algorithms used in the ShakeAlert Earthquake Early Warning System, EPIC has detected thousands of earthquakes along the US West Coast since its inception. EPIC is routinely tested retrospectively using seismic data from historic earthquakes as well as tested in new tectonic environments, including Alaska. Previous tests documented EPIC’s performance detecting and characterizing earthquakes using as-is production values, calibrated to earthquakes expected on the US West Coast. This study goes one step further to identify and implement potential modifications to the EPIC algorithm to better reflect the challenges of implementing earthquake early warning in Alaska. We test modifications to the location algorithm by implementing bEPIC, a grid search weighted by prior seismicity that has been demonstrated to improve location accuracy in offshore regions with poor station coverage. We also test expansions to the allowed maximum distances used for station contributions, as well as modifications to the depth parameter to account for earthquakes with depths that exceed typical crustal fault depths.

POSTER 32

Calibrating Per-station Magnitude Corrections in Epic Using a Large Dataset of Past Detections
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Correctly estimating the magnitude of an earthquake in real-time for use in earthquake early warning requires computationally efficient algorithms using small amounts of high quality data. An overestimate in the magnitude of an earthquake could cause the geographical footprint for alerting to be too large, causing an overalert. If instead the magnitude is underestimated, then no alert may be issued, even if one is warranted. Because such little data is available in the seconds following rupture, magnitude estimates are susceptible to uncertainties in the epicenter location, assumptions about the data built into the scaling laws employed, and incomplete amounts of data at each station. However even after correcting for these complications, some stations consistently report unexpectedly high (or low) displacements. One example is the seismic station BK.TWIT, located on a bed of unconsolidated sediments on Twitchell Island, 30 kilometers northwest of Stockton, California. On average, this station overestimates magnitudes of earthquakes from a range of source locations, sometimes causing large overestimates in the event magnitude used in ShakeAlert. This study collects all magnitude estimates on a per-station level using a large catalog of past detected events from the ShakeAlert EPIC catalog. Using these estimates, we test out the potential for per-station magnitude corrections and analyze if their future use may limit large over or under estimates in magnitude.

POSTER 33

Earthquake Early Warning and Real-time Shakemap Development Using Low-cost Sensors in Taiwan
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This study synthesizes the development and operational performance of Taiwan’s high-density, low-cost P-Alert earthquake early warning (EEW) network by integrating a system-level review with two recent large-earthquake case studies. Based on MEMS-based sensors, the P-Alert network comple-

ments the official regional EEW system by providing rapid onsite warnings within near-source blind zones and by generating real-time shakemaps of peak ground acceleration (PGA), peak ground velocity (PGV), spectral acceleration, and seismic intensity. The 2024 Mw 7.4 Hualien, Taiwan earthquake illustrates how rupture directivity can challenge point-source regional EEW approaches, leading to underestimated ground shaking in distant metropolitan areas. In contrast, the dense P-Alert network successfully delivered timely onsite warnings and high-resolution shakemaps that captured the directivity effect and mitigated missed alerts. The 2025 M_L 6.4 Dapu, Taiwan earthquake further demonstrates the system’s capability to issue onsite alerts earlier than regional public warnings within approximately 30 km of the epicenter and to generate stable shakemaps within tens of seconds, with PGV distributions closely matching observed damage patterns. Together, these results demonstrate that dense, low-cost sensor networks substantially enhance EEW performance, improve rapid damage assessment through PGV-based products, and strengthen societal resilience to complex earthquake rupture processes.

Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches

Oral Session • Wednesday 15 April • 10:30 AM Local
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Version 2 of an Integrated Earthquake Catalog for Aotearoa New Zealand and 3D Earthquake-depth Models
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In 2021-22, for the 2022 New Zealand National Seismic Hazard Model (NZ NSHM), we compiled version 1 of an integrated earthquake catalog for New Zealand by merging the GeoNet operational seismic catalog (the most complete record of NZ’s seismicity) with standardized event magnitudes, relocations, focal mechanisms, and global catalogs. This integrated catalog, and its improved event parameters, are needed for several uses in the NZ NSHM including:

- classifying earthquakes as in the upper plate, on the Hikurangi or Puysegur subduction zone, or in one of the subducting slabs, using event depths and focal mechanisms;
- estimating the magnitude-frequency distributions of those five tectonic regimes using the event classifications and the standardized magnitudes;
- estimating the earthquake depth distribution in various regions of NZ for the NSHM’s Distributed Seismicity Model (DSM), and underpinning the hybrid spatial earthquake-rate forecasts that go into the DSM;

- estimating the geologic detectability of NZ earthquakes as a function of magnitude, used in the NSHM's Inversion Fault Model (IFM).

Version 1 of the integrated earthquake catalog covered through the end of 2020. For the 2028 release of the one-year time-dependent NZ NSHM, we are preparing version 2, through several lines of work:

- adding 2021-2025 earthquakes (eventually 2021-2027) with standardized magnitudes (and relocated depths, locations and focal mechanisms where possible);
- adding relocations and focal mechanisms for several thousand pre-2000 earthquakes from ESNZ archives and literature;
- adding new and previously unused large-scale relocations of post-2000 events;
- adding machine-learning catalogs that fill in missing events from recent aftershock sequences and sparsely instrumented regions;
- improving the record of offshore earthquakes on the Hikurangi and Puysegur subduction zones using updated global catalogs.

Here, we will present current progress on version 2 of the integrated catalog and resulting 3D models of the depth distribution of earthquakes throughout Aotearoa New Zealand.

Should the CEUS SSC Model Be Updated?

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Published in 2012, the *Central and Eastern United States (CEUS) Seismic Source Characterization (SSC) for Nuclear Facilities* model was developed by a consortium of regulators, nuclear utilities, and federal agencies. Because of the anticipated use of the study for the design and safety assessment of nuclear facilities, an extensive effort was devoted to the characterization and quantification of aleatory and epistemic uncertainties. Since the publication of the CEUS SSC report, nuclear and other industries have used the CEUS SSC model extensively for seismic hazard assessment at new and existing facilities. Typically, these studies have been site-specific and have included local “updating” of the CEUS SSC model to include local and recent data. Over the past 14 years, new data, models, and methods have been developed that impact potential earthquake sources and methodologies. For example, the CEUS SSC earthquake catalog extends through the end of 2008 but in the intervening 17 years, there have been notable earthquakes including the 2011 Mineral, Virginia and the 2020 Sparta, North Carolina events, and a significant increase in seismicity associated with human activities. Recent studies also have proposed new earthquake magnitude conversions relations and additional paleo-seismic investigations have been performed across the region Also, the 2023 USGS National Seismic Hazard Map includes updated sources and additional sources not included in the CEUS SSC model.

Up to now, site-specific applications of the model have evaluated the impacts of new data, models, and methods that have become available since the issuance of the model. However, there has not been a comprehensive, systematic, and multi-disciplinary effort to update the entire model. With an increase in siting studies for new nuclear facilities, we argue that the time has come for a comprehensive update of the CEUS SSC model. The CEUS SSC project was conducted by a consortium of owners, regulators, and stakeholders of nuclear facilities, thus leading to broad acceptance by the industry. Perhaps a similar consortium can be organized for its update.

Developing Strong Motion Data Platform for Ground-motion Model Project in Japan

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Japan has developed one of the world's most extensive strong-motion observation networks, significantly expanded after the 1995 Kobe earthquake. Today, seismic intensity data from Japan Meteorological Agency (JMA) and local governments are used for rapid information dissemination and emergency response, while waveform data from multiple public institutions have accumulated since the 1960s. Recent upgrades to the local-government seismic intensity network have enabled real-time distribution of full time-history waveform data, creating new opportunities for data utilization. Despite this rich observational basis, strong-motion data and metadata remain fragmented across institutions, limiting their systematic and integrated use for seismic hazard assessment and earthquake disaster applications.

To address these limitations, we propose the concept of a Strong-Motion Information Infrastructure (SMII) that connects seismic data providers and users through on-demand data registration and access, fostering a sustainable data ecosystem. Based on this concept, Ground-Motion Model Project in Japan (GMM-PJ) was launched in 2025 with the objective of developing GMMs based on a common strong-motion dataset, enabling consistent evaluation of epistemic uncertainty in the National Seismic Hazard Maps for Japan (NSHMJ). In parallel with the launch of GMM-PJ, development of the Japan Strong-Motion Data Platform has been initiated to provide unified system for data integration under the SMII concept. As an initial outcome, a unified dataset, “Flatfile GPJv1” has been constructed from open-access strong motion records, following the K-NET and KiK-net flatfile format. GMM-PJ aims to develop both nation-wide GMMs for NSHMJ applications and targeted models addressing specific PSHA issues.

Scenario ShakeMaps for Cascadia Subduction Zone Megathrust Earthquakes Using 3D Ground Motion Simulations

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The U.S. Geological Survey develops scenario ShakeMaps for hypothetical future earthquakes using shaking estimates from empirical ground motion models (GMMs) or simulations. These scenario ShakeMaps are critical products that are used by communities for emergency response planning and public outreach. Although GMM-based scenario ShakeMaps are most common, they can lack critical features that impact seismic hazard estimates, such as 3-D basin effects and regionally specific rupture characteristics. Here, we develop scenario ShakeMaps for the Cascadia Subduction Zone (CSZ) earthquakes using ground shaking information from 36 full-margin 3D broadband simulations.

To develop broadband synthetic ground motions, we use a hybrid approach that combines (1) low-frequency (< 1 Hz) deterministic synthetics calculated in a 3D seismic velocity model with (2) high-frequency (1-10 Hz) stochastic waveforms using a 1 Hz matched filter. The earthquake scenarios are built using a logic tree approach, varying the up and downip limits of slip, hypocenter location, slip distribution, and event magnitude (M8.7-9.2). Due the minimum shear wave velocity used in the simulations of 600 m/s, we incorporate site adjustments using regional Vs30 values and soil velocity profiles. With these scenario ShakeMaps, we examine inter- and intra-event variability to highlight the impacts of rupture characteristics and 3D velocity structure on ground motion variability. We also compare our ShakeMaps to GMMs developed for Cascadia interface earthquakes, showing that utilizing 3D simulations has a profound impact on regional hazard estimates. These scenario ShakeMaps are the first step in building multi-hazard maps to quantify the regional impacts of ground shaking and cascading hazards such as tsunami inundation, landslides, liquefaction and land-level change.

Development of Stochastic Ground-motion Models for a Reference Rock Condition in South Korea

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Ground motion models (GMMs) play a crucial role in seismic hazard analyses. Developing empirical GMMs is impractical in South Korea due to the

lack of strong-motion earthquake records, leading to the use of alternative approaches such as stochastic simulations. Meanwhile, in the U.S. nuclear industry, site-specific ground-motion response spectra (GMRS) are developed in accordance with U.S. NRC Regulatory Guide 1.208 by defining a reference rock condition for the Central and Eastern United States and developing GMMs applicable to that reference rock.

In this study, GMMs are developed using stochastic simulations (Boore, 2003) for a reference rock condition in South Korea, defined in a separate study (Noh, 2024) as a shear-wave velocity of 2.5 km/s. For the simulations, site characteristics of the reference rock condition, including the high-frequency spectral decay parameter (κ) and site amplification functions, were investigated using a suite of accelerometer stations across South Korea. The traditional method of Anderson and Hough (1984) and the square-root-impedance method proposed by Boore and Joyner (1997) were applied for κ estimation and site response analysis, respectively. The derived GMMs cover moment magnitudes from 3.0 to 8.0 and distances from 10 to 500 km. Median GMMs are provided together with aleatory standard deviations. The GMMs are compared with observed ground motions from available earthquake records for moment magnitudes ranging from 3.0 to 5.5. This study presents a novel set of ground-motion models for a reference rock condition in South Korea. The GMMs incorporate reference rock characteristics in South Korea and explicitly account for associated aleatory uncertainties. These results provide key input for probabilistic seismic hazard analysis (PSHA) in the development of the GMRS for nuclear facilities in South Korea.

Seismic Hazard Evaluation Based on Ground-motion Waveforms Using Machine Learning Techniques

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In probabilistic seismic hazard analysis (PSHA), exceedance probabilities of ground-motion intensity measures (IMs) are evaluated using ground-motion models (GMMs). However, in seismic risk assessment frameworks, structural seismic performance is increasingly assessed through nonlinear dynamic response analyses, which require ground-motion time histories as input seismic hazards. In this study, we propose a waveform-based PSHA framework that directly evaluates seismic hazard in the form of an ensemble of ground-motion waveforms. The framework is built upon a previously developed ground-motion generative model (GMGM), which models the probability distribution of ground-motion waveforms using generative adversarial networks (GANs). The GMGM is trained on a database of strong-motion observed records paired with source, path, and site information, and it can generate synthetic waveforms that are statistically consistent with observed records.

We compiled a dataset of strong-motion records from crustal earthquakes in Japan and trained the GMGM using a model called StyleGAN2. As a simplified problem setting, moment magnitude was used to represent source characteristics, rupture distance for path effects, and the average shear-wave velocity in the top 30 m (V_{s30}) for site conditions. Because the proposed GMGM does not provide an explicit probability density function, we propose a rejection-sampling-based approach to perform the PSHA integration. Using the proposed method, seismic hazard assessments are conducted for an actual site in Japan and its surrounding source faults. The characteristics of the resulting hazard-consistent waveforms are evaluated, and the IM hazard curves computed from the waveform samples are compared with those obtained using conventional GMMs, demonstrating that reasonable hazard estimates are achieved. Furthermore, nonlinear dynamic response analyses of a building model are performed using the hazard-consistent waveforms as input, demonstrating the effectiveness of the proposed method for engineering applications of seismic hazard.

Enhancing Reference Ground Motions: Isolating Site Effect-free Time Series via Application of the Complex-valued Generalized Inversion Technique

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A key component in seismic hazard assessment is the determination of time series that meet criteria for seismological reference conditions (e.g., seismological bedrock). Under these conditions, the time series can serve as input for site response computations. Today, such motions are rare (few surface sta-

tions are located on hard rock sites free of site effects). The common practice is then to apply physics-based corrections (i.e. 1D site response modelling) for removing site effects from surface recordings to obtain the underlying bedrock motion. Such approaches often neglect phase differences, i.e. differences in the temporal shape between surface and bedrock motion. In this study, we propose the application of a complex-valued deconvolution methodology, based on the Generalized Inversion Technique (GIT), to generate a homogeneous database of time series representing seismological bedrock conditions at a reference observation site. Our procedure incorporates a site-specific phase correction, accounting for differences in ground motion arrival times. We first validate the methodology using 90 KiK-net surface-downhole sites which were selected for minimal velocity contrasts and sufficient depth to avoid downgoing wave interference. After assessing the effectiveness of the deconvolved waveforms by comparison of the deconvolved ground-motions with recorded time series at the downhole sensors and ensuring that the method allows a reliable and robust removal of the complex-valued site effects, in a second step, we apply the proposed approach to a large European dataset for creating a homogeneous database of reference ground motion. This resource facilitates the refinement of existing ground motion models and provides hazard-consistent time histories.

Using “Did You Feel It?” Data to Map Spatially Variable Site Amplification in the Central and Eastern United States

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Macroseismic intensity observations, such as those from the U.S. Geological Survey “Did You Feel It?” (DYFI) program, are an underutilized source of high-resolution, site-specific information for assessing site response. Intensity Prediction Equations (IPEs), which estimate Modified Mercalli Intensity (MMI) or Community Decimal Intensity (CDI) from earthquake magnitude and distance, play a key role in real-time seismic hazard assessment and in interpreting shaking from historic and recent earthquakes. By compiling macroseismic intensity data for the Central and Eastern United States (CEUS), we develop an updated IPE that accounts for regional differences within the CEUS. In this study, we leverage this newly developed IPE, together with DYFI datasets, to evaluate and refine regional site and basin terms for ground-motion models in the CEUS. Using DYFI data can help improve the characterization of site and basin effects in areas where seismic stations are sparse. We combine geospatial proxies of site conditions, which provide continuous spatial coverage, with the spatially dense DYFI intensity observations to develop updated, regionalized site and basin terms for intensity prediction. We also examine integrating DYFI data within city-scale site response analyses in selected urban areas in the CEUS. The spatial resolution of DYFI data enables investigation of regional- and city-scale patterns in site and basin effects that are difficult to resolve using instrumental ground-motion recordings alone. Our results demonstrate the value of integrating macroseismic intensity data, geospatial site information, and city-specific geotechnical data to improve IPE performance and enhance characterization of site response in data-limited regions such as the CEUS.

On Implementing the International Macroseismic Scale (IMS) in the United States and Canada

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Macroseismology plays a crucial role in earthquake hazard and risk analyses, linking past earthquake occurrences and impacts with those of the present and future. The popularity of internet-based community contributions and the usefulness of intensities for communicating hazards, early warning, and effects have bolstered macroseismology above and beyond its traditional utility in characterizing shaking from historical and modern earthquakes. Nevertheless, many contemporary approaches to assigning macroseismic intensities have limitations. Even after recent consequential earthquakes, building damage data were often not collected systematically, nor were field-based macroseismic intensities professionally assigned. The United States (U.S.) and Canada, among others, still use variants of the Modified Mercalli Intensity scale, which has significant limitations relative to the recently devel-

oped 1998 European Macroseismic Scale (EMS-98). The new International Macroseismic Scale (IMS), which builds on EMS-98, further expands its international applicability by enhancing the EMS-98 vulnerability table to include additional building types worldwide. The IMS requires well-defined vulnerability classes, structure-specific damage grades, and a statistical basis of damage levels to assign intensities properly. The IMS also provides a framework for additional countries to adopt it, encouraging the preparation of national annexes that adapt IMS guidance to regional construction and intensity-assignment practices. Country-specific guidance can include the relative abundance of structure types, their code era and compliance, and other salient features that affect intensity assignments. The U.S. and Canada, which share many building practices and post-earthquake inspection protocols, are preparing National Annexes and advocating for IMS adoption in their respective countries. We offer an implementation plan that enables one to ingest standard post-earthquake safety inspection data (e.g., using ATC-20 or a similar Canadian protocol) to assign IMS intensities.

Probabilistic Seismic Hazard Assessment for Mainland France and the French Lesser Antilles Islands

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The ALCESTE and ATLAS research projects aim at estimating probabilistic seismic hazard for mainland France and the French islands in the Lesser Antilles, under the umbrella of the Ministry of the Environment and Sustainable Development (department on risk prevention). New datasets were produced during the project that we use here for building the source models. Mainland France is located within an intraplate domain, characterized by low-to-moderate seismicity levels. The historical earthquake catalog extends back to ~1000 years, this observation time window is still short with respect to the recurrence times of significant earthquakes. A set of source models are built as an attempt to cover the uncertainty on the occurrence of future earthquakes, including: background large regions, area sources, and smoothed seismicity sources. The b-value distributions are preferably established from the instrumental part of the catalog, whereas seismic rate distributions are inferred considering both historical and instrumental periods. On the other hand, Guadeloupe, Martinique, St Martin and St Barthélemy islands are located in a more seismically active region, the Lesser Antilles subduction zone. We build a set of source models that account for the upper plate seismicity (area sources or gridded seismicity, and a few well characterized upper plate faults), interface seismicity (3D geometry) and inslab seismicity (either dipping volumes or 3D dipping slab). Preliminary hazard calculations show that if the interface is con-

sidered weakly coupled, hazard levels for sites on the islands are controlled both by the upper plate area sources hosting the islands and by the inslab sources located ~100km below the islands. Overall, we apply the same strategy in both projects: we identify uncertainties at all steps, in the data as well as in the methods, and we quantify the impact on hazard levels, in order to identify which assumptions or parameters control hazard and should be included in the logic tree. Complete seismic hazard models must be delivered for end of 2026.

Probabilistic Seismic Hazard Assessment in Guatemala Incorporating Geodetic Data for Crustal Faults and Subduction Zone

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Recent developments in geodetic monitoring have significantly expanded the ability to constrain long-term seismic deformation, offering a valuable complement to seismic catalogs whose temporal span is often insufficient for robust earthquake forecasting and probabilistic seismic hazard assessment (PSHA). Guatemala represents a particularly challenging tectonic environment, as it lies at the convergence of the North American, Caribbean, and Cocos plates, where seismic hazard is controlled by both the subduction interface and several major crustal strike-slip fault systems.

In this work, geodetic information from the subduction margin and from the principal strike-slip fault zones—namely the Polochic-Chixoy, Motagua, and Jalpatagua systems—is incorporated into a PSHA framework explicitly constrained by geodetic observations. Slip rates derived from geodetic data, together with estimates of interplate coupling, are used to infer seismic moment accumulation and to define magnitude–frequency relationships for both interplate and upper-plate seismic sources. To address epistemic uncertainty, multiple strategies for estimating earthquake occurrence rates and maximum magnitudes are considered and formally represented through a logic-tree structure.

These alternative source models are implemented within an updated version of the KUKAHPAN-25 hazard model, which includes explicit fault-based sources and revised recurrence parameters for the subduction interface. The resulting hazard calculations indicate that ground-motion levels near major fault traces increase by more than 20% relative to traditional zonation-based models, with the largest differences observed along high slip-rate faults such as the Motagua and Jalpatagua systems. For interplate sources, however, the variations remain within the epistemic uncertainty bounds of the reference model, largely reflecting the offshore position of the subduction interface relative to the Guatemalan mainland.

Ontological Testing of Seismic Hazard Models

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Proper and defensible societal uses of seismic hazard and earthquake forecasting models depend on their scientific reliability, which is an essential aspect of “best available science” according to the U.S. Geological Survey [doi: 10.1785/0120230140]. The reliability and forecasting skill of hazard forecasting models can be evaluated through formal statistical testing, but the combination of epistemic uncertainty and aleatory variability severely limits the conventional testing of model reliability. In this talk we review and address these limitations by introducing novel ontological testing procedures. Ontological testing evaluates the reliability of models pervaded by multiple types of uncertainty, e.g., a PSHA or forecasting model defined by logic-tree branches or an ontological ensemble model (a model combination captured as a probability distribution). Specifically, we extend the N(umber)- and S(patial)-tests developed in the framework of the Collaboratory for the Study of Earthquake Predictability [cseptest.org] to account for aleatory variability and epistemic uncertainty. These extended tests can be applied to forecasting horizons of any length, which we demonstrate with two applications for Italy: the national seismic hazard model (MPS19, doi: 10.4401/ag-8579) and the operational earthquake forecasting model (OEF_Italy, doi: 10.1785/0220130219). Based on these examples, we propose general guidelines for conducting an effective ontological testing of hazard forecasting models for any forecasting horizon.

Assessing Seismic Risk in the United States

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Earthquake risk assessment remains a cornerstone of resilience planning at federal, state, and local levels for earthquake-prone communities in the United States. By quantitatively evaluating the potential impacts of future earthquakes, risk assessment empowers decision-makers to strategically allocate resources, refine building codes, prepare emergency response systems, and cultivate public awareness. As a part of the National Earthquake Hazard Reduction Program (NEHRP) collaboration, the 2026 FEMA P-366 publication titled “Estimated Annualized Earthquake Losses for the United States and its Territories,” presents the most up-to-date national assessment of earthquake risk using Hazus 6.1, the 2023 & 2025 U.S. Geological Survey National Seismic Hazard Model (NSHM) for the United States and its territories. This analysis leverages the latest hazard, exposure, and vulnerability information, especially by properly accounting for the improved seismic resistance of newer structures with the adoption of newer building codes. The average annualized loss (AAL) is estimated at \$15.8 billion per year, representing a modest 7% increase from the 2023 study. Over half (56%) of the increase is attributable to Alaska and Puerto Rico hazard model updates. Besides AAL, we also discuss relative earthquake risk in terms of decreasing loss ratio, estimated debris, shelter, and casualties. Escalating asset values, rapid growth in high-hazard areas, and aging building stock continue to drive earthquake risk, which is partially offsetted due to improved seismic design and construction practice. The national assessment underscores a dual message: earthquake risk in the United States continues to rise in absolute terms, but mitigation measures—particularly building codes—are effectively reducing loss severity and saving lives.

Financial Recovery Modelling for Earthquake Risk in Canada

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Large earthquakes have the power to destroy homes, take lives, and disrupt the economic prosperity of individuals and even nations. After the immediate response phase, recovery and rebuilding can take many years. It is most commonly financed through a combination of government aid, insurance, philanthropy, and private funding; however, the balance of these sources depends on the country or sometimes the state/province in which the earthquake occurs.

In Canada, recovery financing after earthquakes is managed primarily through the private insurance sector. However, earthquake insurance penetration and deductibles vary widely between the seismically active western portion of the country and the relatively quiet eastern region. Prior to 2025, government financial aid to support earthquake shaking losses may have been available to those without insurance, depending on the province/territory; however, recent changes to the federal Disaster Financial Assistance Arrangements program now identify these costs as ineligible.

This study describes a custom financial module used with the OpenQuake engine’s scenario risk calculator, within the Canadian Seismic Risk Model framework, to estimate the proportion of ground-up and total losses that will be paid by the insurance sector, policy holders, and the uninsured following select major earthquakes in Canada. It reveals interesting trends in the proportion of costs held by policy holders in western Canada, due to large deductibles, as well as unsurprising findings about the majority of eastern Canadian building owners without adequate coverage. These findings are crucial in working towards narrowing the protection gap for property owners and ensuring the economic stability of the country in the wake of inevitable large seismic events.

Urban-scale Seismic Modeling Reshapes Risk Priorities in Basel, Switzerland

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We present an urban-scale earthquake risk model for Basel, Switzerland, quantifying how spatially variable site effects propagate through hazard and loss estimates. Basel, partly destroyed by a magnitude 6.6 earthquake in 1356, lies near the southeastern edge of the Upper Rhine Graben, where the Rhine Graben fault separates a soft sedimentary basin from a stiffer uplifted block. Unconsolidated Tertiary formations thicken toward the fault zone, while fluvial Quaternary sediments and loose loess deposits cover the basin and southwestern areas. These contrasts produce site amplification factors exceeding three, with sharp lateral variations over distances of ~100 m. The model resolves this complexity at 25 m resolution and integrates high-resolution

exposure data with multiple independent site-amplification estimates derived from empirical observations and physics-based constraints. Building-level analysis covers ~27,000 structures using probabilistic taxonomy assignment and dual vulnerability approaches.

When spatially variable site effects are propagated through building-specific vulnerability functions, projected losses differ by up to an order of magnitude between adjacent districts. Scenario analysis of a repeat of the 1356 earthquake projects damage affecting ~16,500 buildings, with losses concentrated in the historical center where deep deposits resonate with pre-1920 unreinforced masonry buildings. Northeastern and southern Basel exhibit higher damage, fatalities, and losses than predicted by national models, reflecting shallow sediments in the south and fault-related complexity in the north. These results demonstrate that site effects fundamentally reshape neighborhood-scale risk patterns and priorities for retrofit and emergency planning. The workflow remains compatible with Switzerland’s national risk framework through a hierarchical logic-tree structure, enabling aggregated federal estimates while providing building-scale results for cantonal decision-making. Transferability is supported by explicit geological representation, probabilistic uncertainty treatment, and systematic data integration.

Advancing Seismic Hazard and Risk Assessment through Multi-Disciplinary Approaches [Poster]

Poster Session • Wednesday 15 April

Conveners: Chung-Han Chan, National Central University, Taiwan (hantijun@googlemail.com); Matthew Gerstenberger, Earth Sciences New Zealand (m.gerstenberger@gns.cri.nz); Tiegan E. Hobbs, Geological Survey of Canada (thobbs@eoas.ubc.ca); Asako Iwaki, National Research Institute for Earth Science and Disaster Prevention (iwaki@bosai.go.jp); Kishor Jaiswal, U.S. Geological Survey (kjaiswal@usgs.gov); Jessie K. Saunders, California Institute of Technology (jsaunder@caltech.edu); David J. Wald, U.S. Geological Survey (wald@usgs.gov)

POSTER 36

A High-frequency Magnitude Scale (M3HZ): From Instrumental Ground Motions to Historical Earthquake Catalogs

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An accurate characterization of earthquake size is essential for seismology and earthquake engineering, particularly in seismic hazard and risk assessments. Widely used magnitude scales such as Ms and Mw provide robust estimates of overall source size but are not designed to capture variability in high-frequency radiation, which largely controls damaging ground shaking. Conversely, local magnitude (ML) better reflects high-frequency seismic-wave energy but saturates for large earthquakes, limiting its applicability.

Building on the concept of high-frequency magnitude introduced by Atkinson and Hanks (1995), we propose here a novel magnitude scale, m_{3Hz} , which is specifically designed to quantify high-frequency radiation above the source corner frequency. The scale incorporates corrections for crustal structure and site effects. First, we present how m_{3Hz} is computed and applied to instrumentally recorded ground-motion data. Then, we demonstrate its ability to capture high-frequency source effects through comparisons with independent source parameters using datasets from Central Italy and Japan. Finally, we extend the approach to macroseismic intensity data, and illustrate its application to historical earthquakes in Italy. Using macroseismic intensity data from the Italian Macroseismic DataBase Earthquakes (DBMI15), we estimate m_{3Hz} for 1,951 events spanning the period 1117–2020, producing a new high-frequency earthquake catalogue, named ICEM. For each event, we

assign a quality index based on the variance-to-mean ratio (VMR) to quantify the robustness of the estimates.

The ICEM catalogue shows how m_{3Hz} complements M_w by providing information on earthquake source complexity and high-frequency radiation relevant to damage potential. It offers a new approach to integrating source properties into seismic hazard and risk assessments.

POSTER 37

A Partially Nonergodic Seismic Hazard Framework Using Earthquake-cycle Simulations

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Seismic hazard assessment is commonly constrained by the limited duration of instrumental earthquake records, ergodic assumptions and by the simplified representation of the rupture process. These limitations are particularly relevant in regions with complex fault geometries and strong fault-segment interactions, where large ruptures may span multiple segments. In this study, we develop a partially non-ergodic probabilistic seismic hazard assessment framework that couples long-term earthquake-cycle simulations with physics-based ground-motion modeling. We apply this framework to the Gulf of Aqaba fault system, the southern continuation of the Dead Sea fault zone. First, we conduct multi-cycle earthquake simulations to generate 10,000-years-long earthquake catalogs that capture the variability in earthquake recurrence, rupture dimensions, and fault-segment connectivity, including single and multi-segment rupture scenarios. In the next step, we use the source time functions of simulated M6+ earthquakes as input for seismic-wave-propagation computations at over 200 virtual seismic stations. From these, we compute different ground-motion intensity measures and their associated variabilities (between and within-event) and compare them with NGA-West2 ground-motion models. We construct hazard curves and maps using a non-parametric kernel-density formulation of exceedance rates and compare these physics-based results with empirical ground motion models (GMM) applied to the same synthetic catalogues.

Our results indicate that long-period amplitudes fall within the $\pm 2\sigma$ range of GMMs, with systematic underestimation at larger distances that we attribute to the simplified 1D velocity structure. Furthermore, we implement statistical tests on a 100,000-year reference simulation to show that 10,000-year catalogues are sufficient to obtain statistically stable SA distributions and robust regional hazard estimates. This finding reduces computational cost without the computational burden of excessively long simulation periods.

POSTER 38

Modeling Multi-hazard Assessment in the Western Corinthian Gulf, Central Greece, Using Machine Learning and Gis.

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Multi-hazard assessment modeling comprises an essential tool in plans that aim to mitigate the impact of future natural disasters. For a particular area they are generated by combining assessment maps for different types of natural hazards. The HOMEROS project advances the field of multi-hazard assessment by integrating seismological, geodetic, geomorphological, and engineering geological analyses. Leveraging Open Science practices, the project systematically utilizes high-resolution datasets from regions of elevated hazard in Greece, providing a robust framework for the evaluation and mitigation of natural disaster risks. This study reports on multi hazard assessments conducted at the Western Gulf of Corinth (Central Greece) to inform regional risk mitigation strategies. A variety of spatial datasets with recorded landslide and flood events along with delineated hazard zones of the study area were used. Datasets are publicly available through Zenodo. The Random Forest

Algorithm supported by a Geographical Information System was utilized to combine seismic, landslide, and flood hazards into a single multi-hazard map. The landslide-prone areas are distributed across the western, southern, and central regions of the study area, while flood-prone zones are predominantly situated in the north. Seismic hazard results (PGA for return period of 475 years) were obtained through a logic tree approach that combines source area and fault sources with Greek Ground Motion Models. The highest values ($\sim 400 \text{ cm/s}^2$) were obtained in the northwestern section of the study area, close to the Gulf. The study identifies the northern, southern, western, and central areas as exhibiting the highest multi-hazard susceptibility.

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POSTER 39

Regional Seismic Risk Assessment in Taiwan Using Optimized Exposure and Fragility Models: Insights From the 2016 Meinong and 2024 Hualien Earthquakes

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This study developed a high-resolution building exposure model and an optimized fragility model for seismic risk assessment in Taiwan, using the 2024 M_L 7.2 Hualien earthquake and 2016 M_L 6.6 Meinong earthquake as case studies for vulnerability validation, and subsequently established a Probabilistic Seismic Risk Analysis (PSRA) Model for Hualien. The exposure database was constructed using building footprints and tax data, providing detailed information on building locations, structural types, storeys, and construction ages. Fragility curves were adopted from the Global Earthquake Model taxonomy due to the lack of updated local data, and their applicability was validated through scenario assessments of recent earthquakes. For PSRA, we applied probabilistic seismic hazard models from the Taiwan Earthquake Model, along with optimal vulnerability models for Hualien and Tainan developed using historical earthquake simulations. Results indicate significantly higher seismic risk in Hualien City, likely to the active Milun Fault and dense urban development. Elevated risks were also observed in parts of the Longitudinal Valley, associated with active structures and relatively populated cities. The findings provide a valuable reference for earthquake risk management and policy-making in Taiwan.

POSTER 40

Updated Mmax Distributions for Seismic Hazard Analyses of Nuclear Facilities in the Central and Eastern US

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This study examines changes in maximum magnitude (M_{max}) characterization by analyzing an up-to-date earthquake catalog for the Central and Eastern US (CEUS) region. The objective is to assess whether the expanded catalog data warrants an update of the M_{max} distribution of the CEUS Seismic Source Characterization (SSC) model for nuclear facilities (NUREG-2115). The main interest is at lower annual exceedance frequencies, which are of relevance in probabilistic seismic hazard analysis studies concerning critical infrastructure. The CEUS-SSC model was developed following a rigorous Senior Seismic Hazard Analysis Committee Level 3 process and relied on a catalog complete through 2008. In 2015 EPRI published recalculated M_{max} distributions for 8 zones to correct an error in the original estimates. We compiled an updated catalog by adding earthquakes that occurred in the CEUS study region since January 1, 2009, for which there is a seismic moment. We note that many earthquakes in the updated catalog occurred in Texas and Oklahoma and are likely associated with human activities.

The calculation of M_{max} follows 3 main steps: (1) application of the Johnston et al. (1994) Bayesian approach with a set of prior distributions obtained from groupings of stable continental regions with similar crust; (2) application of the Kijko (2004) approach; and (3) assessment of the relative weights to assign to each method. We find that when earthquakes occurred since 2008 are added to the catalog, there is a general tendency for a slight downward shift in the M_{max} distribution for many of the CEUS-SSC source zones. Using three demonstration sites as example locations, we find that the updated M_{max} distributions generally lead to small decreases in hazard rates at low annual frequencies of exceedance computed with the CEUS-SSC earthquake rate parameters.

POSTER 41

Looking for the Possible Epicenters and Magnitudes of Strong Prehistoric Earthquakes Near Boston, Massachusetts

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This study examines evidence of widespread mass wasting that was found in the sediments of Walden Pond, Concord, Massachusetts and Sluice Pond, Lynn, Massachusetts deposited between 1380-1520 CE and shortly after 1386-1509 CE, respectively, along with 15 landslides in the sensitive glaciomarine deposits of the Presumpscot Formation in southern Maine, all of which took place between 1221-1454 CE. In addition, the sediments in Walden Pond show evidence of mass wasting between 1050-1320 CE but which is not seen in Sluice Pond or in Maine. The younger event horizons in Walden and Sluice Ponds and possibly the landslides in southern Maine are attributed to an earthquake ~ 1400 CE; whereas, the older anomalous layer in Walden Pond is attributed to an event ~ 1200 CE. We carried out a modeling analysis to find the range of possible locations and magnitudes of earthquakes that could have disturbed the sediments in the ponds and caused the landslides in Maine. For an earthquake ~ 1400 CE, the area of possible epicenters is in eastern Massachusetts or southeastern New Hampshire, with a possible magnitude range of $5.6 \leq M_w \leq 6.7$ (± 0.3 uncertainty) if the earthquake also caused the landslides in Maine and with a magnitude as small as M_w 4.7 $\pm$ 0.3 with an epicenter in eastern Massachusetts if the earthquake did not cause the landslides in Maine. An earthquake ~ 1200 CE with M_w 4.7 $\pm$ 0.3 or a little larger near or west of Walden Pond is most likely, although an earthquake as large as M_w 6.2 $\pm$ 0.3 and an epicenter as far west of Walden Pond as Worcester, Massachusetts is possible. The results of this study suggest that the seismic hazard in eastern Massachusetts and southeastern New Hampshire might need reevaluation.

POSTER 42

Linked Earthquake and Tsunami Hazard Modeling on Puget Sound's Crustal Faults

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The U.S. Pacific Northwest is home to numerous shallow (≤ 35 km), generally east-west striking crustal faults. Many of these faults, including Washington State's Seattle Fault (SF), underlie the Puget Sound and have produced earthquakes of $\sim M_{6.5-7.8}$ with subsequent tsunamis throughout the Holocene. Recent paleoseismic investigations found that in 923-24 C.E., the SF and the Saddle Mountain Fault (SMF) either ruptured separately within a span of six months or ruptured together as a combined, multifault rupture with an estimated magnitude of M7.8. An M7.8 multifault rupture exceeds the previously-assumed maximum magnitude for the SF (M7.5) and is not currently represented in regional seismic hazard estimates.

We develop 3-D linked earthquake-tsunami simulations of single- and multifault rupture scenarios on the SF and SMF to quantify their associated ground shaking and tsunamigenesis. Our 3-D physics-based kinematic simulations use the code SPECFEM3D Cartesian to generate synthetic ground motions up to 1.5 Hz. The results demonstrate that an M7.8 combined SF-SMF earthquake would generally produce stronger ground shaking at all periods over a wider region, including in the densely populated eastern Puget Sound area. In both combined rupture scenarios and in single-fault SF scenarios, peak ground velocities can exceed 140 cm/s. Comparisons of our simulated results to NGA-West2 empirical ground motion models show that our simulated results are relatively consistent with observations of global earthquakes. Preliminary simulations of the resulting tsunamis, modeled using the GeoClaw and Method of Splitting Tsunamis softwares, yield wave magnitudes

compatible with regional paleotsunami evidence. Together, our linked simulations allow for a time-dependent analysis of earthquake ground shaking and tsunami inundation. They demonstrate the value of linked earthquake-tsunami modeling for improving seismic hazard assessments and for informing engineering design and emergency-planning efforts.

POSTER 43

Development of an Empirical Ground Motion Model for Spectral Displacement Using High Rate GNSS

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Large earthquakes generate intense shaking and pose a significant hazard to human life and infrastructure. They are saturated in low frequency energy, of particular concern to large structures with long period natural resonance (such as long span bridges, high rises, and base isolation systems). Displacement-based ground-motion models (GMMs), typically derived from seismic data, are meant to help quantify this hazard, but are not well constrained because of the inherent difficulties of accurately recovering displacement from inertial strong motion instruments. High-rate GNSS (HR-GNSS) is a solution to this issue, able to avoid the pitfalls of strong motion instruments and accurately record the dynamic displacements. Despite this development, new empirical models using high-rate geodetic data have not been widely developed and implemented within the earthquake engineering community.

We present our progress towards a novel empirical ground motion model for the median effective amplitude of spectral displacement (the root mean square of the orthogonal horizontal components of the Fourier amplitude spectra) using HR-GNSS at the input data. The GMM uses a dataset of 1 Hz HR-GNSS observations of 71 large (M6+) global earthquakes (2003-2021). Displacement spectra are calculated using a multitaper code, and we then use a linear mixed effects regression approach to fitting the model. The initial best fit model is presented. We also discuss ways in which the robustness of the final model could be improved via reduction of variability associated with event, site and path in the specific context of low frequency displacements.

POSTER 44

Seismic Hazard Studies in West Africa Using Integrated Techniques for Planning and Development of Critical Facilities

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No in-depth seismic hazard study for West Africa (WA) has ever been conducted because of incomplete earthquake catalogues, which negatively affects the planning and development of critical infrastructure by construction industries and disaster risk management by the relevant agencies. This bridges the knowledge gap by updating the current earthquake catalogue for WA. The seismotectonic setting of WA is considered stable continental crust despite several recorded earthquakes occurring in the region, the largest being the 22 June 1939 earthquake of magnitude M6.8 with epicentre in Ghana. However, WA has also been classified as a region of shallow crustal seismicity. Therefore, we investigated both research schools of thought using integrated techniques, compared their results using three different ground-motion models (GMMs), and combined to produce each hazard map using logic tree formalism with equal weights. The region was divided into five seismic source zones to compute the earthquake recurrence parameters, with the same parameters computed for the entire WA region. The computed Gutenberg–Richter b -value, activity rates λ , and regional maximum possible magnitudes m_{max} for the five zones ranged from 0.84 to 1.0, 0.3–2.1, and 5.2–7.0, respectively. The calculated b -value, λ , and m_{max} for the entire WA were 0.77, 4.1, and 7.2, respectively. The estimated b -value of 0.77 falls within the generally accepted range for tectonic seismicity. The seismic hazard predicted by GMMs for stable continental areas was higher than that predicted for shallow crustal seismicity in WA, confirming that the region is characterised by stable continental crust. The highest hazard levels were observed in Ghana, Guinea, etc, ranging 0.02-0.03 g. Results from this study will help the construction industries and policymakers, especially in policy making with respect to designing and developing critical facilities in the region, whose damage from seismic hazards could cause enormous losses.

Applying Selena for Seismic Risk Analysis in Kenya
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Kenya is situated within the eastern branch of the East African Rift System, a tectonically active region capable of generating damaging earthquakes. While regional seismic hazard levels are moderate, rapid urbanization, increasing population density, and the widespread presence of vulnerable and non-engineered building stock significantly elevate seismic risk, particularly in major urban centers. This study applies the principles of SELENA (SEismic Loss Estimation using a logic-tree Approach) to develop a comprehensive seismic risk assessment framework tailored to Kenyan conditions. The methodology integrates seismic hazard, exposure, and structural vulnerability within a displacement-based capacity spectrum approach, enabling the systematic estimation of physical damage, economic losses, and human casualties under representative earthquake scenarios.

Seismic demand is defined using scenario-based response spectra consistent with regional seismotectonic characteristics, incorporating local site effects through soil classification and amplification factors. Structural performance is evaluated using nonlinear capacity curves for representative Kenyan building typologies, including unreinforced masonry, reinforced concrete frame systems, and non-engineered constructions. Fragility functions relate spectral displacement at the performance point to probabilistic damage states, while a logic-tree framework explicitly accounts for epistemic uncertainties associated with seismic sources, ground-motion prediction, soil conditions, vulnerability models, and loss parameters. Damage outcomes are aggregated at the level of geographical units and translated into direct economic losses using regionally adapted cost models, while human casualties are estimated based on damage probabilities and time-dependent occupancy patterns. The results demonstrate that even moderate earthquake scenarios can lead to substantial damage and losses due to high exposure and vulnerability, highlighting the suitability of SELENA as a transparent and uncertainty-aware tool for seismic risk-informed planning and disaster risk reduction in Kenya.

Region-specific Empirical Models for Arias Intensity, Cumulative Absolute Velocity, and Significant Duration in the Alborz Region
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New ground-motion models (GMMs) are developed for significant duration (D5–75 and D5–95), Arias intensity (IA), and cumulative absolute velocity (CAV) using the referenced empirical method (REM) introduced by Atkinson (2008). The models are calibrated using a strong-motion dataset from the Alborz region of northern Iran. Existing GMMs by Sandıkkaya and Akkar (2017) for D5–75 and D5–95, and by Campbell and Bozorgnia (2019) for IA and CAV, are adopted as reference models.

Residuals are computed as differences between the logarithms of observed values and corresponding predictions from the reference GMMs. A mixed-effects regression framework is applied to derive region-specific correction factors that adjust the reference models for Alborz conditions. The resulting GMMs adopt a simple functional form in terms of moment magnitude (Mw), Joyner–Boore distance (Rjb), and time-averaged shear-wave velocity (V_{s30}). Model performance is evaluated through comparisons with observed data, existing GMMs, and detailed residual analyses.

The results indicate good agreement with observations, and the between-event, between-station, and event–site corrected residual components show no systematic bias or trends with respect to Mw, V_{s30}, or R_{jb}. The dataset comprises 775 acceleration records from 167 earthquakes recorded at 309 stations between 1976 and 2020, spanning ranges of 3.0 ≤ Mw ≤ 7.4 and 1 km < Rjb < 160 km.

On the Development of Multi-hazard Map at the Lefkada Island (Western Greece) by Combining Seismic and Landslide Hazard Maps
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Developing natural hazard maps is essential for informed urban planning and risk mitigation. The present research examines Lefkada Island, western Greece, which is highly exposed to seismic activity and landslide hazards. Two hazard maps were developed for the island, one addressing seismic and the other landslide hazard. The HOMEROS project seeks to improve how these multi-hazard risks are assessed by advancing methods in seismology, geology, and geomorphology. Using modern big-data technologies and Open Science principles, the project aims to standardize research practices, boost collaboration, and enhance our ability to understand and predict natural hazards. Focusing on areas prone to strong earthquakes, and landslides in Greece, HOMEROS develops detailed earthquake catalogues and analyzes ground deformation to better evaluate seismic hazard. It also deepens knowledge of landslide hazard, supporting more effective mitigation and preparedness strategies. Seismic hazard was evaluated using a probabilistic method. Results were obtained by constructing a logic tree framework that considers area source models and active faults. Seismicity data were obtained through multiple techniques, and several Ground Motion Models were considered for both PGA and PGV. Existing landslides within the study area, along with multiple factors influencing their occurrence, were utilized to generate the landslide hazard map. Statistical analysis and Geographical Information System were used to support the evaluation of the selected factors and to produce a landslide hazard map. The findings indicate that areas most susceptible to landslides are primarily located in the western and central regions of the island. The combination of seismic and landslide hazard maps will be presented.

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Simulation-based Scenario Shakemaps for Earthquakes on the Seattle, Tacoma, and Southern Whidbey Island Faults, Washington, U.S.A.
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We present a new suite of simulation-based scenario ShakeMaps that characterize ground shaking from large-magnitude (M_w6.5-7.5) earthquakes on the Seattle, Tacoma, and southern Whidbey Island faults. These maps are developed using results from recent 3-D wave propagation simulations (Stone et al., 2022, 2023, 2025) that incorporate realistic rupture geometries, variable slip distributions, and a regional 3-D seismic velocity model with shallow soils. Broadband ground motions are estimated by combining the low-frequency (< 1 Hz) deterministic seismograms from these studies with high-frequency (1-10 Hz) stochastic seismograms. Our ShakeMaps represent median ground shaking estimates derived from multiple rupture scenarios with varying source parameters on each fault. To extend ShakeMap coverage beyond the simulation domain (i.e., into eastern Washington, northern Oregon, and southwestern British Columbia), we scale GMM-based ground motion estimates using amplification patterns observed in the simulations. These new ShakeMaps reveal the substantial influence of deep basin structure and seismic wave radiation patterns on shaking intensity, underscoring the importance of considering source and structural complexity in regional hazard assessments for the Pacific Northwest.

Advancing Seismic Hazard and Risk Inputs for Tbilisi
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This work presents updated seismological and exposure inputs for advancing seismic hazard and risk assessment in the Tbilisi region. A new unified earthquake catalogue was compiled using recently published datasets, including

Bondár et al. (2023), Godoladze et al. (2024), and the 2024 release of the ISC-GEM catalogue. Following harmonization and removal of duplicate events, additional earthquakes were incorporated for the broader Caucasus, with a smaller number added within Georgia. Magnitude homogenization to Mw was performed using national conversion relations for energetic parameters (K and mbv; Onur et al., 2020) and regional relations by Zare et al. (2014), producing an updated Mw-consistent unified catalogue for Georgia and the surrounding Caucasus region.

Seismic source characterization was updated using newly published active-fault information (Basili et al., 2024) together with revised area-source geometries. Probabilistic seismic hazard calculations were performed for several return periods using Vs30 = 801 m/s for the Tbilisi region, including standard PGA and SA, as well as the new spectral anchoring parameters Sa and Sß, where Sa represents the short-period spectral plateau and Sß is the spectral ordinate at 1 s, applied here for the first time in Georgia.

In parallel, a preliminary exposure database was developed, describing population, building distribution, and critical infrastructure. These components provide an initial basis for seismic risk assessment in the Tbilisi metropolitan region, and ongoing work will integrate hazard, exposure, and vulnerability information into a full risk framework.

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Gulfnet: Large-scale Nodal Seismic Deployment Along the Texas-Louisiana Coast
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Offshore Gulf of Mexico (GOM) in Texas and Louisiana has been proposed as a major site for geological carbon storage. However, there are many active geological fault systems in the region, such as the Corsair, Clemente-Tomas and Frio Fault Zones. It is critical to study the dynamics of these faults and potential seismic events associated with any fault movement. Currently, there are few seismic stations near the coast to monitor these activities. To fill this observation gap, I have undertaken a massive field deployment effort. We have deployed more than 200 three-component nodes along the Gulf Coast, spanning from Brownsville, TX to Grand Chenier, LA (~800 km), within 80 km of the coastline. Acquired data show clear surface wave dispersion curves of ambient noise correlations, demonstrating high data quality. This 19-month observation effort aims to establish a risk baseline in both seismic structure and seismicity for the GOM northern offshore region. Results on the sensitivity of our network, and a baseline seismicity catalog will be presented.

Ball Lightnings in Earthquakes and Seismic Damage
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The necessity of real estate development in earthquake-endangered areas is beyond question. Nevertheless, danger of ball lightnings in seismic events does not taken into account, although such phenomena are repeatedly observed [1]. They can generate thermal, impulsive, and concentrated loads [1 – 3]. And while the nature of the ball lightning remains unclear, knowing types of its impacts permits to apply design concepts reducing risk of ominous consequences of seismic events. So, considering possible damage because of such effect and ways to reduce risk present some features of interest.

Since the ball lightning can cause fires, it is better to avoid using agents having the potential to burn for earthquake engineering. Therefore, even though wooden structures have high seismic resistance, they are not desirable in seismic regions, at any rate without additional fire protection. Also, electric stoves and electric heating are more suitable than they that operate from natural gas or other combustibles. To withstand impulsive and concentrated loads, panel buildings are very applicable. These measures permit to increase seismic resistance of objects without the essential expenditures. It is important to reduce damage in seismic events.

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Stochastic Analysis of Avalanches and Slushflows Triggered by Earthquakes
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In some regions, for example, in British Columbia and Alaska, both avalanches and strong earthquakes are possible. Seismic slushflows are not impossible too. So, developing mathematical support for estimation of these slope processes risk in the light of data about area's seismicity presents some features of interest

Seismic load and meteorological factors have stochastic and complex nature. Accordingly, Monte Carlo method [1] is used for analysis. For utilizing this methodology, probability density functions of every meteorological factors for each day of year for given avalanche origination site are built at first. Date of a seismic event is randomly selected too. Combination of weather conditions and temblor leads to slope processes in some realization. Risk of occurring an avalanche or a slushflow is estimated as described in [2]. To compute runout distance equation of $\ddot{x} = g \cdot [\sin\alpha(x) - k(x)\cos\alpha(x)] - 0.000271 \cdot [p_{air}/p_{av}(x)]^{0.1402} \cdot \dot{x}^2$, where x is coordinate along the slope, m; g is gravity acceleration, m/s², k(x) is friction coefficient, α is slope inclination, p_{air} is air density, p_{av}(x) is density of avalanche of slushflow material, is solved. All these taken together permit to adequately assess risk of such seismic slope processes.

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Complex Monitoring of Potential Earthquake Localities
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There's no question that the basic method of prevention of human and material losses is provision for adequate strength of constructions. However, there is always a risk of exceeding design loads. Besides, it is known that temblors detrimentally affect environmental situation in regions, where they occur, resulting in panic and worsening various diseases courses. It may lead to mistakes of personnel of hazardous production facility like production and distribution of gas and oil, which may provoke severe accidents. Abnormal seismic slope processes are within bound of possibility too. So, in such case, complex monitoring potential earthquake localities would be relevant. Even though number of successful real time forecasts of earthquakes is not great, it is well in excess such as may be under random guessing.

Experimental performed time-lapse study and analysis of earthquake localities consist of searching seismic, biological, meteorological, and light earthquake precursors and processing such data with the help of fuzzy sets. Look back study of conditions before known earthquakes is done. Situations preceding Ashkhabad, Tashkent, Haicheng, Gazli seismic events are analyzed. Fairish findings are obtained. So, monitoring of potential earthquake localities, including short-term earthquake forecast and predicting possible hazardous consequences of temblors, may be considered as additional risk control system at seismic-prone areas.

Open Scientific Data: A Case Study on the Phoenix Drainage Basin (Greece) for Seismic and Flood Hazard Assessment
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Natural hazards, such as earthquakes and floods pose significant threats to human safety and infrastructure worldwide. The HOMEROS project advances hazard assessment by integrating seismic and flood analyses using Open Science practices. This study focuses on the Phoenix drainage basin in northern Peloponnese (Central Greece), at the Western Gulf of Corinth (WGoC), aiming to identify high-hazard areas and to evaluate the vulnerability of settlements in relation to the seismic and flood hazard. To promote Open Science and reproducibility, the HOMEROS project disseminates all validated datasets and analysis results via a dedicated Zenodo repository, each linked to funders' repositories and assigned persistent identifiers (DOIs) with comprehensive metadata and version control. Initial releases include GIS-based flood and seismic hazard maps under CC BY or CC BY-SA licenses, ensuring transparency, accessibility, and reusability. The datasets and the accompanying documentation for the seismic hazard and flood maps are hosted on Zenodo. The datasets also include shapefiles of rivers, drainage networks, road networks, and settlements for each study area. Seismic hazard is assessed via the probabilistic method. PGA and PGV results are obtained for return periods of 475 and 950 years through a comprehensive logic tree approach that integrates both source areas and faults alongside multiple Ground Motion Models (GMMs). Elevated seismic hazard levels are observed to the northeast of the basin, closer to the (WGoC). Areas with the most pronounced flooding hazard are predominantly situated in the northern and central parts of the drainage basin. In addition, 34% of settlements are in areas of high hazard flooding.

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Advancing the U.S. Geological Survey National Seismic Hazard Models

Oral Session • Friday 17 April • 8:00 AM Local

Conveners: Jason M. Altekruise, U.S. Geological Survey (jaltekruise@usgs.gov); Nico Luco, U.S. Geological Survey (nluco@usgs.gov); Peter M. Powers, U.S. Geological Survey (pmpowers@usgs.gov); Emel Seyhan, Moody's RMS (emel.seyhan@moody.com); Allison M. Shumway, U.S. Geological Survey (ashumway@usgs.gov)

Nonergodic Ground Motion Model for the Central and Eastern United States

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This study develops a non-ergodic ground-motion model (GMM) for the Central and Eastern United States (CEUS) using a varying-coefficient model (VCM) framework in combination with Gaussian process (GP) regression. The approach decomposes ground-motion variability into ergodic backbone behavior and spatially varying non-ergodic adjustments associated with earthquake sources and recording sites. Two existing ergodic GMMs are employed as backbone models to represent regional differences in attenuation behavior: the model of Pezeshk et al. (2018) is used for regions outside the Coastal Plains, while the model of Akhani et al. (2024) is adopted for locations within the Coastal Plains. Within the VCM framework, the coefficients associated with non-ergodic adjustments are allowed to vary smoothly as functions of earthquake and station location. These spatially varying coefficients are estimated using GP regression, which provides a flexible, data-driven representation of spatial correlation while explicitly quantifying epistemic uncertainty. The model incorporates a spatially varying non-ergodic event random effect (source term) to capture systematic differences among earthquakes, as well as a spatially varying non-ergodic site random effect (site term) to represent persistent, location-specific site response effects. For each earthquake and station location, individual non-ergodic coefficients are inferred, each characterized by a posterior median and an associated measure of epistemic uncertainty derived from the GP model. By explicitly modeling source- and site-specific effects, the proposed non-ergodic GMM substantially reduces aleatory vari-

ability relative to conventional ergodic models, in which such effects are implicitly absorbed into random variability. In probabilistic seismic hazard analysis, the resulting median ground motions are adjusted using the spatially varying non-ergodic terms, leading to location-dependent hazard estimates. These adjustments can significantly influence hazard results in the CEUS, highlighting the importance of accounting for non-ergodic behavior.

Efficient Non-ergodic Predictions of Path Effects and Applications to National Seismic Hazard Maps

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Non-ergodic ground-motion models (GMMs) that account for spatially varying path effects can reduce aleatory variability in probabilistic seismic hazard analysis (PSHA) by up to 30-40%. However, non-ergodic GMMs use Gaussian Process (GP) for which computational costs grow rapidly with the number of training observations and prediction locations, making path effect modeling computationally challenging for National Seismic Hazard Maps (NSHM) which involve large regions and multiple site locations. We present an efficient methodology using Scalable Kernel Interpolation for Products (SKIP) to compute path effects for non-ergodic GMMs that leverages these large computational and memory requirements.

SKIP separates covariance functions of multiple spatial dimensions (source coordinates, site coordinates, azimuth, ...) into products of one-dimensional functions, and then uses one-dimensional grids to create sparse approximations of large covariance matrices, greatly reducing computational and memory costs. SKIP is particularly efficient for the longer correlation lengths associated with spatially smoothly varying path effects.

A key computational advantage is that SKIP computes the covariance matrix decomposition of the observed data only once during preprocessing. Path effects predictions at new, arbitrary locations are then rapidly evaluated without recomputing the full covariance matrix, making the method efficient for NSHM applications that require predictions at tens of thousands of source-site pairs. We demonstrate this efficiency for the Alaska region, reducing computation time of path effects prediction from approximately one hour per station at 20,000 source locations using standard GP methods to only a few seconds with SKIP, making non-ergodic path effect prediction practical for NSHM applications.

Overview of the NGA-West3 Project Database

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NGA-West3 is one in a series of Next Generation Attenuation (NGA) projects directed towards database and ground-motion model (GMM) development for applications in seismic demand characterization, and represents the third phase of programs targeting shallow-crustal earthquakes in active tectonic regimes. The NGA-West3 database contains 175,244 (mostly) three-component records from 7,304 earthquakes from eight global regions: Western North America (WNA), Central America (El Salvador and Nicaragua), China, Iran, Japan, the Mediterranean (mainly Italy, Greece, and Türkiye), New Zealand, and Taiwan. The majority of new data are from WNA events and were processed using a semi-automated approach, which is new to NGA projects. The enormous amount of data in NGA-West3 and its extensive spatial coverage across WNA and other seismically active regions provides an opportunity to update the ergodic NGA-West2 GMMs and also explore the possibility of refining the models to account for smaller crustal sub-regions, especially in WNA. Under NGA-West3, there have been six teams of GMM developers working on ergodic GMMs for various intensity measures, including peak ground acceleration and velocity, 5% damped pseudo-spectral acceleration, and effective amplitude spectra. NGA-West3 ergodic GMMs are expected to be finalized in 2026. Non-ergodic GMMs for WUS and models for secondary parameters (e.g., Arias intensity, cumulative absolute velocity, and duration) will be completed in the following years. The NGA-West3 GMMs are expected to figure heavily in the next 2029 National Seismic Hazard Model update.

Suitability of Ground-motion Models for Seismic Hazard Assessments in Guam, the Northern Mariana Islands and American Samoa

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We assess ground-motion models (GMMs) developed for shallow crustal faulting or subduction zones for application in Guam, the Northern Mariana Islands, and American Samoa as part of the 2027 update of the U.S. Geological Survey (USGS) National Seismic Hazard Model for those territories. Our preliminary results indicate that the total residuals with respect to several GMMs exhibit positive trends with rupture distance, suggesting the observed ground motions display less anelastic attenuation than the GMMs. Consequently, we create regional adjustments to the GMMs by modifying the coefficient in the intrinsic attenuation term to fit the observations.

In our analysis, we use the USGS software *gmprocess* to compile a ground-motion dataset for each region. The Guam and the Northern Mariana Islands dataset contains 370 three-component records from 76 earthquakes since 2000, with magnitudes ranging from 5.0 to 7.8 and depths reaching 600 km. The ground-motion dataset for American Samoa and the surrounding region contains 475 three-component records from 128 earthquakes since 2005, with magnitudes ranging from 5.0 to 7.6 and depths reaching 250 km. We use USGS subduction zone earthquake catalog separation software and the USGS Slab-2 subduction zone geometry model to associate ground motions with either subduction zone (interface, intraslab, and outer rise) or shallow crustal earthquakes. We compute within-event residuals using linear mixed-effects regressions relative to the Next Generation Attenuation West-2 (NGA-West2) GMMs for shallow crustal earthquakes, and NGA Subduction (NGA-Sub) global GMMs for subduction zone earthquakes. For each of the as-published and our regionally-adjusted GMMs, we examine trends in the total and within-event residuals with respect to the predictive variables, such as earthquake magnitude, rupture distance, and depth, and the overall bias.

Forecasting Gridded Seismicity Rates for the USGS National Seismic Hazard Models for U.S. Pacific Territories

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Gridded seismicity models are critical for probabilistic seismic hazard analyses, accounting for off-fault and smaller-magnitude earthquakes. Here we present new gridded seismicity models for the upcoming National Seismic Hazard Models (NSHMs) for the U.S. Pacific territories of Guam, the Northern Mariana Islands, and American Samoa, which were last updated in 2012. We update the seismicity catalogs using standard NSHM methodol-

ogy but also consider new relationships to convert various magnitude types to a uniform moment magnitude. Using a catalog separation algorithm developed for recent NSHMs, we classify events into four tectonic regimes: crustal, subduction interface, subduction intraslab, and outer rise. We also probabilistically account for uncertain depths that cause additional uncertainties in tectonic classification.

For each tectonic regime, we follow processes used in the 2023 50-state and 2025 Puerto Rico and U.S. Virgin Islands NSHM updates. We construct a spatial kernel by declustering and spatially smoothing the catalog, using three declustering methods (Gardner and Knopoff, BSSA, 1974; Reasenberg, JGR, 1985; Zaliapin and Ben-Zion, JGR, 2020) and fixed- and adaptive-bandwidth smoothing methods (Frankel, SRL, 1995; Helmstetter et al., SRL, 2007; Moschetti, BSSA, 2015). To account for the tectonic complexity and large depth uncertainty of events in these subduction zones, we consider, for the first time for a U.S. NSHM, depth as well as horizontal location when building the kernel. We construct a total earthquake rate model from the full (not declustered) catalog, defined by a Gutenberg-Richter b-value and the Poisson rate of earthquakes with magnitudes above the minimum magnitude used to compute hazard. This model is computed using Monte Carlo sampling to account for uncertainties in b-value, Poisson rate, magnitudes, and completeness magnitude. Ultimately, the spatial kernels are combined with the total rate models to produce full gridded seismicity models for the Pacific territories that improve the representation of epistemic uncertainty relative to previous models.

Insights From Fault System Inversions for Rupture Modeling in the New Madrid Seismic Zone

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The CEUS-SSCn (2012) report provided many improvements for modeling the New Madrid Seismic Zone (NMSZ). The CEUS-SSCn report includes greatly improved geometry models, a comprehensive set of seismic source characteristic data, and a literature review of the hypothesized sources of deformation for the region. All of this information provides greatly improved guidance for those interested in modeling the region. The report also highlighted many of the uncertainties via a complex logic tree.

As described in the CEUS-SSCn model, the NMSZ is made up of three primary faulting structures. These faults participate together in sequences of ruptures based on historical and paleo-liquefaction data. Because these faults are believed to interact with one another and participate in sequences of events, they seem fit for modeling with a fault system inversion, similar to that used in the western US model of NSHM23.

In this study, we want to explore which insights, if any, we can gain into modeling the NMSZ by attempting to perform a fault inversion using OpenSHA (Field et al. 2003). The following steps will be performed:

- (1) We use both the simple azimuth (e.g., UCERF3; Field et al. 2014; Milner et al. 2013) and Coulomb (e.g., NSHM23; Petersen et al. 2024; Milner et al. 2022) filters to assess which combinations of fault segments connect and compare those to the pre-selected sequences in the logic tree.
- (2) We use the updated Shaw (2023) scaling relations for these ruptures and compare to the pre-selected magnitudes in the logic tree that are based on historical observations.
- (3) We constrain the inversion using the uncertainties on the logic tree recurrence branches and explore the differences in the magnitude frequency distributions (MFDs) as compared to the NSHM23 MFDs.

By taking the known information and some of the uncertainties from the CEUS-SSCn model, we want to see what comes out of an inversion, compare it to the models built by the regional experts, and highlight which insights from the inversions and rupture sets can potentially improve the models for the NMSZ.

Geophysical Studies Provide New Insights of the Tectonic Evolution of the Lajas Valley, Southwestern Puerto Rico

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Southwestern Puerto Rico (SWPR) received significant attention after the 2020-ongoing seismic sequence, including earthquakes near offshore Guayanilla Canyon. Previous research suggested that this seismicity migrated

onshore along left-lateral strike slip and transtensional fault systems, including Punta Montalva and South Lajas faults, respectively. Most previous geophysical work in this region was conducted through offshore seismic reflection surveys, leaving critical gaps for understanding the subsurface character of onshore faults. Strikes, dips, and depths of potentially active fault planes are important factors to comprehensively characterize faults in tectonically active regions and for future seismic hazard assessment updates.

Seismic reflection profiles were collected in the Spring of 2023 and 2024 across the quaternary alluvial deposits of Lajas Valley, SWPR, to image its subsurface geology and structure, including characterization of the South Lajas Fault (SLF). Two phases of data acquisition were completed using a 216-channel seismic system with a weight-drop source. Selected profiles spanned the N-S width of the valley perpendicular to its strike. Seismic data processing was carried out using the Seismic Unix processing system. Ground Penetrating Radar (GPR) reflection surveys were completed in Spring 2024, Fall 2024, and Spring 2025 along the same profile to characterize potential faulting in the shallow subsurface, and were processed using the R language processing package RGPR. Seismic reflection data display a southward-thickening stratigraphy with folded strata extending to 250 m depth, indicating that the SLF developed as a positive flower structure. The GPR profiles displayed two near-surface layers and discontinuous features possibly related to faulting to as shallow as 10 m depth. This information delivers new insights regarding the tectonic evolution of the Lajas Valley along SWPR as significant input for future updates to the Puerto Rico – Virgin Islands Seismic Hazard Map.

Stress and Fault Slip Potential of Alaskan Crustal Faults Included in the USGS National Seismic Hazard Model

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Crustal stress controls the seismogenic behavior of crustal faults, determining their propensity for frictional slip, faulting style, and slip direction, as functions of fault orientation. Alaska presents challenges to understanding stress because it is large and tectonically complex, and until recently seismic data were sparse. Here, we present a new regional crustal stress model of Alaska, northwestern Canada, and the Pacific Northwest, based jointly on focal mechanism inversions and borehole data. This model confirms previously recognized radial compression around the Yakutat block and transpression along the Fairweather-Totschunda-Denali fault system, yet also provides new details of intraplate stress heterogeneity: NNE–SSW extension in the Bering block, transpression with maximal compression rotating from ~N–S to NNW–SSE from central to northern Alaska, transtension in the Richardson Mountains, and arcuate range-perpendicular compression in the Mackenzie Mountains.

The 2023 USGS National Seismic Hazard Model (NSHM) for Alaska includes 105 crustal fault sections (1593 segments), up from only 17 sections in the previous edition. Many of these faults remain incompletely characterized from geology and geodesy, however. To complement these constraints, we conduct detailed analysis of stress along each of the 105 faults, quantifying fault slip potential—in terms of frictional instability—and the expected slip direction and angle on each of 1593 segments. The Kaltag, Iditarod-Nixon Fork, and eastern and westernmost Denali faults are poorly oriented, consistent with low geologic/geodetic slip rates. The Totschunda fault is well oriented, which may be why the 2002 central Denali rupture propagated onto it rather than the eastern Denali. Compressive splays along the Denali system appear to be activated by local stress anomalies. By contrast, stress models disagree with the NSHM faulting style of several intraplate faults: Tintina, Kaktovik, Purcell, Kanuti, Pivot, and Pass Creek. Incorporating stress constraints with geology and geodesy could improve characterization of Alaskan crustal faults in future NSHM releases.

Characterizing Differences in Seismicity Clustering and Background Rates Between Hawaii and California

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The statistics of earthquake populations are governed by stress changes and event interactions at various scales which promote non-linear event cascades and seismicity clustering. Earthquake clustering in space and time is observed in both tectonic and volcanically dominated regions; however, notable differences exist for instance during eruptive sequences.

Here, we characterize seismicity statistics in California and Hawaii and quantify differences in background rates and clustering. We compare three statistical approaches, i.e. i) Reasenberg declustering ii) Gamma distribution fit and iii) Nearest Neighbor Distance which are applied to seismicity

in Hawaii, southern California, and in ETAS catalogs with known clustering characteristics.

Tests with ETAS-catalogs suggest that background rate variations are more consistently resolvable using the Nearest Neighbor and Gamma distribution algorithm without requiring parameter adjustments to the specific study area. Nearest Neighbor method tends to overestimate background rates, whereas the Gamma distribution algorithm shows systematic underestimation, suggesting that an ensemble model can improve the performance over any single method.

The analysis of southern California seismicity produces consistent results between the different methods, and the distribution of background seismicity rates is indistinguishable from Poissonian rates at magnitudes above 3.5. Conversely, the seismicity in Hawaii exhibits notable non-Poissonian background rate changes.

Results from the Nearest Neighbor clustering analysis suggest notable differences between tectonic and volcano seismicity, including background rate changes and more pronounced spatiotemporal clustering around active volcanoes. Hawaiian seismicity is characterized by more localized spatial-temporal clustering in particular during the 2018 eruption. This difference may be a result of magmatic, hydrothermal and eruptive processes which make volcanic areas susceptible to stress perturbations and earthquake triggering at small scales.

Progress on a USGS Nationwide Long-term Time-dependent Earthquake Rupture Forecast

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We present progress on a long-term, time-dependent earthquake rupture forecast for use in nationwide seismic hazard and risk applications. To represent elastic-rebound effects, we apply the methodology developed for the 3rd Uniform California Earthquake Rupture Forecast (UCERF3), which assumes that average normalized recurrence intervals for each large, fault-based rupture follow a classic renewal model. This methodology has several advantages over previous approaches including: (1) applicability to unsegmented fault models and multifault ruptures; (2) being less biased and more self-consistent as implied by Monte Carlo simulations; (3) consistency with multi-cycle physics-based simulators, including apparent magnitude-dependent aperiodicity (which is supported); (4) consideration of historic open intervals, where we know the last event occurred before some point in time even if the exact date is unknown; (5) abandonment of the dubious notion that recurrence at a point on a fault (e.g., in a paleotrench) resembles a classic renewal model; and (6) amenability to testing against global data sets.

Applying this model nationwide has introduced additional issues that we are now contemplating, including whether and how to apply date-of-last-event constraints from individual points on faults (paleotrench data), given the unknown spatial extent of these ruptures and the possibility of undetected, more recent events. We are also exploring whether aperiodicity may depend on other factors (e.g., tectonic regime, fault maturity) and whether logic-tree branches for Weibull and lognormal distributions should be considered in addition to the Brownian Passage Time model utilized exclusively in UCERF3. There is also a daunting number of other epistemic uncertainties that would ideally be explored and possibly represented at some point. We provide an update on all these issues and present preliminary results.

Taming the Logic Tree: Combinatorics and Correlations of Epistemic Uncertainties in National Hazard Models

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Modern seismic hazard models, e.g., the USGS National Seismic Hazard Model (NSHM), treat most epistemic uncertainties as logic trees of independent choices (branching levels) with discrete values that are applied with spatial uniformity. As increased attention is paid to uncertainty quantification, modelers are adding previously excluded uncertainties faster than they are resolving existing uncertainties. Although recent NSHMs are indeed more realistic about their true uncertainty, it comes at the cost of exponential growth in logic tree size.

Consider recent USGS NSHMs for California, and for Puerto Rico and the U.S. Virgin Islands (PRVI). The earthquake rupture forecast (ERF) logic tree for the 2014 California model included 1,440 branches and increased to 121,500 branches in the 2023 update. The 2025 PRVI model, which includes uncorrelated uncertainties combined across 3 tectonic regimes, ballooned to 1.7 billion ERF branch combinations and 2.9 trillion branch combinations

when also including ground motion characterization uncertainties. Although shortcuts can be taken to reduce computational demands, e.g., downsampling and/or combining results across smaller logic trees for independent sources (i.e., each tectonic regime computed separately), the scale and composition of current logic trees are intractable for even the most advanced users and need to be rethought.

We propose a new stochastic framework for epistemic uncertainties in future NSHMs in which the logic tree size is determined considering the stability of hazard metrics and tractability for the user community. Further, this framework allows for relaxation of spatial correlations, correlation between uncertainties, and for replacing discrete parameter choices with continuous distributions. Challenges with this approach include robustly determining the logic tree size for a variety of use cases, determining appropriate correlations, and evaluating the contribution of individual uncertainties in a stochastic framework. We will show results from recent NSHMs and prototype calculations using the proposed framework.

Why are Site-specific Seismic Hazard Analyses and the National Seismic Hazard Model Different?

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It may come as a surprise to many in the engineering community that there can be significant differences in the hazard estimated from site-specific analyses and the National Seismic Hazard Model (NSHM). These differences are largely due to a difference in approach. The objective of the NSHM is to produce national maps where the hazard is uniformly consistent across the U.S. This requires making choices not considered in site-specific seismic hazard analyses. One choice involves addressing epistemic uncertainty. In the NSHM, only peer-reviewed publications can be used in model development. In a well-executed site-specific hazard analysis following the principles of the Senior Seismic Hazard Advisory Committee, all available information and data, published or not, need to be considered in model development to capture the center, body, and range of technically defensible interpretations. There are also computational constraints in calculating the hazard at > 100,000 grid points vs. a single site that may preclude considering all possible sources of epistemic uncertainty. For example, the epistemic uncertainty in fault dip is not addressed in the NSHM and this is particularly important for sites near active faults. The epistemic uncertainties on whether a fault is seismogenic, rupture behavior, and slip rates can be large especially for less well-studied faults but the NSHM often has to make simplified choices. For the NSHM, site effects need to be incorporated by using Vs30 in the ground motion models for the western U.S. and generic amplification factors in the central and eastern U.S. For a specific site, it is not surprising that the amplification can be very different performing a site response analysis versus the NSHM approach. We compared site-specific seismic hazard analyses for > 100 sites across the U.S. with the 2023 NSHM and have noted frequency-dependent differences in rock and soil hazard of more than 50%. Hence the engineering community needs to be aware of such differences when using the NSHM for estimating the hazard at a site particularly for critical and important facilities/structures.

Risk Assessment of the 2023 National Seismic Hazard Model for Alaska: Impact of Subduction Zone Implementation Decisions on Losses

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Verisk develops proprietary catastrophe risk modeling software for the insurance and reinsurance market based on the latest science and engineering knowledge. Significant updates of regional seismic hazard models like the 2023 National Seismic Hazard Model (NSHM) for Alaska generally imply a significant change in the view of risk. While the main purpose of NSHMs is for building codes, which focus on hazard at relatively lower exceedance levels such as 2% or 10% in 50 years, our purpose is to assess risk across many return periods from Annual Average Loss to the tail risk. Assumptions and simplifications embedded in the model may be inconsequential or have insignificant impact on hazard results at moderate to long return periods but can be significant for a short-term risk model strictly based on the NSHM. For the 2023 Alaska NSHM, implementation decisions related to megathrust earthquakes in the Aleutian Arc significantly impact loss estimates for Anchorage and surrounding areas. In this study, we examine several assumptions and implementation details with respect to scenario geometry and rupture dimension scaling in the 2023 Alaska NSHM to evaluate how they impact risk. We compare loss estimates using the USGS's planar approximation for the mega-

thrust to Slab2 geometry, systematically test the impact of down-dip width extent in the context of modeled and historically estimated losses for the M9.2 1964 earthquake, and assess aspect ratios and rupture dimensions of single- and multi-segment ruptures across the Aleutian Arc. We present our results to highlight the downstream implications of NSHM decisions and encourage more realistic rupture geometries to be implemented in future updates.

Updated Shaking Potential and Ground Motion Hazard Maps for California

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The California Geological Survey (CGS) first published the *Earthquake Shaking Potential for California* map (Map Sheet 48, MS48) in 1999 based on the USGS National Seismic Hazard Models (NSHM) and has revised it following each major NSHM update. We present a new MS48 based on the 2023 NSHM, incorporating spatially variable site amplification. As in earlier editions, MS48 depicts shaking with a 2% exceedance probability in 50 years. The new map departs from previous versions by expressing shaking using the Modified Mercalli Intensity (MMI) rather than 1.0-s spectral acceleration (SA). MMI values are derived from peak ground velocity (PGV) using the Worden et al. (2012) ground-motion-to-intensity conversion equation (GMICE), selected because the PGV–MMI relation produces the smallest residuals among available GMICEs and provides a robust proxy for long-period shaking that captures site and basin effects more effectively than short period shaking.

In addition to MS48, we developed an interactive web platform that displays statewide hazard maps for PGV, peak ground acceleration, SA at multiple periods, and MMIs (using several GMICEs) for 2 % and 10 % exceedance probabilities in 50 years. The platform supports side-by-side comparison of any two maps, helping users understand differences among ground-motion parameters and the substantial variation in MMIs derived using different GMICEs. It also hosts supporting datasets: including historical earthquakes, fault slip-rates, site conditions, average annualized earthquake loss estimates, and downloadable ground-motion and MMI data files. Together, the updated MS48 and web tools integrate modern source and ground motion modeling, improved site-response representation, and intuitive shaking metrics to support urban planning, emergency management, and public communication — enhancing the state's ability to assess risk, prioritize mitigation, and strengthen earthquake resilience.

Fully Probabilistic Ground Motions Replace Deterministic Capping in 2026 Update of NEHRP Recommended Seismic Provisions for New Buildings and Other Structures

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Since 1997, the Maximum Considered Earthquake (MCE) ground motion levels in U.S. building codes have been subject to deterministic capping whenever the otherwise probabilistic ground motions exceed specified limits. This persisted even after the introduction of Risk-targeted MCE (MCE_R) ground motions in the 2009 *NEHRP Recommended Seismic Provisions for New Building and Other Structures*. Deterministic capping causes unspecified and irregular increases in the otherwise-uniform estimated risk of collapse of buildings designed to resist MCE_R ground motions, leading to inconsistencies across locations, spectral periods, and soil classifications. Furthermore, defining deterministic caps has become increasingly subjective, particularly following the 2014 Third Uniform California Earthquake Rupture Forecast, which challenged the notions of “characteristic earthquakes” and “active faults.” For these and other reasons, we have led exploration of fully probabilistic alternatives to deterministic capping for the 2026 *NEHRP Provisions*. The options considered included: (1) eliminating the deterministic capping without modifying the probabilistic ground motions; (2) replacing the deterministic capping with a higher, uniform target risk of collapse for the probabilistic MCE_R ground motions; (3) replacing the deterministic capping with higher target risks only where the probabilistic ground motions exceed specified limits; and (4) further confining the higher target risks of the third option to relatively short spectral-acceleration periods. Via formal balloting of written proposals detailing tech-

nical justifications for the changes and their impacts relative to prior building codes, the Building Seismic Safety Council selected the second option for the 2026 *NEHRP Provisions*. This change increased the target risk of collapse from 1% to 1.5% in 50 years, whereas deterministic capping has historically resulted in estimated collapse risks as much as an order of magnitude higher, reaching 13% in 50 years. Thus, this replacement of deterministic capping decreases the MCE_R ground motions in most cases but increases it in others.

Advancing the U.S. Geological Survey National Seismic Hazard Models [Poster]

Poster Session • Friday 17 April

Conveners: Jason M. Altekruise, U.S. Geological Survey (jaltekruise@usgs.gov); Nico Luco, U.S. Geological Survey (nluco@usgs.gov); Peter M. Powers, U.S. Geological Survey (pmpowers@usgs.gov); Emel Seyhan, Moody’s RMS (emel.seyhan@moodys.com); Allison M. Shumway, U.S. Geological Survey (ashumway@usgs.gov)

POSTER 40

An Updated Empirical Probability Model for Surface Faulting Utilizing Rupture-width Ratio for Crustal Earthquakes

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This study presents an updated empirical model for the probability of surface rupture (PSR) for crustal earthquakes for use in probabilistic fault-displacement hazard analyses. The dataset of crustal earthquakes is based on a literature review of source parameters of earthquakes between 1970 to 2023. The new PSR model is based on the rupture-width ratio (RWR) rather than the moment magnitude (M) and style of faulting used in most PSR models. The RWR is calculated as the rupture width (W_{Rup}) divided by the fault width. If the rupture dimension is unavailable, we assumed a source scaling model from Huang et al. (2024) that considers the width limit based on the seismogenic thickness for the region to estimate W_{Rup} . The proposed PSR model uses a bounded, normalized gamma cumulative distribution function (CDF) that incorporates two key physical factors: the influence of fault geometry parameters, such as fault dip angle and seismogenic thickness, and localized rupture locations at depth. The updated functional form, derived from the gamma CDF rather than a typical logistic regression, avoids unphysical trends arising from a sparse subset of earthquakes, such as larger M corresponding to lower probabilities of surface faulting or a step function at a certain M threshold. Additionally, by definition, when RWR equals 1 (meaning the rupture propagates across the entire rupturable fault), the probability is constrained to be close to unity. A logistic regression does not achieve this constraint, but it is met using a gamma distribution for the CDF. Other physical indices, such as styles of faulting, regional differences, surface and source-zone material stiffness, and a longer fault indicated by the fault aspect ratio, were evaluated but not included in the model because of high epistemic uncertainty caused by limited earthquake data in certain subgroups. The proposed PSR model accounts for regional differences in the seismogenic thickness, fault dip, and a normalized average hypocenter depth, while incorporating empirically constrained forms that are better suited to a fault-specific evaluation of the PSR.

POSTER 41

Subduction Zone Earthquake Rupture Forecasts in USGS National Seismic Hazard Models

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Shaking caused by subduction zone earthquakes can be a large contributor to overall earthquake hazard in U.S. Geological Survey (USGS) National Seismic Hazard Models (NSHMs). Recent and ongoing efforts to characterize hazard from subduction zones across the U.S. and its territories have shown that it is difficult to apply the same earthquake rupture forecast (ERF) modeling techniques everywhere. For example, in the conterminous U.S. (CONUS) NSHM, the slow-slipping Cascadia subduction zone is characterized by a reliable geologic and paleoseismic record of large, zone-rupturing earthquakes, but the

earthquake catalog is depleted in $M < 8$ events. The subduction zone ERF is therefore limited to large $M8+$ events and localized patches of low-rate subduction intraslab events. In contrast, the fast-slipping Alaska-Aleutian subduction zone (AASZ) is constrained by a modest paleoseismic record; high slip-rates permit development of geodetically derived slip-deficit rates. The AASZ also has a rich historic record of smaller earthquakes, so the ERF also includes a gridded seismicity component with smaller $M5-8$ ruptures. Other regional NSHMs, such as the 2025 Puerto Rico and U.S. Virgin Islands (PRVI) NSHM and upcoming NSHMs for the inhabited Pacific island territories, lack geologic constraints and rely exclusively on estimates of slip-deficit on the interface to constrain rupture rates. The 2025 PRVI NSHM was the first to adopt an inversion-based fault-system solution for a subduction zone ERF, as was used for the active faults across the western U.S. in the 2023 CONUS NSHM. Going forward, to standardize ERF modeling techniques across NSHMs, the USGS will expand use of the inversion methodology to other subduction zones with varying constraints. To support and plan for this effort, we compare the different subduction zones considered in the USGS NSHMs in terms of geometry, geologic and paleoseismic constraints on historic ruptures, and earthquake catalog rates. We also discuss options for uniform ERF implementations and ways to improve the consistent representation of epistemic uncertainty across subduction zone ERFs.

POSTER 42

Preliminary Regionally Adjustable Models for PGA, PGV, and 5% Damped Pseudo-spectral Acceleration Based on the NGA-West3 Dataset

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We develop earthquake ground-motion models (GMMs) for peak ground acceleration, peak ground velocity, and 5% damped pseudo-spectral acceleration as part of the Next Generation Attenuation (NGA) West3 project. The primary inputs are moment magnitude (M), style-of-faulting, depth to the top of rupture, Joyner-Boore distance (R_{JB}), and the time-averaged shear-wave velocity in the upper 30 m (V_{S30}), with adjustments to account for regional variations (e.g., anelastic attenuation, V_{S30} -scaling). We consider over 91,000 ground-motion records from 1091 $M \geq 3$ earthquakes in the Western Contiguous United States and Alaska, Mexico, Italy, Greece, Turkey, Japan, Taiwan, and New Zealand. Model coefficients are fit period-by-period through independent mixed-effects regressions that include random effects for each earthquake and site. Additionally, we fit a random effect on the attenuation slope for each earthquake to avoid tradeoffs between variations in attenuation and event terms (e.g., Baltay et al., 2020). Model coefficients are smoothed to yield spectral shapes that lack irregularities. The interplay between near-source saturation and geometric spreading when describing amplitude decay in R_{JB} is carefully evaluated in model development. Geometric spreading is modeled using a bilinear function with a hinge distance set to 50 km and slopes that include M-dependence. The nonlinear site amplification model is developed using a semi-empirical approach and is formulated to enforce saturation at the lowest V_{S30} . We are also developing a GMM for the effective amplitude spectra (EAS, the smoothed quadratic mean of two horizontal-component Fourier amplitude spectra) from a compatible dataset in parallel to this model and plan to investigate how its converted PSA model aligns with our model.

POSTER 43

Exploring the Limits of Multi-fault Rupture Modeling and Inversions: Lessons From Offshore Portugal and California

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Multi-fault rupture modeling is essential for capturing earthquake hazard complexity; however, its practical implementation depends strongly on data availability. We present two contrasting case studies - crustal faults offshore Portugal and in California - to highlight challenges and trade-offs in applying rupture inversion methodologies in data-poor versus data-rich settings. Offshore Portugal, where geologic and seismic constraints are sparse, the 1755 Great Lisbon earthquake remains enigmatic, though there is compelling evidence for a complex multi-fault rupture. To represent similar rare but catastrophic events under such uncertainty, we use OpenSHA (Field et al., 2003)

to construct a multi-fault rupture set based on Coulomb favorability metrics (Milner et al., 2022) across the most active offshore faults. Given limited constraints on fault geometry, slip rates, and even fault completeness, we explore a broad parameter space (e.g., varying inversion settings and b-values) to capture a wide range of plausible ruptures. Sensitivity analyses offshore Portugal suggest that some historically proposed connections, such as involvement of the subduction interface, are implausible. The final averaged solution significantly increases the likelihood of $Mw 7.5+$ events compared to single-fault models, offering a more realistic view of regional hazard and tail risk. In contrast, California’s extensive fault, geodetic, and seismicity datasets enable well-constrained multi-fault rupture inversions, as implemented in NSHM23 (Petersen et al., 2024). However, the resulting rupture sets can become prohibitively large for practical hazard and loss calculations. We therefore explore strategies to optimize rupture sets by reducing redundancy while preserving hazard. Together, these case studies show that multi-fault rupture modeling requires balancing completeness and practicality: broad exploration and explicit uncertainty treatment in data-poor regions, and optimization of well-constrained inversions in data-rich environments. These insights inform future seismic hazard models across diverse tectonic settings and applications.

POSTER 44

Referenced Empirical Ground Motion Model for the Coastal Plain Region of the United States

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In this study, we develop a ground motion model (GMM) for the U.S. Coastal Plains using the Referenced Empirical Method (REM) proposed by Atkinson (2008). The host-region reference model is constructed from four NGA-West2 GMMs: Abrahamson et al. (2014), Boore et al. (2014), Chiou and Youngs (2014), and Campbell and Bozorgnia (2014). The dataset includes horizontal peak ground acceleration and pseudo-spectral acceleration over periods from 0.01 to 10 s, compiled from Goulet et al. (2014), Chapman and Guo (2021), and Thompson et al. (2023).

In the first step, residuals are calculated as the differences between observed ground motions and predictions from the reference model in natural-logarithmic space. These residuals are then analyzed using a mixed-effects regression framework to derive period-dependent adjustment factors. The adjustment factors quantify the ratio of observed ground motions in the target region (the Coastal Plains) to those predicted by the host-region GMMs (western North America). Applying these factors transforms the host-region GMMs to represent Coastal Plains conditions. Finally, the robustness of the resulting GMM is evaluated through residual diagnostics and comparisons with previously published models.

POSTER 45

A Ground-motion Model for the Vertical Response Spectra Component Using the NGA-East Dataset

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This study develops a ground-motion model (GMM) for estimating vertical ground-motion components in Central and Eastern North America (CENA) using the referenced empirical method (REM) of Atkinson (2008). To the authors’ knowledge, this is the first vertical GMM for CENA formulated within the REM framework. Epistemic uncertainty associated with the selection of the reference model is addressed by incorporating three alternative host-region models: Stewart et al. (2016), Gülerce et al. (2017), and Bozorgnia and Campbell (2016). Vertical response spectra were computed from NGA-East recordings, and residuals were evaluated between the vertical-component pseudo-spectral accelerations (0.01–10.0 s) and the mean predictions of the reference models.

A mixed-effects regression approach was then employed to derive adjustment factors that refine the predictions and to estimate the associated variance components. The performance of the proposed GMM is evaluated through residual analyses and comparisons with the observed data.

POSTER 46

Robust Imaging of Western US Fault Slip Rates and Off-fault Deformation From GNSS Data and Seismicity

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Fault slip rates are key parameters that are needed to quantify earthquake hazard in tectonically active plate boundaries. Accuracy of these parameters is critical for generating important products such as the US National Seismic Hazard Model (NSHM). However, fault networks in the Pacific/North America/Juan de Fuca plate boundaries system in the Western United States (WUS) are complex, consisting of many hundreds of faults with slip rates that vary by several orders of magnitude, and have varying degrees of connectivity, style, and structural maturity. Recently several studies have shown that geodetic data combined with plate-boundary scale fault databases can help to constrain the slip rates. However, the models contain significant uncertainties and indicate that a substantial proportion (30-60%) of the deformation moment is occurring ‘off-fault’, i.e., is not associated with a specific fault segment in the database.

To address these issues, we apply a new analysis method that integrates geodetic deformation models with a seismicity database to constrain the distribution of rupture potential throughout the fault network. Our ensemble modeling approach generates many models automatically with block boundaries that conform to faults in the NSHM source database and areas with spatially denser seismicity. Kinematics of rotations in each model are constrained by the GNSS velocity field. The robust automated and iterative framework generates large numbers of slip rate solutions, giving many estimates for each fault. The framework effectively reduces the impacts of outliers, reduces reliance on geologic slip rates, reduces biases from subjective choices on block geometries, and explicitly parameterizes off-fault deformation as the strain accumulation not occurring on the set of faults in the NSHM database. In this presentation we will explain the methodology, properties of the solution, and compare our results to fault slip rates and off-fault deformation in previously published WUS plate boundary scale deformation models.

POSTER 47

National Seismic Hazard Model Updates for American Samoa and Guam and the Northern Mariana Islands: Geophysical Source Inputs

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The National Seismic Hazard Model (NSHM) Project of the U.S. Geological Survey (USGS) is preparing updated models to assess earthquake ground-shaking hazards for American Samoa and Guam and the Commonwealth of the Northern Mariana Islands. The previous USGS models for these regions were completed in 2012, and significant updates are currently being considered. The research and development process for these NSHMs is consistent with past USGS workflows. To support the model updates, we reviewed available geologic and geophysical data on the islands and the surrounding ocean floor and developed a geodatabase that summarizes the fault section inputs. New inputs for the earthquake rupture forecast (ERF) components of the models include updated and additional crustal fault sections; recent field studies on the islands of Saipan and Guam contribute datasets that include age constraints and fault section geometries. The Mariana and Tonga-Kermadec subduction zones are also characterized based on available data and published studies. The areas of interest (AOI) have been adjusted from the 2012 models, but they still cover significant regions of Micronesia (Guam and the Northern Mariana Islands) and Polynesia (American Samoa). The previous extent of the Micronesia subregion is largely retained, including the major features of the Mariana subduction zone. The AOI for American Samoa will be smaller than in the 2012 NSHM. The updated model includes only the northernmost section of the Tonga–Kermadec subduction zone and an area of back-arc spreading,

whereas the previous work also included Fiji and islands of New Zealand. The AOI also extends far enough north to capture seismicity related to the Samoan hotspot track. Development of these geophysical inputs for the seismic hazard model represents the initial steps in the workflow that informs the ERF and other components of the source and ground-motion models for the NSHMs.

POSTER 48
Maximum-direction Spectral Acceleration Conversion Factors (RotD100/RotD50, RotD100/GMxy) for Subduction Earthquakes
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Spectral acceleration (SA) is one of the primary intensity measures used in empirical ground-motion models (GMMs), yet it depends on the orientation of the horizontal components. Using a single orientation can therefore overlook important directional characteristics of earthquake shaking. To mitigate this limitation, several scalar definitions have been proposed to combine the two horizontal components into a single SA measure. Ratios between these definitions are critical when integrating multiple GMMs in logic-tree frameworks for probabilistic seismic hazard analysis (PSHA) or when converting hazard-consistent spectra between different horizontal definitions. While these ratios have been extensively studied for shallow crustal earthquakes, their applicability to subduction environments remains uncertain due to fundamental differences in rupture depth, stress drop, and wave-propagation paths. In this study, period- and source-dependent spectral acceleration conversion models are developed using an NGA-subduction strong-motion dataset, excluding small-magnitude events ($M_w < 3.5$) to ensure stable and engineering-relevant spectral shapes. The proposed models are compared with existing crustal-region conversions, revealing notable discrepancies. Results indicate that crustal-based conversion models are not appropriate for subduction ground motions, highlighting the need for subduction-specific relationships to maintain consistency in engineering applications. This study shows the ratios $SARotD100/SARotD50$ and $SARotD100/SAGMxy$ increase with periods > 0.1 sec, with the strongest directional effects observed for intraslab and shallow-crustal events, whereas $SARotD50/SAGMxy$ remains nearly constant across all periods.

POSTER 49
Revisions to the 2023 50-state National Seismic Hazard Model
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We present revisions to the 2023 50-state U.S. Geological Survey (USGS) National Seismic Hazard Model. Following publication of the model, and prior to its adoption by building codes, we identified several issues that necessitated adjustments to the model. These adjustments include: (1) revised weighting of ground-motion models (GMMs) in the Intermountain West to better account for uncertainty in ground-motion amplitudes across the low-seismicity regions of the Colorado Plateau and surrounding areas; (2) revised weighting of gridded seismicity models in the central and eastern U.S. (CEUS) where adaptive smoothing methods overly accentuate increases in earthquake rupture rates implied by the 2023 catalog; (3) revised implementation of magnitude 7 to 8 subduction interface ruptures in Alaska to better distribute earthquake rate across the width of the Alaska-Aleutian subduction zone; (4) corrections to errors in computer-code input files describing the geometry and rate of two faults in the western U.S. and three areal source zones in the CEUS; and (5) adjustments to GMM soft-soil site-amplification terms in the CEUS to extrapolate published models. We present details of each update and the implications for hazard. The revised model is accompanied by high-resolution datasets of gridded hazard for the conterminous U.S. (0.05° spacing), Alaska (0.1° spacing), and Hawaii (0.02° spacing), for spectral accelerations at 21 periods, peak ground acceleration, peak ground velocity, and 8 site conditions. Such hazard data from the revised model is also available via the USGS Earthquake Hazard Toolbox (<https://earthquake.usgs.gov/nshmp/>). The revised model is currently being considered for inclusion in building design provisions and other hazard and risk assessment products.

POSTER 50
Time-dependent Cascadia Subduction Zone Hazard: Sensitivity to Paleo Chronologies, Locking and Renewal-Model Choice
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Paleoseismic and historic records indicate full-margin Cascadia Subduction Zone (CSZ) megathrust ruptures ($M_w 9+$) depart from a Poisson, memoryless process, motivating a renewal-based, time-dependent probability model. In this study, we investigate the sensitivity of time-dependent modeling choices on $M_w 9+$ full margin rupture probabilities. Here we quantify how epistemic and aleatory uncertainties propagate into 50-year earthquake probabilities by (1) comparing alternative interpretations of the paleoearthquake chronology (Goldfinger et al., 2025 update; Nelson et al., 2021; Walton et al., 2021), (2) testing renewal distributions (Brownian passage time, Weibull, lognormal, Gaussian) and mixtures using a tempered maximum-a-posteriori mixed-model approach, and (3) imposing a priori physical constraints through (i) removal of implausibly short inter-event times for $M9+$ events (<100 yr) and (ii) geodetic locking-based bounds on mean recurrence. For $M_w 9+$ full-margin events, a three-component mixture adequately captures observed interval variability, but distributional choices have little influence on hazard because the ~ 300 -year open interval since 1700 CE places the system far beyond a short-recurrence mode (mean ~ 200 yr). Excluding short repeats increases 50-year conditional occurrence probability by only ~ 1 -2%, and alternative locking models likewise produce minor changes. In contrast, hazard is most sensitive to the interpretations of the earthquake-timing history: 50-year conditional rupture probabilities differ by up to ~ 6 -7% across the three chronologies. These results emphasize that uncertainty in paleo-event interpretation can dominate time-dependent CSZ hazard and should be explicitly explored and incorporated, for example, via logic-tree weighting.

POSTER 51
The U.S. Geological Survey 2025 National Seismic Hazard Model for Puerto Rico and the U.S. Virgin Islands
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The U.S. Geological Survey recently updated the National Seismic Hazard Model (NSHM) for Puerto Rico and the U.S. Virgin Islands (PRVI). The first version of the PRVI NSHM was released in 2003, and therefore, this 2025 update includes over 20 years of updated geologic, geophysical, and engineering data, methods, and models. Updates follow similar efforts performed in the recent 2023 50-state NSHM. However, this is the first NSHM in which we (1) apply an inversion methodology to subduction interface fault sources in the earthquake rupture forecast (ERF) model, (2) develop scaled backbone median ground-motion models and independent aleatory variability models that are applied in the ground-motion characterization (GMC) model, and (3) calculate epistemic uncertainty related to alternative scenarios in the ERF and GMC models for all grid points in the study region. Long-term time-independent mean hazard calculations were performed for peak ground acceleration and 5%-damped pseudo-spectral acceleration at 21 periods from 0.01 to 10.0-s, for eight National Earthquake Hazards Reduction Program site conditions ranging from $V_{s30} = 150$ to 1500 m/s, and for 2%, 5%, and 10%

in 50-years probabilities of exceedance (return periods of 2475, 975, and 475 years, respectively). Epistemic uncertainty, in the form of selected percentiles, were also calculated for a suite of test sites and all grid points in the study region for limited periods, site conditions, and probabilities of exceedance. Selected results, including comparisons with the 2003 PRVI NSHM, will be shown and discussed for selected periods, site conditions, and probabilities of exceedance. When comparing the 2025 PRVI NSHM with the 2003 PRVI NSHM, hazard is generally higher at shorter periods and lower at longer periods, as a result of updates in both ERF and GMC models.

POSTER 52
Fault Based Inversion Modeling for the San Francisco Bay Area: Assessing Slip Rates and Characterizing Off Fault Deformation
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The National Seismic Hazard Model (NSHM) produces estimates of earthquake hazards across the U.S. In the tectonically active western U.S., the high weight of geodetic models in the earthquake rupture forecast (80% for the 2023 update to the NSHM), emphasizes the importance of this modeling method for assessing seismic hazard and analyzing deformation in active tectonic regions. One major question is how much plate motion is taken up by slip on faults versus off-fault deformation. We build a detailed fault-based inversion model for the San Francisco Bay Area to characterize regional fault slip rates and off-fault deformation. We consider horizontal strain rates derived from the dense Bay Area Global Positioning System (GPS) velocity field, as these are interpretable with backslip models of slip rates. The effects of increasing complex fault geometry, vertical heterogeneity in elastic properties, and discrepancies between modeled and observed data are explored. The fault-based inversion tool, MODSTRAIN, allows for the inclusion of segmented and geometrically complex faults. Closer fault spacing is possible by converting GPS horizontal velocity gradients to surface strain rates. 4979 horizontal velocity vectors of interseismic displacement are used to extract strain and rotation rates in the Bay Area, spanning westward to the San Gregorio Fault and eastward to the Greenville Fault. MODSTRAIN computes static Green's functions for prescribed faults in either an elastic homogeneous or vertically heterogeneous elastic half-space. Using these Green's functions, slip deficit rates and their standard deviations are derived from inversion of strain (and rotation) rates.

We study three structural models with increasing fault complexity. Each model has two complementary scenarios, one with an elastic homogeneous earth and the other a vertically heterogeneous earth. Modeled on-fault and off-fault deformation are compared across the six model iterations. These local models support future work using field observations to cross-verify model results of off-fault deformation with local geomorphology and test model validity.

POSTER 53
Determining San Francisco Bay Area Fault Slip Rates With a Plate Boundary Geomechanical Model
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This project aims to improve our understanding of fault slip rates along the complex and hazardous tectonic plate boundary in the San Francisco Bay Area. Fault slip rates represent the average amount of movement along a fault per year. Slip rates used in the current National Seismic Hazard Model (NSHM) come from combined geologic fieldwork and laboratory methods as well as geodetic inversions. Geomechanical forward models can also be used to generate synthetic slip rate data. Toward this goal, we develop a mechanical model that simulates fault slip across the complex plate-boundary fault system in the Bay Area. The quasistatic model incorporates the elastic constitutive behavior of the surrounding rocks, as well as the conservation of mass and momentum. The model allows complex, segmented, non-planar, three-dimensional faults to slip simultaneously in response to applied plate motions. As a result, it captures stress transfer and interaction between fault segments, enabling slip to be partitioned across the entire fault system.

Our structural model is approximately 675 kilometers long in the North-Northwest to South-Southeast direction and 450 kilometers wide in the East-Northeast to West-Southwest direction. It honors the relative motions of the

Pacific and North American plates; therefore, we apply 25 mm/yr on the lateral sides oriented at 325 degrees. We develop a texture mapping technique to introduce a plate rate gradient along the model sides perpendicular to the fault. As a result, we get 15 mm/yr average slip rate along a geometrically realistic San Andreas Fault (SAF). This calibrates our model to the geological and geodetic estimates of SAF rates. As we introduce additional Bay Area faults to the model, we continue to update boundary conditions to match the average rate along the SAF. In this way, we determine slip rates on secondary surrounding faults and study how they vary with variations in fault connectivity and segmentation.

POSTER 54
Evaluating Variation in Rupture Directivity From Hypocenter Distributions in PSHA
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Rupture directivity models modify the median and variability of ground-motion models (GMMs), but alternatives remain for how to properly incorporate them into probabilistic seismic hazard analyses (PSHAs). Directivity model modifications depend on either specific hypocenter locations or the cumulative influence of a hypocenter distribution, and hence hypocenter modeling decisions have an impact on hazard calculations. Here, we evaluate key modeling parameters used in representing directivity within PSHA. We vary hypocenter probability distributions along-strike and down-dip, altering how the mean hazard accumulates directivity effects from each rupture. Exponential and Gaussian probability distributions of hypocenters are examined and compared with a baseline uniform distribution that assigns equal weight across the rupture hypocenters. We also explore asymmetric strike-parallel distributions to simulate cases in which faults preferentially rupture in one direction. The rupture representation is progressively expanded from simple geometries to more complex configurations, including those in the third Uniform California Earthquake Rupture Forecast (UCERF3) fault database. Comparing hazard maps, we find that symmetric variations in hypocenter distributions have relatively limited influence on mean hazard. However, asymmetric distributions strongly affect the spatial distribution of amplification that arises from the superposition of multiple directivity adjustments, leading to localized changes off the ends of the fault. Finally, we evaluate the contribution of hypocenter variability to aleatory uncertainty by examining differences in the hazard curves among individual hypocenter realizations. Both this aleatory and the aforementioned epistemic uncertainties might be important to capture when assessing the range of possible hazard outcomes.

POSTER 55
Overview of Updates to the U.S. Geological Survey National Seismic Hazard Models for Guam, the Northern Mariana Islands, and American Samoa
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The U.S. Pacific island territories of Guam, the Northern Mariana Islands, and American Samoa are located near the Pacific plate boundary, face appreciable seismic hazard, and are home to $\sim 265,000$ residents. Probabilistic seismic hazard models for these islands developed by the U.S. Geological Survey (USGS) were last published in 2012. The USGS National Seismic Hazard Model

(NSHM) Project is currently updating these models to incorporate the latest seismic, geodetic, and geological datasets and state-of-the-art hazard modeling methods, and to ensure consistency with the range of outputs for other current NSHMs. The revised models use updated earthquake catalogs, recent fault mapping studies that include faults on the islands of Saipan and Guam, geodetic measurements of crustal deformation and subduction rates, and observed ground motions for selecting and developing region-specific adjustments to recently developed ground-motion models. For example, the new catalog has 22 M6+ events occurring near Guam and the Northern Mariana Islands and 53 M6+ events occurring near American Samoa since 2012. The update also incorporates new and revised methodological approaches, including advances in earthquake catalog analyses and fault-system inversion. In this presentation, we review the prior 2012 hazard models, summarize the components of the new hazard models, and report on the status of ongoing updates.

Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice
Oral Session • Friday 17 April • 10:30 AM Local
Conveners: Sanjay Bora, Earth Sciences New Zealand (s.bora@gns.cri.nz); Asako Iwaki, National Research Institute for Earth Science and Disaster Resilience (iwaki@bosai.go.jp); Grigorios Lavrentiadis, University of Buffalo (glavrent@buffalo.edu); Camilo Pinilla-Ramos, GFZ Potsdam (camilo.pinilla@berkeley.edu); Chih-Hsuan Sung, University of California, Berkeley (karensung@berkeley.edu); Paola Traversa, Electricity of France (paola.traversa@edf.fr)

Implementing Physics-based Ground-motion Simulations in Probabilistic Seismic Hazard Analysis Practice
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Physics-based simulations of ground motions using 3-D crustal models can model systematic physical effects of source geometry and site-source-specific wave propagation that are missing from regional ground-motion models (GMMs). The 3D simulations have the potential to greatly improve the accuracy of ground-motion estimates for a specific site-source pair as compared to traditional GMMs. A goal of physics-based simulations is to replace the GMMs with directly calculations of the time series from 3-D simulations in hazard calculations; however, these simulations have not been widely adopted in probabilistic seismic hazard analysis (PSHA) practice. Before use in PSHA, a requirement is adequate validation of the 3-D simulations for the median, and variability of the ground motion and estimation of the epistemic uncertainty of the median and variability due to uncertainties in the simulation method itself and the uncertainties in the inputs to the simulation method (rupture generator and 3-D velocity structure). After validation, there are two key issues that limit the direct application of 3-D simulations into PSHA: the ground motion is needed for all scenarios in the source characterization; and the hazard is usually controlled by the upper tail of the ground-motion distribution. Directly replacing the GMM with time series from simulations requires a large number of scenarios to model all the sources and a large number of realizations for each scenario to constrain the upper tail of the distribution: if the mean epsilon from the hazard about 2, then 100s of realizations are needed to constrain the probability of exceedance. A practical alternative is to use the simulation results to modify a reference regional GMM using the non-ergodic GMM framework that can mimic the main source, path, and site-specific effects on the ground motion. This approach involves some spatial smoothing of the source-site-specific effects resulting in lose of some of the improved accuracy of the 3-D simulations but with the key advantage that it can be implemented in PSHA. Examples applications of the recommended approach to are shown.

Validation for Cybershake in Northern California
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The SCEC CyberShake platform implements a repeatable scientific workflow to perform 3D physics-based probabilistic seismic hazard analysis (PSHA). CyberShake performs wave propagation simulations to produce strain Green tensors, which are then convolved with kinematic rupture realizations to synthesize seismograms. Low-frequency deterministic simulations are combined with high-frequency stochastic simulations to produce broadband PSHA results up to 25 Hz. In addition to three-component seismograms, spectral acceleration, durations, site-specific hazard curves, and regional hazard maps, CyberShake data products include the recently-calculated smoothed effective amplitude spectra (EAS), utilized by a variety of engineering applications.

We will present new analyses of northern California CyberShake Study 24.8 and discuss results from CyberShake validation simulations using the 1989 M6.9 Loma Prieta earthquake. We find that CyberShake produces better goodness-of-fit results and lower bias at periods ≥ 1 Hz over 64 Loma Prieta realizations than both 1D Broadband Platform simulations and the NGA-West2 GMMs. To further compare CyberShake to GMMs, we develop partially non-ergodic GMMs for CyberShake and compare them to the NGA-West2 GMMs. The median predictions of Study 24.8 are significantly larger than the GMMs at 2s, in contrast to previous studies. Our analysis finds that the more coherent velocity model and strong directivity effects in Study 24.8 contribute to these large ground motions. Several factors lead to the strong directivity, including: 1) all the major faults in Study 24.8 rupture approximately parallel to the sites; 2) the 3D velocity model used in Study 24.8 is highly coherent; and 3) the faults in Study 24.8 tend to be smooth. We also conducted small-scale simulations to quantitatively investigate the impact of each factor on directivity in CyberShake studies. These regional features identified by CyberShake Study 24.8 highlight the need to develop non-ergodic GMMs.

Performance Evaluation Metrics for Velocity Models Used for Numerical Simulations of Ground Motions for Seismic Hazard Applications

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The exponential growth in numerical capabilities for three-dimensional, regional-scale physics-based simulations is driving their adoption in seismic-hazard analyses as a complement to empirical GMMs; however, this transition is impeded by the fundamental question of whether the quality of simulation inputs can yield more accurate ground-motion predictions than ergodic GMMs. We propose a systematic framework for evaluating the performance of regional-scale velocity models used in numerical ground-motion simulations. Two complementary metrics are introduced:

(1) Fourier-amplitude spectra (FAS) across a range of frequencies, quantifying the model's ability to reproduce ground motions at different characteristic length scales, and (2) waveform duration, which serves as a proxy for the temporal phasing distribution of the simulated wave fields. Residuals are defined relative to recorded data and a reference ergodic ground-motion model, enabling the assessment of systematic bias, variability, and source-site-specific accuracy. This methodology is applied to the USGS-developed velocity model for the San Francisco Bay Area. For this example, the median bias in FAS is not significantly different from zero, indicating no systematic bias in the median amplitudes of the simulated ground motions. The variability of the simulated waveforms is consistently lower than observed, suggesting the model is overly smooth at the investigated scales. For frequencies below 0.5Hz, the simulations provide more accurate source-site-specific predictions of the FAS than ergodic GMMs; however, the GMM performs better at higher frequencies. Additionally, the waveform duration in the simulations is, on average, 35% shorter than that of the recordings. These results emphasize the need to incorporate finer-scale characterizations to improve both amplitude and timing/phasing features of simulated ground motions. This evaluation methodology provides a quantitative basis for evaluating velocity models and identifying the frequency bands over which physics-based simulations can reliably complement traditional GMMs in seismic hazard analyses.

Toward the 2028 Short-term Time-dependent Revision of New Zealand National Seismic Hazard Model: A Framework for Ground-motion Characterization Modelling Update
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The 2022 revision of the New Zealand National Seismic Hazard Model (NZ NSHM 2022) employs a state-of-the-art ground-motion characterization (GMC) framework that incorporates NGA-West2 and NGA-Subduction ground-motion models (GMMs) through a logic-tree approach. The updated NGA-Subduction models represent a significant departure from previous global subduction models in both median predictions and aleatory variability, with substantial implications for hazard estimates. In this study, we present a comprehensive plan for updating the GMC logic tree for the forthcoming 2028 one-year time-dependent NZ NSHM revision, addressing several key questions that remained unresolved in the 2022 update: (1) distance and depth scaling of NGA-Subduction models, (2) treatment of back-arc attenuation in the northwestern North Island, and (3) logic-tree optimization. We apply Sammon's mapping to visualize the multidimensional epistemic uncertainty space represented by the GMM suite, revealing model diversity and correlation structures. This analysis establishes a quantitative framework for logic-tree optimization that balances computational efficiency with appropriate uncertainty representation.

Practical Approaches to Physics-based PSHA
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Physics-based probabilistic seismic hazard analysis (PSHA), in which 3D numerical simulations replace ground-motion models (GMMs), can make significant advances in seismic hazard estimation by including complex near-fault source and path effects, enabling extrapolation of ground motion to rare events at close distances. However, a gap remains between research and practice regarding the feasibility of its incorporation in terms of computational efforts. We highlight practical approaches to physics-based PSHA regarding (1) the hazard calculation, with methods that still address the currently missing aleatory variability, and (2) simulation logic trees, of capturing the effect of alternative rupture generators and different crustal models on the median and variability of the ground motion for a given scenario. For the hazard calculation, a practical option is to use a parametric form to extrapolate the distribution from a small set of runs to define the upper tail of the distribution, rather than using discrete ground-motion samples directly. For the logic trees, instead of implementing all possible combinations of rupture generators, velocity, Q models, and Green's function methods, a scaled-backbone approach can be used to approximate the effects of different rupture generators and velocity structures on ground motion. With these approximations, the computational effort is reduced, making the incorporation of simulations more practical and accessible.

Analytical Approximations for Hazard Calculations for Areal Sources Modeled by Virtual Faults

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Modern ground-motion models (GMMs) use closest distance metrics that account for the finite dimension of the rupture. Virtual fault ruptures (VFRs) are used in modern probabilistic seismic hazard analyses (PSHA) to estimate the closest distance metrics for background seismicity rather than the hypocentral distance from a point source. The VFRs include a range of strikes, dips, and depths which creates thousands of scenarios for a single hypocentral location, making hazard calculations over areal zones computationally much more expensive than using point sources.

Moving to non-ergodic GMMs, which adds spatially varying median adjustments with epistemic uncertainties, greatly increases the hazard calculation time even further and is not practical for many applications. As an alternative, we present a methodology that uses analytical approximations to the hazard from VFRs that reduces the calculation times and also allows for the full distributions of strikes, dips, and depths to be sampled. The small loss

of accuracy in the analytical approximation is offset by the more accurate sampling of the distributions of the strikes, dips, and depths of the VFRs.

The methodology employs a preprocessor that precomputes a comprehensive library of VFR geometries and corresponding ground-motion model evaluations for a large set of magnitudes, epicentral distances, strikes, dips, and depths. The hazard calculation extracts only the specific geometries and scenarios for the background zones used in the hazard calculation. For a given magnitude, epicentral distance, and hypocentral depth, an analytical approximation of the median ground-motion distribution from the full distribution of strikes and dips is computed during preprocessing, avoiding repeated computations in the hazard calculations. The sum of the hazard curves over all strikes and dips is estimated using analytical approximations, leading to computational speedups of several orders of magnitude for both ergodic and non-ergodic models.

Evaluating Random Vibration Theory Assumptions for Non-ergodic Ground-motion Modeling
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Fundamentally, non-ergodic ground-motion models rely on regressing repeatable effects from frequent small earthquakes and applying them, through a linear map, to larger events of engineering interest. This approach implicitly requires training non-ergodic models using linear intensity measures, such as Fourier Amplitude Spectra or Effective Amplitude Spectra. However, this requirement stands in strong contrast to the intensity measures used in structural design, such as peak spectral acceleration, which are nonlinear and magnitude-dependent.

This mismatch is commonly addressed using Random Vibration Theory (RVT), which provides a framework for converting Fourier amplitude spectra into response spectral ordinates. However, the assumptions underlying RVT, particularly those related to peak factors, zero-crossing rates, and stationarity, are often violated by real acceleration time histories.

In this project, we systematically evaluate key RVT assumptions using large empirical datasets, such as the NGA-West3 ground-motion database. We examine the validity of zero-crossing and peak-factor formulations against observed time-series behavior and quantify their dependence on magnitude, distance, and frequency content. In addition, empirical data are used to identify optimal duration intervals for peak-factor estimation, improving consistency between theoretical predictions and observed spectral accelerations.

The results provide guidance on when RVT-based conversions are reliable, where they break down, and how they can be modified to better support non-ergodic ground-motion modeling for engineering applications.

Resolving Site Effects in Modified Mercalli Intensity Data to Better Constrain Non-ergodic Path Terms
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Ground-motion models for the Western United States (WUS) show strong site effects with larger ground motions for softer sites. If the seismic intensity is related to the strength of the ground motion, then the intensity is expected to have site effects similar to ground motion models (GMMs); however, intensity prediction equations (IPEs) for the WUS region show weak site effects. The slope of ln(VS30) for intensity is about -0.1 compared to slopes of -0.5 to -1.0 for response spectral values. Because Modified Mercalli Intensity (MMI) data provide dense spatial coverage, it is used to constrain non-ergodic path effects in GMMs. However, if the site effects of intensity data are underestimated, this can lead to incorrect mapping of these effects into the path terms derived.

In this study, we evaluate the cause for this apparent inconsistency in the site effects. If the data are restricted to moderate-to-large magnitudes (M greater than 5.5) and short distances (rupture distance less than 20 km), then VS30 scaling similar to the GMM scaling can be seen in the intensity data. The weak site effects based on the full dataset reflect that the low-intensity MMI data depend on a suite of ground-motion parameters and not a single parameter such as peak acceleration or peak velocity. To use the site effect from high-intensity observations while retaining the stability of the full dataset, we adopt a site term that depends on the median intensity for rock site conditions with stronger site dependence for the larger median intensity values. This framework provides a practical approach for incorporating site effects into IPEs, ensuring that site and path effects are properly separated for further application in a non-ergodic model.

Components of Variability in Ground-motion Model Derived from Distributed Acoustic Sensing

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Distributed Acoustic Sensing (DAS) provides dense, meter-scale ground-motion measurements along fiber-optic cables. However, developing ground-motion models (GMMs) from DAS data is challenging because measurements are influenced by DAS-specific factors such as cable coupling, orientation, and channel correlation. In this study, we present the first regional, partially non-ergodic DAS-based GMM that explicitly identifies and quantifies cable-related contributions to ground-motion variability. We analyze strain-rate data from a 400-channel DAS array at the Milun campus in Hualien City, Taiwan, compiling peak strain rates and Fourier amplitudes (0.1-10 Hz) from 77 regional earthquakes (3<M<7, 45<R<170 km). Building upon the classical seismometer-based GMMs, we extend the variability framework to consider (1) cable coupling affected by installation and environmental conditions, (2) cable orientation, and (3) channel correlation inherent to DAS measurement principles and array geometry. Channel correlation is modeled using Matérn kernels parameterized by along-fiber and spatial proximity distances. The resulting DAS-based GMM exhibits magnitude-distance scaling comparable to classical models, but decomposes ground-motion variability into physically interpretable components. Cable coupling is identified as a dominant broadband source of variability within events, while orientation effects capture repeatable, frequency-dependent radiation patterns. Modeling channel correlation substantially reduces channel-related standard deviations, demonstrating that treating DAS channels as independent observations can bias uncertainty estimates. Overall, our study shows that DAS-derived ground motions require a fundamentally different variability framework than classical GMMs, highlighting the importance of deployment metadata and correlation modeling. The proposed approach establishes a statistical and physical foundation for next-generation seismic hazard assessments using dense fiber-optic sensing.

Physical Calibration of Ground Motion Models for Induced Seismicity: Application to the Prinos CO₂ Storage Site

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Induced seismicity associated with human activities has become more prominent in recent years, yet accurately predicting the level of ground motion remains challenging due to limited data and complex upper crustal structure. Accurate assessment of induced seismic hazard requires ground motion models (GMMs) that accurately represent region-specific conditions for injection-related earthquakes. Traditional GMMs, developed for tectonic events, are often inadequate for the shallow, low-to-moderate magnitude induced earthquakes where source, path, and site effects exhibit significant differences. This study presents the first region-specific, physically-calibrated GMM developed for the Prinos CO₂ storage site in Northern Greece. Our modelling framework utilizes stochastic simulations, constrained by an *a-priori* seismological model, and calibrated against available recordings. GMM parameters are optimized through iterative calibration, with epistemic uncertainty quantified using ensembles of acceptable parameter sets. A synthetic dataset, created by combining regional empirical recordings and simulated events (Mw 2 ≤ 6, distance ≤ 80 km), is used to benchmark the performance against existing induced-seismicity GMMs. This comparative analysis informs the development of a hybrid model, integrating both simulated and machine learning-enhanced observed ground motions. The resulting regionally calibrated GMM provides a robust tool for ground motion modelling and hazard assessment at Prinos, and contributes to broader efforts to improve quantification of induced earthquake ground motion characteristics across Europe.

Using Dynamic Rupture Simulations to Improve Ground Motion Models for Normal Faulting Earthquakes

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Normal-faulting earthquakes are a regular occurrence in the Intermountain West region of the United States. Ground motion models (GMMs) like the 2023 National Seismic Hazard Model (NSHM) characterize the seismic haz-

ards of all U.S. regions, including the Intermountain West. However, the ground motion observations that inform the current NSHM, such as the NGA-West2 ground motion database, are scarce in normal-slip earthquake data, especially near-fault recordings. Numerical simulations are sometimes used to provide complementary information for NSHM ground motion models, but to date have neglected normal-faulting events. This means that seismic hazard in populations within close ranges of normal faults may at present be mischaracterized. In this study, we use SeisSol, a dynamic rupture simulation and wave propagation software tool based on the discontinuous Galerkin method, to study the near-fault ground motion behaviors of normal-faulting earthquakes. We compare dip-slip faults of varying dip and faulting mechanism (normal vs. thrust) to compare their effects on near-fault ground motion intensity and distribution. We find that faults with shallow dips concentrate the strongest ground motions on the footwall side of the fault, while steep dips maintain them on the hanging wall side. This effect is largely absent in GMM predictions. We also find that earthquakes in reverse-faulting stress regimes - where the maximum principal stress is horizontal - have higher maximum ground velocities compared to otherwise similar earthquakes in normal-faulting stress regimes. Overall, our simulation results suggest that (1) fault dip can be a significant factor in the near-fault strong motion distribution, and (2) that this distribution is also dependent on the faulting mechanism and local stress regime. This emphasizes the importance of modeling both types of dip-slip mechanisms as separate, and is a step towards using dynamic rupture simulations to investigate normal faults more closely despite a scarcity of real data.

Physics-based Simulations of the Dead-Sea Fault System – How Unique Geological Features Affect Ground Motion Variability

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The geological structure along the northern sections of the Dead-Sea Fault system (DSF) exhibits pronounced spatial heterogeneity at short length scales. Deep pull-apart basins from along the active plate boundary, filled with soft sediments (up to 10km depth), and bounded by sharp velocity contrasts. The rupturing of a long-vertical strike-slip within such structures - leads to unique effects, such as directivity, super-shear, waveguide, and basin amplification – all superimposed within the resulting ground motions. These unique effects are not captured by global ergodic ground motion models (GMMs), which are used in local seismic hazard analysis (SHA), due to the low seismicity rates and sparse recordings of moderate to large earthquakes.

Physics-based simulations are employed in this study to address this challenge and allow for a better understanding of expected ground motions. The SW4 finite-difference code is used together with a detailed 3D velocity model of the area, which includes the main geological features. Nine Mw7.0 rupture scenarios on three fault segments of the northern DSF are simulated, varying only the location of rupture initiation. The simulations generate a comprehensive synthetic database of over 32,000 three-component seismograms, enabling systematic quantification of source, path, and site effects on ground motions.

We study the results in time and frequency domain, to explore the component-specific nature of these phenomena and their effect on ground motion variability. The results highlight the critical interplay between rupture directivity and basin amplification in controlling spatial patterns and strong ground motion directionality, which cannot be captured by global ergodic ground motion models.

Modeling Hanging Wall Effects for Ground Motion Fourier Amplitude Spectra

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Observations of ground motions have shown that short-period ground motions for sites located on or near the hanging wall (HW) can be factors of two or more larger than ground motions from the same earthquake recorded at sites located on the footwall (FW) at the same rupture distance (Donahue and Abrahamson, 2014). This observation indicates that the rupture distance metric (Rrup) alone does not capture the main characteristics

of the median ground motion scaling for sites near dipping faults. Donahue and Abrahamson (2014) used results from finite-fault simulations to constrain the dependence of HW effects for response spectra. Using the same set of finite-fault simulations, we developed a HW scaling model designed to address the increased Fourier Amplitude Spectra ground motion levels on the HW relative to the FW that are not captured by Rrup. This model has been compared with the HW effects in recorded data using the NGA-W3 global dataset, and was implemented in the median ergodic GMM of Abrahamson et al. (2025). The hanging wall model coefficient used in the ergodic GMM was determined empirically and compares well with the coefficient obtained independently from the finite-fault simulations. New finite-fault simulations using improved methodology for frequencies higher than 1 Hz (Pinilla-Ramos et al., 2025) are ongoing; these will be used to test and potentially refine the HW scaling model. These simulations will also help constrain the model behavior for deeper earthquakes, which are not well sampled in the existing set of simulations.

QuakeF2G: A Transformer-based Ground Motion Prediction Model Considering Fault Segments Modeling

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Rupture directivity remains a major challenge for near-fault ground motion prediction, particularly for urban regions located close to active faults. Empirical ground motion prediction equations (GMPEs), even with directivity correction factors, often oversimplify rupture geometries, while physics-based wave propagation simulations are computationally prohibitive for rapid analysis. To bridge this gap, we present QuakeF2G, a probabilistic Transformer that maps finite-fault geometries and station metadata to the distribution of logarithmic ground motion intensity measures (IMs). To avoid explicit rupture kinematic parameterization, the fault is represented as a set of discrete fault segments with locations and orientations. A dedicated fault encoder is proposed to embed the fault segments into geometry-aware fault sequences. These are subsequently integrated with site sequences through a cross-attention encoder augmented by relative position bias based on site-fault distance and along-strike azimuth. Absolute and relative geometric encoders are utilized to enhance geometry awareness. After training on approximately 626,000 broadband synthetic scenarios from the CyberShake dataset, QuakeF2G achieves over three orders of magnitude speedup in prediction time compared to deterministic wave-propagation simulations while maintaining high predictive fidelity. It accurately captures rupture directivity and basin amplification effects that empirical methods miss. Ablation experiments demonstrate that explicitly incorporating finite-fault geometry reduces root-mean-square error (RMSE) by 36% compared to a point-source baseline. Furthermore, the model's predicted variance is well-calibrated, showing a significant reduction in aleatory uncertainty compared to empirical GMPEs. QuakeF2G provides an efficient and physics-informed framework for near-fault ground motion prediction, offering significant potential for real-time earthquake response, scenario-based hazard analysis, and next-generation probabilistic seismic hazard analysis (PSHA).

Semi-empirical Ground Motion Prediction Equations for the Central Gulf of California, Mexico, Using Stochastic Finite-fault Simulations

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We developed semi-empirical Ground Motion Prediction Equations (GMPEs) for the central Gulf of California, a region where seismic hazard assessment is challenging due to sparse instrumentation. Utilizing the stochastic finite-fault simulation method (EXSIM), we modeled ground motions for earthquakes with magnitudes (MW) ranging from 3.5 to 7.0 and hypocentral distances from 1 to 270 km. The simulation parameters were calibrated using near-field records from the April 12, 2012, MW 7.0 earthquake. Key propagation parameters established for the region include a frequency-dependent quality factor QS = 126.5f0.59, a geometric spreading model of R-1 for distances up to 160 km, and a duration-distance coefficient of 0.069 s/km. The resulting equations predict Peak Ground Acceleration (PGA) and 5% damped Pseudo-Spectral Acceleration (PSA) for frequencies between 0.1 and 12.0 Hz.

The proposed GMPEs were validated against 114 observed records from local events MW 3.4–7.0 that were excluded from the calibration process. Residual analysis demonstrates a robust fit with mean residuals near zero and

no significant trends regarding distance or magnitude, supporting the hypothesis of earthquake self-similarity with a constant stress drop of 27.5 ± 9.2 MPa for the region. Comparisons with global models (Boore and Atkinson, 2008) reveal good agreement at frequencies above 1 Hz, while comparisons with previous regional models indicate that the new equations better capture near-field intensities. These new GMPEs provide a crucial tool for improved seismic hazard estimation in the Gulf of California.

Constraining GMMs via Physics-Based Simulations and Complementary Observations: Integration and Practice [Poster]

Poster Session • Friday 17 April

Conveners: Sanjay Bora, Earth Sciences New Zealand (s.bora@gns.cri.nz); Asako Iwaki, National Research Institute for Earth Science and Disaster Resilience (iwaki@bosai.go.jp); Grigorios Lavrentiadis, University of Buffalo (glavrent@buffalo.edu); Camilo Pinilla-Ramos, GFZ Potsdam (camilo.pinilla@berkeley.edu); Chih-Hsuan Sung, University of California, Berkeley (karensung@berkeley.edu); Paola Traversa, Electricity of France (paola.traversa@edf.fr)

POSTER 33

3D Physics-based Simulation of Basin Amplification in the February 6, 2023 Kahramanmaraş Earthquakes

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Sedimentary basins can significantly amplify ground motions during earthquakes, making basin effects a critical topic in earthquake engineering. Within basins, incident S waves often convert into surface waves, causing wave trapping and prolonged shaking. Because amplification depends on factors such as low-velocity sediments, strong impedance contrasts, and complex three-dimensional basin geometry, 3-D physics-based simulations are essential for quantifying these effects. In this study, we use SPECFEM3D, an open-source spectral element code for 3-D seismic wave propagation, to investigate basin amplification during the February 6, 2023 Kahramanmaraş earthquakes (M_w 7.8 Pazarcık and M_w 7.5 Elbistan). Source characterization is improved using a finite-fault model derived from wavelet inversion to introduce rupture directivity and reduce misfits associated with single-point sources.

Basin response is evaluated using two velocity models: (1) a low-resolution tomography from the IRIS EMC, and (2) a new 3-D velocity model constructed from a V_{SS0} dependent 1-D velocity model that provides a high-resolution definition of the shallow V_s structure. Simulated ground motions are validated against observed seismograms in the time and frequency domains using low-pass filtering and goodness-of-fit criteria. The high-resolution model is then used to compute basin amplification factors (BAFs) in Kahramanmaraş by comparing simulated time histories at identical isosurfaces, defined as the ratio between simulations with and without basin structure. To assess long-period basin effects, spectral accelerations from the simulations are used to quantify period-dependent amplification, allowing evaluation of how structural periods relevant to different building types may require adjustments to design values inside versus outside the basin. This work provides new constraints on basin amplification in the Kahramanmaraş region and highlights the importance of high-resolution velocity models for improving 3-D physics-based ground-motion simulations.

POSTER 34

Initial Calculations of Aleatory Variability and Epistemic Uncertainty for Physics-based PSHA Using California Simulations

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For physics-based PSHA to move from research to practice, aleatory variability and epistemic uncertainty need to be properly calculated and incorporated

into the seismic hazard estimation. We present initial uncertainty calculations for 1D simulations for California using the Liou and Abrahamson (2025) uncertainty framework. We separate the validation sigma, which is the standard deviation of the difference between the simulation prediction and observations, into parametric epistemic uncertainty by calculating the standard deviation of the simulated ground motion from varying the velocity model and rupture generator, and the remainder of the validation sigma is method aleatory variability, which is variability due to simplifications of the simulation method.

Method epistemic uncertainty of the median is the scientific uncertainty in the simulation methods. This is the standard deviation of the medians from different 1D simulation methods. For a single method, the epistemic uncertainty is estimated by the standard error of the mean for between-event and within-event terms. There is also method epistemic uncertainty of the aleatory variability, which is scientific uncertainty in the size of the method aleatory variability from limited cases validation and uncertainty in the distribution of the ground motion. We also quantify parametric aleatory variability, which is variability of ground motion due to variable inputs to the simulation method that are not included in the standard source characterization used in the hazard calculation, representing inner-fault variability for future events. This is quantified by the standard deviation of the resulting ground motion after sampling inner fault parameters, which are not known for future events. Lastly, we quantify epistemic uncertainty in the aleatory variability, which is scientific uncertainty in the standard deviation due to alternative rupture generators, velocity models, and Q models. Together, these uncertainties capture the required aleatory variability and epistemic uncertainty for physics-based PSHA.

POSTER 35

A Nonergodic Ground-motion Model for Türkiye

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Existing ground-motion models (GMMs) for Türkiye have largely adopted ergodic or partially nonergodic assumptions, which limit their ability to capture systematic ground-motion characteristics and to explicitly distinguish between aleatory and epistemic uncertainties. In this study, we develop a fully nonergodic GMM using a comprehensive Turkish strong-motion database comprising more than 35,000 shallow crustal recordings from 1983 to 2023. The model explicitly accounts for systematic source, site, and path effects.

The foundation of the nonergodic framework is a regionalized ergodic GMM developed in this study, which includes an event-specific attenuation term. Nonergodic systematic effects are modeled using Gaussian processes (GPs) applied to the residuals of the ergodic backbone model. GP hyperparameters are constrained using a variogram-based approach, which is shown to offer advantages over direct GP fitting. Path effects are characterized through a combination of cell-specific attenuation and spatially correlated GPs, enabling representation of spatial variability in quality factor and velocity structure.

The inferred source, site, and path terms exhibit distinct spatial patterns and correlation lengths that vary with spectral period, and potential physical drivers of these patterns are discussed. Notably, the correlation lengths of kappa and the site term at short periods are found to be comparable, indicating a dominant role of kappa effects in this frequency range. In addition, the estimated path effects show strong consistency with available quality factor maps for Türkiye, while short-period source effects display spatial similarities to regional stress-drop patterns in western Türkiye.

The proposed nonergodic model achieves a reduction in aleatory variability of approximately 35%–50%, depending on spectral period. When considered alongside epistemic uncertainties, this reduction has important implications for seismic hazard assessment and performance-based earthquake engineering applications in Türkiye.

POSTER 36

A Modeling Strategy for Ground Motion Prediction Equations Based on Relative Importance Analysis

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Existing studies typically present the modeling strategies of ground motion models directly, and there remains a lack of methods for determining such strategies in a quantitative manner. In this study, we developed a modeling

strategy for ground motion prediction equations based on model relative importance analysis.

We quantify the relative importance of different model components by analyzing their contribution to the coefficient of determination. The method first decomposes the contributions of the different components within the ground motion prediction equation to the model's interpretability and then determines the modeling strategy for the prediction equation based on the contributions in ascending order.

Strong motion data from the NGA-West2 project in the western United States were analyzed as a case study, to which the new method was applied to determine the peak ground acceleration prediction equation for the rock sites. The results indicate that the strategy developed herein did not exhibit systematic bias in fitting, thereby demonstrating its validity and rationality. The ground motion prediction equations determined using the modeling strategy also accurately reflected the strong motion characteristics.

POSTER 37

Ground-motion Variability in SCEC Cybershake

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We analyze CyberShake version 22.12 to identify the controlling features of variability from three-dimensional (3D) ground-motion simulations. Low-frequency results ($T > 2$ s) consist of pseudospectral accelerations from seismic sources in the Uniform California Earthquake Rupture Forecast, version 2, simulated at 335 stations in southern California. This dataset comprises one of the most complete sets of simulated ground motions available for earthquakes, $6.15 < M^W < 8.45$. Ground-motion variability, which is used directly to compute probabilistic seismic hazard curves in CyberShake, is governed by variations in slip and hypocenter location, along with minor, stochastic variations in moment, rupture speed, and rise-time parameters. Unlike empirical ground-motion models, CyberShake allows variability to be directly estimated at each site from the standard deviation of the (natural logarithm) ground motions for each seismic source. We extract the subset of 2,680 seismic sources that are simulated at all stations and compute standard deviations for all seismic sources and stations. Standard deviations are comparable to “single-station sigma” values, as they exclude site-to-site variability.

Our results show that rupture directivity strongly influences variability for most individual sources. We fit the azimuthal variations in standard deviation for each source, then remove modeled directivity effects to produce directivity-corrected standard deviations. Mean trends in the fitted directivity parameters and in the directivity-corrected standard deviations are presented. We find evidence of period-dependent trends in the corrected standard deviations with distance, showing lower standard deviations at greater distances. Additionally, we observe positive correlations between corrected standard deviations and earthquake magnitude, with larger effects at longer periods ($T > 5$ s). These magnitude-dependent trends may result from increased rise-time values in larger-magnitude earthquakes. Work is ongoing to better understand the effects of kinematic rupture parameters on ground-motion variability.

POSTER 38

3D Seismic Wave Simulations for Non-ergodic Ground Motion Modeling: Source and Path Variability in an M8 Ryukyu Subduction Scenario

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The Ryukyu subduction zone offshore eastern Taiwan possesses significant seismogenic potential, exemplified by the 1920 M8 earthquake. However, even to date, the scarcity of near-field data leaves the ground motion characteristics of such mega-earthquakes poorly constrained, posing a threat to seismic hazard assessments. To estimate potential ground motions in inland eastern Taiwan from future mega-earthquakes, we simulated an M8 scenario earthquake using characterized source models (CSMs) based on the “Recipe” procedure (Irikura and Miyake, 2011). We employed a 3-D finite-difference method to conduct 1,728 full-waveform simulations, incorporating kinematic fault-rupture parameters, including rupture directivity, rupture speed, source time function, and asperity distribution, along with two recent tomographic velocity models and topography. Synthetic waveforms generated at 4,950

virtual stations (about 1.5 km spacing) were analyzed using RotD50 spectral accelerations (SA) at 1, 3, and 5 s. Detailed analysis highlights two notable characteristics of the dataset: first, rupture speed and directivity primarily govern the spatial variability and intensity of ground motions; second, tests demonstrate that utilizing a Gaussian source time function with periods of 2, 5, and 9 s yields optimal performance for assessing SA at 1.0, 3.0, and 5.0 s, respectively. We further calculated non-ergodic terms based on the CH20 GMM (Chao et al., 2020). The patterns clearly delineate northeastern Taiwan's geological domains: high values in the Ilan area (SA 1.0 s) and Longitudinal Valley (SA 1.0, 3.0, 5.0 s), and low values in the Coastal Range. These patterns mirror the crustal velocity structure, highlighting the dominance of path effects over relatively weak source effects. Consequently, our extensive simulation datasets provide a foundation for refining current GMMs and facilitate the transition toward non-ergodic seismic hazard assessments, thereby improving the accuracy of ground motion predictions for future mega-earthquake scenarios in the region.

POSTER 39

Incorporate Pseudo-dynamic Finite-source Radiation-pattern Effect in Pulse-like Ground Motion Simulation: Validation Cases Derived on Far-field Stations of the 2024 Mw 7.4 Hualien, Taiwan Earthquake

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Pulse-like ground motions are generally expected to occur near the fault rupture. The rupture distances (Rrup) of existing global stations with identified velocity pulses are mostly less than 80 km. However, two stations in Northwest Taiwan, TCU033 and TCU035, located more than Rrup 110 km from the 2024 Mw 7.4 nearshore earthquake in Hualien, Taiwan, have detected velocity pulses. The RotD100 peak ground velocity (PGV) observed in TCU033 is 30.2 cm/s, approximately 1.8 to 2.4 times that at nearby stations with similar site classes (V_{s30} within 400 to 540 m/s) and Rrup ranges (100 to 115 km). We first applied a modern nonergodic ground-motion model (NGMM) for Taiwan and found that it is difficult to explain the high-intensity outliers at the two sampled stations, possibly because the basic ergodic GMM does not account for finite-source (dynamic) radiation patterns or source directivity effects. Meanwhile, this high PGV could not be explained by the source directivity effect, as the source-site angles were approximately 50 to 100 degrees from the rupture direction. Therefore, the stochastic finite-fault simulation procedure, which was validated to well simulate pulse-like velocity waves (Huang et al., 2023), and which typically uses a median scaling of the point-source radiation pattern for a large dataset of small-magnitude earthquakes, was applied to the two sampled stations. In this study, a pseudo-dynamic source radiation pattern accounting for a finite-fault scenario is constructed for simulation to explain the occurrence of far-field pulse-like velocities. When a systematic evaluation of pseudo-dynamic radiation patterns can be incorporated into the GMM, through the advantages provided by the simulation procedure, the aleatory variability can be further reduced and modeled in the near future.

Cryoseismology: Advances in Technology and Scientific Discovery

Oral Session • Wednesday 15 April • 2:00 PM Local
Conveners: Robert E. Anthony, U.S. Geological Survey (reanthony@usgs.gov); Richard C. Aster, Colorado State University (Rick.Aster@colostate.edu); Michael DuVernois, University of Wisconsin, Madison - IceCube Neutrino Observatory (duvernois@icecube.wisc.edu); Katrin Hafner, United States Antarctic Program Antarctic Support Contract (Leidos) (Katrin.Hafner.contractor@usap.gov); Weisen Shen, Stony Brook University (weisen.shen@stonybrook.edu)

Integrated Seismic and Space Geodetic Remote Sensing of Tidewater Glacier Calving in Greenland

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Surface waves recorded by global seismic arrays have proven useful for locating tectonic earthquakes and detecting slip events depleted in high-frequency energy. Glacial earthquakes caused by the calving of icebergs from tidewater glaciers can also generate sufficient surface wave energy to be detected globally, even though they are often missed in standard earthquake catalogs. Understanding the frequency, distribution, and physics of large ice-loss events is critical to assessing their impact on glacier and ice sheet dynamics, and seismic remote sensing of these events opens an important observational window into this phenomenon. Many challenges remain to realize the promise of seismic calving detection, including unanswered questions about the physics that distinguishes seismogenic from aseismic calving, as well as the difficulty of detecting distant calving events in the presence of noise.

Here we show the power of combining seismic and space geodetic data to improve glacial calving detection and characterization along the west coast of Greenland. We focus on 2019, when the 400-station US Array was still operational in the United States. Our seismic processing aggregates small-to continental-scale arrays to detect and then locate seismic sources using three-component surface waves at 20-50 s period. The resulting event locations are precise in time, but have spatial errors of up to 100 km, which in the Greenland context can span multiple glacier termini. We solve the spatial ambiguity problem by using Sentinel-2 satellite optical image differencing to validate the location, size, and approximate timing of all major (i.e., > 0.1 km²) glacier calving events. From these events, we determine the location and activity of the major calving termini on Greenland's west coast, which serve as a prior for our seismic detection inversions. We show that restricting calving to a subset of verified locations improves detection performance, and we demonstrate the value of satellite imaging for characterizing the location, failure geometry, area/volume, and possible deformation precursors of individual events.

Searching for Glacier-related Seismic Events in Greenland with Waveform Similarity and Machine Learning

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Enhanced calving at the marine terminus has contributed to ice loss from the Greenland Ice Sheet at an accelerated rate over the past three decades. However, the characteristics, frequency, and scales of these calving events are poorly resolved, largely due to their challenging observational conditions. Glacial calving events can cause seismic signals, which are termed glacial quakes. Identifying glacial quakes through continuous seismic records enables remote, uniform monitoring of their occurrence, complementing intermittent field campaigns and remote sensing. Seismic signals of glacial quakes often differ from tectonic earthquakes, lacking high-frequency radiation, and conventional detection methods may fail in identifying these events. In this study, we analyze continuous waveform data recorded by regional seismic stations in Greenland in 2019 and search for events using waveform similarity and machine-learning methods. Waveform similarity is particularly useful in this context because many glacial quakes occur at the same locations with similar failure processes. We estimate event locations using back-projection techniques and classify detections into different types and families. Preliminary results suggest that the detected signals include glacial calving events and tectonic earthquakes, as well as additional waveform families that require further analysis to determine their physical origins. Many detections appear to be previously undocumented. The workflow developed here is readily transferable and can be adapted to other cryoseismic study regions. We aim to identify abundant and diverse glacier-related (and other) seismic signals in continuous records in Greenland, expanding and refining existing catalogs with new detection approaches.

Seismic Evidence of Widespread Sediments Beneath the Greenland Ice Sheet

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Ice loss from the Greenland Ice Sheet contributes significantly to global sea-level rise; however, its magnitude and sensitivity to future climate change

remain uncertain in large part due to questions regarding how basal processes influence ice-sheet dynamics. Specifically, the role of subglacial sediments in regulating Greenland Ice Sheet dynamics is not well understood. Thawed and saturated subglacial sediments enhance ice-sheet basal sliding, making it essential to quantify their distribution and properties beneath the Greenland Ice Sheet. Here, we apply high-frequency receiver function (RF) analysis to investigate subglacial sediments using seismic data collected across the Greenland Ice Sheet over recent decades. We find that the observed RFs consistently exhibit arrival-time delays relative to synthetic predictions from ice–over–hard bed models, indicating widespread low-velocity layers at the ice-bed interface. This low-velocity layer can be best explained by subglacial sediments with thicknesses up to ~200 m. The mapped results suggest that deformable sediments are more extensive than previously recognized but are distributed heterogeneously in space. Sediment thickness broadly correlates with modeled basal thermal state, with thicker and weaker sediments generally found beneath thawed regions. The presence of such sediments—even beneath regions not currently undergoing basal thaw—may precondition parts of the Greenland Ice Sheet for future dynamic change. Our findings highlight the importance of incorporating subglacial sediment properties into projections of ice-sheet behavior under a warming climate.

Monitoring Changes in the Greenland Ice Sheet Using Seismic Waves

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In this study, we collected seismic data from 11 stations located in different regions of Greenland and estimated dv/v using cross-component autocorrelations of ambient seismic noise. We calculated near-surface relative seismic velocity changes (dv/v) in different regions of Greenland. Our results show that dv/v measurements at most stations lag surface mass changes, as inferred from GRACE gravity observations, by less than three months. These variations in lag time may provide constraints on the thickness of subglacial sedimentary layers in different regions of Greenland. Through simple poroelastic calculations, we can estimate the thickness of glacial sediments in the relevant areas and compare the results with independent field observations. These findings are important for understanding glacier melting processes and crustal feedback mechanisms.

In addition, in southwestern Greenland we observe long-term dv/v trends at three stations (ILULI, NRS, and SFJD). These long-term trends may be related to changes in the ice-mass change rate (dM/dt) during the “2012–2013 warm-to-cold transition.” These observations demonstrate that seismic noise autocorrelation techniques can be used to monitor both seasonal and long-term variations of the Greenland Ice Sheet.

Furthermore, analysis of vertical-to-horizontal spectral ratios reveals that stations located beneath thicker ice exhibit distinctly different spectral characteristics between winter and summer. By combining dv/v results with other independent geophysical observations, we find that the basal conditions of the Greenland Ice Sheet can be broadly classified into frozen and thawed types. Different basal states have important implications for ice-sheet melting, motion, and internal thermodynamic processes. We further confirm our geophysical observations through two-dimensional hydrological modeling and find significant regional variations in the hydraulic diffusivity of the ice-sheet base. These findings have important implications for future studies of ice-sheet dynamics.

Internal Structures and Seasonal Variations in Antarctica and Greenland Revealed by Teleseismic P- and S-wave Autocorrelations

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Seismic body waves from distant earthquakes travel steeply before arriving at a seismic station on Earth’s surface, carrying rich information about subsurface structures. In an ice-sheet environment, the sharp seismic discontinuity at the ice-bedrock interface effectively reflects the energy that is bounced from the free surface. Thus, the ice sheet acts as a waveguide, trapping a large portion of incident seismic energy and resulting in repetitive ground motions recorded by over-ice seismometers. Weak self-similar signals can be amplified by cross-correlating earthquake seismograms with themselves (i.e., autocorrelation) before stacking across multiple events.

Here, we apply the autocorrelation method to S-wave coda records to enhance the retrieval of S-wave reflectivity from the ice base in Antarctica. This, in turn, enables measurements of the P-over-S-speed ratio (Vp/Vs) at more than 60 stations, nearly doubling the number reported in previous work and covering both East and West Antarctica. Our results reveal a characteristic difference in the speed ratios, with higher Vp/Vs in West Antarctica than in East Antarctica. This corresponds to the large-scale differences in geothermal heat flow and the potential presence of melt in temperate ice in these regions.

In Greenland, we observe seasonal fluctuations in the amplitudes of P-wave coda autocorrelograms at high-latitude stations, including SUMG and NEEM. The correlograms exhibit stronger reflection peaks in summer and weaker ones in winter. We identify and prove the role of the annual cycle of snow densification in modulating the observed seismic signatures. The findings highlight the significant signature of snow densification in glacial seismic wavefields and the use of passive seismology in monitoring polar ice sheets.

Monitoring Glacial Grounding Zone Icequakes With Fiber-optic and Dense Seismic Arrays

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The spatiotemporal patterns and focal mechanisms of icequakes in glacial grounding zones offer critical insights into the dynamic processes governing ice shelf stability. In December 2025, the Grounding zone Long-term Acoustic Sensing of Structure (GLASS) project deployed a high-density seismic network on the Union Glacier, Antarctica. The array comprised 500 single-component geophones, 20 three-component nodes, and a low-SWaP (Size, Weight, and Power) Distributed Acoustic Sensing (DAS) unit with 5-km specialty fiber cable. This hybrid network captured two distinct classes of seismic activity: (1) events characterized by strong dispersive surface waves indicating shallow icequakes, and (2) events characterized by impulsive body-wave arrivals attributed to deep icequakes, likely occurring at the ice-bed interface. The unprecedented spatial density of the DAS and node observations enables event localization with high precision and allows for the detailed inversion of rupture mechanisms. By quantifying source parameters such as stress drop and rupture dimensions, this study provides a new window into the complex mechanical interactions between ice, basal substrate, and tidal forcing, ultimately improving our ability to predict glacial response to a warming ocean.

Single-station Characterization of Tidally Triggered Icequakes Across the Grounding Line of the Ross Ice Shelf at Roosevelt Island, Antarctica

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Glacial systems are among the most microseismically active locales on Earth but are sparsely instrumented. We show how a single three-component seismic station can provide unique dynamic cryoseismic information at a major Antarctic ice shelf grounding line accommodating approximately 400 m/year of lateral translation and 1 m/day tidal modulations, observed in prolific tidally triggered cryoseismicity. Characteristic dispersed P and Rayleigh waves dominated by firn propagation modes enable robust single-station event matched filter detection, source location and magnitude estimation. Low-frequency (< 5 Hz) Rayleigh waves consistently show reverse dispersion, indicating a reduction of wave-speed at depth. Station-source distances are estimated by jointly fitting firn-guided P and fundamental Rayleigh waves group dispersion using a one-dimensional velocity model informed by prior seismic studies and radar imagery of Antarctic firn. Station-source back azimuths are jointly constrained using eigendecompositions of the P and Rayleigh wave variance tensors and by maximizing Rayleigh wave cross-correlation between the Hilbert transform of the vertical and radial components, constrained for retrograde sagittal plane particle motion. STA/LTA transient detection and

machine learning-assisted phase picking identify high signal-to-noise template events for the two-year seismic record. High signal to noise template events sampling the full tidal phase cycle are then used for matched filter detection to construct a catalog of more than 1,800,000 shallow icequakes, which are concentrated 0.5–3 km landward of the approximate grounding line and consistent with a predominance of seismogenic near-surface extensional crevasse or strand crack opening sources. The large catalog of events demonstrates very strong coupling with tidal modulations of the ice shelf, including revealing tidal components that are not included in current tidal models. Rising (flood) and falling (ebb) tide cryoseismicity indicate intense diurnally periodic brittle fracture cycles with more than 95% of events occurring during ebb tide extensional cycles.

Strength and Seismic Properties of Ross Ice Shelf Ice Rifts Constrained through Joint Seismic and Geodetic Deployments

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The Ross Ice Shelf (RIS) located in Antarctica is the Earth’s largest ice shelf. A buildup of tensile stress as the ice shelf flows to the Ross Sea resulted in multiple periodically spaced ice rifts that are ~100km in length. Previous work established that these rifts are seismically active with seismicity modulated with tidally driven stress. Here we utilize joint seismic and geodetic datasets from the 2014–17 Dynamic Response of the Ross Ice Shelf project (DRRIS) deployment and our NASA-funded Antarctic Rift Research for Ocean Worlds (ARROW) deployment in 2022–23 to determine the brittle fracturing properties of two rift zones of the RIS with different material maturities. Using the ARROW data, we produce a high-resolution seismic catalog with more than 6000 icequake events. We determine that seismicity is strongly associated with extensional strain rates based on GPS data. This allows us to estimate a Mohr-Coulomb failure envelope for ice mélange. Using declustering, we identify aftershock sequences and estimate the characteristic relaxation time scale of aftershock sequences following major icequake events. We compare the observed icequake occurrence times with analytical predictions from rate-and-state friction constitutive laws that have been used to model frictional behavior on terrestrial faults. We find that seismicity rate is well predicted by an analytical model based on rate-and-state friction, demonstrating consistent physical properties between crustal material and ice shelves. We find that rift sensitivity to periodic stress is age dependent. We further describe fracture formation and propagation within these rift zones through mapping of high-resolution Worldview satellite imagery. These environments and datasets provide a unique opportunity to better understand the brittle failure processes for ice beyond laboratory scales, providing important constraints on the future stability of the RIS under varying stress conditions. Finally, insights gained from tidally driven seismicity along these ice shelf rift zones can also serve as analogs for terrestrial fault under periodic stress loading.

Large-N Seismic Nodes and Broadband Observations at the South Pole: Enabling High-resolution Cryoseismology in Extreme Polar Environments

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Polar regions present exceptional challenges for seismic observation due to extreme cold, logistical remoteness, limited power, and restricted access. These constraints have historically limited both the spatial density and temporal continuity of cryoseismological measurements, despite the importance of ice–bed interactions, subglacial structure, and cryosphere–solid Earth coupling for understanding ice sheet dynamics and associated hazards. Here we present results and lessons learned from a three-season seismic deployment near the South Pole that integrates large-N nodal seismometers with long-duration broadband stations, demonstrating new capabilities for high-resolution cryoseismology in one of Earth’s most challenging environments.

Deployment was enabled by wheeled over-snow vehicles, which provided flexible, weather-resilient access across the polar plateau and allowed rapid installation and recovery of dense seismic arrays at scales difficult to achieve using traditional polar logistics.

Over three austral summer seasons, we deployed hundreds of short-period seismic nodes along intersecting transects centered on the South Pole, complemented by an array of polar-rated broadband stations operating continuously for up to two years. This hybrid design combines dense spatial sampling with long-term temporal stability, enabling improved characterization of ambient seismic wavefields and shallow subsurface structure beneath thick Antarctic ice. We assess data quality, noise performance, and operational reliability under extreme polar conditions, and demonstrate that dense nodal coverage substantially improves resolution of shallow structural variability compared to sparse seismic arrays. These observations highlight the transformative potential of combining modern polar logistics and large-N seismic technologies for cryoseismology.

Development and Deployment of the Deep (2.46 Km) Ice Seismometer at South Pole, Antarctica

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On 30 December 2025, we deployed the deepest (to our knowledge) broadband borehole seismometer in the world at 2.46 km depth at the base of the Antarctic icecap at South Pole, Antarctica. This installation took place as part of an upgrade of the IceCube Neutrino Observatory and leverages enhanced hot water drilling techniques developed by the University of Wisconsin’s Physical Sciences Laboratory. In preparation for the deployment, we had to overcome extensive engineering challenges including developing the means to mount a seismometer and digitizer in a pressure vessel capable of withstanding 10,000 PSI of pressure during freeze in processes that minimized compromising the fidelity of the seismic data, developing communication and timing protocols over a single twisted wire pair, and designing transportation methods and protocols to avoid damaging the Nanometrics Trillium 360 seismometer on its journey from Canada to 2.46 km in the ice at South Pole. At the time of this writing, the seismometer package is still suspended in the water column at the bottom of IceCube string 88 awaiting final freeze-in. However, we have validated our communication and timing path to the instrument as well as successfully centered the seismometer’s masses. This presentation will highlight the development and testing of the instrument, the process to deploy it at South Pole, and initial results from the installation. If the seismometer package survives freeze in, we anticipate many novel seismic observations from this deployment and perhaps the second deployment on IceCube string 90 slated to take place on 9 January, 2026. Data from a successful deployment will be freely available as a station run by the U.S. Geological Survey in collaboration with the IceCube Neutrino Observatory

Cryoseismology: Advances in Technology and Scientific Discovery [Poster]

Poster Session • Wednesday 15 April

Conveners: Robert E. Anthony, U.S. Geological Survey (reanthony@usgs.gov); Richard C. Aster, Colorado State University (Rick.Aster@colostate.edu); Michael DuVernois, University of Wisconsin, Madison - IceCube Neutrino Observatory (duvernois@icecube.wisc.edu); Katrin Hafner, United States Antarctic Program Antarctic Support Contract (Leidos) (Katrin.Hafner.contractor@usap.gov); Weisen Shen, Stony Brook University (weisen.shen@stonybrook.edu)

POSTER 1
Source Study of Ice-quakes in a Ross Ice Shelf Rift
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Building upon prior research that documented thousands of icequakes at Ross Ice Shelf Rift WR4 using nine broadband seismic stations—events linked to tidal cycles, thermal stress, and temperature variations (Olinger et al., 2019; Huang et al., 2022)—we apply moment tensor inversion techniques to better understand generation mechanisms for icequake and ice deformation dynamics. We conduct full-moment-tensor analyses using the Computer Programs in Seismology (CPS) package, computing Green's functions for a layered subsurface model consisting of surface firn, underlying ice, water, sediment, and crystalline basement rock. Our analysis identifies distinct extensional Lamb-wave signals propagating at velocities of 2.7–3.2 km/s that are successfully modeled by synthetic seismograms. To account for uncertainties in cataloged events, we perform inversions across a grid around each source and identify optimal centroid locations and origin times. Our findings indicate that all centroid depths occur in the upper 40 meters within the firn layer, demonstrating that failure occurs in the shallow brittle layer. The moment tensor solutions suggest a combination of crack opening, one crack collapse, and a DC component oriented in the direction of the WR4 rift, and moment magnitude vary between 0.4 and 1.5. The calculated extensional stress based on the CATS2008_v2023 tidal model shows a stretching stress of 0.3–0.8 kPa at the time of icequakes due to tidally induced tilting of the ice shelf, while the stress for the event with a crack-closing solution falls below 0.2 kPa. These findings provide quantitative constraints on ice shelf rifting dynamics and insights for assessing Antarctic ice sheet stability under evolving environmental conditions.

POSTER 2
Basal Icequake Detection at Eastern Shear Margin of Thwaites Glacier, Antarctica
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Basal icequakes occur throughout Antarctica and have been observed at various locations. Since basal icequakes occur near the sliding interface, icequakes yield the potential for better studying glacial processes. Environmental noise and low signal-to-noise ratios for small events make seismic event detection difficult. We utilized the open-source Python package, Quakemigrate, to identify seismic events from 14 seismometers that were deployed straddling the eastern shear margin of Thwaites Glacier in two 7-element arrays from early 2020 until late 2021. The project was part of the TIME project within the broader Thwaites Initiative. Quakemigrate utilizes waveform migration and stacking algorithms to determine seismic events from every seismometer deployed. While working with the data, we assume a homogenous velocity model for ice. Utilizing Quakemigrate, over ten thousand potential seismic events were identified from the 2020 waveform data. Preliminary results show that these basal icequakes primarily occur from 1 to 2.5 km depth, which corresponds to depths that are either above the basal interface or near the estimated basal interface from both seismic and radar studies in the area. These

event epicenters occur within a small zone with a distribution of 0.1° latitude and 0.5° longitude focused near the arrays. We plan to present our observations, provide sensitivity analysis for the icequake locations, and interpret our findings as it relates to the dynamics of ice stream margins.

POSTER 3
Wind-wave Scaling in Antarctic Coastal Polynyas From Microseism Observations
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Antarctic latent-heat polynyas, partially open areas of water along the coast, are sustained by a wind-driven equilibrium between sea-ice production and export. The same katabatic wind events that sustain polynyas also excite ocean surface gravity waves, which may influence polynya processes by applying a radiation stress at the ice edge, mediating air-sea transfers through breaking, and shaping the ice formation process through wave-induced rafting and collisions. Yet, the scaling of wind-wave growth in partially ice-covered water and, in particular, the wind-wave climatology of Antarctic polynyas remains unobserved, due to the difficulty of conventional buoy measurements in sea ice. Here, we report that episodic bursts of short-period secondary microseism observed at seismic stations in coastal regions of Antarctica can serve as a quantitative proxy for ocean surface gravity wave statistics in nearby polynyas. Interdisciplinary data sets, including seismic noise, remote sensing of sea ice concentration, and ERA5 atmospheric reanalysis, are integrated to constrain the physical process of wind-wave development in the Amundsen Polynya in the Amundsen Sea, West Antarctica. We find that the seismic energy and peak frequency scale with an effective fetch (the distance wind blows over), which is a function of polynya size, sea-ice concentration, and wind speed. Peak frequency scales with effective fetch, defined by a sea-ice concentration threshold of 0.6, following power-law model with an exponent of -0.3, close to the classic fetch-limited scaling law from open ocean, buoy observations (e.g. JONSWAP). The seismic energy and fetch are also highly correlated, following a power law with an exponent of 1.7, about 2 times higher than the classic fetch-limited scaling. This may indicate a positive correlation between directional spreading of ocean waves and fetch, highlighting the scattering effects of ocean waves due to ice floes. Our results demonstrate that seismic observation is an effective way to monitor sea state in polar regions and shed light on the physics of wind-wave development in partially ice-covered seas.

POSTER 4
Seismic Full-wavefield Imaging of the West Antarctica Ice Sheet
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The West Antarctic Ice Sheet (WAIS) contributes considerable yet uncertain projections of sea level rise into the coming centuries. Thwaites Glacier (TG), one of the largest glaciers in West Antarctica, occupies a particularly critical position due to its intrinsic instability. As a complementary geophysical investigation method to airborne sounding surveys, seismic surveys help recover the fine-scale structures and geophysical properties of the ice sheet from shallow firn layers to deep basal conditions. Here, we discuss outcomes of two controlled-source seismic surveys conducted near the Thwaites Glacier, WA, as part of the Thwaites Interdisciplinary Margin Evolution (TIME) project.

Specifically, we observe different types of seismic waves from an active-source acquisition deployed on the WAIS and use seismic full-wavefield imaging methods to uncover the ice sheet's internal structures and physical properties. Surface waves, including leaky and normal modes, are separated from englacial and bed reflections using a cross-component matched filter method. Leaky modes are uniquely strong in the data, possibly due to the firn layer and ice compaction. We use joint inversion of leaky and normal surface waves to estimate P- and S-wave velocities in the near-surface and attribute ultra-low Vp/Vs ratios to pore closure. We observe englacial reflections down to 50 Hz and bed reflections with multiple branches. Such reflection waves are further used to calculate the seismic images of discontinuities in the ice sheet and the bedrock, revealing multiple layers within the ice near the bed and a heterogeneous bedrock with a rugged surface and possibly existing faults. The fine structure of the ice sheet revealed by seismic data helps identify potential drainage points and assess the ice sheet's instability. The study also provides new insights into the glacier's evolution and potentially enhances the accuracy of numerical models predicting future sea level changes.

POSTER 5
Using Ambient Seismic Noise to Characterize the Polar Environment Near Baffin Bay
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Baffin Bay is a marginal sea located between the west coast of Greenland and the northeast coast of Canada. It connects to the Arctic Ocean through Nares Strait and to the Labrador Sea through Davis Strait, and is typically covered by sea ice from November to May. Its location at the confluence of major ocean currents, combined with strong seasonal sea-ice variability and dynamic climatic forcing, makes Baffin Bay a unique opportunity to use ambient seismic noise to characterize polar environment.

In this study, we analyze long-term seismic recordings from stations along the northeastern coast of Canada and Greenland to characterize the spectral and temporal properties of ambient seismic noise across multiple frequency bands. We find that the ambient noise power spectrum can be divided into four frequency ranges: primary microseism (10–20 s), secondary microseism (5–10 s), short-period secondary microseism (1–5 s), and high-frequency ambient noise (<1 s), each exhibiting pronounced seasonal variability. Both the primary and secondary microseisms show stronger amplitudes during the winter months (September to February), with spectral power increasing from high to low latitudes, likely reflecting enhanced storm activity over the Labrador Sea. The short-period secondary microseism also displays a clear seasonal pattern, with stronger amplitudes from July to November and weaker signals during winter, consistent with the influence of sea-ice coverage. In addition, stations along the Greenland margin record transient high-frequency noise in the 1–5 Hz band from June to September, which is likely associated with glacier meltwater discharge.

Data-Driven Advances in Liquefaction Hazard Analysis [Poster]

Poster Session • Friday 17 April

Conveners: Adda Athanasopoulos-Zekkos, University of California, Berkeley (adda.zekkos@berkeley.edu); Laurie Baise, Tufts University (laurie.baise@tufts.edu); Brian Olson, California Geological Survey (brian.olson@conservation.ca.gov); Ellen Rathje, University of Texas at Austin (e.rathje@mail.utexas.edu)

POSTER 19
Nonergodic-based Risk Assessment of Liquefaction-induced Ground Damage
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The seismic risk assessment of liquefaction-induced ground damage requires the hazard estimation of ground motion intensity measures (IMs) through probabilistic seismic hazard analyses (PSHA). Current practice implements PSHA using ground motion models (GMMs) developed under the ergodic assumption, which considers that the distribution of ground motion IMs over time at a single site is the same as the distribution of ground motion IMs over space. With the rapid growth of ground motion databases, recent efforts have shown that ground motion recordings are affected by location-specific systematic and repeatable effects favoring the transition to non-ergodic approaches. However, the impact of using ergodic versus non-ergodic PSHA (accounting for source, path, and site repeatable effects) on the risk assessment of liquefaction-induced damage has not been explored, which is the objective of this study. We consider three sites in California with different availability of ground motion data to investigate the effects of the amount of available information on constraining repeatable effects and how this affects the final risk estimates within a non-ergodic approach. In this context, the non-ergodic-based estimates are compared against their ergodic counterparts, and insights are shared. The results from the assessments show important differences between ergodic and non-ergodic estimates in terms of the mean risk and its uncertainty; the differences are dependent on the amount of data, and highlight the value of information (i.e., data) in non-ergodic approaches.

POSTER 20
Development of USGS Computational Tools for Long-term Forecasting of Liquefaction Ground Failure Hazards
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Long-term probabilistic liquefaction hazard forecasts provide valuable information for identifying infrastructure that is potentially vulnerable to earthquake-induced ground failure. This is most effectively achieved through probabilistic liquefaction hazard analysis (PLHA), which integrates annualized ground-shaking hazard information from all potential earthquake scenarios with probabilistic models of liquefaction limit states (e.g., triggering, surface manifestation, ground deformation). PLHA calculations typically result in annualized rates or long-term probabilities of liquefaction occurrence, which can help inform risk-based earthquake engineering assessments. Such calculations require a thorough representation of uncertainties, reflecting variability in site and groundwater conditions, and both within-model and cross-model uncertainty in liquefaction hazard estimation, and are ultimately represented via ranges and fractiles of the annualized rates of liquefaction occurrence.

We present an in-development Python library for performing PLHA calculations to estimate long-term liquefaction manifestation probabilities. We demonstrate the use of the code for a large set of cone penetrometer test (CPT) sites throughout United States. Probabilistic ground motion hazard data are obtained directly from the U.S. Geological Survey National Seismic Hazard Model and integrated with a set of published liquefaction manifestation models to ultimately estimate the annualized rate of liquefaction manifestation at a given CPT location. We incorporate uncertainties in groundwater levels and susceptibility criteria, and comparisons across multiple manifestation models, into these analyses to demonstrate the sensitivity of model assumptions to hazard estimates. Preliminary results suggest that variations in all three factors can significantly impact the estimated hazard. This computational framework represents a promising avenue towards systematic and comprehensive liquefaction hazard forecasts, both for site-specific design applications and as the basis for improved regional-scale liquefaction hazard mapping efforts.

POSTER 21
Geospatial Liquefaction Model Using Maximum Entropy (Maxent) Modeling for California
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Liquefaction modeling is a critical component of seismic hazard assessment. This study implements maximum entropy modeling to develop probability of liquefaction maps post-earthquake. Maximum entropy modeling is a data-driven methodology requiring only presence points of liquefaction along with geospatial and ground shaking intensity variables as predictors. This study builds on the current state of practice of using broadly accessible geospatial data as predictor variables for liquefaction models, while addressing current limitations of the traditionally used logistic regression model. The logistic regression model requires both presence and absence points of liquefaction; however, the absence points are often estimated and have high uncertainty because ground truth data for liquefaction absence following an earthquake is not generally collected. The maximum entropy model presented here requires only observed presence points of liquefaction, eliminating the added uncertainty in assuming absence points. A second advantage of the maximum entropy model is the ease of including categorical predictor variables such as surficial geology which is known to be a strong predictor of liquefaction occurrence. A dataset of observed liquefaction (e.g. presence) from nine earthquakes in California is used for model development and validation. The predictor variables include: PGV, distance to water, slope-based V_{S30}, water table depth, average annual precipitation, and surficial geology. The MaxEnt (Phillips et al., 2006) software is used to develop a geospatial liquefaction model based on the input geospatial and intensity data for each event. Then an ensemble model is created for use as a geospatial liquefaction model for the state of California. The model performance is evaluated based on a leave-one-out validation approach using the ensemble model. This research aims to improve the accuracy of map-based rapid estimation of liquefaction surface effects after earthquakes through the use of a novel modeling approach and the inclusion of surficial geology as an additional predictor variable.

Machine Learning-based Geospatial Liquefaction Model for California: A Comparative Study
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Geospatial liquefaction models commonly employ logistic regression to estimate liquefaction probability from ground shaking intensity and geospatial site parameters, valued for its straightforward probabilistic output and physical interpretability. However, these simple models may not capture complex non-linear relationships in the data, motivating the exploration of more advanced machine learning techniques. We use a newly compiled comprehensive database of liquefaction observations from 19 historic California earthquakes (Subedi et al., 2026). Using this dataset, we trained and evaluated several machine learning algorithms — Random Forests, eXtreme Gradient Boosting (XGBoost), Support Vector Machines (SVM), and Neural Networks — to predict liquefaction probability. We compared these models against the conventional logistic regression baseline model in terms of predictive accuracy, interpretability, and computational cost. Preliminary results show that the ensemble tree-based models (Random Forest and XGBoost) achieve the highest prediction accuracy, effectively capturing complex nonlinear patterns in the data and outperforming the simpler logistic regression approach. All the machine learning models demonstrate improved predictive skill over the baseline; however, their increased complexity introduces trade-offs. This comparative study highlights the trade-off between predictive performance and model interpretability in liquefaction hazard modeling. Our findings underscore the potential of modern machine learning algorithms to enhance regional liquefaction prediction accuracy in California, while also emphasizing the importance of considering model simplicity and transparency for practical engineering use.

Evaluation of the Lateral Displacement Index Framework for Regional-scale Liquefaction Hazard Assessment
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The lateral displacement index (LDI) framework is a widely used semi-empirical method for assessing liquefaction-induced lateral spreading displacement (LSD). However, its efficacy and limitations for regional-scale liquefaction hazard assessments are not well understood. This study evaluates the performance of the LDI method using 1,683 high-quality Cone Penetration Test (CPT) soundings, paired with field-based and remote sensing-based liquefaction observations from the 2011 Christchurch earthquake. The results indicate that the LDI framework provided acceptable LSD estimates for only 27% of the case histories. A high rate of false positives (45%) was observed, particularly at sites far away from the riverbanks. Overprediction sites (2%) were geospatially located near riverbanks and geotechnically characterized by a competent, fine-grained surface crust. Underprediction sites (26%) were distributed both near and far from the rivers. The analysis further reveals that while LDI correlates with minor to moderate sand ejecta, it does not adequately capture the severe sand ejecta or lateral spreading. To address these limitations, a hybrid screening criterion is proposed that incorporates a distance-to-free-face threshold and a crustal competency index. Application of these constraints reduces model bias and improves predictive performance for regional liquefaction hazard assessment.

From Site-specific Methods to Regional Liquefaction Hazard Mapping: Application to California
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Since the 1970s, substantial progress has been made in site-specific evaluation of liquefaction potential and its consequences, incorporating mechanics-based constraints to improve extrapolation beyond the range of available case histories. In contrast, large-scale or regional liquefaction hazard assessments have seen comparatively limited progress toward a mechanistic foundation and remain largely based on purely geospatial or statistical models. This project develops a statewide framework for evaluating liquefaction potential, liquefaction-induced settlement, and the spatial extent of liquefac-

tion by adapting and scaling site-specific methodologies for regional application. The approach integrates geological classification of USGS CPT datasets with a statewide groundwater table model that combines hydrologic and well observations, providing both mean estimates and uncertainty of the key inputs required for site-specific liquefaction models. In parallel, a liquefaction-extent model is developed to quantify spatial correlation length, improving the representation of liquefaction hazards at regional scale. The proposed framework is optimized for high-performance computing environments, allowing efficient evaluation of liquefaction potential and associated effects over very large spatial domains.

Data-Driven and Computational Characterization of Non-Earthquake Seismoacoustic Sources

Oral Session • Thursday 16 April • 8:00 AM Local
Conveners: Souheil M. Ezzedine, Lawrence Livermore National Laboratory (ezzedine1@llnl.gov); Keehoon Kim, Lawrence Livermore National Laboratory (kim84@llnl.gov); Benjamin L. Moyer, University of Maryland (blmoyer@umd.edu)

Seismoacoustic Source Localization: Case Study from AES Tennessee Explosion
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Accurate localization of explosions is crucial for understanding their impact and for effective monitoring of both natural and anthropogenic activities. This study focuses on the seismoacoustic location of an explosive event that occurred at the Accurate Energetic Systems manufacturing plant in Tennessee on October 10, 2025. We investigate the efficacy of combining reverse time migration (RTM) techniques with traditional arrival-time based methods to enhance the precision of source localization. By employing RTM, we back-project seismic and infrasound waveforms through their respective media, allowing for a comprehensive analysis of the energy release. To address the challenges posed by discrepancies in waveform characteristics between seismic and infrasound signals, we implement enveloped waveforms, which facilitate a more robust integration of the two data types. Similarly, we utilize arrival-time data from the same set of stations to provide complementary seismoacoustic location solutions. Our results demonstrate the effectiveness of joint seismoacoustic solutions in accurately locating the explosive event, highlighting the potential for improved event discrimination and characterization. This work contributes to the ongoing efforts in global monitoring and provides insights into the dynamics of explosive sources. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Seismoacoustic Monitoring of Explosive Sources on the Korean Peninsula
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Seismoacoustic signals propagating through the Earth and the atmosphere provide critical information for detecting, locating, and characterizing natural and anthropogenic sources, as well as for understanding wave propagation in coupled seismic and acoustic wavefields. In this study, we analyze seismoacoustic signals recorded at seismic and infrasound arrays, jointly operated by Southern Methodist University and the Korea Institute of Geoscience and Mineral Resources. Additional data include recordings from the KSRS seismic array of the Comprehensive Test Ban Treaty Organization and available regional seismic networks in and around the Korean Peninsula. We initiated the compilation of a seismoacoustic event catalogue for July–December 2025. Seismic events were identified using real-time SeisComP processing, and each event was associated with infrasound detections characterized by arrival time and azimuth from infrasound arrays using the automatic Adaptive F-Detector. Approximately 16% of detected seismic events are accompanied by infra-

sound signals, most of which originate from inland mining and quarry activities. In addition, we conducted a seismoacoustic wavefield experiment during the summer of 2024 at a limestone quarry in Yeongwol, a known infrasound hotspot. The experiment involved deploying Chaparral infrasound sensors, EpiSensor accelerometers, and Sapphire mini-infrasound sensors, installed both on the ground and on a drone. Seismoacoustic signals generated by three blasts were successfully recorded across a dense sensor network at local distances. This unique dataset enables detailed investigation of short-range seismoacoustic signal observations and propagation. Overall, this study provides valuable insights into the physical processes governing coupled seismic-to-acoustic wavefields and contributes to improved methodologies for explosion monitoring.

Exploring Seismo-acoustic Sources From an Underground Fully Decoupled Chemical Explosion
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Underground subsurface explosions create cavities surrounded by damaged host rock, generating significant heat and byproduct gases. The intense heat melts the surrounding rock, forming a pool of molten material, while gases may exist freely, become entrapped, or dissolve within the melt. This environment gives rise to distinct circulation cells in both the liquid and gas phases, which interact through degassing and diffusion processes. Over time, these interactions reach equilibrium as temperature and pressure decrease within the damaged zone.

At elevated temperatures and pressures, gases vent from the cavity into the fractured zone and eventually seep into the undamaged formation. Thermal exposure causes thermomechanical dilation and subsequent relaxation of explosion-induced cracks, regulating gas venting and long-term seepage.

We have developed a 3D HPC computational model using an AMR finite element method to solve the transient equations governing mass, momentum, heat, and chemical species transport. Various numerical coupling schemes and stability conditions are presented, along with a sensitivity analysis of outer cavity boundary conditions and their impact on heat loss, cooling, and convective mixing between the air gap and molten rock. Additionally, we present synthetic four- and three-dimensional seismo-acoustic wave signatures based on the evolving physico-chemical processes in the chamber, examining the interplay of relevant frequencies, material uncertainties, and the significance of key physical parameters.

Source Model for Non-steady Flow Within Fractures
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Understanding fluid flow in subsurface reservoirs is critical for advancing geothermal energy, subsurface waste and energy storage, and in-situ mineral extraction. In these reservoirs, fractures often serve as the primary conduits for fluid movement. Under certain conditions where high flow rates and steep pressure gradients exist, non-steady flow can occur. This state, which generates seismic energy, has been hypothesized to explain numerous field observations and is considered a key mechanism behind fracture resonance commonly detected in stimulated reservoirs. In this work, we develop a physics-based theoretical source model for turbulent fluid flow within fractures. Our approach extends existing fluid-source frameworks by incorporating fracture-specific characteristics such as geometry, roughness, aperture variability, and the potential for channelized flow pathways. Using this model, we characterize the expected source spectra and identify conditions under which this phenomenon is most likely to occur. By refining fluid-source models for fractured systems, we move closer to achieving precision monitoring and improved control of subsurface reservoirs. LA-UR-26-20136

On the Feasibility of Single-station Scalar Moment Estimation for Earthquake and Non-earthquake Sources
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Scalar seismic moment is the fundamental physically-grounded measure of source scale, yet its estimation is conventionally treated as contingent on network-scale observation and explicit source modeling. For small sources

that cannot be observed across a well-instrumented region, these conditions are frequently absent. Sparse station coverage and uncertainty radiation characteristics impose additional limitations. Fortunately, the operational requirement is often an approximate measure of scale rather than a complete description of mechanism.

This work examines the extent to which scalar moment estimation is feasible when observation is reduced to a single station. We outline a conformer-based machine learning framework intended to infer scalar moment directly from broadband single-station waveforms. This is accomplished with an architecture that combines convolutional feature extraction with attention-based temporal modeling to isolate waveform characteristics diagnostic of source amplitude, while remaining tolerant to variability in source-time function, propagation effects, and site response. Training is formulated over a deliberately broad ensemble of synthetic and observed earthquake and non-earthquake signals, chosen to span diverse source types. We do not seek to recover full source mechanisms, moment tensors, or unique physical source model representations from single-station data. Emphasis is placed instead on exploring inference possibilities under conditions of extremely limited observations. The objective is to systematically explore the potential of single-station, ML-assisted scalar moment estimation as a practical direction for the characterization of earthquake and non-earthquake seismic sources in data-limited settings.

Data-Driven and Computational Characterization of Non-Earthquake Seismoacoustic Sources [Poster]

Poster Session • Thursday 16 April
Conveners: Souheil M. Ezzedine, Lawrence Livermore National Laboratory (ezzedine1@llnl.gov); Keehoon Kim, Lawrence Livermore National Laboratory (kim84@llnl.gov); Benjamin L. Moyer, University of Maryland (blmoyer@umd.edu)

Catalog of Clustered Strombolian Eruptions Using Waveform Cross-correlation and Matched Filtering - Erebus Volcano, Ross Island, Antarctica
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Mount Erebus Volcano, Ross Island, Antarctica uniquely hosts a decades-old convecting lava lake with regular Strombolian eruptions and other seismic events well-documented in dense broadband seismic data1. The structural complexity of the volcano causes strong multipath propagation (scattering) that presents challenges in distinguishing between seismic sources using direct wave analysis methods2, without significant computational expense. Unsupervised learning algorithms have well-recognized potential to classify seismic events from continuous time series but currently lack a comprehensive comparative event dataset at Erebus. Matched filtering, which measures the similarity between a continuous and template waveform using the cross-correlation coefficient7, is an established detection method with promising performance at Erebus2,3,4. At Erebus, lava lake eruptions are characterized by their very long period signals on broadband seismograms, which have been identified in 17 repeating “families” of events throughout the 200-station three component 2007-2009 Tomo Erebus Experiment5,4. Here, we use matched filtering techniques to cross-correlate seismic time series with known eruption signals to detect eruption events with highly similar waveforms. Highly correlated events have highly similar event sources, including their size, origin, and propagation path through the evolving conduit system. By iteratively using matched filtering to detect new events and then extracting the highest-correlated portion of detections as templates for the next iteration, we develop an exhaustive catalog of clustered eruptions at Erebus. Events are detected until the number of unique detections per iteration converges. The eruption catalog is constructed as a tool for evaluating unsupervised learning algorithms for waveform clustering at Erebus and other active volcanoes.

Observed and Simulated Seismic Ground Motions From a 13-story Building Implosion-collapse in Hayward, California

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We study seismic waves emanating from the 2013 demolition of the 13-story Warren Hall building at the California State University, East Bay in Hayward, California. The ~12,500-ton structure was intentionally demolished via implosion due to seismic safety concerns; in anticipation of this, the USGS installed a dense, temporary circular seismic array (2 km radius) using ~600 seismometers surrounding the building to record nearfield shaking resulting from the collapse (Catchings et al., 2015). Recordings from the event show spatially complex seismic motions, indicating effects from the Hayward fault zone (~0.6 km from the building) and shallow subsurface geology.

Here, we perform seismic wave propagation simulations using the finite difference code SW4 to investigate source and velocity structure attributes influencing the observed motions resulting from the building collapse. We model the seismic source as a vertical point force with magnitude derived from properties of the structure and duration estimated by recordings at the nearest stations (~75 m) to the building. The simulations use seismic velocity structure given by the USGS San Francisco Bay region 3D seismic velocity model (SFCVM) which includes geologic features, such as the Hayward fault that are known to affect wave propagation; the most recent version includes shallow sedimentary velocity structure derived from geologic maps and bore-hole data with 25 m vertical resolution. We also consider the distance attenuation of the building-collapse ground motions in comparison with earthquake ground-motion models. This investigation helps us to better understand wave propagation from a semi-controlled seismic source in the presence of complex velocity structure and near-source fault zones. More broadly, this work will help inform seismic hazard and illuminate seismic velocity structure and 3D wave propagation effects in the Hayward fault zone.

Explosion Yield Estimation and Impacts of Small-scale Atmospheric Perturbation on Infrasound Propagation

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Explosions in air radiate part of their energy in the form of infrasound. Infrasound can efficiently propagate in the atmosphere for long distances allowing for effective remote explosion monitoring. Propagation of infrasound in the atmosphere is mainly governed by the major structures of atmospheric stratification. These atmospheric layers often govern propagation efficiency creating an atmospheric duct or produce a silence zone near the ground, which affects the detectability at ground-based stations. Numerical weather forecast models are widely used to represent the atmosphere conditions and predict propagation paths and signal amplitudes. However, spatial and temporal resolutions of weather forecast models often fail to capture small-scale atmospheric variability for infrasound propagation and result in poor accuracy of infrasound prediction. In this study, we investigate the effects of small-scale atmospheric perturbation on infrasound propagation and the uncertainty of explosion yield estimation. We utilize a full-waveform, finite-different method to simulate infrasound propagation and predict waveforms. A set of random realizations of the atmosphere are produced by internal gravity wave perturbation and used for infrasound propagation simulations. Variations of infrasound arrivals and amplitudes in prediction are quantified with respect to various length scales and amplitudes of the perturbation. We apply the simulations results to actual infrasound data recorded from a range of explosions in the atmosphere. Our numerical simulations and yield estimation with small-scale atmospheric perturbations will give the insights on how atmospheric inhomogeneity affects infrasound propagation and explosion monitoring.

Interpretable Spectral Representations of Planetary Signals in Vector Spaces (Spec2VEC)

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The application of Machine Learning (ML) to planetary science is often bottlenecked by a scarcity of labeled data and the complexity of non-stationary seismo-acoustic signals. While deep learning offers powerful feature extraction, it requires massive datasets that are rarely available for phenomena like Martian quakes or deep-ocean volcanism. Consequently, researchers rely on “hand-engineered” features from Time-Frequency Representations (TFRs), but these are often impoverished (simple statistics) and brittle (highly sensitive to subjective TFR hyperparameters). To resolve this, we introduce Spec2VEC, a framework that constructs interpretable spectral representations in vector space. Analogous to generating embeddings in natural language processing, Spec2VEC projects raw, subjective TFRs into a high-dimensional, discriminative feature space. We achieve this by treating the TFR not just as a probability distribution, but as a textured image. Our framework systematically extracts a feature vector using two novel pathways: (1) a Textural path that uses Hilbert space-filling curves to map 2D spectral patterns into 1D sequences for information-theoretic analysis (e.g., Entropy, Complexity); and (2) a Spatial path that uses a novel probabilistic segmentation (PDFSI) to quantify the energy concentration, connectivity, and coherence of signal components. We validate this vector space on a comprehensive benchmark of synthetic geophysical signals, demonstrating that it creates a distinct separation between signal classes where traditional metrics fail. Finally, we demonstrate its utility for label-scarce discovery through the unsupervised clustering of hydroacoustic signals from the 2021 Fukutoku-Oka-no-Ba eruption. The results show that Spec2VEC generates a robust, interpretable feature space that enables the automated discovery of complex planetary processes, independent of the underlying TFR choice.

Cryospheric Clutter

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Glacier dynamics are known to produce seismoacoustic signals that can be detected across local distances and beyond. This study will investigate seismoacoustic data from polar regions to detect near-sensor local clutter associated with cryospheric processes. The processed data is expected to reveal distinct seismic and infrasonic signatures associated with cryospheric events. These events will be cross-checked with visible and infrared satellite imagery to determine where events are taking place.

Seismoacoustic sensing provides continuous, high-temporal-resolution monitoring, and we will explore its use for autonomous cryospheric tracking to gain deeper insight into understanding cryospheric events.

Broadband Seismic and Infrasonic Signals From Two Recent Tornadoes

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Each year, tornadoes cause extensive property damage and endanger lives. While Doppler radar can indicate the potential for tornadoes, it cannot confirm when one is on the ground unless radar reflections detect lofted debris. Once a tornado touches down, its energy can be transferred into the earth as seismic vibrations; thus, tornado seismic signals (TSS) from on-the-ground tornadoes may be detectable by seismometers. Two recent EF-4 tornadoes touched down in the central United States—one on December 10, 2021, which tracked 129 km from NE Arkansas into NW Tennessee, and another on May 16, 2025, which traveled a 97 km path in south-central Kentucky—passing within 2 km of two broadband seismic stations and motivating investigations of TSS. In this study, we identified TSS in continuous broadband data recorded at these two stations using meteorological data from the National Weather Service. We also analyzed infrasound and pressure data recorded at one of the stations. TSS waveform amplitudes generally increased as a tornado approached, peaked when a tornado was closest, and decreased as a tornado departed. Spectrograms showed a strong broadband signal—0.001 Hz up to the Nyquist frequency (50 Hz)—during a tornado’s closest approach. Comparing amplitude spectra from time windows while the tornadoes was in contact with the ground to those from after they lifted off revealed vari-

ous frequency bands that may be unique to tornado-ground contact, the most promising of which was the 1–10 Hz band. East-west vs. north-south particle motion diagrams (PMD) plotted for the 2021 event suggest that tornado azimuth may be trackable in the 0.01–0.03 Hz range and may indicate ground tilting. PMD plotted in the 4–5 Hz band showed elliptical ground motion, suggesting the presence of both Rayleigh and Love waves. Vertical-component seismic and infrasonic time series acquired during the 2025 tornado are strongly correlated (0.8 correlation coefficient) in the 4–5 Hz band, indicating a connection between acoustic emissions and TSS at these frequencies.

Component-dependent Seismic Ambient Noise Amplification During Hurricane Milton (2024) in South Florida

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Continuous seismic ambient noise provides an effective means to investigate interactions between the solid Earth and atmospheric processes. From June to December 2024, we deployed a temporary array of nine seismic nodes in the Miami area, including one located on Virginia Key, to record continuous ambient noise throughout the Atlantic hurricane season. Here, we focus on observations during Hurricane Milton, the strongest hurricane of the 2024 season, as it traversed the Florida peninsula.

Power spectral density (PSD) analysis reveals pronounced noise amplification on both vertical and horizontal components during the hurricane passage. On the vertical components, strong PSD enhancement is observed in the 3–7 s period band, comparable to the secondary microseism range and interpreted as being dominated by ocean-generated sources. In contrast, the horizontal components exhibit two distinct bands of increased PSD, at periods shorter than 0.5 s and longer than 5 s. The short-period (<0.5s) enhancement is likely associated with wind-induced ground vibrations, whereas the longer-period (>5s) horizontal noise may reflect intense atmospheric pressure fluctuations within the hurricane. Notably, the long-period horizontal PSD increase at the Virginia Key station is substantially weaker than at inland stations, suggesting reduced atmosphere–ground coupling due to the buffering effect of the surrounding ocean. These observations highlight the potential of integrating seismological observations with atmospheric science to improve understanding of atmosphere–ground interactions during extreme weather events.

Radiosonde-to-space (R2S) Atmospheric Specifications: Bridging Observations and Models for Infrasound Propagation

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Infrasound propagation is inherently asymmetric and time-dependent, making accurate atmospheric specifications essential for predicting when and where signals arrive. The Naval Research Laboratory’s Ground-to-Space (G2S) model is widely used for this purpose, yet discrepancies between G2S-based predictions and observations highlight the need for improvement. Here we develop Radiosonde-to-Space (R2S) specifications by merging direct radiosonde-based observations of the lower atmosphere with G2S profiles aloft, producing continuous profiles from the ground surface elevation to 150 km. We compare more than 6000 G2S–R2S pairs for Albuquerque, New Mexico, and conduct propagation modeling on representative endmembers spanning the range of differences. While G2S typically reproduces most R2S-predicted arrivals, important exceptions occur that would affect event interpretation in real world scenarios. These results demonstrate that although G2S provides robust global coverage, predictions can change when direct lower-atmosphere observations are incorporated, motivating broader integration of real-time radiosonde data into global atmospheric specifications.

A Multi-year Regional Infrasound Array Network in Utah, USA

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Infrasound, defined as low frequency sound < 20 Hz, is generated by both natural and anthropogenic sources. Infrasound has proven utility in detecting, locating, and characterizing events of interest, and infrasound sensor networks have been used to achieve this at local, regional, and global scales. Despite their utility for monitoring events of interest, few regional infrasound array networks exist. A total of six infrasound arrays were deployed across Utah, USA between 2020 and 2025 through a partnership between Sandia National Laboratories and the University of Utah. Data was telemetered to the University of Utah where it was integrated into operations and is archived at the National Science Foundation (NSF) Seismological Facility for the Advancement of Geoscience (SAGE) Data Services. Data was routinely processed to create a catalog of infrasound detections, including explosions and quarry blasts. When available, the detection catalog incorporates seismic and ground truth data. Here we describe the instrumentation deployment, data quality and availability, as well as present initial observations of the regional infrasound and seismoacoustic event activity.

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Detecting, Characterizing and Monitoring Mass Movements

Oral Session • Wednesday 15 April • 4:30 PM Local
Conveners: Paul Bodin, University of Washington (bodin@uw.edu); Pierre Boymond, Volcanological and Seismological Observatory of Costa Rica (pierre.boymond@una.cr); Nahomy Campos, Volcanological and Seismological Observatory of Costa Rica (nahomy.campos.salas@est.una.ac.cr); Esteban J. Chaves, Volcanological and Seismological Observatory of Costa Rica (esteban.j.chaves@una.ac.cr); Avery E. Conner, University of Oregon (aconner2@uoregon.edu); Joan Gomberg, U.S. Geological Survey (gomberg@usgs.gov); Sonia Hajaji, Georgia Institute of Technology (ssalgado30@gatech.edu); Ezgi Karasozen, University of Alaska Fairbanks (ekarasozen@alaska.edu); Cyril Müller, Volcanological and Seismological Observatory of Costa Rica (cyril.muller@una.cr); Evelyn Nuñez, Volcanological and Seismological Observatory of Costa Rica (evelyn.nunez.alpizar@una.cr); Diego Quirós, University of Capetown (diego.quirós@uct.ac.za); Liam Toney, U.S. Geological Survey (ltoney@usgs.gov)

Modeling Tilt From Near-source Broadband Seismic Records of Lahar and Pyroclastic Density Currents at Volcán De Fuego, Guatemala

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Broadband seismometers deployed for volcano monitoring may also respond to load-induced ground rotation near volcanic flows, offering a new tool for estimating flow characteristics. We analyzed tilt signals on broadband stations deployed along two active lahar channels on the flanks of Volcán de Fuego, Guatemala over parts of three years. The temporary deployment fortuitously captured two moderate pyroclastic density currents (PDCs) as well. Seismic stations were located at distances from 10 to 350 m from the channels and have corner frequencies at 1/60 or 1/120 Hz. These deployments were designed for lahar detection at relatively high frequencies at which lahars are most energetic, but the seismograms also exhibit clear signals below the instrument corners that suggest the lahar masses produce rotation at the stations. We began with a catalog of lahars for years 2021-2024. For each lahar, tilt was derived using a standard approach for signals below the instrument corner. The derived tilt signals are fairly complex and can vary between stations within a single drainage for a given lahar event. Typical signals have a

relatively sharp onset followed by multiple pulses within a single lahar event which are generally consistent with the timing of later flow surges as indicated by the high-frequency seismicity. The PDC catalog is limited and both flows are relatively small, but the derived tilt parameters are similar to those of the lahars. For all flows, the directions of maximum tilt are not perpendicular to the channel at two stations, suggesting topography and channel morphology has a strong influence on the recorded tilt. We model the flow sizes using a finite-difference approach, assuming distributed point forces within the channel. To account for topographic effects on the signals, we used a high-resolution DEM to estimate flow sizes. One notable result is that the 18 largest lahars that flow past multiple stations appear to bulk up after they reach the lower gradient reaches of the channel. Dedicated deployments for measuring tilt could offer an additional tool for understanding volcanic flow processes.

Why Do Some Landslides Give Warning Prior to Failure? Characteristics of Precursory Seismic Sequences in Landslides

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On August 10, 2025, ~65 million m³ of rock collapsed into the Tracy Arm fjord in SE Alaska, generating a tsunami that ran to a height of ~1470 ft across the fjord. This wave represents the second-largest landslide tsunami ever recorded. Subsequent review of seismic data shows that the slide was preceded by days of microearthquakes that became larger and more frequent over time and became nearly continuous in the hour prior to failure. This sequence bears significant similarity to activity recorded before a number of other mass-wasting events, including slides recorded at Mount Baker (Washington), Iliamna volcano (Alaska), Mount Steller (Alaska), Rausu (Japan), Askja Caldera (Iceland), and Nuugatsiaq (Greenland). In contrast, landslides such as those at Oso, WA and Mount Meager, British Columbia exhibited no known seismicity prior to failure.

We present an overview of landslide precursory seismicity, synthesizing observations of sequence duration, waveform similarity, temporal evolution, and failure style, as a step towards identifying why some landslides give seismic warning prior to failure and others do not. The duration of the precursory sequence ranges from weeks to minutes. For a given landslide, most precursory quakes are similar in time series, suggesting a repeating source mechanism and location. In some cases, the interevent timing of precursory quakes decreases on an exponential basis, while in other slides the precursors occur erratically. We find that precursors can exist in failures rooted in many types of source material—ice, shale, sandstone, and gneiss. Where the failure surface is known, most slides with precursory activity seem to include some translational slip along a planar surface; none of these events is known to have initiated as a rockfall or fragmental flow. This pattern suggests that precursory activity may be uniquely associated with accelerating slip at the base of an intact mass. Identifying why some landslides exhibit precursory seismic activity provides a potential pathway toward recognizing hazardous slope failures in advance of catastrophic failure.

Precursory Earthquakes From the Tracy Arm Landslide

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On 10 August 2025, 5:26 am local time (13:26 UTC), a massive landslide (>64 million cubic meters) detached from a slope 95 km southeast of Juneau, Alaska, in Tracy Arm. The impact generated the second-largest tsunami ever recorded, producing a runup of up to 481 m on the opposing fjord wall, 1.6 km from the source. This event is remarkable both for the scale of the hazard and for the unusually energetic precursory seismic activity observed weeks prior to failure, representing the first documented case of landslide precursors recorded at this scale and distance. These signals were sufficiently energetic to be recorded at stations hundreds of kilometers away. Together, they released energy roughly equivalent to a magnitude 4 earthquake.

Hypocenters for more than a hundred of these events, published by the Alaska Earthquake Center, place them all at or near the landslide. Using these events as templates, we apply template matching on continuous seismic data

from nearby stations to identify additional precursory events. This approach reveals more than 4000 precursory events, beginning at least 3 weeks prior to the landslide. Clustering these events by waveform similarity reveals that they are highly repeating, suggesting a common source mechanism. Both the rate and amplitude of the precursory activity increased exponentially with time, peaking at approximately 15 events per minute around 4:00 AM local time on 10 August. For the next hour, the occurrence rate remained relatively constant, but the amplitude reduced significantly. Approximately 30 minutes before the landslide, both the event rate and amplitude declined simultaneously. Based on these observations, we evaluate several candidate mechanisms for generating precursory seismicity. We also consider local geology, tidal impacts, and satellite remote sensing observations. Together, these observations favor some mechanisms over others. Lastly, we examine whether or not these conditions are unique to the Tracy Arm setting and why the precursory sequence was so exceptionally energetic.

Landslide Seismicity Records Slip Events on Lateral Shear Margins and on Internal Faults Accommodating Longitudinal Extension

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The frictional behavior of landslides remains poorly constrained, and comprehensive seismic investigations in landslide-prone regions are still relatively limited. To elucidate the slip processes governing a slowly moving landslide, we deployed a dense array of 60–80 seismic nodes at the Oak Ridge Earthflow in California's Diablo Range for 3–10 weeks during the rainy seasons of 2023 and 2024, intervals characterized by decimeter-scale displacements. In parallel, GNSS receivers and extensometers were installed at the same site. Throughout the deployment, the seismometers recorded numerous low-amplitude seismic signals that were highly localized, being detected exclusively by nearby stations spaced within approximately 100 m. To investigate their underlying mechanisms, we applied automated detection methods and analyzed their spatial and temporal distributions. Specifically, we conducted array-based signal processing using Coveisnet (Seydoux et al., 2016) to extract local seismic signals based on the coherence of dominant frequencies across the array, followed by automated phase picking with Quakephase (Shi et al., 2024) and event localization through beamforming (Beaucé et al., 2023). This integrated workflow enabled the efficient and robust identification of local seismic events. The seismic signals were not continuously observed but instead exhibited pronounced temporal and spatial clustering. Notably, bursts of seismicity occurred prior to acceleration of the landslide toe relative to the body, likely in response to the formation of a new normal fault accommodating longitudinal extension within the landslide mass. We also observe bursts of seismicity at the lateral shear margin of the landslide during discrete mm-scale slip events recorded on extensometers. Overall, these results demonstrate that seismic observations provide critical insights into landslide slip processes and can substantially inform monitoring and hazard mitigation strategies.

Systematic Detection of Glacial Earthquakes in Thwaites Glacier, West Antarctica, by Regional Surface Waves

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Glacial earthquakes are a class of seismic sources generated by the capsizing of icebergs calved from glacier termini, a form of significant mass movement exhibited in polar regions. Although teleseismically observed in Greenland glaciers via the global seismic network, seismic detection of such events in Antarctica has remained elusive. Here, we develop an automatic detection algorithm based on the coherence of relatively short-period Rayleigh waves recorded by the regional seismic network onshore Antarctica. The application to the 2010–2023 dataset resulted in a catalog of 362 largely uncatalogued Ms 2–3 seismic events associated with Thwaites and Pine Island Glaciers. The correlation between the frequency of Thwaites events and episodic speed-ups of its frontal ice tongue between 2018 and 2020 suggests a capsizing-glacial-earthquake nature. Pine Island Glacier events near the grounding line show early evidence of basal sliding and remain under further investigation. This study demonstrated the prevalence of glacial earthquakes in Antarctica, with characteristics distinct from those of their Greenland counterparts. The findings have the potential to enable further research into the (in)stability of the Thwaites Glacier calving front under ocean forcing, which may have far-reaching implications for global sea-level rise.

Detecting, Characterizing and Monitoring Mass Movements [Poster]

Poster Session • Wednesday 15 April

Conveners: Paul Bodin, University of Washington (bodin@uw.edu); Pierre Boymond, Volcanological and Seismological Observatory of Costa Rica (pierre.boymond@una.cr); Nahomy Campos, Volcanological and Seismological Observatory of Costa Rica (nahomy.campos.salas@est.una.ac.cr); Esteban J. Chaves, Volcanological and Seismological Observatory of Costa Rica (esteban.j.chaves@una.ac.cr); Avery E. Conner, University of Oregon (aconner2@uoregon.edu); Joan Gomberg, U.S. Geological Survey (gomberg@usgs.gov); Sonia Hajaji, Georgia Institute of Technology (ssalgado30@gatech.edu); Ezgi Karasozen, University of Alaska Fairbanks (ekarasozen@alaska.edu); Cyril Müller, Volcanological and Seismological Observatory of Costa Rica (cyril.muller@una.cr); Evelyn Nuñez, Volcanological and Seismological Observatory of Costa Rica (evelyn.nunez.alpizar@una.cr); Diego Quirós, University of Capetown (diego.quirós@uct.ac.za); Liam Toney, U.S. Geological Survey (ltoney@usgs.gov)

POSTER 80

Adapting a Granular Flow Model to the U.S. Geological Survey Experimental Debris-flow Flume

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Debris flows produce complex seismic signals. Our current understanding of the ties between the physical processes within these flows and the seismic recordings they produce is limited. By adapting mathematical and physical models of sediment transport, we hope to better understand debris-flow signals. In this study, we aim to adapt a laboratory-validated mathematical model of granular flows to seismic recordings from experimental debris flows at the U.S. Geological Survey debris-flow flume near Blue River, Oregon. We analyze recordings from 12 debris-flow experiments with varying constraints, such as particle size, recording geometry, and flume bed composition, and use these experiments to understand the impact of changes in various model parameters on modeled seismic power. We test several model variations, including: (1) adapting the debris-flow model to allow for particle diameter distributions, (2) cobble or extreme outlier grain sizes, (3) nonuniform velocity variations, and (4) non-bedrock channel conditions. Our final step is to calculate modeled seismograms using previously computed Green's functions at the flume site and compare these modeled seismograms to the recorded seismograms. Our goal for this research is to develop a debris-flow model that can be adapted to observed seismic waveforms from debris flows in natural settings, where limited knowledge exists about model parameters such as channel properties, suspended-sediment volume, or flow characteristics.

POSTER 81

Linking Landslide Dynamics to Seismic Detection at Barry Arm Landslide, Alaska

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Large landslides can generate destructive tsunamis with little warning, posing a challenge for detection. In Prince William Sound, Alaska, the Barry Arm landslide is a well-studied unstable slope capable of triggering a tsunami, but similar unstable slopes exist throughout the region. Seismic signals are likely to provide the earliest evidence of failure, but it is unclear whether these sig-

nals—especially those involving water—can be reliably detected in real time. Following identification of the hazard, the Barry Arm landslide has been closely monitored, motivating the development of numerical landslide–tsunami models and a regional long-period seismic landslide detection algorithm for a prototype early-warning system. However, these tools have not yet been fully linked to evaluate the expected reliability of seismic detection

Here, we bridge physics-based landslide and tsunami modeling with forward modeling of long-period seismic signals, and conduct seismic detection tests. We use numerical landslide simulations for eight plausible failure scenarios, spanning multiple volumes and end-member material properties with and without water. We convert center-of-mass motion from each simulation into equivalent single-force seismic sources, then generate synthetic seismograms at the real station geometry using the forward model of the *lsforce* landslide seismic inversion software. These synthetic seismograms are embedded in real noise and tested with the regional detection algorithm to evaluate detectability, location accuracy, and size estimation under varying network coverage and noise conditions. We validate the workflow using a known landslide at Barry Arm, comparing forces derived from D-Claw simulations with forces inverted directly from observed seismic data. Our results show that some tsunami-generating scenarios are detectable and locatable with the existing network, but others—particularly those with strong water interaction—challenge current methods. This framework provides a path toward using seismic data not only for rapid detection but also for estimating landslide size and tsunami potential in real time.

POSTER 82

Advances in Seismic Monitoring of Landslides in Alaska

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We present recent advances in seismic monitoring of landslides in Alaska, with a focus on operational performance during summer 2025. Over this period, the system successfully detected 15 landslides across Alaska, demonstrating its robustness at the regional scale. One notable example is the Tracy Arm landslide, which generated the second-largest landslide tsunami ever recorded and ranks among the most significant regional landslides of the past decade. Although Tracy Arm lies outside the current real-time detection grid, rapid post-event seismic analysis allowed us to identify the landslide location and estimate its size shortly after tsunami reports were received. This information directly guided early reconnaissance efforts and highlighted the value of seismic monitoring for rapid hazard response in remote regions. We will present analyses of Tracy Arm and other significant landslides, including events in Taiwan (Wanrong rock avalanche) and Switzerland (Blatten landslide), to demonstrate that the approach is applicable beyond Alaska and performs robustly across diverse tectonic and geographic settings.

Building on earlier work in Prince William Sound, we have significantly expanded the spatial extent of the real-time detection system, increasing coverage from a localized regional grid to much of Alaska and incorporating dynamic station selection from more than 200 seismic stations. The system performs well at suppressing false detections from regional and nearby earthquakes, and initial filtering effectively excludes teleseismic signals during their first arrivals across the grid. Ongoing work targets false detections associated with later-arriving surface waves, with additional thresholds currently under development. We will present updates to the real-time detection framework, including expanded spatial coverage, improved earthquake discrimination, and an updated landslide volume–seismic scaling relationship informed by newly detected events.

POSTER 83

Triggering of Slow-moving Landslides in New Zealand and Northern California: Insights From InSAR Time Series Analysis of the 2016 Kaikōura and 2022 Ferndale Earthquakes

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Both New Zealand and Northern California host large numbers of slow-moving landslides and have, in recent times, experienced frequent moderate-to-large earthquakes. Following the 2016 Kaikōura earthquake, Cao et al. (2023) identified 21 earthquake-triggered landslides and modeled their post-seismic evolution using a piecewise exponential decay function. Building on this approach, we present a comparative investigation in Northern California

to detect large earthquake-triggered landslides following the 2022 Ferndale earthquake and characterize their temporal decay. While Cao et al. (2023) used a phase-gradient approach with Sentinel-1, we utilize a 14-day L-band ALOS-2 ScanSAR InSAR time series spanning July 2021–March 2024, capturing responses to precipitation and two moderate earthquakes: Mw 6.2 (December 2021) and Mw 6.4 (December 2022).

After systematically extracting and cleaning displacement time series, we analyze 437 landslides across a $\sim 300 \times 400$ km area, grouping time series by relative velocity changes to identify anomalously fast motion. We test associations with external drivers (PGA, precipitation) and landslide attributes (slope, aspect ratio, area); shaking from the 2022 event shows the strongest association with faster sliding rates. For slides that experienced higher PGA and increased velocities, a piecewise model (linear pre-event trend + exponential post-event decay) yields recovery to within $\sim 10\%$ of pre-event rates in ~ 1.3 years. The localization of triggered slides within the high-PGA footprint, the immediate onset with exponential decay, and the overall pattern together favor a seismic trigger. This work, in part supported by the Landslide Watch Aotearoa program, advances our understanding of triggering mechanisms through detailed time series analysis that will complement physics-based modelling of slow-landslide failure.

POSTER 84

Seismic Monitoring of Flooding, Debris Flows, and Landslide Dynamics After the 2025 Palisades Fire, California

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Burned landscapes are highly susceptible to land-surface hazards because wildfires remove vegetation and alter soil properties, reducing infiltration and enhancing runoff. As post-fire hydrological and geological conditions evolve, diverse cascading hazards—including debris flows, landslides, and flooding—can occur. Differencing digital elevation models derived from drone and terrestrial LiDAR surveys is effective for detecting pre- and post-event landscape changes, but these methods are limited by insufficient temporal resolution and cannot capture the continuous post-fire processes.

In this work, we investigate the temporal evolution of post-fire hazards and their response to rainfall triggering using seismic data. We deployed flow-monitoring stations at five sites in the burned area of the Santa Monica Mountains after the 2025 Palisades Fire. Each site was equipped with a rain gauge, camera, and paired upstream and downstream geophones along the channel. We collected high-quality seismic data together with continuous rainfall intensity and photographic records since November 2025. Preliminary results show seismic amplitudes during storm events are generally higher than background levels, with most energy concentrated at low frequencies below 5 Hz. Distinct seismic events are detected during and following periods of high rainfall intensity, expressed as increased seismic energy across broad frequency bands. Camera imagery confirms these events include flooding, debris flows, debris floods, and landslides. Event types can likely be distinguished by differences in event duration, seismic spectra, and waveform characteristics. Furthermore, seismic data from spatially distributed geophones may be used to infer debris flow velocities and flood discharge. These results highlight the complexity of cascading hazards in steep, post-fire landscapes and demonstrate the potential of seismic data for detecting spatiotemporal changes in post-fire hazards. Improved understanding of the post-wildfire hazard dynamics will contribute to more accurate predictive models of regional cascading hazards following fires.

POSTER 85

Seismic Monitoring of Mass Movements and Cascading Surface Hazards in Mountain Regions

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Surface mass movements such as debris flows, landslides, and outburst floods often initiate hazard cascades that amplify impacts far beyond their source regions, yet their dynamics and evolution remain difficult to observe in real time. Recent advances show that seismic signals provide a unifying, non-invasive tool to investigate these processes across scales. We demonstrate that high-frequency seismic radiation from debris flows can be physically linked to basal force fluctuations generated by both random single-particle impacts and collective multi-particle force chains. Accounting for these mechanisms explains observed non-linear relations between flow depth and seismic amplitude, and enables improved constraints on bulk flow properties.

Seismic observations further illuminate complex hazard cascades involving landslide damming, dam breach, and downstream flooding. We show that different stages of these cascades radiate seismic energy in distinct ways, with some flood processes weakly detectable at distance due to channel stability, while dam-breach dynamics can generate clear seismic precursors well before hazardous discharge levels are reached. Incorporating seismic constraints into numerical models improves the reconstruction of poorly instrumented events and enhances early-warning potential. Finally, we show that scalable seismic monitoring strategies can extend effective coverage to remote, under-instrumented mountain regions at a fraction of the cost of conventional networks. Together, these results establish seismic monitoring as an integrated framework linking particle-scale physics and cascading hazards, with important implications for real-time warning and long-term risk management in mountainous environments.

Developing Data-Driven Methods in the AI Era: New

Approaches to Earthquake Science

Oral Session • Thursday 16 April • 10:30 AM Local

Conveners: Susan E. Hough, U.S. Geological Survey (hough@usgs.gov); Ian McBrearty, Stanford University (imcbrear@stanford.edu); Mostafa Mousavi, Harvard University (mousavim@google.com); Hongyu Sun, University of Texas at El Paso (hsun2@utep.edu); Valeria Villa, California Institute of Technology (vvilla@caltech.edu); Taiyi Wang, California Institute of Technology (taiyi@caltech.edu); Clara Yoon, U.S. Geological Survey (cyoon@usgs.gov); Caifeng Zou, California Institute of Technology (czou@caltech.edu)

Random Splitting and the Risk of Information Leakage in Seismic AI

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Information leakage (also known as data leakage) refers to a problem when the information at inference time is introduced at training time, which can lead to an overestimation of model's performance. Seismology is especially prone to information leakage because seismic events form clusters and many stations operate for years, producing numerous highly similar waveforms. As a result, preparing training, validation, and test datasets by randomly splitting the waveforms (the most common practice used thus far), or even based on event origin times (e.g., for earthquake forecasting studies), can almost certainly cause information leakage. Because of this, many highly optimistic results from studies that report on models with nearly perfect performance or those that demonstrate on solving problems that were previously thought to be unsolvable, could be the outcomes of information leakage. Here, we conduct a series of experiments to demonstrate the effects of information leakage in common seismological applications of deep learning. We discuss how to detect signs of information leakage and provide guidance to prevent this from happening moving forward.

Robust Moment Tensor Inversion on Irregular Arrays With Physics-structured Sim-to-teal Training

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Reliable focal mechanism inversion is important for understanding fault systems and stress fields, yet it remains challenging for small-magnitude events ($M < 3.5$) where signal-to-noise ratios are low and high frequency Green's functions are less reliable. Traditional methods (e.g., grid-search using P-polarities) have large uncertainties when azimuthal coverage is poor, while existing deep learning approaches (e.g., CNNs) typically require fixed station grids or interpolation, limiting their flexibility for real-world ad-hoc networks. In this study, we introduce SourceNet, a permutation-invariant Transformer framework designed to estimate the moment tensor directly from variable sets of waveforms and station metadata. To address the Sim-to-Real gap, i.e. models trained on 1D synthetic Green's functions fail on real data, we implement a physics-structured domain randomization (PSDR) strategy. Rather than relying on standard domain adaptation, we train the model on synthetics generated with randomized velocity models, realistic noise injection, random path and site effects, and stochastic station dropouts. This forces the network to learn features invariant to unmodeled crustal heterogeneity and scattering. Validated on the Southern California Earthquake Data Center (SCEDC) catalog, SourceNet achieves a median Kagan angle error of $\sim 19^\circ$ for $M > 3$ events, matching or exceeding human-reviewed catalogs and most machine learning baselines. Furthermore, we analyze the model's internal attention mechanisms to understand what seismological features drive its predictions. Grad-CAM analysis reveals that SourceNet implicitly utilizes crustal phases in the P-wave coda, which are typically discarded by classical solvers, to constrain the solution. Furthermore, the model shows emergence: it autonomously assigns higher attention weights to stations in azimuthally sparse directions, effectively recovering principles of optimal experimental design. Our results demonstrate that attention-based deep learning can provide robust, interpretable, and real-time source characterization for modern seismic monitoring.

Machine-learned Acceleration of Earthquake Sequence Simulations

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Earthquake sequence simulations involve slow interseismic processes and rapid dynamic ruptures. During the interseismic period, large time steps can be taken efficiently. In contrast, during the seismic period, the time step must be drastically reduced, and the elastodynamic wave memory effects become significant, making long-term simulations computationally expensive. We investigate the use of neural operators to accelerate earthquake sequence simulations. Specifically, we train a Fourier Neural Operator (FNO) to learn a jump map that advances the system state from before to after the seismic rupture, using data generated from high-fidelity earthquake sequence simulations. We propose a hybrid modeling framework in which the conventional numerical solver is used to simulate the slow interseismic evolution, while the trained FNO replaces the computationally intensive seismic periods. The hybrid model successfully reproduces key long-term statistics from earthquake sequence simulations, including event-magnitude and interseismic time distributions.

Development of an Enhanced Seismicity Catalog for the Cascadia Subduction Zone

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Earthquake catalogs provide essential observational constraints for the study of active tectonics, volcanism, and natural hazard assessment along the Cascadia subduction zone. In traditional seismic network catalogs, small-magnitude

earthquakes are typically underrepresented due to the use of amplitude-based detection algorithms. Moreover, locations can contain significant epistemic error due to the use of one-dimensional velocity models that oversimplify 3D Earth structure. To construct a more comprehensive earthquake catalog for the Cascadia margin we apply a transfer-learned EQTransformer to continuous waveform data recorded between 2002 and 2024 on thousands of broadband seismometers across southwestern Canada, Washington, Oregon, and Northern California. We then associate millions of phase picks with the Pyocto associator and locate the associated events with the newly developed 3D CRESCENT community velocity model using NonLinLoc. This results in a 22 year-long catalog with over three times as many events as compared to the COMCAT network catalogs. Despite the improved detection capabilities, the dearth of microseismicity along the Cascadia plate interface remains. However, we find significant increases in seismicity count from intraplate, volcanic, and upper-crustal environments, which are otherwise poorly characterized. Together, these efforts lay out the groundwork for the authoritative earthquake catalog that will serve the CRESCENT initiative and the broader research community.

Automated Labeling to Build Deep Learning Models for OBS Phase Picking

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Seismic phase picking is fundamental to seismic data analysis. Current deep learning-based phase picking is promising when applied to the data from land-based seismometers, while its applicability to ocean-bottom seismometer (OBS) data, especially airgun-shooting data, is limited. Moreover, marine seismometer datasets still rely heavily on manual picking for label generation, which limits the availability of training data and poses a significant obstacle to building efficient workflows capable of handling large-scale seismic datasets.

We propose a method to enable automated P-wave first-arrival labeling and deep learning training for the vertical component of OBS active-source data. We perform binary classification (Liu et al. 2016; Liu & Beroza, 2020) on OBS active-source data into signal and noise, and combine with station-location information to derive P-wave first-arrival picks from the classification results without manual intervention. These automatically picked labels constitute a large-scale training dataset that supports training deep learning models, thereby constructing an automatic phase picking framework. We validate our approach using the OBS active-source records from the Nankai Trough, Japan. The generated first-arrival picks exhibit strong alignment and reasonable errors with manual picks. Based on these labels, we train a deep learning model, demonstrating the feasibility of the method for automated phase picking. Future work will expand the quantity and diversity of training data, which is expected to further improve the accuracy and generalization of deep learning models and enable a fully automated OBS phase picking workflow.

Data-driven Seismology for Nonstationary Wavefields and Hydromechanics

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Earthquake ground shaking and associated ground failures are strongly modulated by near-surface hydromechanical conditions, yet these effects are typically treated as static in seismic hazard assessments. In particular, we explore how transient changes in water table depth and soil saturation – driven by seasonal hydrology, extreme precipitation, drought, and sea-level rise – can substantially alter wave propagation, site response, and ground failure due to liquefaction, using the 2001 Mw 6.8 Nisqually earthquake using wavefield simulations and geotechnical models that predict ground failures from ground motion amplitudes, geotechnical properties, groundwater levels. We demonstrate how the effects of saturation and water table, sea-level long-term trends, fluctuations expected from normal seasonal variations, and extreme variability expected from extreme rainfall events, such as those from repeated

Atmospheric River events, affect ground failures for a given ground motion simulation.

Building on this foundation, we introduce a new sensor-driven architecture for wavefield reconstruction that predicts multi-physics ground motion directly from sparse seismometer observations. The approach is source-agnostic and relies solely on recorded wavefields, with an encoder-decoder network at its core. The common latent representations encode wavefield dynamics without requiring explicit knowledge of the earthquake source. To address missing or imperfect physics, we integrate data assimilation as a model-refinement strategy, using observational constraints to iteratively correct and fine-tune the learned wavefield representations. Together, these results illustrate a path toward dynamic, climate-modulated seismic hazard forecasts that bridge physics-based modeling, sensor data, and data-driven learning.

Large-scale 3D Ground-motion Synthesis With Physics-inspired Latent Operator Flow Matching

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Earthquake hazard analysis and design of spatially distributed infrastructure such as power grids and energy pipeline networks require scenario-specific ground-motion time histories with realistic frequency content and spatiotemporal coherence. However, producing the large ensembles needed for uncertainty quantification with physics-based simulations is computationally intensive and impractical for engineering workflows. To address this challenge, we introduce Ground-Motion Flow (GmFlow), a physics-inspired latent operator flow matching framework that generates high-fidelity, large-scale regional ground-motion time-histories conditioned on physical parameters. Trained and evaluated using simulated events for the San Francisco Bay Area on a single workstation GPU, GmFlow generates coherent ground motion on 9 millions grids in seconds , enabling rapid ensemble generation for scenario-based hazard assessment. These results establish a scalable paradigm for regional ground-motion synthesis that could benefit uncertainty-aware analysis of system-level infrastructure.

The Digital Archivist: Automating Legacy Macroseismic Data Processing Mining Using Large Language Models

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Macroseismic data are a key resource to investigate shaking and damage from pre-instrumental and pre-digital eras. However, data are often stored as inconsistently-formatted reports describing observed shaking and damage, making manually parsing and interpreting accounts a labor-intensive process (Hough et al., 2025). This study introduces a novel workflow using Google’s Gemini 2.5 Pro large language model (LLM) to automate macroseismic data extraction and interpretation from summary reports (Hough et al., 2025). We apply this workflow to the March 22, 1957, M5.3 Daly City, California earthquake as a case study, extracting addresses, MMI values, and descriptions from each report. To address coordinate precision limits, addresses were geocoded via Google’s Geocoding API. . To assess the accuracy of the workflow, we first evaluated the full dataset by generating a ShakeMap and comparing interpolated intensities with instrumental data from five strong-motion stations in the San Francisco Bay Area. Using ground motion to intensity conversion equations, we converted known peak ground velocity and acceleration values to MMI. The dataset closely matched instrumental values with a mean absolute error of ~0.5. When Gemini used 0.5 increments instead of whole numbers, the error decreased to ~0.35, demonstrating the importance of prompt engineering for optimizing results. We also present preliminary results for the 1971 Sylmar earthquake. Our results demonstrate LLMs’ potential for reliably extracting and analyzing large, unstructured macroseismic datasets. LLMs could offer a scalable solution for rapidly digitizing macroseismic archives, enabling broader use in modern seismic hazard analysis to constrain ground motion models and improve understanding of site effects in urban areas.

Scalable Earthquake Phase Association Based on Wadati and Voronoi Diagrams

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We have developed the Voronoi tessellation- and origin time-based Rapid Associator (VoRA), an efficient and scalable earthquake phase association method that exploits the spatial and temporal clustering of earthquake origin times inferred from multiple stations. Recent advances in deep learning models have enabled detection of S-phases and P-phases with similar effectiveness, making it straightforward to estimate corresponding earthquake origin times from P- and S-phase arrival pairs. We predict earthquake origin times either through the fixed-slope Wadati diagram with a prescribed regional Vp/Vs ratio or using a machine learning model trained on millions of labels of origin times. We further introduce the Voronoi tessellation to define the spatial nth-order neighbors for each station, providing an adaptive framework that accommodates variable station densities across the network. Based on these two approaches, VoRA minimizes the number of hyper-parameters to only 3: the uncertainty of predicted origin times, the n-th other of neighborhood, and the minimum number of stations. To demonstrate the performance of VoRA, we apply it to one month of data from California in December 2022. The input dataset comprises ~5.2 million origin time picks and ~6.8 million phase arrival picks from a multi-task model PhaseNet+ (Zhu et al., 2025). VoRA completes the association of these picks and gives preliminary locations in ~5 minutes using a single CPU (Apple M4 Pro processor with 24 GB RAM). VoRA successfully associates most cataloged earthquakes while detecting ~5.5 times more events not present in the existing catalog. As an unsupervised method, it avoids the massive computational resources for the training process and generalizes readily to other regions and network geometries. The method is scalable and efficient, addressing the growing demands posed by expanding seismic networks and the increasing volume of automated phase picks.

Optimizing Seismic Phase Picking in West Indonesia Using Transfer-learned Phasenet Models

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Seismic phase picking in Indonesia is particularly challenging because the region combines subduction zones, collision belts, and active fault systems that generate highly variable local waveforms. Although deep-learning pickers such as PhaseNet perform well on global benchmarks, their pretrained models often trained on large reference datasets such as the Stanford Earthquake Dataset (STEAD) have not been systematically adapted to Indonesian seismicity. Here we investigate how transfer learning can be used to align pretrained PhaseNet models with the diverse tectonic environments of western Indonesia. We compile a West Indonesia Seismic (WIS) dataset from four regional catalogs covering Sumatra, Java, Sulawesi, and the Sunda–Banda Arc, comprising more than 70,000 three-component waveforms sampled at 20 and 100 Hz. Five pretrained PhaseNet variants are evaluated in their original form and after full retraining on the WIS data. Before fine-tuning, mean residuals are large (20 Hz: P_S > 7 s; 100 Hz: P > 4.5 s, S > 4 s) and mean pick probabilities are low (P < 0.6, S < 0.4). After fine-tuning, performance improves substantially, with mean residuals reduced (20 Hz: < 2.5 s; 100 Hz: < 0.7 s) and mean probabilities increased (P > 0.8; S > 0.75–0.8). Among the pretrained

variants, the STEAD-based model shows the most consistent behavior across both before and after fine-tuning evaluations, particularly for S-phase picking. Models trained with matching input configurations (100 Hz) perform better, indicating sensitivity to waveform length and sampling rate, but fine-tuning largely removes these differences and stabilizes performance across both datasets. Regionally, Java achieves the highest accuracy (mean P residual < 2.6 s), followed by Sumatra (< 3 s) and Sulawesi (< 3.5 s), consistent with their relative data representation. These results demonstrate that transfer-learned neural pickers can be robustly adapted to Indonesian seismicity and provide reliable phase picking across complex tectonic settings.

A Machine-learning-enhanced Catalog of California Statewide Seismicity Over Two Decades

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Microseismicity provides important insights into fault geometries at seismogenic depths, and its spatiotemporal characteristics can provide constraints on the mechanics of earthquake nucleation and rupture. The detection of small earthquakes, though challenging due to their weak seismic signals, has been greatly advanced by the development of machine-learning (ML) methods, which have been successfully applied in a wide range of tectonic settings. In California, the complex network of active faults and dense seismic networks highlight the necessity and opportunity for an enhanced earthquake catalog with temporal continuity. Here, we present a ML-based earthquake catalog of California from 2000 to 2024, utilizing continuous seismic data from the Northern and Southern California Earthquake Data Centers. Our earthquake detection workflow, QuakeFlow, includes phase picking, phase association, absolute location, and cross-correlation-based relative relocation. We significantly increase the number of detected earthquakes by about five times against the routine catalog, and lower the magnitude of completeness. Through an augmented view of microseismicity across California, we aim to constrain the geometry of active faults in detail. The improved spatial and temporal resolution of seismicity will advance our understanding of fault mechanics, earthquake interactions, and foreshock-aftershock behavior.

Performance of the Deep-learning Phase Picker Phasenet on Magnitude 3+ Earthquakes in Southern California

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As machine learning tools have become more reliable and vetted, efforts to incorporate them into regional monitoring systems have been increasing. Most commonly, these algorithms focus on phase picking and association. Ideally, a phase picker could be generalized such that it could accurately pick phases from earthquakes of any magnitude or in any geographic or tectonic region. In practice, this has been a challenge, with many studies identifying problems with using generalized pickers in regions they weren't trained on. However, few studies have quantified the performance of such pickers on larger magnitude events which tend to be lacking in training data sets while also being very important for regional monitoring tasks.

In this study, we evaluate the performance of the deep-learning phase picker PhaseNet (Zhu & Beroza, GJI, 2018) on magnitude 3+ earthquakes in Southern California. We applied the standard (i.e., not retrained) PhaseNet algorithm to ~60 events, mostly between magnitude 3 and 6, and compared its picking ability to the current real-time system operated by the Southern California Seismic Network and to human analysts. We observed a noticeable drop-off in PhaseNet’s ability to make picks on earthquakes of magnitude 5 or above, although the accuracy of those picks was similar to those of the M3–4 events. We also found that PhaseNet tended to make earlier picks than the analysts and that there were no geographic trends in pick accuracy. We also consider how the pick quality value and phase score relate to pick accuracy and missed picks. This study provides context for the suitability of using generalized machine-learning phase pickers in regional earthquake monitoring and suggests that networks should consider using multiple pickers or retrain the generalized pickers to improve performance over a wide magnitude range.

A Systematic Comparison of Foundation Models for Earthquake Detection

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In recent years, large foundation models, particularly those developed for natural language processing, have become increasingly prevalent across a wide range of research fields due to their strong generalization capability and versatility, triggering a new wave of advances in artificial intelligence. In seismology, several methods based on large foundation models have also been proposed. These studies suggest that pretrained models have achieved some progress in multitask applications, such as earthquake location and magnitude estimation. However, improvements remain limited in phase picking, the first step and the only task in the seismic data processing workflow for which machine learning methods have been widely and routinely adopted. It is therefore important to carefully examine whether large foundation models can further improve phase-picking performance, or whether their inherent limitations prevent meaningful advances in this task. In this study, we conduct a systematic comparison between our proposed large language model based phase-picking approach and other existing large seismology foundation models. We evaluate different model architectures and training strategies to assess their impact on phase-picking performance. Unlike previous studies that primarily focus on picking accuracy alone, we directly compare the earthquake catalogs obtained after phase association and event location using different models. When applied to seismic data from the 2019 Ridgecrest Mw 7.1 earthquake sequence in California and the 2023 doublet earthquake sequence in Türkiye, our approach achieves performance that is comparable to, and in some cases exceeds, that of existing deep learning-based phase-picking methods. Overall, this study demonstrates that pretrained language models can be effectively adapted to seismological applications through fine tuning, which provides new insights into their potential and limitations for phase picking and subsequent steps in building high-resolution catalogs.

AkiNet: A Physics-informed AI for Wave Extraction From Noise

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High-resolution seismic models of the Earth’s lithosphere are critical for understanding its structure and evolution, yet current global models lack the details that can be provided by ambient noise data. A primary bottleneck is reliably extracting phase velocities from the vast, often noisy data sets produced by ambient noise cross-correlations (noise correlation functions). To address this, we introduce AkiNet, a Physics-Informed Neural Network designed as a “zero-shot” solver for this difficult inverse problem. Unlike supervised learning approaches, AkiNet operates without pre-training or labeled data by directly embedding the governing physics of wave propagation (Aki’s theoretical framework) into its loss function. When compared against a modern waveform-fitting algorithm, AkiNet yields more reliable dispersion estimates, particularly for Love wave data with low signal-to-noise ratios. To further demonstrate the reliability of this algorithm, we develop a novel synthetic benchmark dataset, encompassing a wide range of examples generated from diverse ambient noise source geometries, noise levels, and Earth model combinations. This controlled and physically consistent benchmark enables a rigorous comparison against existing state-of-the-art approaches and highlights the performance of AkiNet across challenging propagation scenarios. AkiNet is conceived as a scalable tool that presents a feasible pathway toward the construction of a global, high-resolution, and noise-derived dispersion model.

Qseek: Scalable Data-driven Earthquake Detection and Localization

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The eternal growth of data, the deployment of large-N and DAS experiments, necessitates the development of scalable, high-performance tools for seis-

mological analysis. We introduce a framework for automatic detection and precise localization of earthquakes in large seismic datasets. By combining AI first-arrival annotations with an efficient delay-sum-reduce backprojection onto an adaptive octree volume, we can detect seismic events in large spatial volumes and in noise-dominant data. The resolution of the search volume is iteratively refined toward the seismic source location using an adaptive octree, thereby enabling efficient, fast, and accurate search. Qseek is a user-friendly, scalable, high-performance open-source software framework that features event detection in layered 1D and complex 3D velocity models, source-specific station corrections, and event magnitude estimation

We demonstrate the scalability of the framework and method for large-N experiments investigating seismicity in the Eifel volcanic fields, Germany, and swarm region in Western Bohemia at the German-Czech border. Both large-N experiments comprised 300+ seismic stations recording for one year. Furthermore we illustrate the method’s scalability by investigating a rapid dike intrusion on the Reykjanes Peninsula, Iceland. Qseek’s accuracy and scalability to large data enables the AI-driven investigation of large and dense data to resolve seismogenic processes and geological structures in high resolution.

Developing Data-Driven Methods in the AI Era: New Approaches to Earthquake Science [Poster]

Poster Session • Thursday 16 April

Conveners: Susan E. Hough, U.S. Geological Survey (hough@usgs.gov); Ian McBrearty, Stanford University (imcbrear@stanford.edu); Mostafa Mousavi, Harvard University (mousavim@google.com); Hongyu Sun, University of Texas at El Paso (hsun2@utep.edu); Valeria Villa, California Institute of Technology (vvilla@caltech.edu); Taiyi Wang, California Institute of Technology (taiyi@caltech.edu); Clara Yoon, U.S. Geological Survey (cyoon@usgs.gov); Caifeng Zou, California Institute of Technology (czou@caltech.edu)

POSTER 61

A Graph-based Generative Framework for Modeling Spatial Correlation of Within-event Ground-motion Residuals

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Accurate simulation of spatially distributed ground motions is a key requirement for regional seismic hazard and risk assessment of distributed infrastructure systems. While traditional ground-motion models provide reliable estimates of expected shaking at individual sites, they rely on simplified representations of spatial correlation in within-event residuals. Existing correlation models are typically derived from semi-variogram analyses and assume only inter-station dependence, formulated within an ergodic ground-motion modeling framework and without consideration of inter-period correlations. Using a large strong-motion dataset from Japan comprising more than 5,000 earthquakes and approximately 450,000 recordings, we analyze within-event and site-specific residuals across spectral periods. The results show a dependence of spatial correlation length on source-to-site distance, with short correlation ranges (~20 km) at near-fault distances (Rrup<30km) that increase gradually to ~50km upto Rrup ~100km and remains constant thereafter, indicating variations in correlation structure not modeled by traditional isotropic models.

To account for these observations, we develop a machine-learning generative framework using graph-based neural networks to model spatially correlated within-event residual fields. Each earthquake is represented as a graph, with stations as nodes and spatial relationships encoded through graph connectivity, allowing treatment of irregular station distributions. Node features include magnitude, source-to-site distance metrics, Vs30, and the model uses correlated noise fields defined across all nodes to generate residual fields. The model is trained on the same large dataset and evaluated by comparing predicted and observed correlation lengths as functions of source-to-site distance and inter-period correlation structure. The results demonstrate that the proposed approach reproduces empirical trends in spatial correlation not captured by conventional models, providing a scalable and physically consistent basis for incorporating spatially variable residuals in seismic hazard and risk analyses.

POSTER 62

Chatting With the Earth: LLMs for Seismic Data Processing

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Recent advances in Large Language Models (LLMs) have opened new research opportunities within the geosciences. While LLMs excel at processing text, their application to continuous temporal data remains relatively unexplored. This work presents an extension of OpenTSLM, a tokenized time-series language model designed with the capability to reason over raw time-series data, and demonstrates its application to seismic data processing and source parameter estimation. We adapt the architecture to the seismic domain by retraining the model on the STEAD dataset, integrating a lightweight multi-layer perceptron (MLP) to tokenize waveforms and ground the language model during training. This approach allows the model to accept natural language queries and return precise waveform and source attributes—including phase onset times, magnitude, source distance, depth, and waveform classification—via chain-of-thought reasoning. Our preliminary results indicate that the model effectively leverages its prior knowledge of seismology alongside features learned from training data to characterize seismograms. This work illustrates the potential of text-based foundation models for seismological applications. Our approach offers unique advantages over traditional deep learning methods: the reasoning component provides interpretability, while the conversational interface lowers the barrier to entry for complex data analysis. This paves the way for a new generation of seismological AI models with conversational capabilities, enabling researchers to interact with data using natural language.

POSTER 63

Seismicity of the Western Idaho Suture Zone Illuminated by Machine Learning

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The Western Idaho Suture Zone (WISZ) is an ~5-km-wide boundary between the Blue Mountains accreted terrane of Eastern Oregon and the Precambrian North American craton in Western Idaho, characterized by shear along north-trending faults. While past studies have used various methods to explore the structure and composition in and around the WISZ, few studies have focused on the instrumental seismicity of the region. Within the narrow WISZ is a proposed active subvertical strike-slip fault zone. This zone has hosted 2 significant earthquake sequences since 2000. The largest earthquake in the area was the February 2nd, 2024, Mw 4.9 Smiths Ferry event which has produced around 600 aftershocks. The second sequence was the 2005 Alpha earthquake swam which consisted of a large number of earthquakes, 5 of which measured magnitudes as high as 4.

Historically, this region of Idaho has been sparsely instrumented, though temporary stations, such as the Transportable Array and the ORIDA array, have been installed. The ORIDA dataset consisted of 85 three-component broadband which were installed between May 2011 and June of 2013. We use machine learning phase pickers to pick seismic phases and a grid associator to associate phases with earthquakes measured by the ORIDA array. In total, around 2,900 previously unknown earthquakes were located across the study region, with around 600 of those events being associated with the WISZ. The majority of the events detected in this study were < 2.0 in magnitude. Quality fault plane solutions were determined for at least 30 earthquakes, indicating primarily left-lateral strike slip motion. This presentation will outline the process of detecting, verifying, and locating the earthquakes found in the ORIDA dataset, and will provide an overview of the seismicity of the WISZ from the early 2000’s till present.

POSTER 64

Cautions for Applying Automated Earthquake Cataloging Workflow to Local Nodal Arrays

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Reduced sensor cost and improved portability greatly facilitated local temporary dense arrays in the past decade. Beamforming and recently devel-

oped ML-assisted workflows made it possible for quick event cataloging using dense arrays. However, due to the small aperture of these temporary arrays, there is a possibility of mis-locating distant earthquakes to within or near the arrays, which creates artificial local event clustering. This can lead to incorrect second-order interpretations, such as spatial source parameter variations. Such patterns are observed for the three nodal arrays in Oklahoma. Employing stricter association or location criteria could help mitigate such issues, however, these criteria could differ among different workflows or different geological settings, and it is often time consuming to manually examine each event.

Here, we have manually examined the events detected using different methods for Pawnee and Cushing nodal arrays, and created manual labels of local-to-regional events based on waveform characteristics and refined distance to the array. For both arrays, we observe distant earthquakes being mislocated within or near the array. We will apply both unsupervised and supervised Machine learning algorithms to automatically classify events based on derived waveform attributes (e.g., incidence angle, linearity) and spectrogram features. The event classifications “learned” from Pawnee and Cushing will be applied towards a catalog detected for the IRIS wavefield array to test the general applicability of these waveform patterns. We will also explore what parameters in the automated catalog building workflows will mitigate these biases. These results suggest cautions need to be taken when applying automated algorithms to localized nodal arrays in regions with widespread seismicity.

POSTER 65

Which is Better: Deep-learning or Manual Seismic Arrival-time Picking?

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Routine earthquake monitoring catalogs are typically based on manually reviewed arrival-time picks from classical, rule-based automatic pickers. Recent advances in high performance, machine-learning pickers can potentially reduce the analysts workload while producing larger earthquake catalogs with lower magnitude of completeness. But the transition to highly automated, routine monitoring based on machine-learning picks requires careful validation: the resulting earthquake locations must be of equivalent or higher quality than those produced by standard procedures. In this study high-precision earthquake relocations and tomographic inversions results are used to verify this requirement. As a reference, we assemble a catalog and picks from a subset of the 2016 Central Italy seismic sequence provided by the INGV bulletin. This catalog is repicked using the deep-learning picker Phasenet, trained on two independent datasets: waveforms from Northern California and from Italy (INSTANCE dataset). These three pick collections are then processed with the high precision non-linear locator NonLinLoc SSST-coherence and with a 3D local earthquake tomography. The high-precision locations of deep-learning pick collections show improved spatial organization, enhanced clustering, and reduced hypocenter separation for events with similar waveforms than the relocations using routine pick collection. Similarly, the tomographic inversions show statistically better convergence and more organized relocations using the deep-learning picks than with the routine picks. These results indicate that routine earthquake monitoring based on deep-learning arrival-time picks can produce higher quality catalogs than current procedures freeing the analysts’ time for higher-level quality control, assessment, interpretation, and dissemination of seismic information. Such improvements may enhance the characterization of the faults activated in the early stage of a seismic sequence allowing rapid and reliable information which can be very useful for the mitigation of earthquake hazard.

POSTER 66

ESM25: A Machine-learning Ready Snapshot of the European Engineering Strong-motion Database

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ESM25 is a snapshot of the Engineering Strong-Motion (ESM) database, specifically designed to provide a dataset of strong motion records that is fully prepared for analyses employing Machine Learning (ML) and Artificial Intelligence (AI) methods. ESM25 includes data from 5,733 earthquakes that have occurred in the Mediterranean and Middle-East region since 1967, spanning magnitudes from 3 to over 7. Following the ESM policy up to 2025, ESM25 focuses on manually reviewed and processed data, for which it provides three-component acceleration waveforms and derived quantities such as velocity, displacement, spectral acceleration, and spectral displacement. Uniquely, it also includes manually reviewed data classified as “bad quality,” providing a valuable resource for noise analysis and quality control training. The data are accompanied by extensive metadata organized into primary groups that follow the standard adopted by SeisBench, an open-source Python toolbox for machine learning in seismology.

The significance of ESM25 lies in its distribution via the HDF5 container format and its integration into the SeisBench platform, mirroring successful datasets like INSTANCE. By providing a static, versioned snapshot of the dynamic ESM archive, ESM25 ensures reproducibility for benchmarks and comparative studies. Possible applications range from the development of Ground Motion Prediction Equations (GMPEs) and site effect analyses, to the training of automated quality control algorithms. This initiative bridges the gap between traditional engineering seismology and data-driven AI research, fostering collaboration within the global community.

POSTER 67

Transfer Learning with Self-normalizing Neural Network-based Ground Motion Models: From NGA-West to CEUS

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Ground-motion models for the Central and Eastern United States (CEUS), including stochastic and empirical approaches, have been extensively developed; however, the limited availability of moderate-to-large-magnitude observations poses fundamental challenges for calibration and uncertainty reduction. In this study, we propose a transfer learning framework to predict PGA, PSA, and PGV in CEUS using the NGA-West2 dataset as the source domain. A self-normalizing neural network (SNN) is employed to learn stable latent representations suitable for tabular ground-motion regression. To account for the pronounced distributional differences between NGA-West2 and CEUS, we adopt a feature-based domain adaptation strategy that focuses on aligning the marginal distributions of the source and target domains. The adaptation is performed in the SNN’s latent feature space, enabling the extraction of domain-invariant representations while preserving regression-relevant physical information. The resulting embeddings are used to train a downstream regressor for final predictions.

For evaluation, model predictions are benchmarked against established CEUS ground-motion models, including the NGA-East Weighted-Average (WeightedAvg) median model obtained from the University of California, Los Angeles (UCLA) ground-motion characterization tool. Results indicate improved predictive accuracy and generalization, particularly in magnitude-distance ranges where CEUS observations are sparse.

POSTER 68

A Critical Assessment of Domain Adaptation Methods for NGA-West2-to-CEUS Transfer

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Domain adaptation enables knowledge from a source domain to be transferred to a related target domain and has become increasingly important in data-scarce scientific applications. The transfer from NGA-West2 to the Central and Eastern United States (CEUS) exemplifies a regression-based domain adaptation problem characterized by shared feature spaces, limited target-domain labels, and pronounced marginal distribution shifts.

In this paper, we present a comprehensive and critical analysis of domain adaptation methods for NGA-West2-to-CEUS transfer. Existing approaches are systematically categorized into instance-based, feature-alignment-based, subspace-based, and deep domain adaptation methods. The main contribution of this study is that it clearly identifies which method classes are suitable for transferring models from NGA-West2 to CEUS and which approaches are

likely to fail, thereby providing a principled foundation for subsequent model development.

POSTER 69
Conditional Ground Motion Generation using Diffusion Transformer (DiT)
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Performance-based earthquake engineering requires ground motion time-history analyses, which are often hindered by the lack of recorded waveforms at the locations of interest. Predicting realistic ground motion waveforms from limited observations remains challenging, especially in post-event scenarios requiring rapid response. Current approaches suffer from notable limitations: numerical simulations are computationally intensive; empirical green function methods rely on source characterization and similarity assumption; and interpolations in reduced feature spaces fail to capture the high dimension and nonstationary nature of ground waveforms. This work introduces a general-purpose diffusion framework for generating ground motion waveforms conditioned on multi-station observations. This framework is built upon transformer blocks with temporal and spatial attention modules to capture the rich spatial-temporal patterns inherent in observed seismic waveforms. A masking strategy is also proposed to unify three important ground motion generation scenarios, i.e., estimation (conditioned on source information only), interpolation (conditioned on spatial observations), and early warning (conditioned on initial waveform segments). Experiments demonstrate that incorporating waveform observations from nearby stations significantly reduces predictive uncertainty in post-event scenarios. The generated ground motions achieve improved performance across multiple metrics, including response spectra and duration measures, consistently outperforming conventional interpolation baselines. The proposed framework provides a flexible, unified, and high-fidelity solution for multi-station conditioned ground-motion waveform generations, and has important applications in regional-scale hazard analysis and loss estimation.

POSTER 70
Space-time Completeness of Seismic Ground Motions via Non-intrusive Model Order Reduction
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Since recordings of large and damaging earthquakes are rare, physics-based wave propagation simulations provide an important path to assess the seismic hazard of future events and to advance understanding of earthquake and shaking physics. However, sufficiently realistic seismic ground motion simulations can be extremely computationally expensive, requiring up to multi-petascale supercomputers (e.g., Roten et al., SC, 2016).

In this presentation we outline the ideas and methods of our newly NSF-funded Collaborations in Artificial Intelligence and Geoscience (CAIG) project which aims to radically reduce the huge computational expense of physics-based wave propagation simulations. Within our CAIG project we will develop a physics-based scientific machine learning model order-reduction technique, Operator Inference (‘OpInf’, see Kramer et al., *Annual Review of Fluid Mechanics*, 2024), to create time-dependent surrogate models of seismic ground motions for California and Nevada earthquakes. This approach will allow us to fuse high-resolution simulated ground motion wavefields with previously observed earthquake records. The OpInf model will be (i) orders of magnitude faster than traditional physics-based methods, and (ii) generalizable to unobserved earthquakes as they are trained on a fused dataset.

The OpInf models will be applied to the varying tectonic faulting regimes in Southern California and Nevada enabling us to quantify differences in source and path effects on simulated and observed ground motions. All software developed will be open-source and publicly available on both GitHub and the Quakeworx Science Gateway. Our research will also allow us to quickly produce wave propagation visualizations in case of events of public interest in California and Nevada to enhance public awareness of earthquake safety procedures.

POSTER 71
Earthquake Forecasting With Single-station Waveform Detection Without Relying on Event Catalogs
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Earthquake forecasting directly from waveforms, bypassing traditional catalogs, offers improved efficiency because catalogs are ultimately derived from waveforms, and the raw data inherently contain richer information. Using continuous waveforms also enables the inclusion of small events that are often missed in published catalogs due to detection thresholds or quality filters. To capture these subtle signals, we employ single-station waveform detection, which preserves critical information on phase arrival times and amplitudes, allowing estimation of origin times, distances, and magnitudes for events that cannot be located by multi-station networks. This approach has proven effective in Guo et al. (2025), which demonstrated improved resolution of dynamically triggered seismicity.

To evaluate the forecasting potential of this strategy, we apply PhaseNet (Zhu & Beroza, 2018) to single-station waveforms to identify P and S phases, derive hypocentral information, and integrate these results into Recurrent Earthquake foreCAST (RECAST), a deep-learning framework based on neural temporal point processes (Dascher-Cousineau et al., 2023). Our results show that this single-station workflow performs comparably to RECAST implementations using published catalogs and achieves strong performance when trained on data from broad regions. This demonstrates the potential for generalized models that enable forecasting in areas with sparse instrumentation. Because incorporating small events introduces uncertainty in hypocentral estimates, we weight their contribution using the phase-arrival probabilities generated by PhaseNet, which improves forecasting performance. These findings suggest that earthquake forecasting from single-station waveforms can effectively exploit lower-quality seismic data that are typically excluded from standard catalogs.

POSTER 72
Constraining Parameters of Earthquake Cycle Models With Uncertainty Quantification Using Paleoseismic Records: A Synthetic Study
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Physics-based earthquake forecasting and time-dependent hazard assessment rely on dynamical models of the earthquake cycle, often formulated with rate-and-state friction. For such models to be useful for forecasting, their parameters must be calibrated so that simulated earthquake sequences reproduce key historical observables, including recurrence statistics and coseismic slip. Systematic parameter estimation for earthquake-cycle PDE models, however, remains challenging because the dynamics are nonlinear, initial conditions are unknown, and observational constraints for large earthquakes are sparse and dominated by noisy paleoseismic records. We present a Bayesian inverse-problem framework to infer heterogeneous frictional parameters in an earthquake-cycle model from paleoseismic-type observations. Rather than matching individual event trajectories, we exploit ergodicity (long-term statistics independent of initial conditions) and invert for stationary, spatially distributed summary statistics of event timing and slip, including mean interevent times, coefficients of variation, interevent correlations, and average coseismic slip at trench-like sites. Observational noise and event-detection thresholds are explicitly accounted for in the construction of these statistics. The resulting inverse problem is solved using a derivative-free ensemble Kalman inversion method, and uncertainty quantification is enhanced by an emulate-sample strategy that leverages machine learning for surrogate modeling, in which a Gaussian-process surrogate of the parameter-to-statistics map enables efficient MCMC sampling without further expensive forward simulations. Synthetic experiments with realistic dating and slip-measurement noise demonstrate that paleoseismic-scale statistics can constrain both earthquake cycle parameters despite chaotic variability. The proposed framework provides a principled and computationally tractable calibration step for earthquake-cycle models, establishing parameter-consistent physical models that match historical observations and form a foundation for subsequent forecasting studies.

POSTER 73
Machine Learning-based Ground Motion Models for Shallow Crustal Earthquakes in California Using NGA-West3 Database
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This study proposes machine learning (ML)-based ground motion models for California, utilizing the recently published NGA-West 3 database applicable to active crustal regions. Two models are developed: the first model is an ergodic model that uses input variables such as moment magnitude, Joyner-Boore distance, hypocentral depth, and Vs30 while the second one is a non-ergodic model that incorporates these parameters along with site- and event-specific coordinates, such as latitude and longitude. Both models are trained using an ensemble of 100 Artificial Neural Networks (ANNs) and 100 XGBoost models, employing a stratified K-fold cross-validation approach to ensure robust performance. Aleatory and epistemic uncertainties are quantified using Gaussian negative log-likelihood (NLL) loss for the ANN models and quantile regression for the XGBoost models. The performance of these ML-based models is validated against NGA-West 2 models in terms of median model predictions and uncertainty estimates. Additionally, event-specific comparisons are conducted for independent post NGA-West 2 earthquakes, including the 2019 Ridgecrest Earthquake sequence and the 2016 South Napa Earthquake. Preliminary findings suggest the potential of ML-based methods to enhance probabilistic seismic hazard assessment (PSHA) by integrating spatial and source-to-site dependencies, resulting in improved prediction accuracy. Further research is being conducted for better understanding and validation of the models.

POSTER 74
Constraining Fault Geometry of the Marlborough Fault System in Aotearoa New Zealand, Using Machine Learning
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The Marlborough Fault System serves as the structural and kinematic link between the Hikurangi Subduction Zone, the North Island Dextral Fault Belt, and the northern segments of the Alpine Fault. It hosted the complex M7.8 2016 Kaikōura earthquake, which ruptured at least 21 distinct faults. The geometry of faults within the Marlborough Fault System, and how they link to the surrounding plate boundaries, likely plays a key role in determining the rupture extent of earthquakes in this region, as well as the possibility of earthquake cascades both within the Marlborough Fault System itself and onto the surrounding plate boundaries. In this work, we use microseismicity to provide critical insight into fault geometry and conditions at seismogenic depths.

In this context, we present the preliminary findings from the 47-station “Marlborough Observatory Researching Interconnectedness beneath the Alps” (MORIA) broadband array and associated networks (DPRI and GeoNet). Using EQTransformer for phase detection, PyOcto for event association, NonLinLoc for absolute location, and GrowClust3D for relative relocation, we have detected 20,801 events between January 1, 2024, and June 30, 2025, compared to the 5,338 reported by GeoNet (an increase of 290%).

The resulting earthquake catalogue reveals spatially coherent clusters and linear trends of seismicity that broadly align with major Marlborough Fault System structures, as well as variations in seismicity distribution with depth between fault segments. These patterns provide new constraints on fault geometry at seismogenic depths and form the basis for ongoing analyses integrating focal mechanisms.

POSTER 75
Interpretable Gradient Boosting Machines for Post-earthquake Building Damage Assessment: Data from the 2015 Nepal Gorkha Earthquake
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Earthquakes cause widespread structural, economic, and social disruption. The immediate aftermath of earthquakes is characterized by a severe “information vacuum” which increases risks for survivors and rescue teams. This study proposes a machine learning framework for post-earthquake building damage assessment based on gradient boosting machines (GBMs). Using the 2015 Nepal Gorkha Earthquake dataset, we evaluate three widely used boosting architectures, XGBoost, LightGBM, and CatBoost, under a multiclass classification setting. To address critical challenges of operational trust and transparency, we introduce a triage score that maps model probabilities onto an ordinal 1–100 scale, offering finer nuance for prioritizing damaged structures, alongside the integration of Shapley Additive Explanations (SHAP) to provide both global and local interpretability of model predictions. Results demonstrate that all three GBMs achieve strong predictive performance, with LightGBM performing best. The interpretability modules reveal meaningful structural archetypes that align with engineering principles. This work positions GBMs as a pragmatic, trustworthy tool for disaster response teams. Beyond Nepal, the framework holds promise for adaptation to diverse seismic contexts and integration with multimodal data sources, offering a scalable pathway toward faster, more transparent earthquake recovery.

POSTER 76
From Redundancy to Coverage: Compact Benchmarks for Seismic Artificial Intelligence Models
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Reliable evaluation of artificial intelligence (AI) models in seismology depends on well-designed benchmark datasets. However, widely used open seismic benchmarks such as STEAD and INSTANCE contain redundant samples, obscuring the role of under-represented signals and lead to potentially biased evaluations. Earthquakes exhibit self-similarity due to the scale-invariant nature of fracture processes in the Earth’s crust. Therefore, self-similar clusters in benchmarks can dominate evaluation metrics and potentially mask meaningful differences in how models handle under-represented signals. We address this by developing a framework to construct compact, coverage-aware seismic benchmarks that retain waveform diversity while substantially reducing the dataset size. Using learned latent representations, we select representative subsets that emphasize coverage rather than redundancy. We compare these compact, coverage-aware benchmarks against randomly selected subsets of equal size to assess waveform redundancy and coverage using both data-driven and domain-expert metrics. Finally, we evaluate multiple models on both full datasets and our compact, coverage-aware benchmarks to quantify the impact of redundancy on model evaluation and comparison. Our framework highlights the role of coverage-aware benchmark design and motivates the use of smaller, carefully constructed datasets for more informative and efficient evaluation of seismic AI models.

POSTER 78
Graph-regularized Receiver-function Interpretation Using Gravity Constraints
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Receiver-function (RF) analysis has traditionally benefited from linear array geometries and longer deployments, where phase conversions at laterally continuous structures can be reinforced through stacking and visual inspection. Short-duration nodal deployments, however, record fewer teleseismic events, making it more difficult to use stacked RFs to track laterally continuous interfaces across an array, particularly in high-noise settings. As a result, multiple plausible phase picks may exist at individual stations, and interpretation must rely on spatial relationships rather than profile-based continuity. We develop

a probabilistic, graph-regularized inference framework, GravNet, that treats RF measurements as a spatially connected dataset and incorporates gravity as an additional physical constraint to guide the interpretation of subsurface boundaries identified in receiver functions. The graph structure encodes neighborhood relationships among stations and promotes spatial smoothness that follows trends supported by both the RFs and gravity data. While demonstrated here using gravity data and nodal array recordings from the San Fernando Valley, California, the framework provides a general mechanism for incorporating other independent constraints into graph-based RF interpretation, which would work across different environments.

POSTER 79
I-Hades: A Seismic Event Locator Combining Deep Learning With Distance Geometry Methods
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Accurate earthquake location of seismicity is a longstanding challenge in seismology, particularly when analyzing clusters of seismicity recorded by sparse and/or asymmetric seismic networks. In such conditions, traditional location methods often struggle to correctly locate seismic events, producing large uncertainties that may lead to wrong interpretations of the results.

Relative location techniques have improved precision by exploiting the similarity between close events. Among them, the HADES algorithm (earthquake location via Distance gEometry Solvers) marked a major step forward, reformulating the problem through distance geometry to reconstruct earthquake clusters even with very sparse seismic networks. However, its effectiveness depends on inter-event distances derived from P- and S-wave arrival-time estimates, which are sensitive to noise and inaccuracies in the velocity model.

Meanwhile, the rise of artificial intelligence (AI) is reshaping how science faces complex problems. By learning from data, AI handles noisy signals, reduces model bias, and finds patterns that traditional methods often miss. Seismology, with its data richness and natural uncertainties, is an ideal field to benefit from this new approach.

This work introduces I-HADES, an AI-powered extension of HADES that integrates machine learning into the earthquake relocation process of seismicity clusters using distance geometry approaches. A fully connected neural network (FC-ANN) was trained on synthetic datasets, where true event separations are known, to directly predict inter-event distances from observed data. Two configurations were tested using two and four stations to evaluate the impact of network density.

The results are clear: AI enhances distance prediction, mitigates the effects of noise and model errors, and makes the I-HADES framework more robust and reliable. By merging distance-geometry methods with the power of AI, this work demonstrates how artificial intelligence can unlock a new level of precision in earthquake location, opening the way for applications from sparse monitoring environments to complex seismic networks.

POSTER 80
A Regional Multi-station Deep Learning Model for Earthquake South Depth Determination in Southern California
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Accurate earthquake source-depth determination is critical for understanding tectonic processes and assessing seismic hazards. However, absolute location methods typically provide less reliable depth estimates compared to epicentral locations. Deep learning holds great potential for extracting depth-related information directly from waveforms, enabling the development of fast and accurate depth relocation algorithms. Focusing on Southern California, we developed a regional multi-station deep learning approach for earthquake depth determination. Our model processes four-channel inputs from multiple stations that recorded the same event: 3C waveforms from each station plus their corresponding epicentral distance (with approximate epicenter assumed known). The model architecture, modified from VGGDepth (Li and Zhang, 2025), uses convolutional layers for feature extraction followed by fully connected layers that map waveform features to Gaussian-distributed depth predictions, with the probability peak indicating the predicted depth. The earthquake locations in the training and testing datasets are based on the double-difference locations archived by SCEDC. The epicenters are randomly perturbed within a range to simulate epicentral uncertainties from traditional location methods. Using over 300,000 earthquakes in Southern California from 2010–2024, we randomly sampled 7–12 stations from available recordings for each event and generated over 10 million event-depth samples after

applying quality control (SNR > 5 for at least 6 stations), which services as our model training dataset. The testing dataset is similarly derived from earthquakes occurring between 2008 and 2009, yielding ~25000 (SNR>0 & at least 4 stations) event–depth pairs. Preliminary results demonstrate that our VGGDepth-SC model achieves consistently good convergence across the entire depth range of 0–25 km with errors within 0.3 km, while maintaining a recall rate above 99%. The method demonstrates strong performance and potential for re-assessing historical earthquakes with sparse station coverage (e.g., earthquakes occurring before 2000).

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Deep Image Prior-based Framework for Simultaneous Regularization and Denoising of Teleseismic Receiver Functions
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Short-period dense seismic arrays have emerged as a powerful tool for probing the Earth’s deep interior in recent years. The abundant wavefield information recorded by nodal arrays enables the application of advanced imaging techniques, such as migration and inversion, to receiver function (RF) analysis for high-resolution subsurface imaging. However, the performance of these algorithms depends strongly on both regular spatial sampling and high-quality wavefields, which are rarely available in practice. To address these issues, we present a deep image prior (DIP)-based neural network combined with the projection onto convex sets (POCS) scheme for simultaneous interpolation and denoising. This data-driven deep learning method requires no labeled data and inherent properties are encoded in the network architecture. We reconstruct the RF waveforms by using an iterative process. At each iteration, the POCS method honors the actual station locations by mapping the irregularly sampled data onto a regular grid, which is then used as input to the neural network for denoising. Through this iterative process, RF data are progressively regularized with enhanced waveform quality.

We first evaluate the performance of this framework using synthetic teleseismic wavefields generated with the SPECFEM3D code, with a model of undulated Moho and randomly distributed station locations. Results demonstrate that the method can effectively handle nonuniform sampling and random noise simultaneously. We then apply the method to real dense nodal array data deployed in the Bayan Obo area in northern China. Our results demonstrate that our method can effectively attenuate strong noise and outperforms conventional reconstruction algorithms such as multichannel singular spectrum analysis. This improved RF data enables exploiting the resolving power of a recently developed least-squares migration technique. The migrated images reveal a sharp Moho discontinuity with clear lateral variations across the boundary fault in the study area, highlighting the importance of RF reconstruction for high-resolution imaging.

Earthquake Ground Motions and Structural Response: Emerging Tools and Applications

Oral Session • Thursday 16 April • 8:00 AM Local

Conveners: Richard Allen, University of California, Berkeley (rallen@berkeley.edu); Felix Bernauer, Ludwig Maximilian University of Munich (felix.bernauer@lmu.de); Farid Ghahari, California Geological Survey (ghahari@gmail.com); Monica Kohler, California Institute of Technology (kohler@caltech.edu); Utpal Kumar, University of California, Berkeley (utpalkumar@berkeley.edu); David McCallen, Lawrence Berkeley National Laboratory (dbmccallen@lbl.gov); Yara Rossi, Ludwig Maximilian University of Munich (yara.rossi@lmu.de)

An Overview of NGA-West3 Research Program
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NGA-West3 is the latest phase of the community-based NGA Research Program with the goals of (a) developing a comprehensive database of ground motions recorded in crustal earthquakes and (b) a set of ground motion models (GMMs). The initial phase of the NGA research program was initiated in October 2003 with a focus on shallow crustal earthquakes in active tectonic regions. The original NGA phase was followed by NGA-West2, NGA-East (for the Central and Eastern North America) and NGA-Subduction. The GMMs derived in these NGA Programs have extensively been adopted by numerous agencies around the world, including for the USGS National Seismic Hazard Model.

Since the completion of NGA-West2 over 12 years ago, there has been rapid growth in the number of ground motions recorded in crustal earthquakes around the world and numerous large-magnitude events have occurred that were recorded over a wide range of distances, representing hazard-critical conditions for coastal California population centers (e.g., Feb 2023 Türkiye Earthquake sequence). Additionally, there has been impressive intellectual growth in ground motion modeling that can account for regional and subregional effects in a manner that can “localize” GMMs. The NGA-West3 database is by far the largest yet produced with 175,244 three-component recordings (over 8 times larger than that in NGA-West2). The enormous amount of data in NGA-West3 and its extensive spatial coverage across Western US provides an opportunity to update the ergodic NGA-West2 GMMs and also explore the possibility of refining the models to account for smaller crustal sub-regions. The large data volume has also opened an opportunity to develop non-ergodic GMMs, which will be developed following the completion of the NGA-West3 ergodic GMMs. This presentation provides an overview and status of NGA-West3 as a community-based research Program.

Testing Data-driven Techniques for Separating Free-field Ground-motion From Building Response in Smartphone Data
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The field of ground-motion modeling has overwhelmingly embraced non-ergodic approaches that explicitly model the large spatial variability in source, site, and path effects in observed ground motions. The field is also increasingly focusing on modeling the Fourier Amplitude Spectrum (FAS), as opposed to peak amplitudes, as a metric that more accurately conforms to modeled physics. While massively improved seismic network coverage has in large part enabled this revolution, the ultra dense resolution sought in urban environments has not yet been attained with traditional sensor networks. A distributed network of smartphones may contribute the high density needed. The MyShake app, a free smartphone app delivering earthquake early warning alerts to users on the US West Coast, offers the citizen science capabilities to harvest this data. However, smartphone data is not free-field, but rather “contaminated” by building response, as previous work has shown. In addition,

exact building responses are not known for these massive sensor networks, precluding direct separation of free-field ground motion. In this work, we use observed earthquake waveform data recorded by smartphones in California running MyShake. We use a derived FAS database to test various techniques to separate frequency ranges that capture pure free-field ground motion from those contaminated by building response in the 0.5–25 Hz band. We test an empirical, heuristic-driven technique as well as a method based on machine learning-driven signal reconstruction. Both methods fuse smartphone observations with free-field ground motion observations and non-ergodic model predictions. We test the separation ability of both methods and investigate how smartphone-derived FAS “corrections” can be fused with existing, traditionally derived non-ergodic effects.

State-of-the-art Use of Simulated Ground Motions to Enhance Urban Seismic Resilience in Turkey
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Estimation and mitigation of seismic risk in urban regions involve a wide range of stakeholders, including geophysicists and earthquake engineers, urban and economic planners, and insurance companies. Effective risk mitigation requires contributions from multiple disciplines, encompassing seismic hazard assessment, building fragility modeling, seismic loss estimation, and resilience analysis. Strong-motion records constitute a key component of these efforts.

In recent years, in addition to recordings from past events, simulated ground motions have become an increasingly important component of earthquake engineering practice, driven by advances in computational capabilities, earthquake source modeling, and site characterization techniques. Simulated motions enable the assessment of seismic response and resilience of urban regions and distributed infrastructure while accounting for complex source, path, and site effects.

This study presents ongoing research on the use of simulated ground motions for integrated assessment of seismic damage, loss, resilience, and social vulnerability in Turkey. Both historical earthquakes and scenario events are considered. Applications focus on urban regions along the North Anatolian and East Anatolian fault zones, as well as the Aegean Sea region. In addition to current practice, data-related challenges and associated uncertainties are discussed.

Quantification of Ground Shaking Effects on Buried Gas Transmission Pipelines
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Pipeline damage observed in past earthquakes that cannot be attributed to permanent ground displacement has typically been ascribed to strong ground shaking, particularly transient ground strains generated by the propagation of seismic energy on the ground surface. This study investigates the potential effects of transient ground shaking on damage to natural gas pipelines. Using a highly dense dataset of simulated ground motions, we assess both ground strain and the subsequent strain induced in buried pipelines over a range of simulated earthquake ground motions covering earthquake magnitudes of M6.5, M7.0 and M7.5. The ground motion dataset covers a 100km × 40km × 30km domain, with a fine grid spacing of 8 m and frequencies resolved up to 5 Hz. To account for pipeline orientation, we established a corresponding pipeline grid oriented in fault-parallel and fault-normal directions, then positioned pipelines along grid lines to capture pipe behavior at various locations within the seismic domain.

We developed a generic pipeline model for the dynamic analysis of buried pipeline subjected to multi-support excitation and analyzed 1,049 scenarios. The maximum and minimum longitudinal strains occurring anywhere along the pipeline were extracted at each time step and compared with the corresponding ground strains. New regression models are proposed to predict pipe strain using peak ground velocity and Joyner-Boore distance along the direction of the pipeline, and the results are compared with trendlines from the previous studies. The results indicate that, for the scenarios considered, seismic wave propagation–induced strains in both the ground and pipelines are generally small and unlikely to account for observed damage, suggesting that other mechanisms play a more significant role in pipeline failure.

Keywords ground shaking effects; transient ground strain; gas transmission pipeline; buried pipe damage;

Towards the Development of Static Ground Displacement and Transient Ground Strain Shakemaps

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Damage to buried structures and lifelines can be caused both by and permanent deformation from faulting, broad uplift, or ground failure and dynamic strains. We are considering developing two new tools to complement the U.S. Geological Survey ShakeMap® product suite: (1) static ground displacement (SGD) and (2) transient ground strain (TGS). SGD maps require vector representation, static deformation estimates rather than response spectral estimates, and geodetic observations. TGS ShakeMaps require strain calculations—often approximated as $= PGV/C$, where PGV is peak ground velocity, and C is a site’s shear velocity—but rigorous strain calculations require C to be the horizontal *phase velocity*. Calibration with three-dimensional (3-D) earth and rupture models aids in our analyses, but we are using waveform analyses to determine whether body- or surface waves are responsible for the TGS. Our initial calibration phases will provide insight into the ground-motion conditions that dominate the effects of SGD versus TGS, which have not been well characterized to date. TGS ShakeMaps require conditioning on TGS observations, including strainmeters, seismic arrays, and distributed acoustic sensing (DAS). Our analyses and ShakeMaps will facilitate the development of more accurate pipeline fragilities and will ultimately be useful to underground life-line utilities, among others, for planning and response. Part of our motivation for presenting these concepts at an early stage is to solicit feedback, identify use cases, and motivate collaboration among scientists, engineers, lifeline utility operators, and other potential users. The challenges and potential benefits of rapid SGD and TGS mapping have the potential to motivate researchers in those disciplines, along with developing applications that incorporate the latest available data processing and modeling tools for necessary input constraints from, for example, InSAR and DAS, along with more traditional ground motion modeling strategies earlier perfected by seismologists.

Automated Operational Modal Analysis of High-rise Buildings Using Crowdsourced Smartphone Data

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Quantifying the dynamic properties of urban infrastructure is fundamental to seismic risk assessment, yet the vast majority of the global building stock remains uninstrumented. We present a scalable computational framework for estimating fundamental building natural frequencies using crowdsourced ambient vibration data from the MyShake smartphone network. To address the inherent challenges of consumer-grade sensors and arbitrary device placements, we developed a rigorous signal processing pipeline. This methodology integrates geospatial association to link devices to building footprints, followed by polarization analysis to autonomously recover principal structural axes without reliance on magnetometers. By aggregating short-duration recordings, we extract stable fundamental modes through automated spectral clustering. The robustness of this framework was evaluated against scientific-grade instrumentation during a full-scale shake table test of a 10-story cold-formed steel framed building. The results demonstrate that smartphones can reliably capture key dynamic parameters, effectively transforming personal devices into a dense, ubiquitous sensor network for the continuous characterization of city-scale structural performance.

Assessment of Building Risk Based on an Affordable Structural Health Monitoring System Developed in Taiwan

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This study develops seismological algorithms to characterize the dynamic behaviors of Reinforced Concrete (RC) and Steel Reinforced Concrete (SRC) structures using the newly designed Quake Structure Integrity System (QSIS). Designed as an affordable solution for diverse stakeholders, the QSIS was deployed across multiple building seismic arrays to monitor key indicators, including natural frequencies, seismic shear wave velocities, and normalized mode shapes. The system’s performance was rigorously evaluated using both earthquake records and ambient vibration signals. Analysis reveals a significant correlation between the temporal variation of dominant frequencies and environmental temperature, emphasizing the necessity of accounting for thermal effects to avoid false positives in detecting abrupt structural changes. Our results demonstrate that this cost-effective structural health monitoring (SHM) framework provides a robust tool for real-time assessment and contributes significantly to seismic hazard mitigation.

Measuring Structural Motion Without Permission

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The experimental assessment of the modal frequencies of engineering structures is a key step in several seismological applications, such as defining the input for seismic response spectra, calibrating and validating dynamic models, evaluating the effects of interventions or retrofitting of existing structures.

Active testing has given way to more convenient passive approaches. Accelerometers are still the preferred transducers within the engineering community, whereas the seismological community favor geophones, due to their higher sensitivity, which make them more suitable for weak-motion analysis.

More recently, sensors that measure displacements—based either on electromagnetic wave source-to-target travel times or on interferometric techniques—have also begun to be used. These have the advantage of being contactless and capable of investigating a larger portion of a structure from a single acquisition point, at the cost of much larger datasets to be processed.

We will present some unconventional approaches for performing dynamic characterization of structures. First, we will show how the dynamic behavior of many buildings can be identified even in ground-based recordings acquired for completely different purposes. Seismic stations themselves, which are almost always installed inside structures of various sizes, contain information about the dynamic properties of the hosting structure. In the case of large structures—such as viaducts, towers, and wind turbines—their dynamic behavior can be detected even at large distance from the structure. Being able to recognize this contribution is a fundamental step in ground-motion studies.

We will then illustrate how instruments external to seismology, such as standard video cameras, can be employed to assess the modal frequencies of structures. Optical approaches have long been used to study mechanical vibrations in laboratory settings where many variables can be controlled. Here, we apply them to detect the modal frequencies of typical structures under operational conditions. We will explore different processing workflows and discuss their performance.

Bridging Numerical Simulation, Cost-effective Condition Monitoring and Experimental Testing for Post-earthquake Resilience

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The shift in seismic design from life safety toward functional recovery and rapid re-occupancy is increasingly moving from theory to practice. A clear example is the newly completed Grimes Engineering Center at the University of California, Berkeley, a critical academic facility located only a few hundred meters from Hayward Fault. Given its role in campus operations and emergency response, the building was designed with post-earthquake resilience objectives exceeding code-minimum requirements.

To meet these objectives, the structural system integrates Shape Memory Alloy (SMA)-augmented tension rods with conventional Buckling-Restrained Braces (BRBs), forming a hybrid lateral force-resisting system that combines energy dissipation with enhanced re-centering. Because SMA devices had not previously been implemented at this scale, an extensive experimental program informed the design. Reduced-scale shaking-table tests at the Pacific Earthquake Engineering Research (PEER) Center, complemented by component- and frame-level experiments at UC Berkeley, demonstrated the superior

re-centering and damage-mitigation performance of the hybrid SMA-BRB system.

Beyond design and construction, continuous condition monitoring supports performance validation and post-event decision-making. The building is instrumented using ambient and forced vibration measurements collected with PEER Cost-Effective Next Technology Sensors (PEER-CENTS) to identify modal properties, calibrate numerical models, and validate analytical predictions.

Post-construction seismic performance evaluation uses 50 realizations of a simulated magnitude 7.0 Hayward Fault earthquake from the PEER–LBNL Simulated Ground Motion Database (SGMD). Non-ergodic, site-specific near-fault ground motions enable assessment of response, damage, and loss through component-level fragility functions and expected recovery timelines.

This presentation shows how integrating experimental testing, numerical simulation, and scalable, cost-effective monitoring technologies supports resilient building design and enables extension from individual buildings to urban and regional scales.

Urban-scale Assessment of Soil–building Resonance Effects Using Ambient Noise Measurements in Matera, Southern Italy

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The interaction between built structures and urban shallow geology can significantly modify earthquake ground motions in urban environments. This study aims to bridge site-effect characterization and structural response analysis by investigating how building vibrations influence the urban seismic response and the potential occurrence of soil–building resonance during strong ground motion. The analysis focuses to evaluate the interaction between the near-surface urban geology and the overlying building stock in the city of Matera (southern Italy). A dataset of 230 single-station ambient noise measurements was collected, including 134 recordings on the main surface lithologies and 96 on representative building typologies.

The spectral analysis of soil and building recordings allowed us to estimate the fundamental frequencies and associated amplitudes of both shallow soils and overlying buildings. A linear relationship between building height and fundamental period, experimentally derived from the dataset, was used to estimate the natural frequencies of the entire building stock in Matera. By combining frequency information from both urban soils and buildings, a citywide soil–building resonance map was constructed assuming linear elastic behaviour. Results highlight that the first resonance frequency of many buildings coincides with that of the underlying soils. Approximately 21% of the buildings show a high probability of resonance, 63% a moderate level, and 16% a low or negligible level. The proposed approach enables the identification and mapping of urban areas with different degree of probabilities of soil–building resonance, providing a valuable tool for city-scale seismic hazard assessment and risk mitigation.

Earthquake Ground Motions and Structural Response:

Emerging Tools and Applications [Poster]

Poster Session • Thursday 16 April

Conveners: Richard Allen, University of California, Berkeley (rallen@berkeley.edu); Felix Bernauer, Ludwig Maximilian University of Munich (felix.bernauer@lmu.de); Farid Ghahari, California Geological Survey (ghahari@gmail.com); Monica Kohler, California Institute of Technology (kohler@caltech.edu); Utpal Kumar, University of California, Berkeley (utpalkumar@berkeley.edu); David McCallen, Lawrence

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POSTER 82

Identifying Reference Stations for SSR-based Site-effect Studies Near the Mississippi

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Several methods are available for estimating seismic site effects, among which the standard spectral ratio (SSR) technique is widely used. SSR is based on the assumption that recordings at a surface rock reference station approximate the incoming motion at the base of the soil column beneath nearby sites. Consequently, SSR requires a carefully selected reference station with negligible local amplification.

Here, we investigate a network of stations around the New Madrid Seismic Zone (NMSZ) to identify candidates near the margins of the Mississippi Embayment (ME) that can serve as stable reference sites. Stations are classified according to their fundamental (resonant) frequencies and average shear-wave velocities. We then use the horizontal-to-vertical spectral ratio (HVSr) approach to estimate amplification at eight stations, mainly along the western flank of the ME. The analysis uses three-component recordings from 42 local and regional earthquakes (M 3–4). HVSr curves are computed over 0.1–20 Hz from Fourier spectra of S-wave time windows.

Overall, most stations display behavior consistent with reference-site conditions. In particular, WHAR and W41B on the western side of the ME, and WVT on the eastern side, exhibit the most favorable attributes and are also situated close to many embayment stations. However, applying these references to other sites requires accounting for distance-related effects, including frequency-dependent attenuation (Q) and geometrical spreading.

POSTER 83

Damage Detection Across California: Using the Myshake Smartphone App to Measure Building Modal Frequencies

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The value of placing seismic instrumentation in buildings has been recognized for decades. By recording the response of a building to shaking before, during and after an earthquake, much can be learned about the properties of the building and its ability to withstand future earthquake shaking. Yet few buildings in California are instrumented, and even fewer make the data publicly available. This is for a variety of reasons including the cost of instrumentation, data privacy and liability concerns, and the challenges of operating such a system at scale.

We present a new approach to instrumenting buildings: harnessing millions of smartphone sensors that are already in the buildings. We use the MyShake app currently deployed on millions of phones across California, and record 5-minute waveforms of ambient vibrations within a building from which we can calculate modal frequencies. By analysing repeated measurements from thousands of high-rise buildings we can track properties over time. Following an extreme event such as an earthquake, we can rapidly assess if there are significant changes to the frequencies which may be indicative of damage. We validated the approach with extensive field deployments and a full-scale 10-story shake table test, showing the sensitivity of the observations to building damage. The methodology has now been applied to the MyShake waveform dataset and we present the first database of observations for thousands of buildings across California.

POSTER 84

Seismological Overview of the Toppling of Easter Island Moai Statues Using Real and Synthetic Ground Motion Records

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The guardian *moai* of Easter Island (Rapa Nui) provide a fascinating enigma: what role did they play to the society developed on the island and why were they toppled by the 18th century? One persistent hypothesis that is raised within the archeological community is that a major earthquake toppled the statues. The volcanic island lies along the Easter Seamount mount, west of the Easter Island hotspot and east of the same-named microplate developing along the East Pacific Rise. Earthquake shaking felt on the island is generated by a mix of normal and strike-slip faulting mechanisms. This study investigates the broader seismotectonic setting and assesses recorded and potential strong ground motions on the island. The elastic thickness for this region has been estimated to be around 4 km, much shallower global centroid moment tensor solutions. We explore sensitivity to depth for near-island moment tensors to better understand potential slip dimensions. For ground motion studies, our research is limited to a single global seismic station RPN at Easter Island. Peak ground acceleration (PGA) values are calculated for all earthquakes ($M \geq 3.0$) recorded in the 1000 km epicentral distance. The largest earthquakes in 1987 (Mw 6.7, 101 km distance), 1998 (Mw 5.1, 45.8 km), and 2011 (Mw 5.0, 37 km) are the focus of synthetic calculations. Synthetic seismograms are generated using the source parameters of these major earthquakes for epicentral distances of 5, 10, 25, 50, and 100 km and magnitudes of Mw 5.0, 5.5, 6.0, 6.5, and 6.7. The PGA value obtained (e.g. max $\sim 0.1g$ for 6.7 Mw to min 0.001g in vertical component for Mw 5.0) provide insight and source data for further engineering studies of statue stability. Finally, as part of the broader work, we test the hypothesis [Walker, 1999] that earthquake rates around the region respond to climate forcing; using the ISC catalog, we calculate temporal variation in strain. Our integrated approach provides an assessment of whether earthquakes can generate sufficient ground shaking to topple the moai.

POSTER 85
Ambient Noise Deconvolution Seismic Interferometry as a Complementary Tool for Structural Characterization of Civil Infrastructures
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Recent advances in seismic interferometry have expanded the use of ambient vibration analyses from traditional seismological applications to structural diagnostics. In this study, we illustrate how Ambient Noise Deconvolution Seismic Interferometry (ANDI) can serve as a complementary, wave-based non-destructive tool for the seismic characterization of bridges and other civil infrastructures. The method relies on short ambient noise recordings acquired through compact seismic arrays strategically deployed on structural elements, allowing rapid data collection without disrupting service.

The recorded signals are processed through an integrated workflow that combines standard analysis (Operational Modal Analysis–Frequency Domain Decomposition, OMA–FDD) with the ANDI method to extract key structural parameters — eigenfrequencies, mode shapes, equivalent damping ratios, and wave propagation velocities — interpreted as distributed indicators of stiffness and directional mechanical behavior. The approach was applied to two representative viaducts in southern Italy — an arch bridge and a multi-span girder bridge — demonstrating consistent results across distinct structural typologies. The Gravina Bridge, a newly constructed arch bridge, provided baseline dynamic parameters for future monitoring, while the 1970s Monticello Viaduct enabled comparison between estimated parameters and varying levels of material degradation.

The joint use of waveform-based and modal-based analyses provides a more comprehensive and sensitive framework for non-destructive structural characterization. Its fully non-invasive, in-situ implementation under ambient excitation offers significant practical advantages, enabling continuous assessment of infrastructure without artificial sources or traffic interruption.

POSTER 86
Monitoring Multimodal Frequency Variations in a 10-story Cold-formed Steel (CFS10) Building for Damage Assessment
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The Community Seismic Network (CSN) has expanded across California and now comprises more than 1,200 permanent triaxial accelerometers that measure near-real-time response to a cloud-based infrastructure. Here, we present results from a targeted deployment of 76 triaxial accelerometers during the testing of a 10-Story Cold-Formed Steel-Framed Building, conducted at the UC San Diego 6-DOF Large High-Performance Outdoor Shake Table. In total, 18 earthquake tests were conducted using earthquake ground-motion inputs scaled to various risk targeted hazard levels. The results provide a realistic evaluation of the structural health monitoring capabilities of the CSN hardware and software architecture.

Frequency-domain analyses reveal multiple resonant modes of the structure that are identifiable during both ambient conditions and active shaking. Spectrograms of continuous data show persistent, elevation-dependent bands of high energy corresponding to the fundamental and higher-order modes of the building. During strong shaking, resonant frequencies decrease transiently and subsequently recover, although often not to their pre-shake values, indicating the accumulation of permanent structural damage with indication that higher modes are impacted. Large-amplitude earthquake tests generated appreciable permanent reduction in stiffness, largely attributed to damage distributed throughout the building’s wall finishessubstantial damage throughout the structure.

These results demonstrate that the building’s dominant dynamic characteristics are largely resilient under repeated seismic loading. Modal properties are strongly perturbed during shaking but rapidly re-establish a stable, elevation-dependent pattern within minutes. At the same time, both transient and residual frequency changes are consistently preserved, enabling quantitative comparison across modes, floors, and tests. This study highlights the capability of dense, low-cost seismic instrumentation to support operational structural health monitoring in real-world building systems.

POSTER 87
Only Very Strong Shaking Can Break a Tree
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We can potentially improve our understanding of near-field ground motions along major continental strike-slip earthquakes not only by recording new observations and exploring computational approaches, but also by exploiting all available data from past earthquakes. For example, accounts in recent and historic times describe standing trees being snapped by shaking. Apart from landslides and tsunamis, such accounts are uncommon, suggesting that trees only break where ground acceleration is extreme, or trees are especially vulnerable. I first consider the question: what ground acceleration is required to break a living tree? I present simplified calculations from first principles, focusing on tall, thin trees that can be approximated as uniform vertical cantilevers. The results suggest that, possibly excepting tall trees with heavy canopies, standing trees can only be broken by shaking approaching or exceeding 1 g, anticipated by the rarity of documented accounts of snapped trees. Tall trees moreover potentially provide unique constraints on long-period energy that will not necessarily damage small historical structures. I consider documented instances of tree damage during strong earthquakes, drawing inferences about local ground motions. These include, an account of dead trees broken by the 1886 Charleston, South Carolina earthquake, and accounts of trees broken by the 1906 San Francisco earthquake. The former suggests that the most severe shaking in 1886 occurred near the upper edge of the rupture model proposed by Bilham and Hough (2025). In 1906, tree breakage occurred primarily in three areas: near Loma Prieta, near Fort Ross, and along a ~ 125 km swath near Cape Mendocino. The northernmost swath is well inland, 25–40 km inland of the mapped San Andreas Fault, through a region that was not surveyed by contemporary geologists. The high intensities can be explained by wave propagation effects (directivity, Moho reflections, and topographic amplification), but it might be fruitful to reconsider the original triangulation data that constrains the northernmost rupture.

POSTER 88
The Güralp Stratis: A Commercial Six-degree-of-freedom Seismometer for Ground Motion and Structural Monitoring
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Traditional research-grade three-component seismic sensors are inherently sensitive to both translational ground motion and rotational (tilt) motion, particularly on the horizontal components. The outputs of traditional seismometers represent a sum of rotation and displacement information. As a result, recorded signals represent a superposition of displacement and rotation, even though most processing and interpretation workflows assume purely translational motion. This limitation becomes increasingly important for applications involving near-field ground motion, ground-structure interaction, and structural response monitoring, where rotational effects can significantly influence observed building and infrastructure dynamics. Recent advances in sensor technology are now allowing accurate and precise discrimination between translational and rotational motion.

Stratis is the world’s first integrated seismic sensor to provide simultaneous, co-located measurements of all six degrees of freedom, delivering concurrent velocity (m/s) and rotational velocity (rad/s) outputs in the Z, N, and E directions. By measuring all six degrees of freedom at a single point, Stratis avoids the spatial differencing and approximation errors associated with multi-instrument rotational estimates. The availability of co-located rotational measurements enables correction for tilt-induced contamination in translational records, supporting the derivation of rotation-corrected displacement signals and improving the fidelity of ground motion and structural response observations. By integrating rotational and translational sensing into a single compact instrument, the installation process is also greatly simplified, thereby enabling wider access to rotational seismic data. This supports interdisciplinary applications spanning seismology, structural engineering, and seismic risk mitigation, including post-event damage assessment, long-term monitoring of structural health, and improved characterization of earthquake ground motion relevant to robust infrastructure design.

POSTER 89
Integrating Distributed On-premises Linux Back-ends With Scalable Azure Web Infrastructure for Real-time Seismic Data Distribution
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Modern seismic monitoring requires the seamless integration of high-availability data acquisition with scalable public-facing distribution channels. This architecture bridges on-premises Linux-based Earthworm and ringserver environments with a containerized Azure Kubernetes Service (AKS) web platform. The back-end infrastructure consists of specialized Linux servers, hosting Earthworm instances and ringservers to ingest real-time data from station sources and partner networks. These systems maintain critical services including Winston Wave Servers and FDSN web services, exporting data through secure modules to a centralized staging pipeline.

The publicly available “QuakeMap” web page utilizes Microsoft Azure to address high-concurrency demands. The page is designed to serve hundreds of emergence responders in an authenticated section, but also handle the general public’s 50,000 requests per second during an incident. This cloud-based front-end integrates two primary data streams: real-time station peak ground acceleration generated by the on-premises Linux servers, and alert notifications from the USGS Product Distribution Layer (PDL). The PDL stream provides metadata and partner notifications from the National Earthquake Information Center, US Regional Seismic Networks and the Tsunami Warning Centers. Leveraging AKS, SignalR, and CDN integration, the system ensures low-latency delivery to emergency responders and the general public across mobile and desktop platforms, demonstrating a robust model for scaling geophysical data from research tools to massive audiences.

POSTER 90
Assessing the Role of Low-cost MEMS Sensors in Strong-motion Networks Through Industry’s Lens
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Strong-motion networks such as the California Strong Motion Instrumentation Program (CSMIP) and the USGS National Strong-Motion Instrumentation Program (NSMP) are essential for earthquake engineering and public safety. Globally, more than 100 publicly funded networks operate tens of thousands of accelerometers permanently installed on the ground and civil structures. To maximize return on the public’s investment, these networks rely on high-quality force-balance accelerometers paired with high-resolution digitizers—a “traditional” configuration that has proven both reliable and maintainable. Operating under constrained budgets, these attributes are essential because large earthquakes are rare and smaller (more frequent but equally important) events producing low accelerations require high resolution. Historically, these networks have evolved slowly, with only two major shifts in fifty years: the move from analog to digital recording in the 1980s and the adoption of network-based communication in the early 2000s. Over the past decade, low-cost systems, often wireless, using MEMS accelerometers, have emerged as potential alternatives. While promising for certain applications, their suitability for long-term, mission-critical monitoring remains uncertain. This presentation offers an industry perspective on the technical and commercial implications of integrating low-cost instrumentation into established strong-motion networks. Leveraging our decades of experience as a leading technology provider to many global programs, we analyze operational resilience, lifecycle costs, and performance trade-offs between traditional high-quality solutions and emerging low-cost solutions. The discussion addresses key questions regarding quality, reliability, operability, and maintenance, downstream data interpretation, etc. Our analysis aims to guide decision-makers (i.e., network operators, researchers, policymakers) in balancing innovation with reliability, ensuring future seismic monitoring strategies maximize coverage, cost-effectiveness, while fulfilling public obligations.

POSTER 91
1D Velocity Profiles and Site Characteristic Assessment, Using Bayesian SPAC Analysis, in Puerto Rico
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After the structural destruction observed in Puerto Rico due to the M6.4 earthquake and subsequent seismic sequence, it was evident that the island was not prepared for these types of events, with hundreds of residences damaged. In 2022, the United States Geological Survey and the University of Puerto Rico at Mayagüez started a collaborative research initiative to acquire average shear wave velocity measurements within 30 meters beneath the surface (Vs30) employing a conventional Multichannel Analysis of Surface Waves (MASW) method at 22 seismic stations across the island to determine the subsoil types and update the previous Vs30 results of Odum et. al. (2007). Sites associated with the updated MASW study focused on sites occupied by the Puerto Rico Seismic Network and the Puerto Rico Strong Motion Program that are primarily located away from dense population centers. This project surges from the need to provide the subsoil type of residential areas, focusing mainly on the towns impacted by the 2020 Southwest Puerto Rico Seismic Sequence, and expands to provide data critical to earthquake and tsunami hazard mitigation. However, MASW is challenging to apply in the densely populated areas. This study analyzes the azimuthal average of the normalized cross-correlations of microtremors recorded by station pairs within an array of geophones (i.e., Spatial Autocorrelation – SPAC), applying a Bayesian approach to obtain the shear-wave velocity profiles and Vs30 values for site characterization. Our results for site characteristics provide the tools for structural resilience within populated areas; such data are critical for future mitigation plans especially for coastal communities that may require vertical tsunami evacuation structures.

POSTER 92
Seismic Strain Demand Prediction of Natural Gas Pipelines via Active Learning With a Query-by-committee Approach
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Accurate prediction of seismic strain demands in natural gas pipelines subjected to permanent ground deformation is critical for infrastructure risk assessment. Developing strain predictive tools applicable to a broad inventory of pipeline, geotechnical, and geological parameters presents a challenge because of the number and variability of these parameters. Performing discrete nonlinear finite element analysis (FEA) for each specific set of parameter combinations is computationally intensive and becomes impractical as the number of parameters to be covered expands. This study introduces an active learning-driven machine learning framework that employs a query-by-committee strategy to efficiently construct a surrogate model for pipeline strain prediction while explicitly quantifying epistemic uncertainty. The proposed framework represents pipeline response using an ensemble of artificial neural networks, where each committee member provides an alternative approximation of the strain-response relationship. Disagreement among committee predictions is used as an information criterion to identify regions of the high-dimensional input space where the surrogate model is weakly informed. These regions are selectively explored using constrained Sobol quasi-random sampling that enforces physical feasibility and engineering design constraints, enabling targeted acquisition of additional FEA simulations rather than uniform data expansion.

Results to date show that committee disagreement can be concentrated in certain input regions, and that uncertainty-guided sampling substantially improves surrogate reliability with limited additional computational cost. Model performance is evaluated using both accuracy-based metrics and uncertainty-based indicators, including mean absolute error and the 95th percentile of committee prediction standard deviation. The resulting strain demand predictions are intended to be integrated within a Bayesian network framework to probabilistically combine strain demand and strain capacity and to estimate pipeline failure likelihood.

Earthquake Rupture Hazard and Forecasts from

Integration of Paleoseismic Datasets

Oral Session • Friday 17 April • 2:00 PM Local

Conveners: Alex Hatem, U.S. Geological Survey (ahatem@

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Earthquake-cycle Modality Revealed by Paleoseismic Inter-event Time Distributions

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Time-dependent seismic hazard models predict earthquake likelihood as a function of time elapsed since a prior event. The most widely applied model at present is Brownian Passage Time (BPT), based on the periodic characteristic earthquake model with added noise that leads to aperiodic behavior. Using long paleoseismic records ($n \geq 10$ events) we show that time-dependent hazard for plate-boundary strike-slip faults in California and New Zealand is better fit by the Weibull distribution, defined by hazard increasing as a power-law of time. Unlike the BPT model, the Weibull model implies no fixed upper limit to the amount of loading a fault can sustain. The Weibull model distinguishes between two modes of fault behavior that can be explained by whether a fault tends to produce fewer, large, system-spanning ruptures or more frequent, smaller, partial ruptures. Quasi-characteristic systems such as the Alpine fault exhibit a system-spanning rupture mode, with strongly convex hazard functions (exponent $k \geq 2$). We hypothesize that this mode is sustained by cyclic renewal: As the fault recovers from the previous system-spanning event, greater fault area contributes to the likelihood of rupture through a paleoseismic site. Systems with irregular recurrence such as the San Andreas and San Jacinto faults exhibit a partial-rupture mode, with hazard functions that are linear ($k \approx 1$) or decelerating ($k < 1$) but still monotonically increasing ($k > 0$). Events are more frequent on these systems, but most rupture only part of the fault; system-spanning events are rare. One mechanism to explain decelerating hazard on these systems is the survivor effect: Partial-rupture events on adjacent fault sections temper the likelihood of an earthquake initiating and propagating through a site. A second mechanism is super-cycles, when

infrequent, system-spanning events are followed by unusually long periods of quiescence before returning to a partial rupture mode. A survey of other long paleoseismic records worldwide shows that the partial-rupture mode and hazard functions with $k \leq 1$ are the norm, and that quasi-characteristic behavior is unusual.

On the Behavior of Faults and Fault Systems: Geological Insights Into Patterns and Controls on Earthquake Occurrence in Time and Space

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The controls on and potential predictability of the occurrence of large-magnitude earthquakes remain poorly understood, at least partially because the phenomenology of past earthquake recurrence remains woefully under documented. But after much effort spanning decades, an increasingly large number of geological data are allowing us to place basic constraints on earthquake recurrence patterns. For example, comparison of the incremental slip-rate behavior of isolated faults with that of faults embedded within complex, integrated systems of mechanically complementary faults reveals that the steadiness of fault slip is largely controlled by the degree of structural complexity of the surrounding fault system. Extending this further, comparison of incremental slip-rate data with geodetically constrained slip-deficit rate estimates reveals that elastic strain accumulation rates remain constant on isolated faults but vary through time on faults in complex fault networks. These data demonstrate that wherever a mechanically complementary alternative fault exists, the system will “trade-off” slip between the various faults that comprise the system. This is illustrated well by the first comprehensive analysis of an entire plate-boundary fault system (the Marlborough fault system in New Zealand), which reveals that, while the overall plate-boundary system-level rate remains constant, the slip rates of individual faults vary, with alternating periods of fast and slow slip. Moreover, where data from these and other strike-slip faults are sufficiently detailed, all of the studied faults exhibit periods of fast slip that accommodate ~ 25 m of fault slip, suggesting that the mechanical controls on fault slip operate at this displacement scale. A comprehensive review of possible mechanisms in the brittle-ductile transition region that might control these behaviors reveals a small subset of possible mechanisms, providing additional focus to better understand these mechanisms and the roles they play in controlling patterns of fault displacement through time, with important implications for eventual incorporation into future PSHA.

Spatiotemporal Clustering of Paleo-earthquakes Along the Central Altyn Tagh Fault: Rupture Termination and Near Geometric Complexities

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Numerical models of strike-slip faults indicate that restraining double bends, can function as ‘earthquake gates’, conditionally impeding rupture propagation, thereby introducing variability in rupture segmentation and recurrence intervals. Robust long paleoseismic records from field observations are essential for reconstructing historical rupture scenarios and for estimating the timing and upper bounds on the magnitude of future large earthquakes. Here we present new paleoseismic records from the LaPeiQuan site in central Altyn Tagh fault. The site is situated at the transition from the straight Xorkoli section into the Aksay restraining double bend. We identify nine and probably

eleven earthquakes from event evidence including vertical offsets, open fissures, folds, and unconformities. Using OSL dating within a Bayesian framework, we model event ages of A.D. 1658 (1504-1789) yr (event LP1), A.D. 620 (371-876) yr (LP2), B.C.829 (1138-568) yr (LP3), B.C.1712 (1932-1498) yr (LP4), B.C.2048 (2318-1784) yr (LP5), B.C.2328 (2639-2023) yr (LP6), B.C.2805 (3146-2465) yr (LP7), B.C.3354 (3677-3032) yr (LP8), B.C.3481 (3814-3154) yr (LP9), B.C.3892 (4293-3508) yr (LP10), B.C.4233 (4718-3767) yr (LP11). The mean recurrence interval is 591 ± 408 years with a coefficient of variation of 0.69, and individual intervals range from 128 to 1,448 years. Integrating these results with published datasets, we reconstruct a spatiotemporal rupture history for the fault that exhibits clustering in both time and along strike. As the Altyn Tagh Fault transitions from the straight reach into the restraining bend, the frequency of paleoearthquakes decreases, consistent with restraining bends acting as conditional barriers to rupture propagation. This spatial trend further suggests that sequences of ruptures terminating before the bend promote a subsequent large event to breach the bend. We also find that earthquakes at this site conform to both the displacement-predictable model and the time-predictable model.

Keywords: Altyn Tagh fault, strike-slip fault, paleoseismic records, recurrence behavior, rupture terminations, restraining bend

Illuminating Earthquake Histories: Using Luminescence Dating to Decode Fault Slip and Magnitude Variability of Earthquake Ruptures in the Carrizo Plain, CA

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Earthquakes are among the most destructive natural disasters, and understanding whether faults produce only large or mixed-magnitude events is critical for improving hazard models. To reconstruct earthquake histories and understand the behavior of faults, scientists rely on evidence preserved in the landscape, such as offset stream channels, where the size of offsets is used to infer earthquake magnitudes. Advances in high-resolution topographic data have made geomorphic methods increasingly attractive for hazard analysis worldwide. By analyzing clusters of offsets, paleoseismologists infer the magnitudes and recurrence intervals of past earthquakes. However, this method depends on a critical but untested assumption: that new stream channels form between each earthquake. If channels instead record cumulative displacements from smaller events, the magnitudes of past earthquakes may have been systematically overestimated.

This study challenges long-standing assumptions about fault behavior by introducing a transformative approach to reconstructing past earthquake magnitudes. Using post-infrared – infrared luminescence (pIR-IRSL) dating of K-feldspar grains from the sedimentary fills of offset channels, we infer channel formation events. To test this approach, we analyzed two offset channels, Sieh32 and Sieh33, in the Carrizo Plain, California, with offsets of 16 m and 10 m, respectively, representing distinct earthquake histories. pIR-IRSL dating reveals incision events at 770 CE, 1260 CE, and 1760 CE. Our findings suggest a quasi-periodic incision events every ~ 500 years, far exceeding the fault’s earthquake recurrence intervals of 45-145 years over the last millennium. By overcoming traditional assumptions about channel formation timing and the number of earthquakes responsible for each offset, this approach provides a more accurate reconstruction of earthquake histories.

Mapping Maximum Post-glacial Earthquake Magnitudes in the Northeastern U.S. From Precariously Balanced Erratics

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Precariously balanced rocks (PBRs) are a form of fragile geologic features (FGFs) that provide an upper limit on the strength of earthquake ground motions that could have occurred while the rocks were in fragile positions, which for the erratics we are studying in the northeastern U.S. (New England and western New York state) is the age of ice retreat. PBRs provide one of the few ways to infer upper limits of the strength of ground shaking over tens of thousands of years. The resulting ground motion estimates are generally compared to hazard models to test the probability of the PBRs surviving given those model parameters. Here we take a different approach and use each PBR to estimate the largest earthquakes in the surrounding area that could have occurred without toppling the PBR. Combining the results from the 44 widely dispersed erratics, we produce a regional contour map of the largest possible post-glacial earthquakes that could have occurred in the entire region without

toppling any of the observed PBRs, which also means the earthquake magnitudes with recurrence intervals greater than the age of ice retreat. Results show that it is unlikely that a $M_w 7.5$ or larger earthquake has occurred in the northeastern U.S. since ice retreat, and it is unlikely there has been a $M_w 7$ or larger earthquake in eastern Massachusetts where there is a large concentration of PBRs. We complement the map by computing how many PBRs would be toppled by earthquakes of different magnitudes in the region, by mapping the maximum magnitude that would have toppled only 1 or 2 PBRs under the assumption that a few could survive despite strong ground motions (“lucky survivors”), and by looking at the maximum magnitudes assuming one standard deviation in the ground motion models. Similar methods could be employed in other stable continental interiors where earthquake recurrence intervals are often long.

Earthquake Rupture Hazard and Forecasts from

Integration of Paleoseismic Datasets [Poster]

Poster Session • Friday 17 April

Conveners: Alex Hatem, U.S. Geological Survey (ahatem@

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POSTER 66

Earthquakes and Criticality: A New Understanding

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Based on the observation that earthquake moments follow a near-perfect power law relationship over at least eight orders of magnitude, it has long been hypothesized that earthquakes are critical point processes. In order for a physical phenomena to be a critical point process, it must satisfy two criteria: first, its physics and geometry must allow it to be in a universality class; second, that universality class must be tuned to its critical point. As to the first criterion, it has been argued that as propagating phenomena on an approximately planar surface, earthquakes can be placed in the universality class of isotropic 2D percolation. When this universality class is operating at the critical point, it produces a power law exponent equivalent to a Gutenberg-Richter relationship b-value of 1.05. This agrees well with empirically measured b-values, which are typically near 1.0.

As to the second criterion, why fault stress should be tuned to the critical point, the most popular explanation has been Self Organized Criticality (SOC, Bak and Tang (1989)). Yet it has been commonly overlooked that no form of SOC produces criticality on a 2D grid and as result the model cannot uniformly produce a stable b-value near 1.0. The classic SOC model under a best case scenario might produce criticality on a Bethe Lattice (Broker and Grassberger, 1997), but this universality class is non-physical. In our proposed model, stress is not perpetually tuned to the critical state — it varies over time — but earthquakes only occur when stresses have reached the critical point. This, in turn, is because fault gouge lithifies to a large extentbetween earthquakes, requiring new shear planes to form for each event. These shear planes can only be formed by the opening and connection of Type I extensional cracks. It is the existence and linkage of these cracks that require stresses to be precisely at the percolation threshold/critical point. Below the percolation threshold, the cracks will not be dense enough to link; above the threshold, the cracks will be too linked, causing pore fluids to drain and cracks to close.

POSTER 67

Initial Exploration of Correlated Uncertainties Within Deformation Models Used for Probabilistic Seismic Hazard Assessment: Towards Development of a Geologically Informed Model of Fault Behavior and Fault Interactions Within Southern California

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Emerging geologic datasets indicate that mechanically complementary faults within plate-boundary fault systems not only exhibit pronounced decelerations and accelerations of fault slip that span multiple earthquake cycles, but also alternate periods of faster-than-average and slower-than-average slip

rates while maintaining an overall constant system-level moment release rate. Most modern seismic hazard models do not consider these behaviors and instead rely heavily on single values of slip rate averaged over a wide range of time and displacement scales, which may under- or over-estimate hazard. Ideally, fault slip rates would be expressed as probability density functions that could be sampled. However, a challenge arises when mapping potentially correlated or uncorrelated epistemic uncertainties in slip rates across a fault system. We present preliminary development of a covariance matrix using geologic observations of intra-system fault behavior, beginning with a simple model of four parallel strike-slip faults that exhibit the same average slip rate and variance to establish a basic framework methodology to sample slip rates from multiple probability distribution functions representing each fault. This framework samples the slip rate distribution of each fault under an imposed covariance matrix, producing numerous valid interpretations of slip rates on multiple faults from the entire uncertainty space of a single deformation model. Continuation of this study will include exploration of the uncertainty space by using distance between faults, various probability distribution function shapes (e.g., skewed triangular, trapezoidal, bimodal) for individual faults, and construction of a systematic method for defining the magnitudes of correlation and anticorrelation among the faults within the covariance matrix. This will involve leveraging incremental slip rate records and the relative complexity of regional fault systems. Ultimately, this project will continue to improve seismic hazard assessment by considering a broader uncertainty space in seismic hazard modeling within mechanically integrated fault systems.

POSTER 68
Characterizing Fault Slip Rates in a Low Strain Rate Intracontinental Region
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Fault slip rates with temporal and spatial variability, and limited well-characterized sites, present challenges for their use in seismic hazard assessments (SHA). Here, we develop an uncertainty-integrated workflow to estimate slip rates for the Para fault in Adelaide (~1.5 million residents), South Australia. Our approach incorporates geologic age and offset uncertainties in Monte Carlo simulations and represents slip rates as cumulative probability distributions, making the results suitable for a range of end users.

Site-specific slip rates are derived from a single location with clear offset markers, where modal displacements of 210 m and 165 m are reconstructed for Late Pliocene and Early Pleistocene marine stratigraphic markers, respectively. Using a uniform age distribution and PERT displacement distributions, we calculate cumulative probability density functions (CPDF) for slip rates, yielding a time-integrated site-specific slip rate of 69 m/Myr (mode) with a 95% confidence interval (CI) of 54–96 m/Myr. To estimate a slip rate for the entire fault, we use length–displacement scaling regressions to calculate fault-scale representative cumulative displacements, assuming a time-invariant slip distribution. Two rupture scenarios are used: (I) rupture termination at a fault step-over, yielding representative displacements of 180 m (Late Pliocene) and 140 m (Early Pleistocene), and (II) full-length rupture, yielding 185 m and 145 m, respectively. These scenarios yield similar modal time-integrated slip rates of 57–61 m/Myr. The limited displacement variability implies that the site lies within the 10th–90th percentile of normalized fault length and that displacement is relatively insensitive to fault-length extension, with little effect on the modal slip rate. The 85th percentile of the CPDF provides a more conservative slip rate estimate of 70–73 m/Myr, while the 95% CI is comparable at 50–80 m/Myr for both rupture models. This workflow is applied to other Australian fault systems to constrain slip rates for the National SHA and provide key inputs for a state-wide 3D Community Fault Model under development.

Earthquake Swarms Across the Earthquake Cycle: Precursors, Transients and Aftereffects
Oral Session • Thursday 16 April • 10:30 AM Local
Conveners: Kate Chen, National Taiwan Normal University (katepili@gmail.com); Aitaro Kato, University of Tokyo (akato@eri.u-tokyo.ac.jp); Kristine Pankow, University of Utah (pankowseis2@gmail.com)

Examining Swarm and Foreshock Behavior in Tiny Earthquakes Resolved by Nodal Arrays around the San Jacinto Fault in Southern California
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The prevalence of foreshocks before larger earthquakes has long been debated and remains central to understanding earthquake nucleation processes. Foreshocks are recorded far less frequently in standard seismic catalogs than suggested by some experimental studies. Recent advances in template matching and machine-learning approaches have improved earthquake detection, revealing a greater fraction of events with foreshocks. However, detectability limits for small (M < 0) earthquakes have not yet been reached by most seismic networks, leaving a hidden frontier of microearthquakes that may help resolve foreshock properties.

To detect tiny earthquakes, beamforming techniques that align and stack waveforms recorded by small-scale nodal seismic arrays can achieve signal-to-noise improvements over single station methods. By combining dense array observations with advanced processing, we aim to construct a highly complete regional catalog and reassess foreshock occurrence. To overcome limitations of past single-array experiments in locating events, we deployed five 81-element nodal arrays with 100 m aperture around an active section of the San Jacinto Fault from October 2024 through February 2025. We constructed a seismic catalog by combining stacked array waveforms with nearby Southern California Seismic Network data, applying machine-learning-based phase picking and association, and relocating events using waveform cross-correlation. This approach detects seven times more earthquakes than the standard catalog, with a magnitude of completeness of ~0.5. We find that foreshock rates exceed predictions from an Epidemic-Type Aftershock Sequence background seismicity model constrained by Bath’s law, an empirical relation implying self-similar earthquake triggering. Instead, foreshocks exhibit swarm-like behavior, suggesting underlying physical changes not captured by self-similar triggering models. We next apply template matching to further improve catalog completeness. This work demonstrates how dense nodal deployments combined with modern processing improve observations of earthquake nucleation and foreshock activity.

Fault-zone Evolution During the Preparatory Stage of the 2024 Noto Peninsula Earthquake in Japan
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On January 1st, 2024 a M_w7.5 earthquake struck Japan’s Noto peninsula, which was preceded by a 4-year foreshock sequence comprising fluid-driven seismic swarms and aseismic slips. This earthquake sequence provides an exciting opportunity to investigate its dynamic preparatory stage and nucleation processes. Here we investigate how the fault-zone environment evolved over time in advance of the mainshock. We use the region’s evolving seismicity patterns and high-resolution in-situ V_p/V_s ratios to infer fault-zone pro-

cesses and conditions, respectively. Clustered seismicity, or seismicity bursts, may reflect fault zone processes such as pore pressure changes and aseismic slip. We identify such seismicity bursts by analyzing seismicity from the Japan Meteorological Agency unified earthquake catalog with new statistical methods. We find that the detected seismicity bursts migrate upwards and towards the hypocenters of major M≥5 foreshocks, and that bursts occur episodically. We also probe fault-zone conditions by resolving high-resolution in-situ V_p/V_s ratios. Such in-situ measurements are sensitive to Poisson’s ratio, fluid pore pressure and saturation, and the geometry of cracks. We observe anomalous and temporally varying V_p/V_s ratios throughout the fault zone, indicating heterogeneous and evolving fluid and crack conditions. Notably, we observe a systematic decrease in the V_p/V_s ratio over the year prior to the mainshock, potentially consistent with the organization of fracture networks. Comparatively studying the temporal evolution of fault stress and fluid conditions provides new insights into the preparation and nucleation processes of large earthquakes and the physical mechanisms of seismic swarms.

Spatio-temporal Migration Patterns of Micro-seismicity Driven by Fluid Injections and Induced Aseismic Slip
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Seismic swarms are commonly attributed to fluid flow and aseismic slip, yet directly resolving the underlying driving mechanisms remains challenging. Aseismic slip can sometimes be detected using geodetic observations, whereas fluid-pressure transients are generally difficult to image at depth. Injection-induced seismicity associated with energy-related industrial operations provides a natural laboratory, as injection rates and pressures are known and aseismic slip may occasionally be resolved.

Here we combine analytical and numerical modeling with seismicity catalogs and injection pressure and flow-rate histories from hydraulic stimulation of enhanced geothermal systems to investigate the physical controls on seismic swarms. We introduce a theoretical model for seismicity migration in deep geothermal reservoirs that accounts for the coupled effects of pore-pressure diffusion and stress changes induced by aseismic slip. The model is governed by two dimensionless numbers that predict a transition from early-time, pore-pressure–diffusion-dominated migration to late-time, aseismic-slip-dominated migration.

Because the model is derived for fault reactivation in an equivalent single-fault framework, we further test its applicability to complex fracture networks using numerical simulations in which injection activates thousands of randomly oriented fractures. The combined analytical and numerical results successfully reproduce observed seismicity migration patterns and the typically elongated geometry of seismicity clouds, commonly attributed to anisotropic reservoir permeability, but here shown to arise naturally from aseismic slip. Our findings further suggest that the spatiotemporal evolution of injection-induced seismicity can be used to infer key properties of the reservoir, including its stress state.

Seismic Moment Release Patterns in a Swarm-dominated Fault System
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Since 2000 more than 10 earthquake swarms exceeding ML 3 occurred in the main focal zone of West-Bohemia/Vogtland, Central Europe. Each swarm activated a distinct part a complex, N-S oriented steeply dipping fault system with left-laterally slipping focal mechanisms in depths ranging from 5 to 13 km. While most clusters gradually filled the fault zone indicating a successive rupture growth, some of them overlapped and repeated activations occur.

We analyze the relocated seismic catalog of 30 000 events to better understand the regime of seismic moment release and interactions between different segments of the fault zone.

The clusters are first classified in terms of their swarm or mainshock-aftershock character using the timing of the mainshock, skewness of moment release and its autocorrelation along the fault plane. Seismic moment density and effective stress drop is evaluated along the focal zone to identify repeated activations of fault segments and gaps prone to failure. Coulomb stress analysis indicates mutual triggering between the fault segments. The fault segments

hosting mainshock-aftershock sequences show strongly uneven seismic moment density compared to those hosting the swarms.

Low-activity, Steady-state Earthquake Clustering in SW Australia: Evidence for Significant Prehistoric Activity?
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Earthquake clustering normally exhibits some degree of measurable temporal correlation, be it power-law decay following large earthquakes or discrete periods of swarm-type behavior corresponding with ephemeral subsurface fluid mobilization. In the highly seismic southwest Australia, a stable Archaean craton far removed from plate boundaries, a new high resolution earthquake catalog (Pickle et al., 2026) observes a form of atemporal low-volume and low-magnitude “drip-type” clustering, alternatively interpreted as “very long tail” Omori decay behavior. These clusters are spatially proximal (< 5 km radius) and span 5-24 years with mean interevent times that flatten with age and unity std/mean ratios, indicating declustered or random time correlation. If this behavior corresponds to long-decayed aftershock activity, these clusters could be used to infer the existence and location of significant prehistoric earthquakes as well as regions of elevated future hazard. It may also mean that traditional probabilistic hazard analysis involving declustering of background seismicity may be ill-suited for this region, as well as other areas potentially containing very old hidden earthquake sequences.

Earthquake Swarms Across the Earthquake Cycle: Precursors, Transients and Aftereffects [Poster]
Poster Session • Thursday 16 April
Conveners: Kate Chen, National Taiwan Normal University (katepili@gmail.com); Aitaro Kato, University of Tokyo (akato@eri.u-tokyo.ac.jp); Kristine Pankow, University of Utah (pankowseis2@gmail.com)

POSTER 93
Depth-dependent Interaction of Tectonic Tremors, Repeating Earthquakes, and Earthquake Swarms in a Collision Zone of Taiwan
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Seismological signatures of aseismic slip include tectonic tremors, repeating earthquakes, and earthquake swarms. They are most commonly documented in subduction margins, where their depth distribution and temporal behavior reflect slab geometry, fluid release, and plate interface rheology. Their occurrence in continental collision belts, however, remains unclear. Taiwan provides a unique natural laboratory to address this gap. Here we investigate how earthquake swarms interact with repeating earthquakes (REs) and tectonic tremors, and how their coupling varies with depth along the west-dipping Central Range Fault.

Using a 24-year seismic catalog, we show that tremors (mostly >25 km), REs (15–25 km), and swarms (<20 km) align spatially along the same fault system but exhibit distinct recurrence behaviors and interaction thresholds. We find that temporal interaction among these phenomena is strongly depth-dependent and controlled by spatial overlap. Swarms and REs display the strongest coupling within shared fault segments, consistent with asperities being repeatedly loaded by surrounding aseismic creep and transient slip-rate accelerations, supported by the rapid diffusivity of catalogued swarms (several m²/s). In contrast, tremors occur in the lower crust under near-critical frictional conditions and generally interact with seismogenic activity only during periods of elevated aseismic slip, most notably following M6-class earthquakes. Tremors alone exhibit strong tidal modulation (~90% during increasing tidal levels), indicating markedly higher stress sensitivity at depth. Elevated V_p, V_s, and V_p/V_s ratios further delineate a high-stiffness, high-pore-fluid-pressure lower-crustal environment that enables tremor generation beneath the mountain root. Overall, these observations indicate that swarms, REs, and tremors represent depth-stratified manifestations of aseismic slip, with interaction style and stress sensitivity systematically varying with depth.

Aseismic Slip and Seismic Swarms Leading Up to the 2024 M7.3 Hualien Earthquake

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Understanding the role of aseismic slip in earthquake cycles is essential for assessing seismic hazards and short-term forecasting. Eastern Taiwan's double-vergence suture zone, where the Philippine Sea Plate subducts beneath the Eurasian Plate, experiences frequent $M \geq 6$ earthquakes and widespread aseismic slip, making it an ideal natural setting to study earthquake triggering processes. Here we demonstrate how aseismic deformation contributed to the April 3, 2024 Mw7.3 Hualien earthquake by analyzing a 24-year catalog of repeating earthquake sequences (RESs) and earthquake swarms. We find that six out of nine swarms in the epicentral area, northern Longitudinal Valley, were accompanied by increasing aseismic slip rates, as revealed by RESs on the west-dipping Central Range Fault (CRF). A notable aseismic slip episode in 2021, indicated by GNSS signals, the accelerated RES-derived slip rate, and a four-month-long swarm sequence with high diffusivity ($\sim 5.2 \text{ m}^2/\text{s}$), suggests joint contributions from over-pressured fluids and deep fault creep. Following this episode, a sequence of M6+ events occurred in 2022, and both seismicity and aseismic slip gradually increased again starting in 2023. Coulomb stress modeling indicates that the accumulated aseismic slip and seismic slip since 2021 produced positive stress changes (up to 30 kPa) on the CRF that later ruptured in the 2024 mainshock. This study provides compelling evidence for aseismic-slip-induced stress triggering of a major earthquake and highlights the importance of integrating aseismic processes into earthquake hazard models for collisional fault systems.

Automated Workflow for Earthquake Cluster Detection, Classification, and Migration Analysis: Application to California Seismicity

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Recent advances in machine learning have dramatically expanded earthquake catalogs, often yielding an order of magnitude more events with richer information content. However, efficiently extracting meaningful patterns from these large-scale catalogs remains challenging. Here we present a comprehensive automated workflow that integrates three key components: seismicity clustering detection, automatic classification, and migration pattern identification. This end-to-end system requires minimal manual intervention and can process large-scale seismic catalogs efficiently.

Our workflow employs multiple clustering algorithms to identify spatiotemporal groupings of earthquakes from catalog data, automatically classified into different categories based on the characteristic features of seismic sequences, and detects migration patterns that reveal potential triggering mechanisms and stress transfer processes.

We apply this workflow to multiple California earthquake catalogs, including the relocated caltalgos from Southern California (Hauksson et al, 2012) and Northern California (Waldhauser & Schaff, 2008), and a template-matching enhanced catalog (QTM) (Ross et al., 2019). Results demonstrate that the proposed workflow can robustly identify and characterize diverse seismic sequence types spanning a wide range of spatial scales and activity levels across different tectonic settings. Migration analysis of identified swarms reveals widespread fluid-driven migration characteristics in California sequences, providing further evidence for pervasive fluid activity in the region.

This automated approach uncovers migration patterns potentially overlooked in manual analysis while providing consistent, reproducible results. The workflow enables rapid seismicity characterization, offering timely insights into earthquake behavior and improved understanding of fault zone processes and seismic hazard assessment in tectonically active regions.

Comparison of Swarm Activity in Natural and Induced Intraplate Tectonic Settings

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Swarm activity in natural and induced intraplate tectonic settings provide insight into the balance between seismic and aseismic slip on near-critically stressed faults far from active plate boundaries. We use high resolution earthquake catalogs to calculate time-variation in b-value using the b-positive method (van der Elst, 2021) and assess earthquake swarm behavior using nearest neighbor determination (NND, Zaliapin and Ben Zion, 2020). We are particularly interested if there is a clear statistical separation between induced earthquake swarms versus repeating earthquakes in earthquake catalogs, and what that reveals about event triggering. Presentation will focus on three regions: the intraplate New Madrid seismic zone, host to the large (M7+) earthquakes of 1811-1812; ongoing earthquake sequences in the Delaware Basin, west Texas; and earthquakes in the Fort Worth Basin, north Texas. New Madrid seismicity and Texas earthquakes occur along reactivated ancient faults located in the basement granites or overlying sedimentary units. New Madrid has a long paleoseismic record of large earthquakes, however, while the Texas earthquakes studied here have been linked to local wastewater injection and have only been active over the last 15 years. Our New Madrid and North Texas catalogs use relative earthquake location paired with machine-learning based detection-association-relocation approaches. The Delaware Basin catalogs are an extension of the TexNet High Resolution Earthquake Catalog using GrowClust using cross-correlation information and an independent Hypocentral Decomposition catalog that reduces spatial bias in depth but does not include correlation information. Preliminary comparison work using these earthquake catalogs indicate that statistical approaches, and resulting interpretations, are sensitive to biases in time and space, especially depth. The depth bias occurs in both the automated, relative relocation catalogs and in machine-learning based catalogs, as will be discussed. Interpretation of NND for physical mechanism (natural vs induced, swarms repeating earthquakes, etc.) should proceed with caution.

Stress Heterogeneity of Seismogenic Structures Revealed by Waveform Similarity: Before and After the 2024 Mw 7.4 Hualien Earthquake, Taiwan

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A M_w 7.4 earthquake struck Hualien, Taiwan, on April 3, 2024, followed by hundreds of felt aftershocks occurred on offshore structures that remain poorly studied. In this study, we use seismic waveform similarity as a proxy to investigate stress heterogeneity on these structures, where reduced similarity reflects spatially variable stress states.

We analyze one-month aftershock pairs of M3-class (April 3–28, 2024), using the catalog of Yang et al. (2025) and broadband waveform data from the Broadband Array in Taiwan for Seismology (BATS). Two sets of earthquake pairs are defined with inter-event distance thresholds of less than 3 km and 1 km, respectively, to ensure similar source locations and Green's functions. P- and S-wave travel times (T_p & T_s) are estimated by ray tracing. Data processing includes instrument response removal, application of a 0.1–8 Hz filter, and extraction of waveform windows from 0.5 s before the P-wave arrival to $3.0 + 0.3 T_s$ s after the S-wave arrival. The results show waveform similarity measurements of 25,399 pairs within 3 km and 2,068 pairs within 1 km. Based on cross-correlation coefficient (CCC) values, five similarity levels are defined ($CCC \geq 0.7$, ≥ 0.6 , ≥ 0.5 , ≥ 0.4 , and < 0.4). For the 3-km dataset, the proportions of pairs in each category are 0.1%, 0.3%, 0.4%, 0.8%, and 98.4%, respectively, while the corresponding proportions for the 1-km dataset are 0.6%, 2.3%, 2.0%, 2.8%, and 92.3%. The spatial distribution of high-similarity pairs ($CCC \geq 0.4$) highlights regions of relatively consistent stress and delineates seismogenic structures associated with the sequence, whereas low-similarity pairs indicate areas of increased stress complexity. Comparison of the two datasets reveals scale-dependent differences in inferred stress heterogeneity. These results demonstrate that waveform similarity offers high-resolution constraints on fault geometry and stress heterogeneity in the 2024 Hualien earthquake sequence. In future work, we will extend this approach to back-

ground seismicity (1996–2016) to investigate how large earthquakes change the regional stress field.

Characterizing Aseismic Stress Transients During Earthquake Swarms in California and Nevada From Seismicity Rate Observations

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Distinguishing the physical processes driving earthquake swarms is critical for understanding fault slip behavior. Aseismic fault slip can change the stress state of a surrounding crustal volume and modulate seismicity rates. However, quantifying the timing and evolution of the associated stress history from earthquake catalogs remains challenging. Here, we treat seismicity rate variations as a stress-sensitive observable and aim to reconstruct the stress history of aseismic fault slip from observed seismicity rate changes.

We introduce a physics-informed Bayesian inversion framework to infer the timing and evolution of aseismic stressing transients from seismicity rates based on the rate-and-state friction law. Because earthquake catalogs contain seismicity generated by both earthquake-earthquake triggering and aseismic stressing, we first apply an earthquake declustering procedure (Zaliapin & Ben-Zion, 2013) to remove triggered events and define the remaining non-earthquake-triggered seismicity rate, R . We then use the approach of Zaliapin & Ben-Zion (2020) to identify background seismicity and estimate the long-term background rate, r . The temporal evolution of stressing rates is modeled as a flexible asymmetric trapezoidal function, capable of capturing acceleration, steady-state, and deceleration phases. From the rate-and-state formulation, we derive a closed-form integral expression for R/r , and estimate probability distributions for key model parameters within a Bayesian framework. We validate the approach using synthetic experiments and apply it to eight earthquake swarms in California and Nevada, performing sensitivity tests on declustering parameters. Six swarms exhibit elevated seismicity rates consistent with transient aseismic stressing preceding the largest events, with independent support from GPS data (2008 Reno-Mogul and 2020 Westmorland swarms) and InSAR data (2011 Hawthorne swarm). These results suggest that seismicity rates can serve as a sensitive stress meter for quantifying aseismic slip transients, providing new insights into the interplay between seismic and aseismic fault slip.

Burst-like Rapid Earthquake Migrations During the 2025 Tokara Islands Seismic Swarm, Japan

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An intense earthquake swarm has been occurring near the Tokara Islands, Japan, since late June 2025. Although earthquake swarms have repeatedly occurred in this region, the current activity represents the largest observed in the instrumental record. We constructed a high-resolution earthquake catalog by jointly analyzing continuous waveform data from seismic stations on several islands operated by Kagoshima University, together with surrounding permanent seismic networks. Phase arrivals were automatically detected using the machine-learning picker PhaseNet, followed by grid-based event detection. Relative travel-time differences derived from waveform cross-correlation were used for precise relative relocation, and a matched-filter technique was applied to detect smaller events, yielding a substantially more complete earthquake catalog.

The refined catalog reveals two prominent earthquake clusters in the eastern and western parts of the source region, with most hypocenters shallower than 15 km, significantly shallower than those in the JMA catalog. Seismic activity intensified on June 21 and migrated upward by $\sim 1\text{--}2$ km at ~ 10 km/day, followed by repeated northeastward and southwestward migrations. After June 29, activity further intensified, showing northeastward migrations of up to 5 km with faster speeds of $20\text{--}50$ km/day, and the centroid of seismicity gradually shifted toward Akusekijima Island. In contrast, the western cluster exhibited diffusive migration and rapid southwestward expansion at speeds of up to ~ 70 km/day. These migration speeds are comparable to those of slow earthquakes in subduction zones and to those observed during

the 1998 dyke intrusion east of the Izu Peninsula, suggesting that intrusion of magma or hydrothermal fluids induced slow slip and associated stress concentration, triggering the earthquake swarm.

Physically Scaled Nearest-neighbor Clustering for Identifying Swarm and Aftershock Regimes in Tectonic and Volcanic Environments

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Earthquake clustering provides critical insights into fault interaction, stress transfer, and fluid-driven seismic processes. However, distinguishing swarm-like seismicity from classical aftershock sequences remains challenging, partly due to variable spatio-temporal scales associated with swarms. In particular, nearest-neighbor distance (NND) clustering implementations that rely only on combined space–time distances and neglect physically motivated rupture scaling can lead to artificial merging of concurrent seismic sequences. In this study, we integrate two existing NND-based clustering algorithms by incorporating the physical relationship between earthquake size, spatial extent, and temporal interaction. The modified workflow is implemented in a modular Python pipeline and supports objective threshold estimation, joint space–time clustering, and reproducible statistical analysis.

We test this framework to high-resolution earthquake catalogs from Northern and Southern California from 2019 to 2024. Southern California is dominated by secondary fault systems associated with the San Andreas Fault network and exhibits widespread swarm-like clustering behavior, particularly in geothermal and transtensional regions such as the Brawley–Salton Trough. In contrast, Northern California shows stronger mainshock–aftershock dominance, with many sequences displaying clear Omori-type temporal decay and fault-controlled spatial organization. Detected clusters will be further characterized using sequence attributes, including duration, spatial extent, temporal skewness, coefficient of variation, seismic moment release, and effective stress drop. We are extending the method to relocated earthquake catalogs in California, with a focus on long-term history in swarm-rich regions, and Hawaii Big Island, and examine the sensitivity of swarm identification to the magnitude-dependent rupture scaling parameter (b) and thresholding. We will further evaluate the spatiotemporal signatures of swarm sequences and physical characteristics across tectonic and volcanic settings.

Study of Seismic Stresses and Foreshock Patterns Before the 1978 Magnitude 7.8 Oaxaca Earthquake

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To study the spatiotemporal patterns of local earthquakes $m_b < 4.0$, a local seismic network of six smoked paper seismographs was installed on the Oaxaca Coast three weeks before November 29, 1978, $M=7.8$, Earthquake, as part of a Research Project between the Institute of Geophysics of the UNAM and the California Institute of Technology. This study aimed to obtain relevant information on the Oaxaca Seismic Gap proposed by Kelleher et al. (1973). During this period, 395 earthquakes were recorded, with coda magnitudes ranging from 0.6 to 3.8; most of the seismicity occurred between the coastline and the Chacalapa Fault. The depths of the precursors range from 10 to 35 km and are located primarily in the continental crust. We observe an NS alignment of seismicity at 96.6° (east of the earthquake epicenter). Three clusters of earthquakes are observed in the study area; two of them are within the aftershock area. A frame of the quiescence period centered at the main event epicenter in profiles NS and EW is observed. Using composite focal mechanisms, an analysis of the variation in previous stresses in the earthquake epicentral area is presented. Three groups of composite focal mechanisms (strike-slip, normal, and reverse) were found, each one with four solutions. A sequential migration of the mechanisms is observed in both normal and reverse solution groups.

Earth’s Structure from the Crust to the Core

Oral Session • Wednesday 15 April • 2:00 PM Local

Conveners: Chuanming Liu, University of Texas (chuanming.liu@jsg.utexas.edu); Maureen Long, Yale University

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Complex Lithospheric Structure of North America Revealed by a New Sp Receiver Function Stack

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Converted-wave imaging is a powerful method for understanding the structure of the Earth's interior at plate scales. Specifically, S-to-p receiver functions have been used to investigate the depths of seismic wavespeed gradients at crustal and upper mantle depths, which have been interpreted as boundaries such as the Moho and Lithosphere-Asthenosphere Boundary. Here we leverage the vast amount of seismic broadband data available in the contiguous United States, alongside recent methodological improvements, to generate a cross-country dataset of Sp receiver functions, which are assembled into a Common Conversion Point (CCP) stack.

In the western US, the upper mantle is dominated by a shallow (60-100 km depth) negative gradient inferred to represent the base of the lithosphere, in agreement with prior work. The lithosphere in cratonic and near-cratonic settings is marked not by a single continuous basal discontinuity, but by multilayered, complex, and heterogeneous wavespeed gradients. These depict structures that may be laterally continuous over 100s of km and appear to be related to regional-scale tectonic features such as basins and plateaus. We perform clustering on vertical profiles through the CCP volume to determine the spatial distribution of gradients, and report metrics of statistical similarity between the distribution of clustered profiles and the boundaries of major tectonic features. Distinct clusters are most clearly associated with recently-formed tectonophysical domains such as the Basin and Range province, which exhibits a thin lithosphere, and also the allochthonous terrane of the Mississippi Embayment and Gulf Coastal Plain. Cratonic boundaries are not strongly associated with clusters, while intracratonic basins such as the Illinois and Williston Basins are characterized by a deeper, more subtle, Moho. This work indicates that the lithosphere is a dynamic system that is susceptible to healing and reshaping. Furthermore, we infer that intracratonic basin formation involves the mantle and the crust, imparting a unique signature that might explain subsequent re-activation of structures.

Seismic Evidence for Slab Breakup Triggering Deep Mantle Upwelling Beneath Central America

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Understanding the interaction between subducted slabs and the lowermost mantle is fundamental to unraveling Earth's thermochemical evolution. Here, we present seismic evidence of slab breakup triggering deep mantle upwelling. By analyzing pre-critical shear wave reflections off the D" discontinuity (SdS) using advanced array-based processing, we enhance the resolution of arrival-time and amplitude measurements to constrain the height and elastic properties of the D" discontinuity beneath Central America. In most regions, the D" discontinuity lies 180 to 240 km above the core-mantle boundary, consistent with the accumulation of cold slab remnants. Lateral variations in shear-wave velocity contrasts suggest compositional heterogeneity, potentially reflecting separation of basaltic crust from the harzburgitic slab mantle. In contrast, a pronounced ~80 km depression of the D" discontinuity, spatially coinciding with tomographic low-velocity anomalies, indicates localized mantle upwelling. We interpret this upwelling to be dynamically linked to slab breakup, driven by thermal insulation beneath stagnant slabs and may be influenced by hot material from the Pacific Large Low Velocity Province. Our findings provide new constraints on the coupling between slab dynamics and deep mantle processes, emphasizing the role of slab breakup in triggering localized upwellings and contributing to the thermochemical evolution of Earth's deep interior.

Unified Mapping of the African Rift System: Lithospheric Strength and Magmatic Evolution

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The interaction between mantle plumes and continental lithosphere results in a complex spectrum of rifting outcomes, ranging from magma-rich breakups to failed rifts. Current research in the Turkana Depression posits a “Refractory Paradox,” suggesting that failed rifts like the Anza Graben remain “dead zones” because prior melting events extracted volatiles, leaving behind a mechanically strong, dried-out lithosphere resistant to modification. However, it remains unclear if this “baked-dry” signature is a global requirement for rift failure or a local anomaly. We investigate this hypothesis by mapping the subtle architectural differences—specifically Moho sharpness and seismic lid preservation—that distinguish magma-poor regions from their magma-rich counterparts. To overcome the limitations of standard receiver function (RF) analysis, which is often degraded by noise and reverberations, we apply a rigorous, high-resolution workflow. We first denoise seismic data using the CRISP-RF algorithm, employing sparsity-promoting Radon transforms to suppress incoherent noise while preserving full-wavefield phases. These clean data are then inverted alongside surface wave dispersion measurements using a transdimensional probabilistic Bayesian framework. This approach allows us to quantify non-uniqueness and robustly constrain multi-layered crustal properties (Vp/Vs ratios) and lithospheric velocity structure without placing limiting assumptions on elastic properties. By integrating these refined seismic constraints with common-conversion-point (CCP) stacking, we resolve the trade-off between magmatic underplating (gradational Moho, Vp/Vs > 1.8) and tectonic thinning (sharp Moho, Vp/Vs ~1.74). Finally, we pair these structural observations with thermo-chemical modeling (WINTERC-G/PerPleX) to convert velocities into temperature and composition. This study aims to determine if the lithospheric strength beneath the African Rift is governed by volatile depletion or alternative weakening mechanisms, such as anisotropy or eclogitization.

Reflection Seismic Profiling of Mantle Structure Under the Contiguous United States From Ambient Noise Cross-correlation

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P-wave reflections from the 410- and 660-km mantle discontinuities are visible in stacks of ambient noise cross-correlation functions of USArray stations spanning the contiguous United States. The reflections are most visible on the vertical components at frequencies between 0.1 and 0.3 Hz during low-noise periods, which generally occur during the summer months in the Northern Hemisphere. Common reflection point stacking can be used to resolve apparent lateral differences in discontinuity structure across the continent and suggests the possible existence of sporadic reflectors at other depths. Visibility of the 660-km reflector is correlated with faster P-wave velocities at similar depth in a tomographic model for North America. However, the lack of clear agreement between these P-wave ambient noise features and prior mantle-transition-zone imaging studies using other methods suggests caution should be applied in their interpretation. Ambient noise sources from the southern oceans may not be distributed uniformly enough for cross-correlation stacks to provide unbiased estimates of the true station-to-station P-wave Green's functions. However, the clear presence of 410- and 660-km reflections in the ambient noise data suggests that it should be possible to unravel the complexities associated with varying noise source locations to produce reliable P-wave reflection profiles, providing new insights into mantle structure under the contiguous United States.

Hierarchical Bayesian Joint Inversion of HVSR and Surface Wave Data for Multi-scale Crustal Imaging of the Lower Appalachians & Atlantic Coastal Plain Sediments

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Accurate prediction of earthquake ground motion in the Atlantic Coastal Plain (ACP) requires a high-fidelity shear-wave velocity (V_s) model with real-

istic sediment properties. In the southeastern US, however, existing models remain limited in depth and spatial resolution. Direct constraints on sediment are sparse because geotechnical surveys rarely extend beyond tens of meters, while deep boreholes and high-resolution reflection profiles are expensive and uncommon. Consequently, key uncertainties persist within the upper 1–5 km, including basement depth, internal sedimentary layering, and the magnitude and sharpness of impedance contrasts.

Here, we demonstrate that carefully processed information from four passive-seismic observables — horizontal-to-vertical spectral ratios (HVSR), Rayleigh-wave ellipticity, and phase/group-velocity dispersion — enables improved imaging from the shallow subsurface into the crust, overcoming key depth resolution limitations of existing ACP models. We present a hierarchical Bayesian inversion framework that jointly inverts these four seismic observables to constrain from the near surface to ~70 km depth and apply it to the SESAME array in the southeastern US. The hierarchical formulation estimates both model parameters and data-noise hyperparameters, enabling robust uncertainty quantification with reduced sensitivity to outliers and data-quality variability across observation types. We implement a Gibbs-within-Metropolis Markov Chain Monte Carlo (MCMC) sampler with a fixed ten-layer parameterization designed for sediment-over-crystalline-crust geology typical of the southeastern US. Our inversion yields new constraints on ACP sediment thickness and velocity structure overlying Paleozoic terranes, improving inputs for ground-motion simulations, site amplification estimates, and seismic hazard assessment across the southeastern US.

Imaging the Architecture of the Main Himalayan Thrust in Central Nepal With 3D Local Earthquake Tomography

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The 2015 Mw 7.8 Gorkha earthquake struck Nepal, rupturing approximately 140 km long segment along the Main Himalaya Thrust (MHT) fault. Several configurations have been proposed for the MHT, but no clear consensus has been reached yet. In this study, we use arrival time data from aftershocks that were recorded in central Nepal on the NAMASTE seismic network to perform a local tomography to image the MHT. Results from the tomographic images delineate the MHT with a shallower southern flat decollement followed by a clear upper ramp and a deeper northern flat decollement. In addition, the northward portion of the MHT experiences a sudden depth variation suggesting a complex configuration of the MHT. Furthermore, under the Lesser Himalaya in the eastern region, there is a zone of low velocity anomaly that is consistent with a duplex system. Our 3D velocity model suggest that the MHT displays significant geometrical complexities which could have played a role in controlling the rupture extent of the 2015 Gorkha earthquake.

Subtle Long-wavelength Topography of the Earth’s Core-mantle Boundary

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Earth's long-wavelength core-mantle boundary (CMB) topography is closely linked to mantle convection, the origin of large low-velocity provinces (LLVPs), and geodynamo processes. However, reliable measurements of CMB topography are challenging due to the substantial three-dimensional complexity of the mantle structures, as manifested by previous CMB topographic models showing considerable discrepancies. Here, we apply a deep-learning approach to identify the seismic phase P9KP, which reflects eight times at the underside of CMB and follows a mantle path nearly identical to that of the first-arriving P wave. Thus, the travel-time difference between P9KP and P phases can greatly reduce the influence of mantle heterogeneities, allowing for precise measurements of CMB topography. Our results show subtle CMB elevation beneath LLVPs and slight depression beneath high-velocity regions. Geodynamic simulations demonstrate that our observations are best explained by topography models derived from thermochemical LLVPs

with a weak chemical density contrast, implying dominant thermal mantle convection.

Rank-reduction Based Uncertainty Quantification for FWI

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Rank-reduction based uncertainty quantification for FWI

Full-waveform inversion (FWI) is capable of providing high-resolution Earth models, but quantifying uncertainty in these models remains a challenging and costly endeavour. The computational limitations of FWI mean that practical uncertainty estimates are necessarily based on highly incomplete information. This makes significant the difference between aggressive approaches, which systematically underestimate uncertainty, and conservative approaches, which systematically overestimate it. Here, we investigate an approach for inexpensive, conservative uncertainty quantification for high-dimensional FWI problems [1].

This uncertainty quantification strategy is based on truncated singular value decomposition of the inverse problem Hessian. It takes as input a set of model and gradient pairs, which can, but do not have to be the inversion update history. This machinery can be used for both standard deviation estimation and hypothesis testing, using a targeted nullspace shuttling approach. In addition to its flexibility, comparatively low cost and large-problem scaling, a key advantage of this approach is its conservatism; it provides a guarantee that the estimated uncertainty is greater than that which would be achieved with a full-rank Hessian estimate.

[1] Keating, S., Zunino, A., & Fichtner A, 2026. A comparison of rank-reduction strategies for uncertainty estimation in full-waveform inversion. Accepted for publication in *Geophysical Journal International*

Constraining Slab Geometry and Seismic Velocity Structure From Tillamook to Portland, Oregon

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Constraints on the location of the megathrust interface, as well as information about local geologic structure that may impact wave propagation (e.g., seismic wave velocities, sedimentary basins), are important for estimating ground shaking and seismic hazard. In Cascadia, precisely constraining the location of the plate interface and properties of the overriding and subducting crust has remained challenging due to the paucity of local seismicity. This is particularly true for the greater Portland area, where there have been few attempts to constrain slab geometry and high-resolution seismic velocities at depth. In this study, we use active and passive source data recorded on 192 three-component 5-Hz nodal seismometers in summer 2021 and 2022. The nodes were deployed in an east-west linear array from Tillamook to Portland, Oregon, to better characterize subduction zone structure between the seismogenic zone at depth and population centers at the surface. Teleseismic receiver functions were used to interrogate sharp impedance contrasts at depth, while 2-D travel time modeling using recordings of offshore air gun shots from the Cascadia Seismic Imaging Experiment (CASEI21; Carbotte et al., 2024) was used to constrain P-wave velocities. Results suggest that the depth to the top of the Juan de Fuca plate is ~20 km near the coastline. This is ~5 km shallower than commonly used slab models (McCrory et al., 2012; Slab2, Hayes et al., 2018) and could increase estimated peak ground acceleration from Cascadia megathrust earthquakes by approximately 9-17%. In addition, we note a potentially thickened subducting crust and change in dip of the slab beneath the western edge of the Coast Range, as well as a ~2.5 km thick sedimentary layer beneath Tillamook, Oregon. Overall, this work provides an improved understanding of the slab geometry and seismic velocity structure beneath northwestern Oregon, which will improve seismic hazard estimates in the region for future earthquakes.

Modelling 3D Teleseismic Waveforms Above 1 Hz Using a SEM-DSM Hybrid Method

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Efforts to improve the resolution of deep-Earth imaging have driven increasing use of higher-frequency (≥0.5 Hz) teleseismic waveforms, yet full 3-D

numerical modelling of global high-frequency wave propagation remains computationally challenging. I present a hybrid Spectral Element Method–Direct Solution Method (SEM–DSM) tool that efficiently models the effects of localized 3-D heterogeneities on teleseismic phases while substantially reducing computational cost. In this hybrid approach, wave propagation through the bulk of the Earth is computed using the fast 1-D Direct Solution Method (DSM), which operates in the frequency domain and decomposes the wave-field into spherical harmonics to efficiently compute depth-dependent coefficients. Computationally expensive 3-D Spectral Element Method (SEM) simulations are restricted to a localized target “box” containing prescribed 3-D structures, where wave propagation is simulated using SPECFEM3D. Using moderate high-performance computing resources, this hybrid method can generate global synthetic waveforms at frequencies up to 2 Hz. The hybrid method is benchmarked against full 3-D SPECFEM simulations. Depending on the size of the SEM domain, mesh design, and time-stepping scheme, errors of the 3-D synthetics are typically below 2%, meeting the accuracy requirements of most applications. Applications to widely observed seismic phases—including P’P’ scattering, PKiKP coda, PKP precursors, and PKiKP coda—demonstrate the ability of this approach to efficiently model and image localized 3-D mantle and core structures such as discontinuity topography and volumetric heterogeneities.

Earth’s Structure from the Crust to the Core [Poster]

Poster Session • Wednesday 15 April

Conveners: Chuanming Liu, University of Texas (chuanming.liu@jsg.utexas.edu); Maureen Long, Yale University (maureen.long@yale.edu); Carl Tape, University of Alaska Fairbanks (ctape@alaska.edu); Xiaotao Yang, Purdue University (xytang@purdue.edu)

POSTER 99

Constraining Depths of Basin and Crustal Discontinuities Across the Powder River Basin, Wyoming, and Black Hills South Dakota

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We attempt to constrain the depths of basin and mid-crustal velocity discontinuities across the Wyoming and Superior cratons using P-to-S teleseismic receiver functions. We compute frequency-domain receiver functions for 24 broadband stations at linearly spaced intervals of ~4-47 km across the Powder River Basin (PRB) and the Black Hills (BH). Tighter spacing is in the eastern end of the profile through the BH (~10 km). To verify Ps arrivals and subsequent multiples, we compute synthetic receiver functions for the profile. We use established sedimentary-basin basement reflector depths to guide the forward modeling of synthetics. Back-azimuth bin stacking helps identify any directional influence on Ps arrivals, providing more robust Ps arrival and multiple verifications. Furthermore, we constrain the depth of these identified velocity discontinuities through sequential H-κ stacking to establish a 2D depth profile across the transect. We then exploit the tight spacing across the BH to perform a common conversion-point (CCP) stack, thereby further investigating inner-crustal discontinuities. Our Results identify a gradual shallowing of velocity discontinuities trending ENE to WSW. The sedimentary basement discontinuity is traced across the PRB into the BH, thinning towards the east and terminating on the western edge of the BH. Conventional CCP stacking and the stacking of the differenced East-West radial components reveal west-preferred anisotropy at an apparent dipping mid-crustal interface within the BH that may be a feature of a hypothesized Proterozoic shear zone that sutures the Wyoming and Superior provinces.

POSTER 100

Inherited Lithospheric Structure Controls Cenozoic Intraplate Basaltic Volcanism in Central Mongolia Due to Mantle Upwelling

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The mechanisms responsible for intracontinental basaltic volcanism are not well understood. The Cenozoic long-lived (~30 Myr) and diffuse intraplate

volcanism in central Mongolia is an ideal natural lab to address this issue. Here we present a high-resolution lithospheric 3-D shear-wave velocity model using ambient noise tomography with data mainly from two dense seismic arrays. Our model shows strong lithospheric heterogeneities beneath central Mongolia, correlating well with the occurrence of Cenozoic basaltic volcanism. Specifically, relatively thick, high-velocity lithospheric mantle is imaged beneath the central Hangai Dome and the Hövsgöl region where Precambrian basements have been suggested to exist, which likely represent relicts of old cratonic lithosphere. Step changes in lithospheric thickness formed at their peripheries due to heterogenous lithospheric thinning or modification likely caused by recent deep mantle upwelling. More interestingly, most basaltic volcanism in central Mongolia is located at or near these strong lateral gradients of lithospheric thickness, suggesting the important role of small-scale convection in their formation due to lithospheric thickness undulations. Taken together, the Cenozoic intraplate volcanism in central Mongolia was likely controlled by inherited lithospheric heterogeneities and mantle upwelling.

POSTER 101

Joint Body and Surface Wave Inversion for the Structure of the Northern Los Angeles Basins

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Characterizing the seismic velocity structure of populated basins is critical from a hazard preparedness perspective. Two such basins of interest are the San Gabriel and San Bernardino basins, to the north of Los Angeles. Li et al., 2023 inverted surface wave travel times through the basins for an S-wave velocity structure, which showed disagreement with the Statewide California Earthquake Center’s most recent Community Velocity Model (CVMS4.26) in the top 3-5 km. At shallow depths, surface waves are dependent on both P- and S-wave structure, but most inversions solely invert for the S-wave structure (as in Li et al., 2023), reducing the non-uniqueness inherent to inverting surface wave dispersion curves. To address this issue and provide an updated model, we jointly invert body and surface wave data. The body wave side of the inversion helpfully decouples the P and S wave structures, while the short period surface waves give powerful constraints on shallow structure, where body waves have limited cross ray paths.

POSTER 102

Possible Layered Crustal Seismic Anisotropy in the NE Tibetan Plateau

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In the NE margin of Tibetan Plateau often occurs strong earthquakes. Researchers conclude mass of materials from Tibetan Plateau are moving towards NE with the complicated tectonic deformation and high seismicity. However recent research results show contradictory modes of material movement and deformation in the crust, resulting in some argument about material movement types. Seismic anisotropy could indicate the physical characteristics and the deformation information, which could help us with better understanding on the regional tectonic movement and its deep process. With GNSS data, local seismic data and teleseismic data, it is possible for us to detect the possible different deformation models, from the surface, the upper crust and the whole crust, in different scale and different depth.

GNSS data could indicates the surface deformation. The S wave splitting of local earthquake records indicates seismic anisotropy and deformation in the upper crust, although it is influenced by the crustal stress and faults. The receiver functions of teleseismic data could show seismic anisotropy and deformation in the whole crust. In order to investigate the crustal deformation in three scales, i.e. the surface, the upper crust and the whole crust, this study reveals complex deformation pattern using lots of seismic records including local events and teleseisms, as well as GNSS data. It indicates the possible layered crustal deformation in the NE margin of Tibetan Plateau.

The polarizations of fast S waves (PFS) and the time-delays of slow S waves (TDSS) in the study area show spatial changes in both the upper crust and the whole crust. Further, different patterns between these scales in specific zone reveals the possible layered deformation, but influenced by the stress, fault and other more factors, including velocity structure and fluids. Anyway, seismic anistropy provides us with chance to detect complicated deforma-

tion mode and tectonic implications [supported by NSFC Major Program 42494863].

POSTER 103

Imaging the Crust and Upper Mantle of Georgia Using Receiver Functions TRANSECT and SNECCA Seismic Arrays

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The crustal architecture of Georgia reflects the interaction of the Eurasian and Arabian plates and the influence of major terrane boundaries across the Greater and Lesser Caucasus. Strong lateral variations in crustal thickness, sedimentary basin depth, and upper-mantle structure significantly affect regional phase propagation and earthquake locations, yet existing velocity models do not adequately represent this complexity. Recent improvements in national network coverage, combined with temporary broadband deployments from the NSF-supported TRANSECT experiment, installations from the DOE/STCU-supported SNECCA project, and additional short-term arrays, now provide a dense dataset for resolving crustal structure at higher resolution. Teleseismic P-wave receiver functions were computed for all permanent stations in Georgia as well as temporary TRANSECT and SNECCA stations to estimate crustal thickness, Vp/Vs ratios, and major discontinuity geometry.

To complement the teleseismic observations, we incorporated local earthquake tomography using high-quality P- and S-arrival times from Georgia’s national seismic network and from temporary deployments following major regional earthquakes (Racha 2009, Javakheti 2010, Kakheti–Zakataly 2012). The combined results reveal pronounced crustal thickening beneath the Greater Caucasus (>50 km), thinner crust beneath the Lesser Caucasus volcanic arc, and strong basin velocity contrasts in the Kartli and Adjara–Trialeti regions. Receiver-function discontinuities correlate with major tectonic domains, while tomography highlights shallow low-velocity zones associated with active deformation and inherited lithospheric structures. The integrated dataset from permanent stations, TRANSECT, SNECCA, and post-earthquake temporary arrays yields the most detailed crustal and upper-mantle model for Georgia to date, with direct implications for seismic hazard assessment, earthquake location calibration, and improved regional velocity models.

POSTER 104

Mantle Transition Zone Imaging Beneath the East Sea (Sea of Japan) Using Teleseismic Receiver Functions

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The mantle transition zone (MTZ), bounded by seismic discontinuities near 410 and 660 km depth, plays a key role in mantle convection by regulating heat and material exchange between the upper and lower mantle. In this study, we image the MTZ structure beneath the East Sea (Sea of Japan) using common conversion point (CCP) stacking of teleseismic receiver functions from a dense array of broadband stations located on the Korean Peninsula and the Japanese Islands. The resulting CCP-stacked images reveal a generally thickened MTZ, likely reflecting the presence of the stagnant Pacific slab at the base of the MTZ. In contrast, a near-normal MTZ thickness is observed beneath Ulleung Island, potentially indicating localized thermal or compositional heterogeneity. These findings allow us to assess the relationship between MTZ structure and major tectonic processes in East Asia, providing constraints on mantle temperature, composition, and volatile content.

POSTER 105

Resolving the Deep Structure of the Yellowstone Mantle Plume

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The Yellowstone hotspot, one of the largest continental intraplate volcanic systems, remains enigmatic in terms of its mantle source depth and whether it resembles other global plumes. Whole-mantle models often image broad low-velocity conduits beneath plumes rooted in the Pacific and African large low-shear-velocity provinces (e.g., French & Romanowicz, 2014), yet Yellowstone appears weaker and less continuous in such models. In contrast, a regional SKS study (Nelson and Grand, 2018) suggests a much narrower conduit extending to the core–mantle boundary, including a lateral deflection near ~1000 km depth—behavior also observed elsewhere and potentially linked to changes in mantle rheology. These differences underscore the need for improved resolution below the transition zone.

We apply full-waveform inversion of broadband surface and body waves (20–300 s) to refine mantle structure beneath Yellowstone. Synthetic seismograms are computed using the global 3-D spectral-element solver SPECFEM3D_GLOBE with the radially anisotropic reference model SEMUCB-WM1 (French and Romanowicz, 2014) as the starting model. A multistage Gauss–Newton procedure progressively sharpens the recovered structure. The first iterations of the inversion resolves shear-velocity variations to ~400 km depth and reveals a coherent and laterally focused slow anomaly beneath Yellowstone that confirms some features seen in recent regional models including WUS324 (reference), and is particularly consistent, locally, with the recent P-wave model of Zhao et al. (2024). We will present progress extending the model toward ~1200 km depth, and implications for the continuity and spatial behavior of the plume in the mid-mantle.

POSTER 106

Layered Seismic Anisotropy and Tectonics of the Anatolian Plate

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Tectonic deformation in Anatolia is caused by slab retreat in the west and gravitational potential energy and continental collision in the east, leading to westward motion of Anatolia with respect to Eurasia, partially accommodated on the North and East Anatolian transform faults. We construct a three-layer, azimuthal seismic anisotropy model using new Rayleigh wave measurements and compare results against geodetic strain-rates and new receiver function analysis for the crust as well as shear wave splitting for the mantle to link surface kinematics and deep dynamics. In the crust, anisotropy is primarily controlled by recent deformation, especially along major fault zones. In the lithospheric mantle, anisotropy reflects ongoing deformation in western Anatolia, whereas eastern Anatolia mainly preserves prior deformation signatures. In the asthenosphere, anisotropy reflects mantle flow driven by slab retreat beneath western Anatolia. Our model provides new constraints on lithospheric deformation and geodynamics in the Eastern Mediterranean.

POSTER 107

Rayleigh-wave Attenuation in the Southern Korean Peninsula From Helmholtz Tomography

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Seismic attenuation offers insights into subsurface material properties, which are independent of the velocity information obtained from seismic tomography. Because seismic-wave amplitude attenuation is sensitive to several factors such as temperature, mineral grain size, partial melt, and compositional variations, quantitative attenuation analysis provides additional constraints on the thermal and rheological state of the Earth’s interior. However, compared to seismic imaging studies, attenuation characteristics of the subsurface beneath the southern Korean Peninsula remain poorly constrained. In this study, we analyze seismic waveforms recorded at approximately 30 broadband seismic stations deployed across the southern Korean Peninsula between 2009 and 2012, and derive preliminary Rayleigh-wave attenuation estimates over the period range of 20–120 s. The results show generally low attenuation at short periods (20–30 s), which are primarily sensitive to the crust and uppermost mantle, whereas relatively high attenuation is observed at longer periods (80–120 s), corresponding to asthenospheric depths. These patterns likely reflect increasing temperature and rheological heterogeneity in the upper mantle. Future work will expand station coverage and invert the attenuation measure-

ments to construct a detailed depth-dependent attenuation model beneath the southern Korean Peninsula.

POSTER 108
Mantle Transition Zone Thickness Variation Across Tibet Using P-wave Receiver Functions
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The Tibetan Plateau is the world’s largest and highest plateau, formed by the convergence of the Indian and Eurasian continental plates over the past 50 million years. To understand the mantle dynamics associated with the evolution of the Tibetan Plateau, it is important to determine the structure, thickness, and thermal properties of the mantle transition zone as well as the absolute depths to these discontinuities. Our research aims to determine the thickness of the mantle transition zone using 41,016 high-quality P-wave receiver functions from 571 temporary and broadband seismic stations deployed across Tibet. The adaptive common conversion point imaging technique is used to create a three-dimensional velocity discontinuity model of the mantle transition zone. The migrated receiver function images help determine the absolute depth of the 410-660 km discontinuity and the thickness of the mantle transition zone across Tibet. Our study uses absolute three-dimensional Vp and Vs models to calculate receiver functions with greater accuracy than previous studies. We observe a clear 410-660km discontinuity across the Tibetan Plateau for the most part. The migrated receiver function sections show a slightly depressed 660 km discontinuity across three zones: the central Himalayas, southeastern Tibet, and eastern Tibet. This is consistent with the high-velocity zones observed at 650 km in the three-dimensional velocity model. These results will provide further insight into the fate of the subducted “Greater” Indian lithosphere in the mantle transition zone. For future work, we will use an iterative approach to update the three-dimensional model using the depth of the 410-660 km discontinuity determined in this study. This iterative process will help produce a more accurate three-dimensional velocity model and receiver function migration stacks. In addition, we will perform receiver function migration to determine thickness variations of the 410-660 km discontinuity across Southeast Asia.

POSTER 109
Deep Learning for Deep Earth: Global D’’ Reflections in Massive Seismic Dataset
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The lowermost ~300 km of Earth’s mantle (D’’) are fundamental to understanding heat and chemical exchange across the core-mantle boundary. The properties of its top and internal discontinuities provide robust constraints on mineralogical phase transitions, yet its global structure remains poorly constrained because seismic discontinuity-reflections are weak, spatially variable, and difficult to identify consistently. Previous reflection studies have relied on regional datasets and manual inspection, limiting their ability to resolve global patterns. Here we present a scalable framework for detecting and characterizing D’’ reflections using deep learning applied to a massive global seismic dataset (named ADEPT). We combine physics-based synthetic seismograms generated with AxiSEM3D and real seismic observations from ADEPT in an iterative simulation-to-data training strategy designed to overcome limited labeled observations and bridge the synthetic–real domain gap. Our neural network architecture explicitly leverages multi-station waveforms, enabling the model to exploit waveform characteristics, relative timing, and moveout coherence across seismic arrays to robustly identify D’’ reflections. Preliminary results demonstrate systematic detection of SdS reflections in both synthetic tests and real waveform records, enabling objective identification of reflector presence across diverse areas. Applied globally, this approach provides new constraints on the lateral variability and continuity of the D’’ discontinuity, offering a path toward improved understanding of lowermost mantle structure, while illustrating the potential of machine learning to transform global investigations of deep Earth interior.

POSTER 110
A Comprehensive Crustal Coda Attenuation Map of Continental China
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Seismic coda wave attenuation (Q_C) reflects both intrinsic inelasticity and small-scale heterogeneities in the Earth’s crust, offering insights into its thermal state and structural complexity. Continental China, characterized by widespread plate boundary deformation, is among the most tectonically active regions globally. Using over a decade of data from the China National Seismic Network, we apply the Multiple Station and Multiple Event Method to estimate station-side Q_C across 1–14 Hz, yielding high-resolution maps that reveal block-scale patterns aligned with tectonic boundaries. The Northeast, South, and North China blocks show consistently high Q_C values, while significantly lower values are observed in Xinjiang, Tibetan Plateau, and North–South Seismic Belt, consistent with theoretical expectations that low values are observed in active regions. Furthermore, we identify a negative correlation between Q_C and shear strain rate at higher frequencies, suggesting a fundamental link between attenuation and crustal stress heterogeneity.

POSTER 111
A Machine Learning Enhanced Catalogue for New Zealand: Observations From Two Decades of Seismicity
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New Zealand’s nationwide seismic catalogue produced by GeoNet is primarily intended to facilitate rapid hazard communication and response. This emphasis, combined with the heterogeneous nature of the New Zealand seismograph network, can mean that some earthquakes are mislocated or not detected at all. In contrast, regional catalogues developed for research purposes offer a much more in-depth view of seismicity but require additional data and/or manual or otherwise time-consuming analysis that are not efficient or available for a near real-time nationwide catalogue. We have developed and applied a novel automated workflow to generate a research-grade national earthquake catalogue for New Zealand that balances the best of large- and small-scale earthquake catalogues. This workflow expands and improves the current national catalogue, enabling further research into New Zealand’s seismo-tectonic setting and a better understanding of present-day seismic hazard.

Our methodology was able to pick and locate 99.7% of all earthquakes in the GeoNet catalogue between 1st January 2001 and 1st January 2021. This totals 407,553 earthquakes and includes systematic and robust location uncertainties. In this presentation we present notable seismic activity to illustrate how this enhanced catalogue can enable improved understanding of seismicity in New Zealand. We discuss our observations of inconsistent changes in location across the spatial and temporal extent of the catalogue, reflecting the unique and diverse tectonic settings of New Zealand. Highlights include the impact of our locations on constraining subduction zone structure, as well as more accurate characterisation of spatial relationships between earthquake sequences. At a national scale we calculate the 95% seismogenic depth, discussing the agreement of our observations with previous models as well as key regional differences. In particular we discuss observations around the Alpine Fault, Central North Island and the subduction margins.

POSTER 112
Upper Crustal Structural Heterogeneity and Its Role in Intracontinental Seismogenesis in the Western United States
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Earthquakes are among the most destructive natural hazards, yet the role of upper-crustal structural heterogeneity in controlling earthquake distribution, magnitude, and rupture behavior remains incompletely understood. The western United States, extending more than 1000 km inland from active plate boundaries, is characterized by distributed intracontinental deformation, dense fault networks, and abundant seismicity. Therefore, it is an ideal natural laboratory to investigate how upper-crustal structural heterogeneity impacts intraplate seismogenesis. However, most existing seismic velocity models that are broad enough to span this region lack sufficient resolution in the shal-

low crust to resolve fine-scale heterogeneities, which are key to understanding structural control on earthquake distribution. Here, we derive high-resolution P- and S-wave velocity models of the upper crust (≤ 15 km depth) from full-wave ambient noise tomography. Integrating these models with mapped fault traces, regional stress field estimates, and numerical modeling of strain rate, we examine correlations between structural heterogeneity and seismogenesis. Preliminary results reveal pronounced lateral variations in upper-crustal structure that are spatially associated with zones of elevated seismicity, strain localization, and boundaries in the crustal stress field. These observations suggest that inherited and evolving crustal heterogeneities play a key role in modulating earthquake frequency and potentially influence rupture behavior across the western United States. By improving constraints on shallow crustal structure and quantifying its relationship to seismicity, this study advances our understanding of the physical processes governing earthquake generation in distributed intracontinental fault systems away from plate boundaries.

POSTER 113
The Shallow Moho Below the Los Angeles Basin
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The Bouguer gravity of the Los Angeles Basin is unexpectedly small, given the thickness of its sedimentary fill. The basin contains a sedimentary fill approaching 10 km in thickness, which, assuming a density contrast of ~ 0.8 g/cm³, would be expected to produce a Bouguer anomaly of approximately –300 mGal if uncompensated; however, observed anomalies are only –80 mGal, indicating near-isostatic compensation (Turcotte and McAdoo, 1979). Receiver-function analysis by Ma and Clayton (2016) imaged Moho shallowing beneath the basin, consistent with this mass balance. Using data from a dense nodal deployment acquired in fall 2022, when 273 seismic stations were installed across the Los Angeles Basin, we identify P-to-S conversions from the sediment–basement interface, intrasedimentary layers, and the Moho. Our results delineate a narrow, elongate basin with a maximum sediment thickness approaching 10 km. Assuming isostatic equilibrium, we infer Moho uplift of up to 45% relative to the surrounding crust and estimate stretching factors between 2 and 5.5 in the deepest portions of the basin, implying extreme crustal thinning, mantle upwelling during basin formation, and a significant contribution from post-extension thermal subsidence.

ESC-SSA Joint Session: Advanced Methods for Harnessing Seismic Noise Analysis in Applied Seismology
Oral Session • Wednesday 15 April • 8:00 AM Local
Conveners: Sean Ahdi, ARUP (sahdi@g.ucla.edu); Ettore Biondi, Stanford University (ettore88@stanford.edu); Cecile Cornou, University of Grenoble Alpes (cecile.cornou@univ-grenoble-alpes.fr); Sebastiano D’Amico, University of Malta (sebastiano.damico@um.edu.mt); Francesco Panzera, University of Catania (francesco.panzera@unict.it); Stefano Parolai, University of Trieste (stefano.parolai@units.it); Matteo Picozzi, National Institute of Oceanography and Applied Geophysics (mpicozzi@ogs.it)

Performance Assessment of the Hybrid Standard Spectral Ratio Approach in the Norcia Basin, Central Italy
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Seismic site response is a key component in seismic hazard assessment. In the frame of the project MODERN - Advanced seismic interferometry methods and technologies for engineering seismology, we applied the earthquake standard spectral ratio (SSR), the ambient-noise SSR (SSRn), and the hybrid SSR (SSRh) methods to evaluate site response in the Norcia basin. For the analysis are used the Norcia temporary seismic network data in EIDA (European Integrated Data Archive). The basin is characterized by a complex sedimentary structure, with thicknesses exceeding 200 m and reaching up to 600 m in its central area. The classical SSR method estimates amplification

by comparing earthquake recordings at basin stations with those at nearby rock reference site. Although robust, this approach requires a large number of high-quality seismic events, which are not always available. Ambient vibration methods overcome this limitation by exploiting continuously recorded seismic noise, allowing for stable and repeatable estimates without the need for earthquakes. However, the reliability of SSRn may decrease when reference and target stations are far apart, due to differences in noise source distribution. To take advantage of both datasets, the SSRh method combines earthquake and noise observations. Earthquake SSR is first used to define the relative response between a rock site and a selected basin station, which then serves as an internal reference. Ambient vibrations are subsequently used to characterize spatial variations in site response across the basin. The use of ambient noise allows for dense spatial sampling and improved characterization of site effects, particularly in areas with limited earthquake recordings. Results from the SSRh method show good agreement with those obtained from classical SSR. While spectral shapes are similar, SSRh generally yields slightly higher amplification levels, especially in zones with thicker sedimentary deposits. These findings highlight the effectiveness of ambient vibrations in enhancing site response studies and support the SSRh method as a reliable tool for seismic microzonation.

Improved Bedrock Mapping in the Upper Mississippi Embayment, Kentucky, Using Ambient Noise HVSR
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Numerous global studies have demonstrated that horizontal-to-vertical ratios of the amplitude spectra of ambient noise (HVSR) relate to underlying shear-wave velocity structure. Specifically, the frequencies corresponding to HVSR peaks depend on the depths of prominent impedance contrasts and on the average S-wave velocities (V_s) in the layers above those contrasts. Here, we use HVSR curves determined from a dense array (~ 10 km spacing) of broadband seismometers deployed recently in a 120 km x 30 km swath across the Kentucky part of the Upper Mississippi Embayment (UME) to map the depth to the profound impedance boundary associated with the sediment–bedrock interface. Relevant borehole data are sparse in this region, and we calibrated the relationship between the first peak frequencies and bedrock depths using surface-to-bedrock V_s profiles developed elsewhere in the UME, including the profiles developed at the two deep vertical seismic arrays in and near the project area. We also used the HVSR curves previously developed at those vertical arrays to assist with interpreting the HVSR curves determined in this study. Our new depth-to-bedrock model provides important constraints both on the region’s V_s structure, needed for reliable site response modeling, and hydrostratigraphy, needed for reliable groundwater modeling using surface seismic techniques.

Ambient Seismic Imaging of Subsurface Fractures at the Newberry Volcano Geothermal Field Using the Method of Permeable Fracture Imaging
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In 2023 and 2025 we deployed 982 and 1320 nodal seismographs in the area surrounding the Newberry Volcano Geothermal Field’s 3 km deep 55-29 test well. These arrays were used as ambient seismic detectors for potential non-earthquake seismic signals from permeable, fluid-filled, fractures. The 2023 survey covered ~ 27 km² and focused on a $\sim 1.6 \times 1.6 \times 1.8$ km³ imaging volume around 55-29. It was designed to image down to ~ 2.2 km. The 2025 survey covered ~ 37 km² and was aimed at extending this coverage to ~ 3.2 km. Both networks were operated at 500 Hz sampling for several days (5 and 11). The data were processed using the 1-way travel time, fracture-source to surface-

receiver, PFI™ steaming-migration method. A critical step was the development of an accurate velocity model for use in focusing the PFI stack. This was accomplished in 2023 by improving previous velocity models. In 2025 we used a DAS-based calibration method that gave accurate travel times from near the bottom of 55–29.

The 2023 survey was conducted during environmentally and culturally quite time. The time-lapse imaging detected near-and-far well signals (~0 to ~1.2 km offset) and seismically dead zones. Based on previous verified interpretations of PFI maps, we identify these signals as coming from fluid-filled fractures, originating from local microstrain induced slip events. The dead zones coincide with the clay cap. Signal orientations in the active zone are consistent with the regional geology. Our interpretation in terms of fractures is also supported by a low-pressure stimulation in 55-29 (~22 bars), which activated signals up to distances of 0.4 km. The 2025 survey was conducted during a period of high industrial activity with only a score of quiet hours, significantly interfering with shallow signal processing. Consequently, our efforts were focused on the deeper volume around 55-29, were we detected stimulation generated signals. In addition to geothermal resource mapping, we suggest that PFI can also be used to directly profile the pluming of volcanic systems.

Estimation of the Complex Site Response Including Cross-coupling Effects: Toward the Calculation of Virtual Seismograms

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An accurate estimate of local site effects is essential for seismic risk assessment. However, existing empirical and numerical methods for characterizing site response have significant limitations. In particular, most current methods are limited to estimating the amplitude of site response, neglecting its complex nature and the cross-coupling between ground motion components.

This study addresses two questions: First, is it possible to reliably estimate a broadband complex site response function (CSRF) using only ambient seismic noise? Second, can this CSRF be used to generate virtual seismograms at a site from recordings at a rock reference site?

This study proposes a new approach based on a cross-coupling inversion scheme that exploits environmental seismic noise recorded at three seismic stations (designated as Reference, Bridge, and Target). This approach eliminates the need for seismic recordings to estimate site response and enables recovery of the full nine components of site transfer functions, including both amplitude and phase information.

The CSRF is estimated in separate frequency bands to account for variations in environmental noise sources across the spectrum. These band-limited estimates are then combined using a weighted mixing strategy to produce a single broadband CSRF, which is adapted to the specific azimuths of the incident waves. The resulting responses are first validated, in terms of frequency-dependent amplitude, against those derived from standard spectral ratio (SSR) analysis of earthquakes. Subsequently, taking advantage of the full amplitude and phase information, the CSRFs are used to compute three-component virtual seismograms at the target site using earthquake recordings at the reference site.

The approach is validated using seismic data from the island of Kefalonia in the central Ionian Sea. The derived CSRFs show excellent agreement with those obtained from the SSR. Furthermore, the generated seismograms reproduce with good accuracy the ground motions observed at the target sites.

Monitoring Seasonality and Directionality in Ambient Seismic Noise Generated by Africa’s Circumfluent Oceans

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Ocean-generated seismic noise in Africa shows strong seasonal and directional variability that broadly tracks overall ocean-wave and -current activity and can bias seismic velocity measurements from ambient noise. We analyzed vertical-component cross-correlations from 27 broadband stations, including those from the DRIAR seismic array in Uganda, spanning August 2022 to August 2024. In the primary (0.03-0.10 Hz) and secondary (0.10-0.30 Hz) microseism bands, amplitude asymmetry between positive and negative time lags reveals dominant source sectors from the North Atlantic (NW), South Atlantic/Southern Indian Ocean (S-SW), and Indian Ocean (E). Boreal-winter months (Nov-Mar) strengthen NW illumination, consistent with hemispheric

storm forcing, while austral-winter months enhance S-SW propagation and produce clear reversals in NW-SE oriented station pairs within Uganda.

Dispersion measurements from monthly stacks show that group velocities and amplitudes exhibit seasonally varying, lag-dependent asymmetry that reflects changing source directivity and can map into tomography as bias. These results demonstrate that African microseisms can be a proxy for ocean state, while motivating source-aware stacking and averaging when the noise field is strongly anisotropic.

ESC-SSA Joint Session: Advanced Methods for Harnessing Seismic Noise Analysis in Applied Seismology [Poster]

Poster Session • Wednesday 15 April

Conveners: Sean Ahdi, ARUP (sahdi@g.ucla.edu); Ettore

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POSTER 86

Toward Monitoring Groundwater-induced Seismic Velocity Changes Using Ambient Noise Correlation in the Upper Mississippi Embayment

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We apply ambient noise interferometry to investigate groundwater-driven seismic velocity variations (dv/v) in the Kentucky portion of the Upper Mississippi Embayment (UME), where monitoring wells are sparse and groundwater resources are poorly characterized despite the region’s heavy reliance on groundwater. In late fall 2025, we began deploying an array of 35 continuously recording three-component broadband seismometers in a grid across the project area with ~10 km station spacing covering an area of approximately 130 km × 30 km. Our analysis focuses on low-frequency ambient noise (0.1–1 Hz), which is expected to be particularly sensitive to hydrologically induced velocity changes in UME aquifers.

To aid interpretation of the observed dv/v signals, we developed a two-dimensional finite-element model (2D FEM) to examine the elastic response of an unconfined aquifer to water-table fluctuations, enabling assessment of the relative contributions of poroelastic effects and direct water loading. Here, we present preliminary array performance metrics, describe the ambient noise processing workflow, and show dv/v measurements at existing UME groundwater monitoring wells. Also, we demonstrate a conceptual two-dimensional forward modeling framework, informed by our 2D FEM, that explains the temporal variations in dv/v due to groundwater fluctuations.

POSTER 87

Beyond Source Homogeneity: High-frequency Control for Empirical Green’s Function Retrieval

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The prevailing view in noise interferometry holds that empirical Green’s functions (EGFs) emerge only when ambient noise sources are homogeneous. Yet, most field data that exhibit clear Green’s function-like waveforms are recorded under far-from-uniform source distributions. We argue that EGFs retrieved from ambient-noise correlations depend fundamentally on the high-frequency (long-distance) condition rather than on the often-assumed homogeneous source distribution. Using analytical formulations and field cross-correlations, we show that the time-domain cross-correlation function (TDCF) converges toward the true Green’s function as the dimensionless ratio

$\alpha = r/\lambda$ increases, regardless of the source configuration. The apparent success of homogeneous models in earlier studies reflects the implicit satisfaction of this HF condition. Our results demonstrate that α —not source uniformity—controls empirical Green’s function retrieval, and that symmetric averaging of TDCFs can introduce systematic travel-time bias. Recognizing this distinction reshapes the theoretical basis of ambient-noise tomography and calls for α -aware interpretations of interferometric measurements.

POSTER 88

Traveltime Tomography Using Ambient Noise P Body-waves From Distant Typhoons

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Ambient noise tomography using surface waves extracted from ambient noise is routinely employed to determine subsurface velocity models at various scales. In contrast, fewer studies have used ambient body waves for tomography, particularly with seismic arrays far from the ocean. In this study, we successfully extracted reliable mantle body waves using a temporary dense seismic array deployed in the Zhangbaling segment of the Tanlu Fault Zone, China. Through an ambient noise analysis workflow with beamforming, time-frequency spectral analysis, and polarization analysis, we demonstrate that western-Pacific typhoons work as noise sources for exciting body waves recorded by this inland array. We further adopt rigorous data segment selection and signal enhancement techniques to improve the signal-to-noise ratios of the extracted P waves. These body waves are then used to determine the three-dimensional (3D) P-wave velocity (V_p) structure of the upper crust surrounding the Tanlu Fault Zone, which reveals patterns matching the 3D S-wave velocity (V_s) model obtained from ambient noise surface wave tomography. Our study shows that high-quality mantle P-waves can be extracted via cross-correlation and stacking of ambient seismic noise for an inland seismic array during an intense storm. These body waves provide additional constraints on the subsurface structures, which augment conventional ambient noise surface wave tomography.

POSTER 89

Characterizing Fundamental Frequencies Across Geologies Using Ambient-noise HVSR

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Ambient-noise Horizontal-to-Vertical Spectral Ratio (HVSR) provides a cost-efficient estimate of a site’s fundamental frequency (f_0) using a single three-component sensor. Site specific geology is expected to significantly influence the HVSR peaks, trend of HVSR curve and f_0 . We deployed broadband seismometers simultaneously to synchronously record ~2 hours of ambient ground vibration data at representative different geologic settings (basin interior, basin edge, hill/mountain rock, and deep basin) in Los Angeles. Data acquisition at all four sites is done synchronously to reduce temporal variability in the noise field and enable direct, geology-driven influence of ambient vibration for comparisons of f_0 . The goal is to isolate and understand geologic controls on the f_0 derived from ambient-noise HVSR. Waveforms are preprocessed (de-trend, instrument correction, cosine taper, and band-pass filtered), windowed, and problematic windows are rejected prior to HVSR computation. Preliminary investigations show that although there is some difference in the estimated f_0 from HVSR peak between the four different sites, the difference is not significantly distinct. We are working to identify site-specific controls (e.g., impedance contrast, sediment thickness, topography, and non-stationary ambient noise) that could explain the muted differences in f_0 .

POSTER 90

Capturing Subsurface Impacts of Recent Rainstorms in the San Joaquin Valley Using Coda Wave Interferometry

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The 2022-2023 atmospheric rivers (ARs) resulted in intense precipitation across California. Over a 3-month period, 332 mm poured over Central California, providing a new opportunity to study the crustal response to rapid

hydrological loading. Recent development of coda wave interferometry with ambient seismic noise has demonstrated to capture seasonal variations in aquifers with high temporal resolution. We use continuous waveform data from the Northern California Earthquake Data Center (NCEDC), focusing on 14 three-component broadband stations across the Southern Central Valley of California. We compute daily ambient noise cross-correlation functions to monitor relative seismic velocity changes (dv/v) over the 2020–early 2026 period.

Using the moving-window cross-spectral (MWCS) method on coda waves band-passed between 0.1 Hz and 0.9 Hz, we observe a distinct dv/v signature associated with the early 2023 events. Our preliminary results suggest a maximum velocity decrease of approximately 0.1% following the onset of the ARs. This transient drop is consistent with increased pore pressure and episodic surface loading. To investigate the underlying mechanisms, we implement a first-order 1D elastic loading model. The model suggests that while hydrologic loading explains the long-term seasonal trend in dv/v , the high-magnitude fluctuations during the 2022-2023 ARs likely require a coupled hydromechanical approach to fully resolve. Our efforts represent a first step towards separating elastic versus poroelastic effects in the shallow crust in the Central Valley using seismic data.

POSTER 91

Preliminary Shallow Subsoil Velocity Imaging of the Contursi Terme Hydrothermal System (Southern Italy)

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The seismic imaging of the shallow subsoil in geothermal environments plays a key role in improving the assessment of the hidden energy resource potential of an area. Among the available techniques, the ambient noise tomography is one of the most adopted methods, as it is cheaper than active seismic investigations and more flexible than the local earthquake tomography, whose resolution depends on the spatial distribution of the earthquakes. We present an ambient noise tomography study carried out in the framework of the Italian National Recovery and Resilience Plan (NRRP) “TOGETHER” Project, focusing on a low-enthalpy hydrothermal system located between Contursi Terme, Oliveto Citra and Colliano municipalities (Southern Italy). After a preliminary investigation of the noise properties in the target area, we deployed a seismic array consisting of twenty-nine 0.5 Hz six components low-cost Sentinel GEO MKII sensors, recently acquired by CNR – IMAA in the context of the NRRP ITINERIS project. The geometrical configuration of the array, spanning the whole azimuthal range, provided a final inter-station distance ranging from 400 m to about 9 km. The seismic stations simultaneously acquired ambient seismic noise data over a period of about 1 month with a sampling frequency of 125 Hz. The collected ambient noise dataset was then analyzed through the Multiscale Ambient NOiSe TomogrAphy (MANGOSTA) code. Cross-correlations (CCs) were computed from the vertical component seismic signals of all selected station pairs using time windows of about 21 minutes: a total number of 300 cross-correlation functions were retrieved, showing coherent wave trains of Rayleigh waves propagating along distance. The frequency – time analysis (FTAN) allowed us to retrieve the dispersion curves which were then inverted into 2-D group velocity maps of the target area at different periods. Finally, the retrieved images have been jointly interpreted with resistivity subsoil models obtained within the TOGETHER project.

POSTER 92

Shear-wave Velocities in the Bellingham and Everett Basins, Washington State: Insights From Multimethod Characterization With krSPAC and Active-source Linear Arrays

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Characterizing earthquake ground motions through three-dimensional simulations has become an important focus for seismic hazard assessment in urbanized sedimentary basins. However, realistic ground motion prediction requires shear-wave velocity (Vs) at depths that capture the extent of the sedimentary column (i.e., usually >30 m), which is often poorly constrained. We acquired microtremor array data at 19 sites throughout the Everett and Bellingham basins in the Puget Lowland, Washington State, and applied the wavenumber-normalized spatial autocorrelation method (krSPAC) to characterize Vs at depths capable of delineating the Quaternary and upper Tertiary deposits, possibly >1000 m at some sites. In contrast to a traditional SPAC approach, where modeling high wavenumbers within the SPAC spectrum requires array symmetry, in the krSPAC approach we interpolate observed coherency-versus-frequency spectrum to coherency-versus-kr (where k and r are wavenumber and averaged interstation spacing, respectively), prior to Vs modeling in the kr domain. We deployed ten-sensor nested asymmetric triangular arrays with nominal interstation spacings that varied from ~100 m to 1000 m. We complement the krSPAC microtremor data with two colinear active-source, 72-sensor linear array seismic datasets (1.5 m sensor spacing) at the center of each site: one with single-component (1C) 4.5 Hz vertical and one with 1C 4.5 Hz horizontal sensors. We analyze the active-source horizontal-component data for both SH-wave refraction traveltimes and Love wave dispersion, and the vertical-component data for Rayleigh wave dispersion and P-wave refraction traveltimes. For modeling, we first use the active-source dispersion and traveltime datasets in an iterative least-squares joint inversion to constrain Vs in the upper ~50 m; these shallow profiles then constrain the krSPAC microtremor modeling, which resolves Vs to greater depths. Preliminary Vs profiles in both basins are generally consistent with those observed farther south in the Seattle and Tacoma basins, with Vs ranging from ~200 m/s to ~900 m/s in the upper 600 m at the deeper basin sites.

POSTER 93

Artius: A Revolutionary Broadband Node to Enable Passive Seismology
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The Artius broadband node represents a transformative innovation in seismic instrumentation, designed to bridge the gap between traditional broadband seismometers and popular nodal systems. While broadband seismometers offer unparalleled sensitivity and frequency range, their cost and complexity often limit large-scale and dense deployments. Conversely, geophones provide cost-effective solutions for high-frequency applications but lack sensitivity to low-frequency seismic signals, which are critical for many research and monitoring purposes. Artius provides a cost-effective compromise, delivering the increased sensitivity and a true broadband frequency range at an economic price point.

Designed by Gralp Systems, Artius integrates a compact, highly sensitive broadband seismometer with an environmentally sealed anodised aluminium enclosure, ensuring optimal performance and robustness across diverse geophysical applications. Boasting a response of 30 seconds to 200 Hz, Artius greatly outperforms geophone-based systems while still being perfectly suited to rapid temporary deployments where it can be either pushed or staked into the ground and connected to an external power supply. Artius pushes the limits of versatility, facilitating real-time data monitoring, as well as passive data collection. Artius has an onboard SEEDlink server, compatible with all standard seismological monitoring techniques, truly setting it apart from anything on the current market. Artius is designed to be docked into an eight-node capacity docking station for data validation and mass data download. The docking station also serves as a 'huddle' system for configuration and testing prior to deployment, ensuring each node is performing optimally. The Artius nodes are intended to be deployed in large arrays, perfect for passive seismology, ambient noise studies, and earthquake investigations.

ESC-SSA Joint Session: Interpreting Volcanic Unrest and Eruption Data for Effective Crisis Management
Oral Session • Thursday 16 April • 8:00 AM Local
Conveners: Luca D'Auria, National Center for Volcanology
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Detection and Monitoring of Volcano-seismic Processes During an Eruption Cycle at Axial Seamount
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Cabled ocean bottom seismometers (OBS) placed on top of Axial Seamount, a hotspot volcano that lies on the Juan de Fuca mid-ocean ridge in the Northeast Pacific Ocean, stream continuous data since late 2014. The 7-station OBS network, which is part of the Ocean Observatories Initiative (OOI), captured the most recent eruption in April 2015 and has since then recorded seismic activity leading up to the next eruption which is believed to be imminent based on the level of inflation. We use supervised and unsupervised machine-learning, cross-correlation, and double-difference methods in a real-time monitoring framework to detect, discriminate, and characterize the broad spectrum of signals from diverse solid Earth processes and other sources, including whale calls, anthropogenic activity, and ocean noise. The data reveals rich details about the nature of seismogenic processes and the behavior of active faults in the months prior to and during the 2015 eruption, the subsequent quiet period, and the current eruption preparation period. For example, we found short-term precursory mixed frequency earthquakes which we interpret as brittle crack opening driven by influx of magma or volatiles before the 2015 eruption, impulsive seafloor events caused by hot lava reaching the sea floor during the eruption, and spatio-temporal patterns of fault activation that may be characteristic in the months prior to an eruption. These observations, combined with findings from a 15-station temporary OBS array from 2022-2024 covering the entire caldera, ambient noise analysis, and active source seismic and compliance data, are used to gain insight into the structure, mechanics, and dynamics of Axial Seamount and enable monitoring of the volcano for precursory signals as it prepares for the impending next eruption. While an eruption of Axial volcano poses no risk to society, the underlying processes of volcanic unrest and the methods we use for monitoring them may apply to other volcanic systems, including those close to densely populated regions.

Rapid Seismicity Migration in the 2025 Santorini-Amorgos sequence
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We applied a machine learning-based workflow to monitor the Santorini-Amorgos seismic sequence (Dec. 2024–June 2025), detecting over 60,000 earthquakes, including 212 events with magnitudes greater than 4. While most earthquakes show brittle-failure characteristics, we also identified a small number of long-period earthquakes activated late in the sequence. We found that seismicity is concentrated between 8 and 12 km depth, with localized activity reaching up to 15 km deep. The resulting high-resolution earthquake catalog, combined with focal mechanism solutions, reveals a sharply defined network of dominantly northeast–southwest–trending normal faults extending from northeast of Thera (Santorini) to southwest of Amorgos, and passing beneath Anydros Island. The sequence initiated near the southwestern end of the fault system on January 27, followed by rapid intensification and northeastward propagation beginning on February 1. Subsequent activity activated a 30 km-long zone to the northeast, as well as reactivating the fault zone to the southwest. Throughout the first 19 days of the sequence, we observed 47 recurring seismic bursts—each lasting 1–2 hours with hundreds of events, including many of the largest. Within some seismic bursts, the speed of rapid

migration of seismicity along the fault zones reached up to 2 km/h. Such a fast migration speed of many hour-long burst sequences, and also of the overall sequence (kilometers per day), is comparable with that of previously observed dike intrusion swarms, slow slip events, and aseismic-slip-driven swarms. Overall, the large and sustained number of M>4 magnitude earthquakes during the Santorini-Amorgos sequence, combined with the burst-like nature of the seismicity, is remarkable. Only a few historical analogs exist, all of which were related to magmatic intrusion or eruption. All these observations suggest that the evolution of seismicity is most likely driven by fluids propagating through the crust above a magmatic intrusion. Though a deep stationary intrusion is possible, the swarm characteristics most closely resemble those associated with propagating dikes.

Bulk Locations and Mechanisms of Repetitive Long-period Seismicity at Mount St. Helens in July 2005
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The 2004–2008 eruption of Mount St. Helens exemplified the practical challenges of high volcano-seismic event rates and data volumes. This protracted multi-year eruptive sequence was accompanied by a near-continuous occurrence of long-period (LP, 0.5–5 Hz) seismicity. Single-station event detection, characterization, and multiplet analyses proved valuable tools for monitoring and understanding the evolving eruption; however, network-based picks and locations were performed for only a relatively small subset of the overall seismicity, and source mechanism moment-tensor and single-force inversions have previously been performed for just two event types during the eruption. We present a new workflow for the bulk detection, cluster picking, 3D location, and full-waveform source-mechanism inversion of repetitive LP volcanic seismicity recorded by a local broadband seismic network. Our emphasis is on methods that exploit waveform similarity (multiplets) commonly observed for volcanic LP seismicity swarms, can take into account 3D topographic and velocity structure heterogeneity typical of volcanoes, can process high event rates with relatively low analyst burden, and do not require *a priori* catalog picks or known waveform templates. We develop and illustrate the workflow using data from Mount St. Helens in July 2005, a time-window characterized by high-rate LP seismicity including numerous lower-amplitude small LPs, and for which relatively dense seismic network coverage is available. Approximately 40% of seismicity (20,561 events out of 52,141 triggers) during 29 June 2005 to 31 July 2005 is repetitive enough to be grouped into 17 multiplets of at least 300 events. We present 3D locations of the 17 multiplets, representing 20,108 events having picks from at least 8 stations, along with full-waveform source mechanism inversions of the 17 separate multiplet stacks. The seismicity accompanying the 2004–2008 eruption of Mount St. Helens has been interpreted in different ways; thus, a more comprehensive event detection, location, and source mechanism inversion procedure can help to address current ambiguity.

Interpreting Campi Flegrei Unrest Through Integrated Seismic Tomography and Earthquake Analysis: Implications for Fault Reactivation and Hazard
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The Campi Flegrei caldera is one of the most critical examples of long-lasting volcanic unrest without eruption, posing major challenges for its interpretation and crisis management. Since 2005, renewed uplift, shallow seismicity, and enhanced degassing have generated a rich multidisciplinary dataset, offering new opportunities to investigate the physical processes controlling unrest evolution and its potential outcomes. Recent high-resolution seismic tomography [1] provides a detailed image of the subsurface architecture beneath Campi Flegrei, revealing a shallow low-permeability caprock overlying an overpressured, steam-rich hydrothermal reservoir at ~2–4 km depth, underlain by a mechanically competent basement. This structural configuration constrains how pressure accumulates and is redistributed within the system, exerting a primary control on ground deformation and seismicity. Complementary analyses of earthquake source properties[2] and spatio-temporal clustering show that stress perturbations associated with reservoir pressurization and depressurization modulate fault activation during unrest. Structural studies [3] further indicate that part of the recent seismicity concentrates along pre-existing volcano-tectonic faults, including the La Pietra fault, which has hosted several of the strongest earthquakes during the current crisis. Altogether, these results provide an integrated physical framework that links subsurface structure, seismic processes, and deformation, contributing to the interpretation of unrest at Campi Flegrei and offering insights relevant to seismic hazard assessment and crisis management in densely populated volcanic areas. References 1. De Landro et al. (2025), *Nat. Comm.*, <https://doi.org/10.1038/s41467-025-59821-z> 2. Nazeri et al. (2025), *Nat. Comm. Earth and Env.*, <https://doi.org/10.1038/s43247-025-02808-x> 3. Scotto di Uccio et al. (2024), *Geoph. Res. Lett.*, <https://doi.org/10.1029/2023GL107680>

Recurrent Hydrothermal Pressurization at Campi Flegrei Revealed by Seismic Tomography and Laboratory Rock Physics
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Geophysical signatures of subsurface processes remain ambiguous because they are remotely measured and provide no direct information on rock properties without experimental constraints. Even such experiments are challenged by the heterogeneity of fluid flow in natural systems. We investigate the unrest mechanism of the Campi Flegrei caldera through an integrated analysis of seismic tomography and experimental rock physics on site-relevant core samples from geothermal wellbores. Datasets from two independent unrest episodes, from 1982–1984 and 2011–2025, are compared using seismic tomography, revealing strong similarities in structure and anomalies. Both episodes exhibit a persistent low Vp/Vs anomaly, indicating a recurrent source process involving pore pressure buildup within a confined hydrothermal reservoir. Additionally, waveforms from micro-earthquakes show a sharply impulsive, high-amplitude P-wave followed by rapid decay. The primary difference between the episodes lies in the rate of deformation, suggesting variations in pressurization dynamics rather than changes in the underlying mechanism. To constrain the physical origin of the observed seismic signatures and inflation rates, we conducted rock physics experiments on representative core samples under controlled hydrothermal pressure–temperature conditions. The experiments reproduce the Vp/Vs signatures observed in the field and demonstrate a clear link between fluid pressurization and phase-dependent fluid compressibility (steam transitioning to liquid water) on Vp/Vs, as well as between fluid recharge, microstructural core inflation, and strain rate. Finally, we present preliminary laboratory-generated waveforms from 3D-printed samples designed to replicate pore structure and fluid flow, subjected to rapid changes in effective stress due to fluid pore-pressure venting. This induces cracking, allowing simple gas decompression and liquid fluid flashing to gas to be studied separately, and provides a novel experimental framework to investigate the mechanisms driving unrest hydrothermal-volcanic regions.

ESC-SSA Joint Session: Interpreting Volcanic Unrest and Eruption Data for Effective Crisis Management [Poster]

Poster Session • Thursday 16 April

Conveners: Luca D'Auria, National Center for Volcanology Canary Islands Volcanological Institute (ldauria@iter.es); Stephen McNutt, University of South Florida (smcnutt@usf.edu); Stephanie G. Prejean, U.S. Geological Survey (sprejean@usgs.gov); Mario C. Ruiz, Ecuadoran Geophysical Institute of the National Polytechnic School (mrui@igepn.edu.ec); Margarita Segou, British Geological Survey (msegou@bgs.ac.uk); Anna Tramelli, National Institute of Geophysics and Volcanology (anna.tramelli@ingv.it)

POSTER 102

Source Modelling of Surface Deformation and Seismicity at the Campi Flegrei

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Campi Flegrei, a restless caldera near Naples, Italy, has experienced significant ground uplift, elevated seismicity, and intense gas emissions over the past two decades. The physical source driving the observed deformation and seismicity remains debated, with proposed mechanisms including magmatic intrusion, hydrothermal pressurization, or hybrid processes. Recent seismic tomography images reveal a gas-rich reservoir at depths of ~2–3.5 km, coincident with concentrated seismicity, highlighting the potential dominant role of the shallow hydrothermal system.

In this study, we investigate whether a shallow reservoir can jointly explain both surface deformation and seismicity during the ongoing unrest. We use geodetic observations to constrain time-dependent volume changes of the shallow reservoir, integrating multi-year InSAR data from Sentinel-1 with continuous GPS measurements. To isolate signals associated with distinct deformation sources, we apply variational Bayesian Independent Component Analysis (vICA). The reconstructed reservoir volume-change history is then incorporated into the induced-seismicity framework *Flow2Quake* to compute Coulomb stress changes, which are assumed to modulate seismic activity.

Our results show that volume changes within the shallow reservoir can consistently reproduce both the observed surface deformation and the spatial–temporal patterns of seismicity at Campi Flegrei. These findings place new constraints on the dominant source of unrest and improve our understanding of the coupled hydrothermal–mechanical processes governing the current state of the caldera.

POSTER 103

Surface-wave Relocation and Characterization of the 2024-2025 Dyking Episode Along the Fentale-Dofen Segment of the Ethiopian Rift

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From late-December 2024 to mid-March 2025, a 50-km-long dyke intrusion triggered over 300 earthquakes (magnitude 4 to 5.9) between Fentale and Dofen volcanoes along the Northern Main Ethiopian Rift. Dyke intrusions periodically occur along the Fentale-Dofen magmatic segment and are an expression of ongoing rift extension. Preliminary analyses using Interferometric Synthetic Aperture Radar revealed extensive ground deformation (up to 60 cm), which closely matched the temporal and spatial evolution of phreatic eruptions and other surface manifestations and earthquake locations from global catalogs. While global catalogs are critical for real-time monitoring, the precision of locations in remote and/or sparsely instrumented

regions can be low. In this investigation, we present surface-wave relocation results of the dyking episode that began near Fentale volcano in December 2024. We estimate relative locations using differential travel times measured from regional-to-telesismic distance surface-wave observations of earthquakes reported by the United States Geological Survey. Relative relocations reduce the initial region of diffuse seismicity to a 50-km-long narrow band bounding the strike of surface manifestations and the zone of maximum surface deformation. We demonstrate the precision of surface-wave relocations over incremental time periods, capturing the progression of dyking from seismic onset through seismic migration and caldera subsidence. Results showcase the utility of surface-wave relocations in the characterization of dyking episodes and provide complementary insights into the current understanding of the Fentale-Dofen volcanic plumbing system.

POSTER 104

Spectral Energy Distribution and Multiplet Analysis of Seismicity at Nevado del Ruiz Volcano Near Eruptive Events

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Volcano seismology provides key insights into volcanic processes and is fundamental for assessing activity and forecasting eruptions. Among the most informative parameters are changes in the spectral content of seismic waveforms, which can reflect modifications in the physical properties or dynamics of volcanic systems. These are critical for both hazard assessment and understanding seismic source mechanisms. With the objective of characterizing seismic sources and identifying potential precursory signals at (NRV), Colombia, we analyzed nearly 27,000 volcano-tectonic (VT), long-period (LP), and hybrid events recorded in 2012, when NRV produced two VEI 2 eruptions (May 29 and June 30). A semi-automatic ObsPy-based workflow was implemented to select optimal stations and seismograms based on signal-to-noise ratio and proximity to seismic clusters, followed by waveform preprocessing and extraction of dominant frequency and high-to-low frequency spectral ratios.

We identified 76 families of repeating LP and hybrid events (multiplets) recorded at a minimum of three seismic stations, indicating stable and recurrent seismic sources persisting from days to weeks. Analysis of waveform similarity, recurrence rate, and spectral characteristics constrains their source behavior and resonant properties and enables comparison with variations in frequency content and surface observations such as gas and ash emissions. We examine how the occurrence, persistence, and spectral evolution of these multiplets change in the weeks preceding both eruptive episodes, as these variations may reflect short-term changes in the conduit and magma–hydrothermal system. Notably, the average high-to-low frequency ratio decreases by ~85% in the 24 hours prior to the first eruption, while the number of active multiplet families increases from February to April, marking peak unrest, and exhibits sharp step-like increases coincident with both eruptive episodes. These results demonstrate the value of combined spectral and multiplet analyses for constraining seismic source processes and improving short-term eruption forecasting.

POSTER 105

Challenges and Opportunities for Seismic and Infrasound Monitoring at Ecuadorian Volcanoes

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The Andes mountain range, which crosses Ecuador's mainland, and the Galapagos Islands offer a wide variety of volcanic structures. The first seismic station installed to monitor volcanoes was established in 1976, following signs of reactivation at Cotopaxi. Since its founding in 1983, the Geophysical Institute initiated a volcano monitoring program. In 2006, the seismic networks of Cotopaxi and Tungurahua were upgraded with broadband and infrasound sensors with JICA support. Since 2011, a national program has improved the monitoring capabilities of the remaining volcanoes. Currently, 18 volcanoes in the Andes and 5 in the Galapagos have seismic instruments, all broadband stations that transmit their signals in real time to the Institute's

headquarters. Seven volcanoes have infrasound sensors, some of them micro-barometers. The eruptions of Tungurahua (1999-2016), Guagua Pichincha (1999-2001), Reventador (2002-present), Cotopaxi (2015 and 2022), Sangay, Sierra Negra (2018), Wolf (2015 and 2022), and Fernandina (2018, 2020, and 2024) posed significant challenges for detecting precursors, making accurate assessments of future activity, and informing and advising the community and authorities. New methods are being implemented, such as seismic antennas (Cotopaxi and Fernandina) and infrasound arrays at Sangay, which offer new opportunities to improve our detection capabilities and, ultimately, our understanding of volcanic behavior.

POSTER 106

Exploring Automated P-wave Polarity Picking for Focal Mechanism Determination for Seismicity on the Island of Hawai'i

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The island of Hawai'i hosts continuous seismic activity associated with Kilauea and Mauna Loa volcanoes, their associated rift zones, and earthquakes driven by regional tectonic loading. These events provide valuable constraints on subsurface stress conditions and magmatic processes. Focal mechanism determination traditionally relies on manual P-wave first-motion polarity picking, a labor-intensive process that limits the number of earthquakes that can be analyzed from the thousands recorded annually. We experiment with the method of Uchide (2020), who developed a neural network trained on seismic data from Japan to automatically pick P-wave polarities, and plan on applying it to the seismic records from the Island of Hawai'i since 1986. Machine learning derived polarities will then be used to determine focal mechanisms using the SKHASH algorithm (Hardebeck and Shearer, 2002; Skoumal et al., 2024). Our approach should better elucidate the stress field patterns across the different volcanic and tectonic environments of the Island of Hawai'i.

POSTER 107

Volcanic Tsunami and Its Prediction for Early Warning

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Submarine volcanic eruption disturbs both ocean and atmosphere. These disturbances often trigger two barotropic (depth-averaged) waves: the air-pressure wave (or lamb wave) in the atmosphere and the tsunami in the ocean. Because the atmosphere depth is much higher than the ocean water depth, the air-pressure wave travels faster than the oceanic tsunami. From observational evidence of the 2022 Tonga volcano incident, we found that the air-pressure wave could be scaled to forecast the oceanic tsunami in the near field.

POSTER 108

Interpretation of Shallow Hybrid Earthquakes at Campi Flegrei

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Since late 2022, more than seventy hybrid seismic events have been identified within the seismic records of the monitoring network operating in the Campi Flegrei caldera. Although the majority of these signals are characterized by a low signal-to-noise ratio, a discernible subset was identified, recorded on 6 May 2024, 17 August 2024, and 17 February 2025, which was identifiable by the naked eye. These well-resolved events are consistently located at very shallow depths (shallower than 600 m b.s.l.) beneath the Accademia and Mt. Olibano lava domes, located close to the caldera center, and systematically coincide with tilt transients recorded by the borehole tiltmeter installed at the summit of the Accademia dome.

Our analyses indicate that these hybrid events are most plausibly associated with the circulation and pressurization of hydrothermal fluids within the shallow crust of the Campi Flegrei, a medium already distinguished by markedly low seismic velocities and strong attenuation. In this context, the lava domes emerge not merely as passive volcanic remnants, but as structural and mechanical heterogeneities embedded within the hydrothermal system of the central caldera. Their anomalous elastic properties and density contrasts likely exert a first-order control on the local stress response, modulating fluid–rock interactions and favoring the generation of hybrid seismicity. Together, these observations underscore the pivotal role of shallow hydrothermal processes in shaping the present-day unrest dynamics of the Campi Flegrei caldera.

Evolving Frontiers in Explosion Monitoring and Source Physics

Oral Session • Thursday 16 April • 10:30 AM Local

Conveners: Miles Bodmer, Sandia National Laboratory (mabodme@sandia.gov); Jonas A. Kintner, Los Alamos National Laboratory (jonas.kintner@gmail.com); Colin N. Pennington, Lawrence Livermore National Laboratory (pennington6@llnl.gov); Michelle Scalise, Nevada National Security Sites (scalisme@nv.doe.gov); Daniel Trugman, University of Nevada, Reno (dtrugman@unr.edu)

Posterior Source-type Classification for Explosion Monitoring Using Moment Tensors

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Probabilistic discrimination of explosions, earthquakes and other events is often reduced to a single best fitting moment tensor interpreted with deterministic rules on source type diagrams. We present a posterior based classification method based on moment tensor uncertainty mapped to the source type lunc. Ensembles from waveform estimation are transformed to a uniform source type domain (v,w) to construct empirical probability density functions p(v,w). Canonical source type hypotheses (+ISO, -ISO, DC, +CLVD, -CLVD) are encoded as Gaussian membership kernels in (v,w), calibrated under a uniform prior to provide comparable hypothesis weights. Event classification probabilities P(H_i) are computed by integrating p(v,w) against these kernels, and a residual probability P_{residual} measures posterior mass not explained by the modeled hypotheses. We apply the framework to published regional moment tensor posteriors for underground nuclear tests at the Nevada National Security Site and the DPRK Punggye Ri test site, together with nearby earthquakes and collapse events. Well recorded tests produce tightly focused +ISO dominated probability vectors with small residuals, whereas tectonic earthquakes and collapses map to DC or CLVD dominated vectors and, in some cases, significant -ISO components. Poorly constrained events show broader probability vectors and increased residuals. The approach yields hypothesis probabilities with uncertainty in a form suited for operational explosion monitoring and downstream decision pipelines wherever source type posteriors are available.

Identifying Sensor Types and Models Using a Deep Learning Model

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Proper network station coverage is vital to the task of detecting and locating seismic events as without good azimuthal coverage and close stations detect-

ing and locating small magnitude events becomes far more difficult. There exist many stations across the United States, and beyond which would be useful for improving monitoring capabilities if we could incorporate them into our monitoring networks. However, there exists issues related to incomplete, incorrect, or lacking metadata for sets of these stations meaning that incorporating them into our seismic processing pipelines may lead to issues of ingesting incorrect data that could worsen our monitoring capabilities. Here, we seek to create a deep learning classification model that is designed to ingest waveform data products generated from raw waveform data collected by a target station to determine both the sensor type and instrument model of said station. We first tested four different image classification model architectures to determine which model architecture was best suited for our task. Although, most of the architectures were able to achieve good results on the simplified task of classifying only the sensor type of a station (classifying stations as being either an accelerometer, broadband, or short-period sensor). We found that the EfficientNet architectures provided the best performance with the lowest associated computational cost. We are now expanding our training datasets to incorporate waveform data collected from a set of 20 temporary and permanent networks from across the United States to expand upon our developed model to now also classify the instrument model as well.

Seismo-acoustic Analysis of the 22 September 2023 Pingtung, Taiwan Chemical Explosion From Near Source Records

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This study analyzes infrasound and near source ground motions data from the Taiwan seismic networks to confirm the location, time, and yield of the chemical explosion that occurred in Pingtung on September 22, 2023 and to track and verify its subsequent explosions. The study demonstrates that the Taiwan earthquake monitoring data is valuable for reconstructing the Pingtung explosion sequence. The collected result provides insights into the timeline of the event and can serve as forensic reference for the potential controversy. To achieve the goal of reporting and rapid response to large explosion events in Taiwan, this study recommends a simple upgrade the earthquake network. By adding a small number of infrasound stations and optimizing the data processing workflow, the seismic network may provide real-time, accurate information on future catastrophic explosions, supporting disaster relief efforts and providing rapid responses to public needs.

Aircraft Detection with Surface-draped Fiber Optic Cable

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Aircraft generate sound waves that travel long distances and can be recorded by both optical fiber sensing technologies (e.g., distributed acoustic sensing, DAS) and by surface-deployed seismographs. These signals permit the remote and independent monitoring of flight activity in areas of limited radar coverage. Recent studies have utilized underground telecommunications fiber (Gurevich et al., 2025) and surface-deployed snow-sited seismometers (Seppi et al., 2025). We demonstrate the ability to record aircraft signals with surface-draped fiber. This method is useful for rapid deployment in environments not suitable for buried fiber or other more demanding deployment scenarios. During the OSIRIS-REx field campaign, a T-shaped surface-draped fiber was deployed at an airfield in Eureka, Nevada. Three days of DAS recordings with a gauge length of 5 m reveal aircraft signatures in the frequency range of 30 to 100 Hz. Observations of several single-engine aircraft maneuvers were logged during the field campaign. Spectrogram features with potential signatures of distant aircraft activity were classified using a recently published spectral comb catalog of aircraft signals derived from seismic network observations (Seppi et al., 2025). This spectral-based classification was cross-referenced with aircraft types listed in historical radar flight tracking data. Our work demonstrates a novel method for detecting aircraft using surface-draped fiber that is useful for signal detection in austere environments and for identifying and filtering aircraft noise from other datasets.

Sparse Seismo-acoustic Data Reveals the Timing and Size of the Accurate Energetic Systems Explosion

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On October 10, 2025 an explosion occurred at a facility operated by Accurate Energetic Systems (AES) near Bucksnot, Tennessee. The incident resulted in 16 fatalities and creating a debris field spanning several square kilometers. While investigators identified the likely origin, they relied on a facility inventory to estimate explosive yield. Our study analyzed seismic and acoustic signatures recorded up to hundreds kilometers away to determine timing and yield. Using nine physics-based models with varying assumptions about confinement, environment, and propagation, we conclude that the event was effectively a single, aboveground explosion at 2025-10-10 12:47:50.8 ±0.1s with a yield equivalent to 11.8 (+4.6, -9.6) tons of Trinitrotoluene (TNT). Infrasound U-wave observations support a yield exceeding several tons. Our estimates align with Bureau of Alcohol, Tobacco, Firearms and Explosives storage inventory reports of 11-13 tons. This multi-method approach validates the timing and size of the explosion, and provides a comprehensive forensic assessment beyond conventional investigation techniques.

Characterizing Anthropogenic Signals at Rellis Campus Explosion Site Using Nodal Arrays

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Repeated controlled-source experiments provide a tool to investigate subsurface structures and wave propagation characteristics. Explosions in urban settings are rare, but at the RELIS campus of the Texas A&M system, the explosive training classes from the Police Academy provide repeated explosion events, producing an ideal dataset for anthropogenic source characterization with ground truth. Here, we deploy a small nodal array with IGU 3-C smart-solo seismic stations in fall 2025, with the goal to characterize and investigate ground motion using automatic cataloging and spectrogram-based clustering. Near the explosion site (within 0.5 km), six short-term stations were deployed for one month in September, and seven long-term stations were deployed for three months (September to December). At another field site (approximately 4.5 km from the explosion site), a linear array of 8 short-term stations was deployed in September.

The workflow begins with automated data preprocessing to identify time windows with signals and noise. Short-term and long-term arrival triggers (STA/LTA) were applied to identify and confirm individual events. Preliminary analysis identifies different types of events, including impulsive events during training classes, and repeating harmonic signals with long durations and low amplitudes, with currently unknown sources. With event times automatically identified, these events were then processed as time-frequency spectrograms to help understand the intensity of individual events. The combined approach of using automatic cataloging, STA/LTA triggering, and spectrograms creates an efficient network for filtering anthropogenic signals and assessing ground motion characteristics. The current results are preliminary; as more testing occurs and data is added, the visualization of events and event picking becomes more accurate.

The Source Physics Experiment on Seismic Waves Generated by Explosions: Results So Far and Future Plans

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The NNSA DNN R&D sponsored Source Physics Experiment (SPE) is a large, multi-institutional (LANL, LLNL, SNL, NNSS and UNR) effort to improve our understanding of how explosions generate seismic waves, particularly shear waves, to improve nuclear monitoring capabilities. The SPE includes a series of chemical explosions in southern Nevada in three Phases, each in a different borehole in contrasting geologies: SPE Phase I (2010-2016) was a saturated granite site; the Phase II (2016-2020) in Dry Alluvium Geology (DAG), and the current Phase III – Rock Valley Direct Comparison (RV/DC) in dolomite. For each Phase the explosions vary in size and depth and are recorded on a common network, allowing ratios between events to be formed, canceling path and site effects and illuminating near source effects. Data for the first two Phases are available at EarthScope.

Near-field chemical SPE and historic nuclear data show high-frequency tangential motion is 20-30% of radial amplitudes, although the mechanisms that cause this vary with emplacement media. Within a few kilometers, these amplitudes are comparable across the 3 components, and the buried and surface explosions have comparable P/S amplitude ratios - both effects require rapid scattering and conversion to explain. The spectral ratios formed between small explosions used as Green's functions and larger explosions are not well matched by existing explosion models, and the dry alluvium geology produces smaller amplitudes and appears deficient in high-frequency energy relative to explosions in granite. This shows the importance of material effects on explosive wave generation. In 2025 we drilled and instrumented a 2.1 km deep corehole and are now studying the ongoing shallow and deep micro-seismicity. We are examining factors such as absolute depth, scale depth, and material effects on shear wave generation, P/S and low/high frequency amplitude discrimination performance, and correlation behavior. These results are being used to develop a new explosion spectral model and in preparation for a future direct comparison of shallow earthquakes with chemical explosions.

Physical Mechanisms of Underground Explosion-generated Shear Waves

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The Source Physics Experiments (SPE) are a series of controlled underground chemical explosions conducted at the Nevada National Security Site to investigate explosion source physics and advance seismic monitoring capabilities. The program aims to improve the detection, discrimination, and yield estimation of underground explosion events. The third phase of SPE, known as the Rock Valley Direct Comparison (RV/DC) experiment, will involve two chemical explosions emplaced near the hypocenter of a shallow earthquake sequence that occurred in 1993. This unique configuration enables a direct comparison between seismic wave generation from explosions and natural earthquakes. The goal is to develop improved seismic source models and gain deeper insights into the mechanisms responsible for explosion-generated shear waves.

In this study, we demonstrate how different physical mechanisms generate shear waves during underground explosions using advanced numerical simulations. We utilize the Hybrid Optimized Software Suite (HOSS), a cutting-edge computational framework developed at Los Alamos National Laboratory. HOSS simulates shock wave propagation, large material deformation, damage evolution, fracturing, and fragmentation in geological media, making it well-suited for modeling the strongly nonlinear near-source seismic response to underground explosions. Our results indicate that the breakdown

of spherical symmetry in the system plays a central role in generating near-field shear waves.

Simulation of P/S Amplitude Ratio Discriminant at the Rock Valley, Nevada

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Analysis of seismic records of local earthquakes and a series of underground chemical explosions conducted during the Source Physics Experiment (SPE) at the Nevada National Security Site (NNSS) have shown that at local distances (<200 km) the effectiveness of the single-station seismic P/S amplitude ratio source discriminant is reduced. The network averaging can improve the discriminant at local distances, but can be problematic if only a sparse network of stations is available. The current SPE Phase III, the Rock Valley Direct Comparison (RV/DC) experiment, will compare signatures of a shallow chemical explosion and small earthquakes located at very close hypocentral proximity to the explosion.

We used high-performance computing to simulate the RV/DC experiment by computing ground motion on the local RV/DC seismic network for a pair of collocated isotropic and double-couple point sources with properties similar to those of the sources that will be analyzed during the experiment, including epicenter, depth, focal mechanism, and emplacement conditions. We first simulated recorded ground motion from five local earthquakes to assess the performance of the Rock Valley Seismic Velocity model (SVMv1.0) in modeling local wave propagation effects. The selected earthquakes are part of an earthquake cluster that is being investigated as part of the RV/DC experiment. Using synthetic waveforms computed on a dense grid of stations for the collocated explosion source and earthquake source, we then investigated the discrimination performance of the P/S ratio, its spatial variation, and its correlation with the shallow geology. We found that the shallow wave scattering deforms the radiation pattern and amplitude of source generated P and S waves for explosion and earthquake sources, thus reducing the efficiency of the P/S discriminant. Our simulations suggest that P/S performs well along wave paths and areas with simple geology. Also, good azimuthal station coverage and the network averaging can improve the performance of the P/S discriminant at local distances.

Effects of Lateral Heterogeneity, Shallow Scattering, and Variable Crustal Thickness on High-frequency Explosion Waveforms

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Despite the routine use of crustal body waves for distinguishing explosions from naturally occurring seismicity, our understanding of how such crustal phases propagate remains incomplete. For example, why do the most reliable crustal amplitude signatures emerge only at high frequencies? Does the explosion source itself give rise to these distinctive explosion signatures, or merely the shallow depth of explosions compared to naturally occurring events? To help answer such questions, we combine several recent lines of work, including forward and adjoint modeling at practical monitoring frequencies (>1 Hz) and distances (>100 km), stochastic heterogeneity, and 3D crustal models. The results reveal physical processes important to explosion monitoring but not accounted for in conventional amplitude ratio discriminants, including non-ray spatial sensitivity, waveguide leakiness, and strong but highly-erratic scattering and P-to-S conversion.

Evolving Frontiers in Explosion Monitoring and Source Physics [Poster]

Poster Session • Thursday 16 April

Conveners: Miles Bodmer, Sandia National Laboratory (mabodme@sandia.gov); Jonas A. Kintner, Los Alamos National Laboratory (jonas.kintner@gmail.com); Colin

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POSTER 43
DL-G25: A Deep Learning Ground-to-space Uncertainty Model for Infrasound Propagation
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Infrasound, low frequency sound less than 20 Hz, is generated by a variety of natural and anthropogenic sources (chemical and nuclear explosions, volcanic eruptions, earthquakes, etc.). Propagation modeling allows us to understand the path an infrasound wave takes through the atmosphere, and is important for both predicting and understanding signal arrivals. Infrasound propagation is driven by effective sound speed, which is a function of wind and temperature. Therefore, atmospheric specification profiles and corresponding uncertainty are essential for accurate infrasound propagation modeling. Current atmospheric uncertainty models rely on large datasets and are computationally expensive. A deep learning solution promises portability and speed. Here we present a new deep learning model, a conditional Generative Adversarial Network, for atmospheric specification uncertainty analysis for infrasound propagation modeling. We show comparisons to the current state-of-the-art, quantify increase in accuracy and speed, and show applications for explosion monitoring.

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POSTER 44
Source-type Discrimination of Local-distance Seismic Events in the Utah Region Using Machine Learning Differential Seismic Phase Detection Probabilities
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Effective event discrimination is essential for seismic monitoring. While established methods exist for distinguishing events at regional and teleseismic distances (≥ 200 km), there is an increasing need for reliable discriminants for low-yield events that can only be detected at local distances (< 200 km). While earthquakes, which mainly consist of shear slip, generate strong S waves, explosions, as mostly isotropic sources, predominantly produce P waves. These fundamental differences in source excitation provide the basis for utilizing P/S ratios to discriminate between earthquakes and explosions. In addition to the traditional phase amplitude ratio method, a recent study by Duan *et al.* (2025) demonstrated that utilizing the differential probabilities of P and S phases—derived from a machine learning detection algorithm—holds promise for revealing information about source types. In this study, we assess the capability of differential detection probabilities obtained from the pre-trained PhaseNet model (Zhu *et al.*, 2019) for discriminating between earthquakes and explosions recorded at local distances. We consider a recently developed catalog of $\sim 10,000$ seismic events that occurred in the Utah region during 2012–2023 and were recorded by stations at distances ranging from 10 to 300 km (Koper *et al.*, 2024). We evaluate the performance of the phase probability approach in separating the earthquake population from the explosion group, and compare it with traditional phase ratio approaches.

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POSTER 45
Uncertainty Quantification of Two Recent Chemical Explosion Experiments Using Time Variable Moment Tensor Seismic Source Inversions
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Estimating the characteristics of a seismic source can be challenging; often there are both algorithmic and practical constraints and considerations that need to be accounted for to reliably represent a source. One of the most common source characterization methods involves inverting seismic data for a moment tensor representation, a set of scalar force couples describing the source behavior at the focus of a seismic event using an assumed source time function. However, for such representations, a complex source, such as an explosion followed by slip on preexisting joints, could be overly simplified in this method where only one moment tensor representation for the entire time is solved for, and instead mischaracterized as an earthquake source. Time variable moment tensor (TVMT) inversions can aid in separating out the various components of a complex source, as a representation of the evolving moment tensor in time is solved for instead of a single moment tensor. However, just like in a traditional time-invariant moment tensor inversion, there are uncertainties associated with the a priori information used in the TVMT inversion. The frequency content of the source can be higher than what a full waveform simulation could feasibly model, and varying frequency bands used to filter the data can highlight different aspects of the source, depending on the frequency content of any one mechanism in time. Additionally, station coverage and azimuthal gaps can influence the result of both a time-invariant and time-variable moment tensor inversion. To estimate the impact of each of these effects, we compare TVMT inversion results from the Low Yield Nuclear Monitoring (LYNM) Blue Canyon Dome Phase II and PE1-A experiments. We vary the frequency bands and station geometries used in the inversion of these nine events to quantify the effect that frequency and station geometry uncertainties have on characterizing the source mechanism and estimating the yield of low-yield chemical explosions using TVMT inversions.

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POSTER 46
Signatures of the Damage Zone of Underground Explosions
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When an underground explosion occurs, some of the released energy goes into damaging the surrounding rock. The nature of the damage zone depends on the shot yield, the coupling between the explosive materials and the adjacent rock, the rock properties, and the ambient stress field including both the overburden and tectonic stress. The damage zone is expected to evolve following the shot at a range of time scales as the cavity produced by the shot collapses and fractures heal. Understanding the damage zone is important to interpreting and modeling the formation and propagation of seismic waves in both the near field and far field. Without extensive excavation or core drilling, the extent and properties of the damage zone are often not well known. Seismic travel times are only marginally affected by rock damage. However, scattering properties and nonlinear behavior of fractured rock may be detectable from surface seismic observations. Using continuous seismic recordings before and after a shallow subsurface chemical explosion at the Nevada National Security Site, I use auto correlations, spectral ratios, and both traditional and machine learning data analysis techniques to find evidence of the damage zone following the shot. There is evidence for enhanced reflectors near the shot depth that corresponds in time with the period following the shot. Nonlinear effects are so far inconclusive.

POSTER 47
Monitoring Ongoing Seismicity in the Southern Nevada National Security Site: Toward Understanding the Shallow Structure of the Rock Valley Fault Zone
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The Source Physics Experiment (SPE) Phase III: Rock Valley Direct Comparison (RV/DC) project at the Nevada National Security Site (NNSS) aims to differentiate between natural earthquakes and explosive sources at regional and local scales. This is achieved by detonating conventional explosives near the hypocenter of the 1993 Mw 3.8 Rock Valley earthquake (~ 2 km depth). Monitoring seismicity in the southern NNSS surrounding Rock Valley has been ongoing since the late 1970s. Portable instruments deployed during the 1993 sequence confirmed shallow event depths. Since 2012, additional telemetered instrumentation has augmented the central Rock Valley seismic network. Recent specialized deployments include a 48-station nodal array, continuously operational since early 2022, and an 8-element, 3-component geophone string, approximately 100 m in length at about 2 km depth, deployed in summer of 2025. The Nevada Seismological Laboratory's earthquake catalog contains approximately 32K earthquakes recorded since 2000. While these events span the entire Rock Valley Fault Zone (RVFZ), the southern NNSS catalog is predominantly composed of aftershocks from the 1992 Little Skull Mountain earthquake. We are focused on developing high-quality locations to resolve event depths and image the shallow fault structure, particularly near the RV/DC testbed. The results will inform refinements to the RV/DC Geologic Framework Model, which is essential for the project's waveform modeling efforts. Significant challenges involve testing and modifying velocity models to accurately represent the complex geologic structure of the RVFZ and leveraging the new data from special deployments. Multi-statistical analysis of the locations suggests that existing velocity models overestimate the shallow velocity structure, a finding potentially corroborated by observations from the newly installed downhole geophones.

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POSTER 48
Decoding Underground Explosions with Time-domain Seismic Source Functions
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Seismic signals generated by explosions vary due to source design and emplacement conditions. We investigate these effects by isolating the seismic source signatures from underground chemical explosions conducted during the Source Physics Experiment (SPE) Phase II Dry Alluvium Geology (DAG) experiments, as well as from near-field simulations for the SPE Phase III Rock Valley Direct Comparison (RV/DC) experiments. We derive absolute and relative Source-Time Functions (STFs) which represent the seismic source time-history of explosions. These temporal signatures are equivalent to source spectral amplitude in the frequency domain, but preserve phase information, creating new insights and enhanced resolution in the time domain. We validate observations by comparing the STFs to analytical explosion source models, to demonstrate that varying emplacement conditions, high scaled source depth, and experimental design require additional considerations to reconcile with the observed source time histories. Furthermore, our solutions from RV/DC simulations are combined with regional seismic propagation and noise models to evaluate detection capability, informing future decisions for experimental design and execution. This work provides new insight into chemical explosion source processes of the SPE experiments and enables a computationally efficient and scalable workflow for rapid spectral amplitude predictions at local to regional distances.

POSTER 49
Source Characterization of Nuclear Tests From Reloaded Tunnels in Degelen Mountain From Digitalized Regional Short-period Seismic Data
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We are utilizing digitalized regional legacy analog seismograms from the 1960's – 1980's of nuclear explosion tests in the Semipalatinsk Test Site (STS) to better understand the generation and characterization of nuclear explosion waveforms. Most nuclear testing was conducted during the era of analog seismic recording, thus there are few digitally recorded waveforms available for research, particularly for unique geological conditions. Accurate digitalization of these legacy analog records (seismograms) recorded in Kazakhstan and the Kyrgyz Republic into digital waveforms provide us with a unique opportunity to study real nuclear explosions with modern seismic analysis tools. Within the Semipalatinsk Test Site (STS), nuclear tests conducted in tunnels in Degelen Mountain were often done in pairs, with multiple detonations occurring within the same tunnel, often a few years apart. The result is that emplacement conditions and surrounding rock rheology of subsequent tests are likely quite different. The first detonation occurs in solid unfractured granite, while the later tests occur in the fractured rock zone of the first. This study utilizes short-period digitalized waveforms to characterize differences in the seismic waveforms between both tests using multiple approaches. Relative to the Degelen test area, most stations are at regional distances to the south in the republics of Kazakhstan's and Kyrgyzstan's territories. We specifically investigate differences in phase amplitudes, overall frequency content, and yield estimation between several pairs of initial and reload events.

POSTER 50
Recovery and Digitalization of Legacy Semipalatinsk Test Site Nuclear Explosion Seismograms From Kazakhstan and the Kyrgyz Republic
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The Institute of Seismology of the National Academy of Sciences of the Kyrgyz Republic, the National Scientific Center for Seismological Observations and Research of the Ministry of Emergency Situations of the Republic of Kazakhstan, and Michigan State University are recovering, scanning, and digitalizing historic analog seismograms of Soviet Nuclear Explosions that took place at the Semipalatinsk Test Site between the 1960s and 1980s. We specifically focus on explosions that occurred in Degelen Mountain. Thousands of high-quality paper analog seismograms for these tests are still retained within the archives of seismic networks within central Asia. We are indexing these irreplaceable legacy analog seismograms to preserve them against loss for future generations. We are also generating high resolution scans and using them to generate high quality, digitalized signals that can be analyzed using modern seismic analysis tools. Our initial efforts focused on long period seismograms but we have now expanded into both short and long-period channels enabling us to capture additional frequency content from these, from 20 seconds up to 5 Hz. Along with the seismograms, we have recovered the original station calibrations, instrument response, and metadata for each station. We have developed a method to generate dataless SEED and XML files for use with the newly digitized data that correctly describes channel response for effective recovery of ground motion at the station site. Most seismograms are from short period instruments, and when combined with the correct station calibration information, the digitalization process accurately recovers ground motion signals to at least 5 Hz. In recent efforts, we have also implemented software that can bridge small data gaps with neutral waveform, which reduces artifacts when removing instrument responses, filtering, and conducting other signal analysis procedures. The resulting digital waveforms are of sufficiently high quality to be usable for quantitative research (see Likhovod et al. at this conference).

POSTER 51
Low-magnitude Seismic Source Inversions for the Rock Valley, Nevada
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Characterizing small earthquakes is important for understanding the seismicity of the Rock Valley located within the Nevada National Security Site, and ultimately, for helping improve low-yield explosion monitoring. Accurate characterization of Rock Valley events smaller than Mw 3 has been challenging, however, on account of relatively sparse station distributions, unusually shallow seismicity, signal quality limitations, and Earth model fidelity issues. To understand which small events can be reliably characterized, we inverted 21 earthquakes using broadband seismic waveforms and corresponding wave-equation synthetics. This work differs from previous Rock Valley inversions primarily through use of wider passbands, encompassing body and surface waves, and through more detailed misfit space exploration. Misfit surface comparisons involving midnight noise appear particularly helpful for giving a sense of the reliability of the inverted solutions, revealing contrasts between noise-driven and signal-driven misfit patterns.

POSTER 52
Modelling Observed Backazimuth and Slowness Deviations From Local Earthquakes at a Small Aperture Broadband Seismic Array
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A ten-element, 300m aperture broadband seismic array [PWGYJ] has been installed and running for 3 years on the Eastern edge of the Pahute Mesa, at the Nevada National Security Site. We perform frequency-wavenumber analysis on the incoming P-wave onsets for local earthquakes [source-station distances of 20 - 100 km and range of back-azimuths] listed in the ANSS Comprehensive Earthquake Catalog recorded by the PWGYJ seismic array. Large systematic variations are observed for both the measured backazimuth [up to 100 Deg.] and horizontal slowness [up to 0.28 s/km].

Previous observations (e.g., Hao and Zheng, 2010) of backazimuthal and slowness deviations at large seismic arrays are commonly attributed to lateral velocity variations in the mantle or crustal effects beneath the recording site. The PWGYJ array is located close to the edge of the Silent Canyon Caldera Complex, a buried, multiple collapse caldera with a low-density basin fill. The shape and extent of the complex is still debated. We use SW4 (Peterson et al., 2023) to model waveforms from a range of distances and backazimuths through a variety of caldera models to the PWGYJ array. The simulated waveforms can recreate the observed trends in both backazimuthal and slowness deviations when a more complex caldera model, derived from inverted gravity data (McKee et al., 2001), is used. Accurate backazimuth estimates will likely be required to constrain event locations for low magnitude events recorded across sparse station networks. This study demonstrates the importance of understanding the local velocity structure beneath and close to small-aperture seismic arrays, such that signal backazimuth and slowness corrections can be estimated.

POSTER 53
Detection Capability Analysis for the RV/DC Experiment Design
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The Rock Valley Direct Comparison Experiment (RV/DC) aims to compare seismic signals from a controlled chemical explosion with those from a nearby earthquake at nearly the same location. Achieving this scientific goal requires drilling and detonating the explosive at the location of earthquakes at roughly 2 km of depth. This requirement significantly constrains the experimental design and the specific choices made will directly impact the achievement of the scientific goals of the RV/DC experiment. To understand the potential of each design option, we conduct an empirical evaluation of seismic detection capability at the Nevada National Security Site (formerly the Nevada Test Site) by analyzing seismic event signal-to-noise ratios (SNR) across the existing station network. We fit observed seismic arrival data to a physics-based attenuation model that predicts SNR as a function of distance, frequency band, and magnitude and we validate it against historical observations across multiple frequency bands. We extrapolate detection thresholds to estimate how various explosion designs would perform at different distances and frequency bands.

These estimates enable quantitative assessment of experimental design trade-offs, helping identify optimal designs and placement strategies that balance drilling feasibility with scientific data quality requirements.

POSTER 54
Discriminating Between Natural Earthquakes, Induced Events, and Explosions in West Texas
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West Texas has experienced a dramatic increase in seismicity over the past decade, largely attributed to oil and gas production and wastewater disposal. This study leverages a unique seismic dataset from the region comparing natural earthquakes, induced earthquakes, hydraulic fracturing events, and chemical explosions (≤ 2000 lbs) to develop and validate a novel stress-based discriminant for distinguishing between natural and anthropogenic seismic sources. Stress drop and apparent stress are fundamental source parameters that characterize rupture dynamics and radiated energy. We employ 2D propagation models to isolate source effects from path and site contributions, and estimate these parameters across our dataset. By exploring variations in source spectra, stress drop, and apparent stress, we aim to identify source characteristics that can distinguish between natural and induced earthquakes, explosions, and hydraulic fracturing events. This research provides new insights into source processes in tectonically complex, hydrocarbon-producing regions and explores new seismic source discriminants.

POSTER 55
Quantifying Uncertainty in Regional-scale Seismic Moment Tensors
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Distinguishing earthquakes from potential explosions is a critical element of underground nuclear explosion monitoring. A common tool used to characterize seismic sources is moment tensor analysis, which can be used to quantify how much of a source's energy is isotropic. However, the task of determining whether an event of interest is likely an explosion that should be studied further is complicated by many sources of uncertainty. Understanding and quantifying these uncertainties are key to this characterization task. In this work, we investigate several of these sources of uncertainty, including imperfect knowledge of Earth structure between the source and receivers, signal to noise ratios, and station geometry. Additionally, we evaluate the data and methods used in the moment tensor analysis, such as using only P-first motions, P- and/or S- amplitude picks, up to full waveform inversions. We will present quantitative results of a synthetic study of the uncertainty in the recovery of seismic moment tensors by including sources of error from Earth models, noise, and the techniques used to solve for the moment tensors. Although this is a synthetic study, we base our analyses on two different well-characterized regions in the western U.S., one centered over Utah and other over Nevada. We evaluate how well 1-D Earth models, both global and regional, which are often used in source inversions, compare to results from 3-D stochastic Earth models based on actual Earth structure in these two regions. The effects of realistic seismic noise are evaluated by using noise models based on actual earthquakes recorded at regional seismic stations within their respective model regions. We will also compare and contrast results from the two regions to evaluate which aspects of the uncertainty analysis may be extended outside specific study areas.

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POSTER 56
Reevaluating the 1993 Rock Valley Sequence: How Can New Information Help Constrain Historic Event Locations?
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The Rock Valley Direct Comparison (RV/DC) Experiment is a novel venture that seeks to make the first-ever direct comparison of co-located seismic earthquake and chemical explosion sources. For this purpose, a sequence of shallow earthquakes (< 3 km depth) that occurred in 1993 in the Rock Valley Fault Zone on the Nevada National Security Site has been targeted. The project aims to drill to the estimated hypocentral location of one of these earthquakes and conduct a chemical explosion that will be recorded at common sensors to minimize path and site effects that can muddle source effects. At the onset of this endeavor, a detailed relocation analysis of the 1993 sequence was performed, incorporating phase arrival times from eight analysts, nine different 1D velocity models and two 3D models, and four different location methods. Depths were evaluated from the location methods, waveform modeling, moment tensor analysis, and P-to-S arrival times at a station located directly on top of the event sequence.

The initial relocation report focused solely on the largest events in the 1993 sequence. However, the region continues to be seismically active. As part of the project, seismic instrumentation in the region has been ramped up, including reoccupation of historic seismic station sites, additions to the existing regional network, and a large-N style array. Additionally, a corehole (CH) drilled in 2025 near the target location provided direct geophysical measurements at depth, and instrumentation in the CH provided additional estimates of seismic velocities in the upper 2 km of the crust. With the availability of new information from the CH and ongoing, well-recorded seismicity, we revisit the event locations of the 1993 sequence and nearby (within 5 km) modern seismicity with a similar workflow encompassing multiple pick sets, velocity models, location algorithms, and analysts. The goal of this effort is to place new constraints on the historic earthquake locations, further characterize the fault zone seismicity, and provide additional well-characterized direct comparison events.

POSTER 57
Waveform Tomography for Improved 3D Wavespeed Models and Moment Tensors for Nuclear Explosion Monitoring
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Moment tensor (MT) inversion is an important tool for seismic monitoring, providing characterization of predominately double couple earthquakes, isotropic explosions and more exotic and/or mixed sources. However, MT inversion is challenged by our limited knowledge of detailed three-dimensional (3D) seismic wavespeed structure needed to compute synthetic seismograms represented path-specific propagation. This problem is especially acute for reliable characterization of small magnitude events at regional distances (< 2000 km) which require inversion of shorter period complete waveforms (minimum periods < 20 s). Full waveform inversion (FWI) tomography is a method to infer 3D seismic models that by design improve waveform fits. FWI employs a multiscale approach starting with long-period waveforms to infer large-scale structure and reduces the minimum period to iteratively infer smaller-scale features. For regional-scale domains FWI can produce models of crustal and uppermost mantle structure that accurately reproduce waveforms for distances to 2000 km and periods as low as 10-15 seconds. This study will report on FWI tomography models for various regions including those with past underground nuclear explosions. These include the Middle East and Southwest Asia, Northwestern China and Korean Peninsula and East Asia. We will present progress on the development and validation of these models. We will also show how reciprocity can be used to compute the fully 3D waveform response at regional stations from any seismic event within a spotlight source region. This can be used to pre-compute the Greens functions and make them available for on-demand analyses in operational environments.

POSTER 58
Simulating Locally Recorded Earthquakes to Evaluate the Rock Valley Geologic Framework Model
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The Rock Valley Direct Comparison (RV/DC) Experiment targets a series of shallow earthquakes in the Rock Valley Fault Zone on the Nevada National Security Site (NNSS). The experiment aims at improving seismic source discrimination techniques by directly comparing waveforms generated during collocated chemical explosions and shallow earthquakes recorded by a local seismic network. To support the numerical modeling of the experiment, a Seismic Velocity Model (SVM) derived from Geologic Framework Model (GFM) of the Rock Valley area was constructed by combining existing geologic, borehole, and geophysical data in a 3D representation of the subsurface. The GFM will continue to be updated and improved over the course of the project as additional data becomes available. The most recent update to the Rock Valley GFM integrates new gravity data, as well as geophysical logs from a corehole drilled in 2025. We simulate well-recorded earthquakes located within the area covered by the RV/DC SVM to assess the model performance in reproducing the recorded waveforms. Simulations using two iterations of the RV/DC SVM are used to characterize the fit to ground truth data, while highlighting potential improvements to the model which will be targeted in future updates.

POSTER 59
Signal Separation and Enhancement in the Stockwell Transform Domain and Application to Local and Regional Seismic Data
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Because of the nonstationary character and frequency dependence of seismic recordings, the signals and noise that make up those recordings are effectively dealt with in the time-frequency domain. Popular tools used to transform time series into time-frequency domains include short-time Fourier transforms (STFTs), continuous wavelet transforms (CWTs), and Stockwell transforms (STs, Stockwell et al. 1996). The ST contains some elements of both STFT and CWT; and compared with the others, the power of ST lies in the frequency-dependent resolution it provides. We implemented polarization filtering and non-linear thresholding techniques in the ST domain. We show that the combined linearity and directionality parameters exploited in the polarization filter algorithm successfully enhance linearly polarized *P* and *S* signals and suppress elliptically polarized *Rg* waves. Conversely, the ellipticity parameter obtained from the analysis of complex polarization properties can be used to suppress *P* and *S* signals and enhance *Rg* waves. However, polarization filtering also enhances polarized noise; and, for that reason, it results in low signal-to-noise ratios (SNRs) in some cases. We demonstrate that polarized noise that persists after polarization filtering can be successfully removed with ST thresholding, improving the SNR further and allowing an effective exploitation of the different phases.

POSTER 60
Waveform-based Machine Learning Detection and Characterization of Small Events
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Due to the inherently low amplitudes of signals generated by low-magnitude events, they can be difficult to detect and build in the absence of a dedicated local network of stations. We developed a machine learning (ML) detection algorithm for local distances that uses 3-component recordings for the detection and classification of possible events. Based on features extracted from the 3-component data, each detection is classified either as noise or a signal from an event that occurred within one of the following 6 distance ranges: 0-30 km, 30-60 km, 60-90 km, 90-120 km, 120-150 km or > 150 km. The main advantage of the approach is that both detection and classification can be achieved using a single 3-component station. A preliminary model achieves a recall, accuracy, and precision of ~71%, ~78%, and ~76%, respectively. The reported values for the recall and precision represent the average over the 7 classes. These parameters are better for some classes than others. Most misclassifications are noise that are misclassified as events from distances >150 km and vice versa.

Fault Networks and Seismic Hazard in the Nevada-California Borderland

Oral Session • Wednesday 15 April • 10:30 AM Local
Conveners: Christopher B. DuRoss, U.S. Geological Survey (cduross@usgs.gov); Richard D. Koehler, Nevada Bureau of Mines and Geology (rkoehler@unr.edu); Henry B. Mason, University of Nevada, Reno (hbmason@unr.edu); Ian K. D. Pierce, Pacific Gas & Electric (ipiercegeology@gmail.com); Christie D. Rowe, Nevada Seismological Laboratory (rowec@unr.edu)

Characterizing Walker Lane Aftershock Geometry and Productivity with a Novel High-resolution Catalog of the 2020 Mw 6.5 Monte Cristo Earthquake

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High-resolution, near-source earthquake recordings can provide critical information about the earthquake process that may be obscured at further distances. Such data is particularly valuable in the Walker Lane, allowing us to observe otherwise imperceptible seismicity patterns and aftershock behavior characteristic of this complex transitional tectonic zone. In 2020, scientists from the Nevada National Security Sites (NNSS) deployed a nodal array at ground zero of the M_w 6.5, Monte Cristo Range earthquake, the largest earthquake to occur in the Central Walker Lane this century. From this 3-month deployment and supplemental station coverage by the Nevada Seismological Laboratory (NSL), we use a machine learning-driven workflow to compile a new earthquake catalog on the order of hundreds of thousands of events, over 20-fold larger than the existing published catalog. [DT1] The catalog, which features event location and magnitude estimates provides a uniquely detailed snapshot of a vigorous aftershock sequence that can enhance our understanding of earthquake dynamics and triggering within the Walker Lane and beyond.

Evaluation of Complex Transtensional Fault Systems Distributed Between Lake Almanor and Madeline, Northeastern California

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The northern Walker Lane accommodates ~4-5 mm/yr of geodetically measured dextral shear through complex transtensional faulting distributed across an 80-120 km wide zone spanning the California-Nevada border. Near Reno, high quality paleoseismic data exists for well-defined dextral faults (e.g. Mohawk Valley, Honey Lake, Warm Springs). However, farther north, a series of faults distributed across the width of the northern Walker Lane from the vicinity of Lake Almanor to Madeline have received limited paleoseismic research attention, contributing towards uncertainties in seismic hazard characterization. The 2023 update to the USGS National Seismic Hazards Model (NSHM) included a system of faults near Lake Almanor (Keddie Ridge, Walker Spring, Skinner Flat and Almanor faults), a generalized fault zone near Susanville (Susanville-Eagle Lakes fault), and the Likely fault near Madeline to the northeast. Recent earthquakes including a M4.7 near Susanville (Dec. 29, 2025) and a M5.5 (May 11, 2023) beneath Lake Almanor attest to the activity of these faults and their potential to pose risks to societally important infrastructure in the region (e.g. hydroelectric, gas transmission, dams, transportation corridors). Herein I summarize the current state of knowledge on rupture parameters for these faults, evaluate existing mapping, and assess sites for better defining their paleoseismic behavior. The aim is to produce a dataset from which to plan future collaborative research with industry partners and graduate students with the goal of better characterizing this complex region.

Estimating Long-term Fault Slip Rates Using Geomorphological Evidence

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Mountains bounded by normal faults commonly have planar facet slopes. The facet slope steepness reflects a balance between fault slip and erosion rate. First, we show that facet dip angles along the Wasatch fault zone correlate with fault slip rates. Next, we demonstrate that by constraining millennial-scale facet erosion rates, absolute fault slip rates can be estimated. Estimating slip rates is critical for using the fault deformation models embedded within the U.S. Geological Survey's National Seismic Hazard Model. After providing a description of our methodology and results using the Wasatch fault zone, we will switch focus to the Nevada-California borderland and talk about recent and future work. In particular, we will discuss the implications our work has on probabilistic seismic hazard computations within this tectonically interesting region as well as the implications of using longer-term slip rates for seismic hazard computations. Finally, we will discuss the overall appropriateness of using slip rates as a quantitative measure for probabilistic hazard computations.

Improving Reno Earthquake Hazard Assessment Through Ground-motion Model Comparisons and a Paleoseismic Study

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We present the results of two complimentary methods to assess earthquake hazards around Reno, a major population center within the Walker Lane. First, we evaluate the performance of commonly used ground-motion models (GMMs) in the context of the Reno Basin. We focus on the four NGA-West2 (2014) Active Crustal models – Abrahamson et al. (2014), Boore et al. (2014), Campbell and Bozorgnia (2014), and Chiou and Youngs (2014) – which are trained on a global dataset of ground motion recordings. Reno sits in a geometrically distinct and relatively shallow sedimentary basin when compared to the well-studied basins from where much of the NGA-West2 dataset is sampled. This disparity leaves the possibility that seismic waves propagating in the Reno Basin will behave differently from the model estimates, as shown by numerical simulations of Eckert et al. (2021). To address this gap, we compare the NGA-West2 GMM estimates with a new dataset of ground motion measurements derived from seismic recordings from over 400 earthquakes around the Reno area. This comparison identifies various source, site, and path effects which contribute to unexpected ground motions with the goal of updating the NGA-West models with improved parameters for regional use. Second, we present age constraints developed from relative soil development and Optically Stimulated Luminescence (OSL) samples obtained from two alluvial surfaces. The adjacent surfaces are both displaced across the Mt. Rose range-bounding normal fault to the south of Reno. The age constraints are used along with topographic offset to place bounds on the fault slip rate and earthquake recurrence interval. Combined with the improved model parameters, the fault characteristics can be used to conduct more accurate assessments of seismic risk to Reno and facilitate future hazard mitigation.

Automated Extraction of Surface Fault Rupture Profiles for Fault Displacement Hazard Analysis

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We present an automated processing framework for extracting key parameters from surface rupture slip profiles, including the 3-component displacement vector, rupture width, and number of individual ruptures. This approach significantly reduces processing time compared to existing methods. Current models often cannot fully characterize fault ruptures; some do not estimate fault zone width, while others fail to accurately represent the full 3-component displacement vector. Improving the efficiency and completeness of remote sensing surface fault rupture profiles is vital for both Probabilistic Fault Displacement Hazard Analysis and fault characterization.

Our automated process addresses these limitations using a flexible functional form that models both the rupture offset and the linear segments. This form allows for fault-normal, fault-parallel, and vertical displacements while

honoring constraints such as common rupture location and width across components. We fit this idealized profile shape to observed data using a stochastic gradient descent algorithm that optimizes the functional parameters to minimize misfit. Additionally, the method detects and accommodates multiple rupture offsets within a single profile by summing the functional form, yielding a more accurate characterization. The method provides a purely mathematical characterization of profiles, removing human bias and enhancing comparative metrics. The primary outputs of the model include fault displacement, rupture width, rupture center location, and slope characteristics. We applied this approach to the M7.7 Mandalay, Myanmar, earthquake, using pixel correlation of imagery from Sentinel-2, Landsat-8, and Landsat-9 satellites. Preliminary results show that the automated method produces displacement estimates consistent with those from manual analysis, while significantly reducing processing time. Ongoing efforts focus on fully automating the characterization of displacement uncertainty, developing a user interface, and extensive testing on existing data.

Principal Surface Rupture Hazard: Moving Beyond Aggregate Displacement Metrics

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While Probabilistic Seismic Hazard Analysis (PSHA) is well established in seismic design, Probabilistic Fault Displacement Hazard Analysis (PFDHA) remains relatively less developed. Early formulations introduced the probabilistic framework by replacing ground-motion models with fault displacement models to estimate the probability of surface rupture. Although these methods provided a valuable foundation, they were constrained by limited datasets, simplified fault geometries, and the treatment of displacement as an aggregate parameter without explicit consideration of geometric effects such as rupture curvature and structural footprint. These limitations emphasize the need for more physically consistent and statistically robust frameworks that can better capture the complexity of surface fault rupture behavior.

This research develops a comprehensive probabilistic framework for modeling principal fault displacement using the global Fault Displacement Hazard Initiative (FDHI) database, which includes more than 40,000 displacement observations from 75 earthquakes (M_w 4.9–8.0) across all faulting styles. The framework integrates a Bernoulli–Poisson hurdle model for the number of overlapping principal ruptures, governed by earthquake magnitude and rupture curvature; a Beta distribution to represent physically consistent displacement partitioning through the amplitude ratio between ruptures; and a Student's t-distribution to capture the heavy-tailed variability in rupture distance from the pre-mapped fault trace. Together, these probabilistic components form a unified model that quantifies the influence of magnitude, curvature, and faulting style on principal displacement and supports future integration of PSHA and PFDHA into a cohesive seismic hazard platform for improving the resilience of lifeline systems crossing active faults.

Challenges and Opportunities for Earthquake Early Warning in Nevada

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Nevada is one of the most seismically active states in the U.S., with numerous large, M6-7 events in the historic and paleoseismic record. Most of Nevada's population lives within or near the Walker Lane, a tectonic province along the border of Nevada and California which has the highest seismic hazard in Nevada. Seismic risk in Nevada is high due to this overlap of population and hazard, combined with aging and historic infrastructure in many areas and several critical military and energy facilities. Implementing an earthquake early warning system could improve the outcomes for Nevadans during large and damaging earthquakes events. Earthquake early warning systems aim to lower the risk of earthquakes by sending alerts to potentially affected people before shaking arrives at their location. ShakeAlert is the current EEW system in place in the U.S., but at present is only operational in the West Coast states of California, Oregon, and Washington. Our research is focused on characterizing the potential value of EEW in Nevada and determining what steps are needed to bring EEW to the state. We look at how capable the current ShakeAlert system is for EEW in Nevada and the changes adding more of the Nevada network stations would have. We expand upon this by adding grids of potential stations to see how changing grid density influences the system. ShakeAlert uses multiple different methodologies to estimate the parameters of an event, and we study how the changes in the network set up affect the

accuracy and performance of FinDer and EPIC. This research provides a scientific basis for cost-benefit analysis of a future expansion of ShakeAlert to Nevada.

Seismic Faults Inside Principal Underground Laboratory for Subcritical Experimentation at the Nevada National Security Site

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The Defense Nuclear Facilities Safety Board (Board) conducted a review of seismic faults within the Principal Underground Laboratory for Subcritical Experimentation (PULSE) at the Nevada National Security Site (NNSS). The National Nuclear Security Administration (NNSA) performs subcritical experiments at PULSE providing data to support stockpile stewardship. The Board communicated the results of this review in a letter to the Secretary of Energy dated July 25, 2024.

The Board's staff found that seismic faults are extensively present within PULSE. Fault-associated phenomena, such as displacements, fault gauges, slickensides are common. However, neither NNSA nor NNSS personnel have adequately characterized the seismic faults in the PULSE underground tunnels to determine whether they are active. Confirmation that these faults are active would have significant safety implications because the seismic design for both existing and new controls in PULSE does not account for the effects of seismic shaking and displacements caused by the faults within the facility. As a result, these controls may not be able to perform their intended safety function during and after a seismic event. Similarly, the seismic hazard may be underestimated for other NNSS facilities, including the Device Assembly Facility.

Fault Geometry From 12 Years of Relocated Earthquakes (2013-2025) Near Lake Almanor, Northern California, Reveals a Connection at Depth Between Two Mapped Surface Faults

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The 2023-05-11 M_w 5.5 Lake Almanor earthquake, and a M_w 5.2 aftershock ~11 hours later, ruptured normal faults in a sparsely instrumented region in northeastern California, with only one strong-motion seismic station and two broadband stations within 10 km and 25 km epicentral distance, respectively. The 2013-05-24 M_w 5.7 Canyondam earthquake and its aftershocks occurred ~5 km southeast of the May 2023 earthquakes (Chapman et al., 2016). The presence of several dam facilities within 15 km motivates a detailed study of the causative fault and its geometry at depth to inform site-specific seismic hazard. Within two days of the 2023 mainshock, the U.S. Geological Survey (USGS) deployed 34 three-component nodal seismometers from 2023-05-13 to 2023-07-27 to record the Lake Almanor aftershocks at close (<5-10 km) epicentral distances with dense (~3 km) spacing and comprehensive azimuthal coverage. Data from these nodal seismometers helped to improve event locations, refine the local velocity model, and reduce uncertainty in focal mechanisms. Double-difference methods were used to precisely locate ~1,700 ComCat earthquakes (USGS, 2017) between 2013-04-01 and 2025-07-01 and delineate fault structures at depth. These results reveal that the 2023 M_w 5.5 sequence was located northwest of the 2013 M_w 5.7 sequence without spatial overlap and occurred on the same steeply dipping fault structure. This underlying structure may be large enough to host a M6+ earthquake and appears to connect two mapped surface faults from the Statewide California Earthquake Center Community Fault Model 7.0: the Almanor Fault to the northwest, and the Skinner Flat Fault to the southeast. A hypothetical single rupture of all three faults could generate an earthquake that exceeds M7. This study shows how seismological analysis of nodal aftershock data in sparsely monitored areas can contribute useful information for site-specific seismic hazard.

Rupture Process of the M5.7 December 9, 2024 Parker Butte, Nevada, Earthquake

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The M5.7 December 9, 2024 Parker Butte earthquake ruptured a part of central Walker Lane about 60 km west of the Central Nevada Seismic Zone that has been historically very active. Focal mechanisms of the mainshock and the dominant trend of aftershocks are consistent with left-lateral strike slip on an unmapped ENE-striking fault. The unwrapped phase from interferometric synthetic aperture radar (InSAR) data and field observations (Koehler et al., 2025) indicate that coseismic slip did not reach the surface but was followed by shallow afterslip on secondary faults. In order to clarify the distribution of coseismic slip and its relation with afterslip, we assemble three-component broadband and strong motion seismograms from 58 regional stations within 250 km of the main shock epicenter, combined with 6 horizontal static offsets derived from GNSS time series and two (one ascending and one descending) Sentinel-1 interferograms. These data are interpreted with a model of coseismic left-lateral strike slip distributed on a 80° SSE-dipping, 9 km long fault striking 61° combined with normal slip or right-lateral strike slip on cross faults constrained by aftershock seismicity and the secondary surface rupture pattern. We find that slip propagated from a hypocentral depth of ~9 km both upward and westward to yield net slip concentrated between 2 and 7 km depth, with rupture velocity averaging 2.5 km/s. A local coseismic slip maximum ~1 km west of and ~5 km up dip of the NEIC hypocenter lies directly beneath part of the main secondary surface slip zone, which has inferred after-slip of several cm reaching the surface. This suggests a primary role for static and/or dynamic stress transfer in triggering shallow afterslip.

Fault Networks and Seismic Hazard in the Nevada-California Borderland [Poster]

Poster Session • Wednesday 15 April

Conveners: Christopher B. DuRoss, U.S. Geological Survey (cduross@usgs.gov); Richard D. Koehler, Nevada Bureau of Mines and Geology (rkoehler@unr.edu); Henry B. Mason, University of Nevada, Reno (hbmason@unr.edu); Ian K. D. Pierce, Pacific Gas & Electric (ipiercegeology@gmail.com); Christie D. Rowe, Nevada Seismological Laboratory (rowec@unr.edu)

POSTER 94
Quaternary Geologic and Fault Mapping to Inform Future Paleoseismic Characterization at Yucca Mountain, Nevada
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Yucca Mountain is a potential geological repository for high-level radioactive waste that sits in the southern Basin and Range adjacent to the southern Walker Lane in Nye County, Nevada. Multiple north-south trending normal faults traverse the site and are capable of generating earthquakes with the potential to affect the suitability of nuclear waste storage. Although previous studies have clearly shown that these faults are active, there are large uncertainties in paleoseismic parameters (timing, recurrence, slip rate, etc.), compromising probabilistic seismic hazard assessments. In this study, we aim to critically evaluate previous geological mapping and trenching studies at Yucca Mountain to better characterize seismic sources and improve fault rupture parameters. In some cases, reported maximum displacements and number of paleo earthquakes are inconsistent with the surface expression of faults as observed on modern satellite and digital elevation models not available at the time of the original studies. Herein, we present new Quaternary geologic and fault mapping at several previous fault trenching study sites. The mapping will be used to rank data quality at each site, prioritize sites for future detailed study (including geochronologic analyses), and help plan a long-term paleoseismic assessment program aimed at improving seismic hazard models at Yucca Mountain.

POSTER 95
Active Faulting in the Klamath Mountains Revealed by Lidar Data
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The Klamath Mountains Province (KMP), which lies in northwestern California at the intersection of San Andreas transform motion, Cascadian subduction, and Basin and Range extension, has long been considered tectonically rigid because it lacks mapped active faults. However, the relatively weak rheology and geodetically observed contraction across the KMP indicate that the region should be actively deforming. This study presents a new analysis of high-resolution lidar data to show that the KMP is transected by active faults which have gone unnoticed until now because the region is elevated, eroding, and densely forested. Newly discovered normal, dextral strike-slip, and reverse faults in the KMP provide evidence that the region acts as a rheologically weak, diffuse boundary zone accommodating varying styles of deformation due to the complex tectonic forces acting on its margins. The application of single-grain feldspar IRSL dating to sedimentary deposits adjacent to the Scott Valley normal fault (in progress) will quantify its slip rate. These findings will improve local and regional seismic hazard assessments and provide key input to geodynamic models of the broader plate-boundary system.

POSTER 96
Earthquake Hazard and Geomorphic Mapping in the Reno Urban Area
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The Reno area is one of the fastest growing urban regions in the USA and lies within the Walker Lane tectonic zone. The Reno-Sparks metro area lies in a triangular valley containing a network of N-striking normal faults, NW-striking right-lateral faults and NE-striking left-lateral faults. Potentially damaging earthquakes of M4.5 or greater were frequent in the late 19th and early 20th centuries in the Reno-Tahoe-Carson City region, with at least 20 events between the 1850s and 1960s. The Reno-Sparks area is therefore considered to lie in an area of high hazard and risk given the tectonic setting and record of historical and recent earthquakes. High resolution digital elevation models have been available for about a decade, allowing for detailed mapping of some Quaternary active faults. Local studies have helped constrain their dip direction, linkages, and in some cases, total displacement, slip rate and recurrence. A few potential earthquake scenarios for use in planning have been developed, along with a community velocity model for scenario-shaking computation.

However, a comprehensive reassessment of the Reno basin has not been completed. Commonly used fault map sources (e.g., the USGS Quaternary Faults and Folds database, NSHM2023, etc.) require updates and curation using higher resolution datasets. The 3D orientation, length, and relative connectivity of some major faults and fault systems are insufficiently constrained, notably between the Mount Rose fault zone and faults north and west of downtown Reno. Additionally, given long recurrence intervals on some Walker Lane faults, it remains ambiguous whether the faults with geomorphic surface expression should be considered the most hazardous or whether buried faults still pose modern threats. We present ongoing geomorphic mapping of Quaternary faults for the Reno urban area, compare geomorphic indicators to mapped faults, consider de-emphasizing faults previously mapped as short segments lacking surface expression, and identify sites for shallow geophysical investigations that could potentially constrain the location and geometry of faults in the Reno basin.

POSTER 97
Right-oblique Slip Rate of the Round Valley Fault, Eastern California
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The Walker Lane band accounts for approximately 20% of Pacific-North American plate motion, but geologically recorded dextral slip rates across the belt often underestimate geodetic rates. One proposed explanation for this disparity is distributed deformation on faults that primarily exhibit normal motion but also accommodate a dextral component. In this study, we quantify the dextral-oblique slip rate of the Round Valley fault (RVF), a notable range-bounding normal fault in the southern Walker Lane belt near Bishop, California. Using newly released airborne lidar data, we trace fault scarps and geomorphic markers along the RVF and identify evidence for right-lateral displacement of late Pleistocene glacial moraines. We focus on offsets of late Tioga-stage moraine crests (19–17 ka), which provide well-preserved, age-constrained piercing lines for slip-rate calculations. Along a set of lateral moraines at Horton Creek, we measure 6.5 ± 1.6 m normal offset and 15 ± 3 m of dextral offset, yielding a dip-slip rate of 0.4 ± 0.1 mm/year and a lateral slip rate of 0.8 ± 0.2 mm/year. At Pine Creek, we observe two dextral-oblique normal faults cutting moraines and an outwash channel. The western fault, located at the range front, exhibits 10 ± 1 m of dip slip and 4 ± 2 of dextral slip. The eastern fault, located within the hangingwall 1.4 km northeast of the range front, exhibits 6 ± 1 m of normal slip and 8 ± 3 m of dextral slip. Taken together, these measurements yield a dip-slip rate of 0.9 ± 0.2 mm/yr and a lateral slip rate of 0.7 ± 0.3 mm/yr. These results collectively show that the RVF plays an active role in transferring dextral slip between the southern and central Walker Lane belt, and that oblique slip on normal faults represents a previously overlooked component of the Walker Lane strain budget. Accounting for this deformation helps reconcile discrepancies between geologic and geodetic slip-rate estimates and improves our understanding of how strain is distributed across the Walker Lane belt.

POSTER 98
ELVIS: A Seismic Array for Hazard and Structure in the Las Vegas Basin
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Several faults within the Las Vegas Basin present either significant or unknown seismic hazards. The city also lies within an up to 5-km-deep sedimentary basin that is likely capable of amplifying seismic energy. Losses within the city from a major earthquake are estimated to be as high as 300 fatalities and \$7 billion in infrastructure damage (dePolo & Taylor, 2008). We deployed a temporary seismic array named ELVIS –Evaluating Las Vegas’ Internal seismicity and Structure – to characterize seismic activity and tomographically image the basin. Cities are notoriously difficult places to conduct seismic surveys due to high background noise levels, but recent developments in machine learning have shown promise in enhancing the detection of earthquakes behind typical cultural noises. The array was deployed in two phases. First, a network of 16 broadband stations (all Nanometric Meridian or Trillium Compact Posthole) collected data from February to October 2025. All broadband stations were deployed around the urban core in the surrounding countryside, where low anthropogenic noise levels are expected. In a second phase, 91 short-period seismometers (SmartSolo IGU-16HR 3C 5Hz) were deployed for ~1 month in June to July, forming an ~4-km-spaced grid within the urban core, in total covering a 60-by-40 km wide area. Preliminary analysis is underway for both the detection of seismicity with machine learning techniques and seismic tomography from cross-correlation of ambient noise. Based on the current

USGS catalog for the area, we expect to have recorded ~100 events of magnitude zero and greater within the basin during the nodal deployment. While not the primary focus of the experiment, we expect to evaluate both basin and deeper structures with delay times, receiver functions, and other techniques from the set of 35 teleseismic events above Mw 5.5 (including a Mw 7.3 in Alaska) that occurred during the nodal deployment, and the many earthquakes, including the 2025 Mw 8.8 Kamchatka earthquake, that occurred during the broadband deployment.

Fiber-Optic Sensing Applications in Seismology and Environmental Science

Oral Session • Thursday 16 April • 4:30 PM Local

Conveners: Mahbubah Ahmed, Virginia Polytechnic Institute and State University (mahbubah@vt.edu); Ettore Biondi, Stanford University (ettore88@stanford.edu); Xiaowei Chen, Texas A&M University (xiaowei.chen@tamu.edu); Valey Kamalov, International Institute for Ocean Fiber Sensing (vkamalov@gmail.com); Voon Hui Lai, Australian National University(voonhui.lai@anu.edu.au); Jiaxuan Li, University of Houston (jxli@uh.edu); Mikael Mazur, Nokia Bell Labs (Mikael.mazur@nokia-bell-labs.com); Meghan C. Quinn, U.S. Army Engineer Research and Development Center (meghan.c.quinn@usace.army.mil); Qibin Shi, Rice University (qs20@rice.edu); Joseph P. Vantassel, Virginia Polytechnic Institute and State University (jpvantassel@vt.edu); Qiushi Zhai, California Institute of Technology (qzhai@caltech.edu)

Unveiling Stick-slip Dynamics in Deep-seated Landslides Using Borehole Distributed Acoustic Sensing
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Deep-seated landslides pose significant threats to infrastructure and public safety, making the understanding of their internal dynamics critical for effective risk assessment. In this study, we utilize Distributed Acoustic Sensing (DAS) technology to monitor the subsurface deformation of a deep-seated landslide in Lantai, northern Taiwan. By deploying a fiber-optic cable across multiple slip zones within a borehole, we leverage DAS to create a dense array of seismic sensors capable of detecting high-resolution ground motion. Our results reveal that DAS successfully captures accelerated landslide movements and recurring stick-slip events at the soil-bedrock interface approximately 20 meters deep. We observe that the temporal clustering and inter-event intervals of these events are strongly modulated by typhoon-induced rainfall and strong earthquake shaking. These periodic stick-slip behaviors, undetectable by conventional surface geophones, suggest velocity-weakening frictional properties and highlight the high spatiotemporal complexity of slip activity within the landslide shear zones. Our findings provide new insights into landslide mechanics and demonstrate that borehole DAS is a promising tool for real-time monitoring and disaster mitigation.

Ultra-broadband Fiber-optic Strain Sensing: Development and Applications to Plate Boundary Processes
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We are trying to observe the temporal evolution of interseismic plate locking along the megathrust earthquake source region of the Nankai Trough. Fiber-optic strain sensing is well suited for this purpose because it enables highly sensitive, ultra-broadband observations targetting from slow slip events to regular earthquakes.

Since 2019, we have deployed seafloor fiber-optic strainmeters with a 200 m gauge length. At one site, in addition to earthquakes and slow earthquakes, we have detected strain changes of approximately 0.7 microstrain associated with slow slip, demonstrating the effectiveness of seafloor strain observations for resolving a wide range of fault slip processes.

We are also advancing distributed fiber-optic sensing using submarine optical fiber cables as a core technology for ultra-broadband, high-sensitivity seafloor monitoring. We have developed a broadband DAS that enables crustal deformation measurements through stabilization of the optical wavelength reference, as well as a Rayleigh strain sensing method based on Rayleigh backscattering that relies on a physical principle distinct from DAS. These techniques are being continuously tested on a 120 km submarine cable crossing the Nankai Trough off Muroto.

In long-period strain observations such as for tsunamis and slow slip, the temperature sensitivity of optical fibers introduces large apparent strain associated with temperature variations. This effect is mitigated by using multiple sensing fibers with different thermal coefficients in strainmeters, but is difficult with distributed fiber-optic sensing. So, we deployed temperature sensors near the submarine cable and compared the records with distributed strain measurements, revealing a correlation of approximately 7 microstrain per degree Celsius. After temperature correction, residual strain records show tidal-synchronous variations attributed to deformation of seafloor sediments, with deviations below 1 microstrain, exhibiting a steady rate of about 2 microstrain per year, suggesting that improved long-term stability may enable future resolution of spatial variations in plate locking.

ILLuminating Ruptures of Moderate Earthquakes With Multi-fibre Networks

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Being able to image the ruptures of moderate earthquakes would significantly increase our observations towards comprehending earthquake source physics, fault properties and seismic hazards. However, resolving their rupture characteristics remains challenging for conventional seismic networks due to limited station density. The emergence of Distributed Acoustic Sensing (DAS) offers a potential solution by providing dense and continuous measurements. In this study, we systematically evaluate the resolution capabilities of multi-fibre DAS networks for back-projection (BP) and demonstrate the feasibility of using DAS networks through both synthetic tests and analysis of a Mw 4.9 event in the Eastern California Shear Zone. Furthermore, we propose a two-step inversion procedure that strategically integrates DAS with the conventional network. Our results suggest that strategically deployed multi-fibre DAS network can serve as the next generation of earthquake observation system and significantly enhance our understanding of earthquake rupture physics, as well as seismic risk preparedness.

Investigating the Feasibility of Incorporating DAS Into Ground Motion Modeling

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Distributed Acoustic Sensing (DAS) has been recently applied to many research areas in seismology. However, its potential for improving ground motion quantification has not been rigorously investigated yet. This study investigates the feasibility of incorporating DAS into ground motion modeling. We combine two DAS datasets in California to achieve good magnitude and distance ranges, including the Ridgecrest cable that recorded aftershocks of the 2019 M7.1 Ridgecrest event and the Arcata-Eureka cable that recorded several earthquake sequences around the Mendocino Triple Junction.

Our study involves two major components. First, we take advantage of the strain measurements from DAS and develop a strain-based ground

motion model (GMM). Buried structures (e.g., pipelines, railways, aqueducts, etc.) are less sensitive to forces imparted by ground acceleration and more sensitive to the strains. However, since the instrumentation of strain sensors is very rare, most seismic hazard analysis of such structures is done approximately with other ground motion intensities (e.g., PGV and PGA). Our results show that strain-based GMMs can be developed with DAS data, which can improve our understanding of the seismic performance of ground-strain sensitive structures.

Second, we convert the strain time series from DAS to a velocity time series with a regularized rescaling of the frequency-wavenumber domain. The Fourier Amplitude Spectra (FAS) computed from the velocity time series at different frequencies are compared to results from co-located nodal seismometers. At each frequency, we find a consistent amplitude ratio between amplitudes from DAS and the co-located nodal seismometers for all recordings. The amplitude ratios are frequency dependent. The correlation between site-to-site residuals from DAS and co-located nodal seismometers computed with an empirical GMM is high up to 10 Hz, ranging from 0.65 to 0.8. The preliminary results suggest DAS may be used to characterize site response at very high spatial resolution, but requires co-located seismometers to calibrate the conversion from strain to velocity.

Acoustic Coda-based Yield Estimation of Surface Explosions With Distributed Acoustic Sensing

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We use acoustic coda measurements recorded with Distributed Acoustic Sensing (DAS) and apply spectral ratio methods to estimate the relative yield of surface chemical explosions. High-frequency acoustic source processes are important for explosion monitoring and characterization, particularly at regional distances where conventional seismic phases may be weak or absent; however, detailed waveform analysis is complicated by atmospheric variability, propagation effects, and coupling between the atmosphere and the ground. To reduce sensitivity to these effects, we neglect waveform phase information and instead analyze the spectral properties of late-arriving acoustic coda. We apply this approach to DAS recordings of controlled 1-ton and 10-ton TNT-equivalent surface explosions conducted near Socorro, New Mexico, in 2024, recorded on small-aperture fiber-optic arrays at ~12 km range. Beamforming of the coherent acoustic arrivals is used to confirm source direction and association prior to yield analysis. Spectral ratios of acoustic coda provide a stable and repeatable measure of source energy scaling that is largely insensitive to path effects, and the observed scaling is interpreted using simple blast waveform models combined with empirical overpressure-yield relationships. This work demonstrates that modest, rapidly deployed DAS arrays can be used to estimate relative explosion yield using acoustic coda alone and supports the application of DAS-based coda methods in operational explosion monitoring environments.

A Contribution to the Assessment of DAS Performance With Surface Waves: A Case-study From Northern Italy

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Distributed Acoustic Sensing (DAS), a technology that transforms fiber-optic cables into dense seismic arrays, has rapidly become a widely used tool for a broad range of Earth and environmental studies, both onshore and offshore. With the aim of improving our understanding of DAS instrumental response, this research explores the potential of DAS data for near-surface imaging through surface-wave analysis. We present results from a case study in northern Italy, an area of tectonic interest due to the possible surface emergence of a major fault system. Two fiber-optic cables with a total sensing length of about 550 m were deployed at the site, and both active and passive DAS data were analyzed to construct a two-dimensional surface-wave velocity model. The results are compared with those obtained from traditional geophone arrays, including horizontally polarized sensors, in order to evaluate the relationship between the axial strain measured by DAS – its intrinsic DAS observable – and the horizontal ground motion in the same direction recorded by geophones. At the same site, a single-station ambient-noise survey was conducted to produce contour maps of the main seismo-stratigraphic reflectors using an independent method. Complementary electrical resistivity tomography (ERT) data were also collected. We discuss the comparison between all datasets, highlighting the potential and limitations of DAS for near-surface characterization, as well as possible directions for future developments.

The DAS data were collected within the framework of the project “NASA4SHA – Fault segmentation and seismotectonics of active thrust systems: the Northern Apennines and Southern Alps as laboratories for new Seismic Hazard Assessments in northern Italy” (Principal Investigator R. Caputo, University of Ferrara). We acknowledge N. Piana Agostinetti and F. Bonali (University of Milano-Bicocca) for providing these data. All other data were collected by the authors.

Coda Wave Interferometry with DAS for Continuous Relative Velocity Change Monitoring of a Tailings Dam in British Columbia

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Distributed Acoustic Sensing (DAS) enables spatially continuous seismic monitoring at meter-scale resolution over kilometre distances, making it well-suited for geotechnical monitoring of tailings storage facilities. We present results from a pilot study conducted from May to December 2025 at an active tailings dam in British Columbia, where ~1 km of fiber optic cable was installed along a 886 m section of the tailings dam crest. DAS data were acquired using three interrogators (OptaSense ODH-4, Sintela ONYX Nano, FEBUS A1) with channel spacings ranging from 1 to 4 m and data acquisition rates of up to 500 Hz. Ambient noise cross-correlations recover clear fundamental and higher-order mode surface wave arrivals across most of the array. However, a persistent anthropogenic noise source from a nearby tailings deposition point introduces spurious arrivals that require careful treatment. We apply coda wave interferometry to estimate relative velocity changes (dv/v) and examine their correlation with environmental factors, including precipitation, temperature variations, and mining activity. We compare dv/v time series with pore water pressure measurements from collocated vibrating wire piezometers. The multi-month dataset demonstrates the feasibility of passive seismic velocity monitoring with DAS for tailings dam applications and highlights practical considerations for distributed fibre optic sensing deployments in active mining environments. Because seismic velocities in saturated granular materials depend on changes in effective stress, dv/v monitoring provides a spatially integrated proxy for detecting deviations from expected geotechnical behavior that may precede deformation detected using conventional geotechnical instrumentation.

Subsurface Characterization Along Rail Lines - Distributed Acoustic Sensing in the Swiss Alps

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We explore the feasibility of using pre-existing telecommunications fibers installed along railways for shallow subsurface characterization and structural health monitoring. As most rail infrastructure includes telecommunications, Distributed Acoustic Sensing (DAS) systems can be readily deployed where active seismic sources are prevalent (i.e., trains). In collaboration with the Swiss Federal Railways (SBB), we collected seismic data using a Sintella DAS interrogator along approximately 30 km of fiber. We use an approximately 3 m channel spacing and an approximately 6 m gauge length; we find this is an optimal trade-off between spatial resolution and sensing range. Our primary goal is to demonstrate the feasibility of unobtrusively measuring subsurface shear-wave velocity and thus potentially identify weak areas requiring further geotechnical maintenance, with additional perspectives on using the DAS data for regional earthquake monitoring and for basin-scale hazard estimates.

The dominant source of seismic energy is, unsurprisingly, trains. We test several approaches to measure Rayleigh wave dispersion and subsequent inversion for shallow structure: (1) ambient noise interferometry, stacking all available time windows with various forms of pre-processing, (2) an FK-domain based threshold to determine when strong single direction wave is present (e.g. when a train is approaching or has passed) with subsequent

interferometry, and (3) a coherent source subsampling approach using a Symmetric Variational Autoencoder to identify time windows that contribute useful surface-wave energy. We find that the approaches which use only very specific time windows associated with the strong train signals (the 2nd and 3rd methods above) far outperform traditional noise correlation stacking in this environment. We use the extracted dispersion curves to invert for shallow structure focusing on the top 50 meters. We are able to recover a 2D profile along most of the 30 km fiber, and focus on several areas of interest to demonstrate the robustness of both our processing and inversion workflow.

Distributed Acoustic Sensing-based Joint Inversion for the Structure of the Reykjanes Peninsula, Iceland

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Iceland’s Reykjanes Peninsula experiences episodic volcanism separated by hundreds of years of quiescence and has recently entered a period of renewed activity. The peninsula sits on an obliquely spreading boundary between the North American and Eurasian plates. This transtensional stress regime biases the geometry of volcanic and geologic structures, which take on a northeast-southwest strike in their surface expression. We image subsurface structures, leveraging a 100 km distributed acoustic sensing (DAS) array, eleven permanent broadband stations, and a temporary nodal deployment to perform a joint body and surface wave tomography. Moving from the surface to about 5 km depth, we observe a broad transition from seismic anomalies which take on the aforementioned NE-SW strike towards alignment with the plate boundary. These plate-boundary-aligned anomalies are interpreted as thermally driven, and capturing their variation along the boundary may aid an understanding of the temperature character of the peninsula. Further, the shallow crust sees a low velocity zone aligned with recent eruption-feeding dikes, which may illuminate aspects of the intrusion and eruption process. In better characterizing these structures, we highlight the value of DAS in efficiently imaging the subsurface at high resolution.

DAS Surface-wave Observations of Deep-crustal Structure in Western Nevada From a 56 Km Infrastructure Fiber

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In June 2025 a collaboration between Terëan*, Sintela, and the University of Nevada, Reno (UNR) made distributed acoustic sensing (DAS) recordings with Sintela’s ONYX™ peta interrogator. One of the trials was on infrastructure dark fiber operated by the Nevada Department of Transportation. A 56 km segment of this fiber runs from the UNR campus in Reno eastward to the town of Fernley, closely following Interstate Highway 80. The route east of Reno is in the narrow Truckee River Canyon, which hosts a busy freight railroad, fuel pipelines, overflights by airliners, and major industrial operations. All these sources of seismic microtremor contributed high-amplitude, broadband microtremor signals along the cableway. The trial recording of this fiber lasted more than 24 hours and used a channel spacing of 3.12 m derived from a gauge length several times longer. Processing of a 50-minute section of the recording used Terëan’s VsSurf ReMi* 2dS+ software, revealing fundamental-mode Rayleigh-wave dispersion between periods of 1.0 to 15.4 sec. Using the same technologies applied to shallow shear-wave site classification (Vs30), extending a ReMi DAS array to 56 km provides velocity constraints to about 40 km depth. Average crustal Vs (Sg) is 3.1 km/s. Assuming the crust is a Poisson solid, that Vs value implies a Pg of 5.4 km/s. Rayleigh dispersion picked at 10-15 sec period constrains crustal thickness to 30-35 km, like prior studies, and Sn velocity to 4.4-4.6 km/s (a Pn between 7.6 and 8.0 km/s is implied). Modeling found a distinctly lower Vs in the seismogenic upper crust, 2.9 km/s versus 3.6 km/s (implying Vp of 5.1 km/s vs. 6.3 km/s). Flattening of the dispersion curve from 2 sec to 5 sec period is evidence of a low-velocity zone, with perhaps a 24% drop in Vs, between 12.9 and 14.5 km depth. This depth corresponds with the base of the seismogenic zone in this region, as well as with the depth of the transition between lower-velocity upper crust and higher-velocity lower crust seen in nearby P-wave refraction studies, possible evidence of a distinct Conrad discontinuity in this area.

Fiber-optic Seismic Sensing of River-amplified Permafrost Warming

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River-controlled permafrost dynamics are critical for sediment transport, infrastructure stability, and the carbon cycle, yet remain poorly understood under climate change due to observational limitations. This study employs distributed acoustic sensing (DAS) to transform existing telecommunication cables into dense seismic arrays, enabling unprecedented monitoring of permafrost dynamics beneath river channels. Our observations on the Qinghai–Tibet Plateau reveal that the active layer beneath rivers is substantially thicker than in non-inundated permafrost and that lateral expansion of inundated areas drives additional warming. These findings provide critical validation for physics-based thermal models and offer new constraints for model parameterization. By integrating observational data, we refine model representations of heat transfer processes, revealing that river-induced warming accelerates permafrost degradation more rapidly than previously simulated. The enhanced model projects that under future warmer and wetter climates, intensified sub-river permafrost thaw will increase risks to riverine infrastructure and amplify permafrost carbon release.

Illuminating Tidally Modulated Grounding Zone Migration at Constellation Inlet: A Seismic Motion Picture With Distributed Acoustic Sensing

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A critical zone of interest for glaciologists sits at the perimeter of the Antarctic continent, where the Antarctic Ice Sheet transitions from grounded to floating ice, known as the grounding zone. The ice sheet is modulated by the tides of the Southern Ocean, such that over diurnal and fortnightly tidal cycles the transition between grounded and floating ice migrates up and downstream. The intrusion of warm seawater onto the ice base has significant implications for basal melt rates, a major contributor to ice mass change. However, due to the thick ice cover, direct interrogation of basal properties over a tidal cycle is challenging, and their dependence on local topography, basal material, and ice structure remains poorly constrained. Borehole drilling and ApRES offer only point measurements, and InSAR remains indirect. Active source seismic arrays provide a complementary approach, offering controlled source timing and geometry, enabling monitoring of time dependent basal conditions.

In December 2025, our team deployed a dense, multi-sensor geophysical array at Constellation Inlet near the grounding line of Union Glacier, a slower-moving tributary of the fast-flowing Rutford Ice Stream on the Ronne Ice Shelf. Instrumentation included a low-size, weight, and solar-powered DAS interrogator in addition to 500 Stryde vertical geophones, 20 three-component SmartSolo nodes, and IPR, deployed at and around the InSAR-derived high-tide grounding-line extent and optimized for basal PP and PS reflections using a static PEG hammer source. Over 12 days, we conducted a near-continuous active-source survey, designed to capture the time-dependent migration of the grounding line. We present preliminary results including a high-resolution static image of the full ice column derived from seismic and radar data. We identify the change in subsurface signal as a function of tides, enabling construction of the first “movie” of grounding-line motion over a full tidal cycle. Additional observations further illuminate ice-sheet structure and dynamics, providing a time-resolved view of grounding-zone behavior at Union Glacier.

Direct Ice Density Constraints from Multimode Surface Waves using DAS

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Constraining subsurface density from seismic data is challenging, although density is fundamental to quantifying mass and structure in both the solid Earth and the cryosphere. Empirical scaling relationships between seismic wave speeds and density are therefore widely used. In this contribution, we show that glacier density can instead be constrained directly from surface-wave observations when multimode dispersion and fully nonlinear inversion are combined.

We analyze distributed acoustic sensing (DAS) recordings acquired in glaciated environments, where strong serendipitous anthropogenic sources generate coherent Rayleigh-wave overtones with high signal-to-noise ratio. These dense DAS measurements allow robust extraction of surface-wave multimode dispersion. We invert the data using a probabilistic Hamiltonian Monte Carlo (HMC) framework that accounts for nonlinearity, parameter trade-offs, and uncertainty, while avoiding biases introduced by subjective regularization choices. Our results show that Rayleigh-wave overtones carry resolvable sensitivity to density structure down to depths of order 100 m, enabling direct density estimation from seismic data with quantified uncertainties. We further evaluate commonly used velocity–density scaling relationships for firn (the transitional layer between fresh snow and glacial ice) and find that their application can lead to density errors on the order of 10%, with direct implications for inferred mass estimates.

Overall, these findings demonstrate that overtone-based probabilistic inversion enables constraints on weakly sensitive parameters and highlight the potential of DAS for quantitative near-surface parameter estimation.

Chasing Storms with Distributed Acoustic Sensing (DAS) in Fiordland, South Island, New Zealand

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Distributed Acoustic Sensing (DAS) is an emerging technology that uses laser pulses of a range of frequencies to exploit imperfections in fibre optic cables for measuring changes in the axial strain rate along the cable through coherent optical time-domain reflectometry. The Fiordland Seismological Sounding of Landslides and Earthquakes (FISSLE) experiment saw the deployment of a DAS array comprising ~7800 channels across ~31 km using a Silixa iDAS interrogator, through Milford Sound (Piopiotahi) within the Southern Alps mountain range of New Zealand. We use the FISSLE data to find and analyse records of thunder during storms from August to October 2024. Through synthesis with lightning strike data from the New Zealand Lightning Detection Network (NZLDN) operated by MetService, we have investigated the properties of these thunder signals.

Spectral analysis, waterfall plots, the computation of synthetic arrivals, and mapping of the events relative to the DAS array have enabled us to explore traits of the thunder signals and determine properties of a lightning strike that are conducive to a visible thunder signal recorded with DAS. We find that within a radius of 30 km, the sign and magnitude of the current is the primary control in the strength of the signal; with positive lightning strikes producing a much stronger signal. We observe and analyse both cloud-to-ground and intracloud lightning strikes; exploring differences in their properties. We also seek to utilise this data for constraining properties of the thunder signals, such as altitude where the shockwaves due to lightning strikes (thunder) originate, and the velocity at which this signal propagates. A further constrained and more complex understanding of how thunder signals propagate and arrive at DAS arrays could allow for the precise monitoring and tracking of thunderstorms using this technology; furthering knowledge and efforts in natural hazard management.

Distributed Acoustic Sensing for Environmental and Weather Monitoring Using Existing Fiber-optic Infrastructure

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Distributed Acoustic Sensing (DAS) transforms optical fiber cables into dense arrays of ground-motion sensors and is increasingly used in seismology. Beyond conventional seismic applications, DAS is also sensitive to environmental and weather-driven processes that contribute to long-period ground motion and seismic noise. We present results from a 16-km dark-fiber loop deployed on the research campus in Hamburg, Germany, demonstrating DAS sensitivity to wind-induced vibrations, temperature variations, thunderstorms, tidal effects, vibrations from heating and ventilation systems, and solar-radiation-driven thermal forcing.

Continuous DAS measurements collected over five months are compared with data from meteorological stations, tidal gauge data, and ERA5 atmospheric reanalysis. The DAS data shows strong correlations with air temperature (up to 0.85), wind-induced vibrations with characteristic spectral content between 10^{−4} and 10^{−2} Hz, and semi-diurnal tidal constituents (M₂ and S₂) with correlations up to 0.90. DAS also records long-period signals consistent with solar shortwave radiation through thermally induced fiber strain. These observations demonstrate that existing terrestrial and aerial telecommunication fibers can serve as dense, ground-based environmental sensor networks that complement conventional seismic, meteorological, and satellite observations. We further discuss the potential of integrating DAS with biosensing observations to support multi-hazard monitoring and early-warning applications.

Integrated Fiber-optic Sensing for Multi-environment Monitoring: Earthquakes, Ocean Waves, and Vehicle Signals

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Microwave-Frequency Fiber Interferometry (MFFI) is a specific implementation of Integrated Fiber-Optic Sensing (IFOS), which offers a scalable solution to the critical gap in transoceanic monitoring, leveraging existing telecommunication cables to measure integrated strain over thousands of kilometers. Unlike Distributed Acoustic Sensing (DAS), which is limited to near-shore observations (< 100 km), MFFI enables basin-scale sensing but suffers from a lack of interpretability regarding its signal nature and broadband capabilities. In this study, we present the first comprehensive empirical calibration of MFFI using a co-located DAS array on a 15.3 km terrestrial-submarine cable in Kefalonia, Greece. We derive and experimentally verify a conversion model demonstrating that MFFI signals can be quantitatively approximated by the spatial mean of DAS strain rates. Our analysis over a two-month period confirms MFFI’s broadband sensitivity across diverse environments: (1) In the oceanographic band (0.1–0.3 Hz), signals show a strong correlation with significant wave heights, validating sensitivity to seafloor pressure variations; (2) In the seismic band (1–12 Hz), we establish empirical detection thresholds of M_L 1.7 at 13 km and M_L 3.0 at 100 km, with high waveform coherence relative to DAS; (3) In the high-frequency band, the system effectively resolves localized anthropogenic signals (e.g., vehicles). These results validate MFFI not just as a timing tool, but as a reliable, quantitative long-baseline strainmeter for multi-environment monitoring.

High-resolution Directionality of Ocean Swell With the SWOT Mission and Fiber Sensing

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Observing swell direction is essential for wave forecast, coastal sediment transport, and microseism generation. Conventional buoys and satellites cannot well resolve the full direction due to lack of spatial resolution, which distributed acoustic sensing (DAS) and the SWOT satellite offer. However, both new technologies require calibration and validation. For DAS, it remains unclear whether strain results from seafloor compliance or direct pressure loading via the Poisson effect. What SWOT exactly measures at small scales is also not fully understood, as we expect filtering of the true wave field due to the acquisition and processing geometry. Using data offshore central California, we find that the spatial variation of wave phase is highly coherent between DAS and SWOT. Moreover, both DAS and SWOT provide much finer directional observation than a buoy. We also find strong directional sensitivity on DAS, where sensitivity maximizes along cable and minimizes at normal incidence. This suggests that the compliance effect dominates over the Poisson effect. The directional sensitivity also needs to be accounted for using DAS to sense other waves, such as for tsunami early warning. Whether other seafloor DAS systems sense via compliance can also be tested with SWOT.

What Is the Upper Frequency Limit of Secondary Microseisms?

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We present results from an experiment conducted with fiber-optic cable deployed on the seabed for telecommunication purposes off the coast of Freeport, Texas. The experiment’s settings allow us to measure horizontal strain at a dense spacing of 12.76 m over a 65-kilometer segment of the cable, which stretches from shore to a water depth of about 40 m. Given this multichannel system, we analyze the characteristics of the ambient seismic wavefield in the frequency-wavenumber domain. We observe ocean waves that travel at 8–15 m/s and exhibit a gravity-based linear dispersion relation for frequencies between 0.025 and 0.25 Hz and wavelengths between 40 and 500 m. We report that the energy of ocean waves attains either a single broad peak at 0.13–0.16 Hz or two separated peaks at 0.08 and 0.16 Hz. We also observe seismic waves in the form of multi-mode Scholte waves, with frequencies ranging from about 0.3 Hz to 2.0 Hz and 2.5 Hz for the fundamental and first modes, observed without correlation. The amplitudes of the Scholte waves are comparable to those of the seaward ocean waves and weaker than those of the landward ocean waves. The nonlinear interaction between landward and seaward waves, as described by the Longuet-Higgins mechanism, can give rise to Scholte waves at frequencies up to 0.5 Hz, since the highest ocean-wave frequency is 0.25 Hz. Our study shows that, for an enclosed body of water, e.g., a gulf, primary and secondary microseisms propagate at frequencies slightly higher than those generated near the open ocean, and other sources of seismo-acoustic energy must be considered to explain the excitation of Scholte waves at frequencies between 0.5 and 2.5 Hz.

Denoising Distributed Acoustic Sensing (DAS) Data for Shallow-water Observations

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Distributed Acoustic Sensing (DAS) offers a cost-effective means to complement existing offshore monitoring networks by enabling long-term, spatially dense observations. However, field data from multiple DAS deployments consistently reveal strong, non-stationary high-frequency noise in shallow-water environments (water depth < ~100 m). This noise substantially degrades DAS data quality and poses a persistent challenge for DAS applications in shallow waters, including marine mammal monitoring.

Using DAS data collected on the Martha’s Vineyard Coastal Observatory (MVCO) submarine cable (water depth < 20 m), we investigate the characteristics and impact of this shallow-water noise. We observe that high-frequency noise (>1 Hz) is strongly correlated with ocean gravity waves in the 0.1–0.5 Hz band, with noise levels systematically elevated near the peaks and troughs of gravity waves. The noise is spatially incoherent, even between adjacent DAS channels, and is absent in recordings from a co-located hydrophone. This incoherency significantly limits the effectiveness of conventional denoising approaches, such as *f*–*k* filtering. To mitigate this type of noise, we develop a coherency-based muting and reconstructing approach that combines non-

stationary thresholding with damped rank reduction. The method is applied to MVCO DAS data, where fin whale calls are used as representative high-frequency signals to evaluate performance. The denoised DAS records exhibit substantial improvements in signal-to-noise ratios and show agreement with the co-located hydrophone. During periods of strong signals, denoised and stacked DAS achieves whale-call detection performance comparable to the hydrophone, reaching up to ~70% of the hydrophone detection rate. These results demonstrate that the proposed approach effectively suppresses shallow-water noise and enhances the recovery of weak high-frequency signals, thereby improving the utility of DAS for shallow-water seismic and acoustic observations.

Improving Travel-time Estimation in Distributed Acoustic Sensing Data Through Denoising

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Distributed acoustic sensing (DAS) provides high-resolution wavefield measurements compared with conventional seismic arrays. By applying waveform cross-correlation, channel-wise time differences can be estimated and subsequently used to locate and distinguish different seismic sources. However, channel coherency is often degraded by high-frequency noise, cable coupling, and signal polarization, leading to unstable delay measurements or cycle skipping, particularly when signals are weak. Here, we apply a deep learning-based denoising model to improve the quality of DAS data for better travel-time estimates. Using the Physics Experiment-1A chemical explosion dataset from the Nevada National Security Site (Myers et al., 2024), we find that denoising improves channel-wise coherency, with the median cross-correlation coefficient (CC) increasing by ~0.1 for both the 06Bypass and P-Main segments, based on 81 candidate aftershock events. To further quantify the improvement in travel-time estimates, we fit a constant apparent velocity by minimizing the misfit between observed inter-channel delays and the delays predicted from channel spacing. The median root mean square error improves from 0.15 s to 0.08 s for 06Bypass segment, and 0.78 s to 0.32 s for P-Main segment. These results indicate that denoising can improve the stability of travel-time and apparent velocity estimates in DAS data, which has the potential to enable more reliable event detection and source localization.

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Observation of Submarine Earthquake Swarm Activity in the Tokara Islands Region Using Distributed Fiber-optic Sensing on a Submarine Telecommunication Cable

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Since June 2025, earthquake swarm activity has intensified in the Tokara Islands region of the southwestern Ryukyu Islands, Japan. On July 2, a Mw 5.7 earthquake and significant offshore crustal deformation occurred, resulting temporal evacuation of the residents of nearby islands. However, because the source area is located offshore and conventional seismic stations are limited to the islands, it has been difficult to resolve the detailed spatial distribution and temporal evolution of the activity. To address this observational gap, we applied distributed fiber-optic sensing to an existing submarine optical fiber communication cable connecting the islands. Two fiber cores of the Akuseki Island–Takarajima submarine telecommunication cable were connected to distributed fiber-optic sensing systems (distributed acoustic sensing and Rayleigh-based strain sensing), and continuous observations were conducted from 16 September 2025 to 13 January 2026. This experiment represents the first application of distributed fiber-optic sensing to monitor ongoing earthquake swarm activity in the Tokara Islands region using operational telecommunication infrastructure. Extremely frequent seismic activity, at a rate of

approximately one event per minute, was detected by distributed acoustic sensing. Most of the observed earthquakes were shallow crustal events. The observed earthquakes are often not detected by the island-based seismic network, including of those occurred at very shallow depths beneath a spatially limited offshore area, suggesting a possible link to submarine volcanic processes. In parallel, Rayleigh-based strain observations of the submarine cable revealed tidal but non-stationary strain variations, which are likely to reflect temperature changes in the seafloor water. These results demonstrate that distributed fiber-optic sensing using submarine telecommunication cables provides a novel and highly effective means of monitoring offshore seismic and volcanic activity in island regions, and continuous utilization of such infrastructure is expected to significantly enhance regional hazard assessment and safety.

Volcanic Crisis Unraveled Using Fiber Optic Sensing of a Sub-haul Cable on the Reykjanes Peninsula, SW Iceland

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We present the first(?) fully operational volcano early-warning system based on distributed acoustic sensing (DAS) data. The system is operated by the Icelandic Meteorological Office (IMO), the State Volcano Observatory, and represents a major advance in real-time monitoring of volcanic activity in Iceland. Iceland is one of the most tectonically active regions on Earth, hosting 32 active volcanoes and forming the only subaerial expression of the Mid-Atlantic Ridge. On the Reykjanes Peninsula in southwest Iceland, volcanic activity resumed in 2021 after ~800 years of quiescence. Since then, 2 volcanic systems have erupted repeatedly: Fagradalsfjall (3 eruptions between 2021–2023) and Sundhnuksgígarod (9 eruptions since December 2023), threatening the town of Grindavik and critical infrastructure, including a geothermal power plant. Basaltic fissure eruptions in the area produce fast-flowing lavas that can inundate roads and infrastructure within less than an hour from eruption onset, making reliable early warning essential for evacuation and hazard mitigation. The warning system builds on a collaboration initiated in early 2024, when a DAS interrogator detected a low-frequency signal, related to minute-scale ground deformation prior to eruptions. This signal has now been observed before 6 eruptions, each time providing a clear and actionable warning. In January 2025, IMO permanently deployed a DAS system monitoring 2 fiber-optic sub-haul cables with a total length of ~150 km. Real-time processing uses a simple amplitude-stacking threshold to trigger automatic alerts in the monitoring center. In addition, data from both fibers are used to produce automatic distributed dike models showing magma-induced deformation. The July 2025 eruption demonstrated excellent performance, correctly predicting both timing and location. The system detects a wide range of volcanic and microseismic signals and remains effective during severe weather when conventional seismometers degrade. To date, the system has successfully warned for all 6 eruptions, with lead times between 40 minutes and 3 hours, and zero false or missed alerts.

Ocean Bottom Boundary Layer Turbulence Scaling From the Vibrations of a Subsea Cable With Long-range Fiber-optic Sensing

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Bottom boundary-layer (BBL) turbulence is a key sink of ocean kinetic energy and a major control on the boundary-interior exchanges that shape large-scale circulation. Yet, turbulence and bottom-drag parameterizations remain poorly constrained at basin scales. We use vibrations of an operational Ireland-Iceland subsea telecommunication cable, measured with long-range fiber-optic interferometric sensing, to recover near-bed velocity fluctuations and infer turbulence scaling. Where the cable is locally unburied, vortex-induced vibrations (VIV) generate narrow spectral peaks in fiber-sensing data whose dominant frequencies map to flow speed via the Strouhal relation, following Mata-Flores et al. (2023).

Although repeater-spaced sensing averages strain over ~100-km spans, VIV peaks remain resolvable because vibration amplitudes are large. We detect and track peaks to form vibrational frequency time-series, convert frequency to velocity with the Strouhal relation, and analyze the resulting velocity fluctuations. Using Taylor’s frozen-turbulence hypothesis to map frequency to wavenumber, we find that velocity spectra follow the classic $k^{-5/3}$ scaling of Kolmogorov (1941) for isotropic turbulence. We then fit an inertial-subrange spectral model over length scales of ~100-10 m to estimate time-dependent and location-dependent variability in turbulence parameters.

VIVs are strongest over rough shelf bathymetry. Some spans shows continuous, tidally-modulated frequency wandering with multiple simultaneous peaks, consistent with several exposed segments responding to evolving near-bed flow. Other spans exhibit intermittent, tidally-gated quasi-stationary peaks with overtones, suggestive of episodic lock-in (vortex shedding frequencies matching or exceeding cable vibrational modes, which may inhibit flow velocity estimation). Inferred values for turbulence intensity and dissipation rate are physically reasonable, demonstrating that existing telecom infrastructure can provide sustained, basin-scale constraints on BBL turbulence relevant to ocean circulation models.

Analysis of Seismic Body-waves Observed on Multiple Spans of the Iris Subsea Fiber-optic Cable Connecting Iceland and Ireland

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About 70% of the Earth’s surface is covered by ocean, making observations of seismic waves difficult and expensive in vast regions of the globe. Recently, seismic waves have been observed using transmission fiber-optic sensing on trans-oceanic subsea cables, making them an exciting potential addition to global seismic networks (f.ex. Marra 2018,2022; Zhan, 2021; Mazur 2024; 2025).

In this study we investigate the potential of using observations of seismic body-waves on subsea cables for quantitative seismological studies. We use a fiber optic sensing instrument prototype capable of measuring the integrated strain over each span between repeaters (typically 100 km) of a subsea cable, over its entire length. This way each span acts as an individual sensor, allowing for a separation of signals from different parts of the cable, leading to higher S/N ratios on quiet deep-water segments and more easily interpreted waveforms. The instrument recorded data on 17 spans of the IRIS subsea cable, which connects Iceland and Ireland, and operated from May 2024 - March 2025. During this time almost 300 earthquakes larger than M 5.5 occurred globally.

We attempt to pick P-waves for all events with M > 5.5 and at distances < 100° on all the spans. We compare the timing of the picks to predicted P-wave arrivals and investigate how the quality of the picks varies with observed

frequency, subsea environment and back-azimuth relative to local cable orientation. Furthermore, we simulate the waveforms of the body-wave train, using the seismic wavepropagation software SPECFEM3D, and compare to observed data. We find that some phases are relatively well recovered whereas others are not, and discuss possible reasons for this difference.

DAS Beyond Repeaters: Multi-span Monitoring Using Submarine Cables in the Pacific Ocean

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Distributed acoustic sensing (DAS) transforms seafloor fiber-optic cables into dense arrays of strain sensors. Until recently, observations have been limited by optical repeaters to the first cable span, typically <100 km offshore. Advancements by Nokia Bell Labs, which leverage the high-loss loopback couplers within repeaters, now allow for multi-span recordings of strain across the entirety of transoceanic cables. This technique has been used to successfully record the 2025 M8.8 Kamchatka earthquake and tsunami at teleseismic range with a spatial resolution of ~100 m across 4400 km of seafloor fiber. In November 2025, the multi-span system was deployed for 3 months on both cables of the Ocean Observatories Initiative Regional Cabled Array (OOI RCA) offshore Oregon, spanning the forearc of the Cascadia subduction zone and extending ~500 km to Axial Seamount. Simultaneously, the first span of the south cable was interrogated with a multiplexed conventional DAS unit and data continued to stream from cabled seismometers, hydrophones, and other oceanographic instruments on the OOI RCA. During the initial testing, a regional earthquake was successfully recorded by the multi-span system. The dataset will be publicly available following documentation and data quality checks. We seek to characterize the noise floor and sensitivity of this technique in comparison to co-located seismometers and conventional DAS interrogators, and in turn, explore its potential for applications including routine earthquake monitoring, earthquake early warning, and oceanographic and marine mammal observation. We will report preliminary results from the experiment including the overall background noise characteristics and the nature and consistency of seismic, oceanographic and acoustic signals between the data types. These results represent an important step toward detailing the broader value of this technique for the seismic community and beyond.

Fiber-Optic Sensing Applications in Seismology and Environmental Science [Poster]

Poster Session • Friday 17 April

Conveners: Mahbubah Ahmed, Virginia Polytechnic Institute and State University (mahbubah@vt.edu); Ettore Biondi, Stanford University (ettore88@stanford.edu); Xiaowei Chen, Texas A&M University (xiaowei.chen@tamu.edu); Valey Kamalov, International Institute for Ocean Fiber Sensing (vkamalov@gmail.com); Voon Hui Lai, Australian National University (voonhui.lai@anu.edu.au); Jiaxuan Li, University of Houston (jxli@uh.edu); Mikael Mazur, Nokia Bell Labs (Mikael.mazur@nokia-bell-labs.com); Meghan C. Quinn, U.S. Army Engineer Research and Development Center (meghan.c.quinn@usace.army.mil); Qibin Shi, Rice University (qs20@rice.edu); Joseph P. Vantassel, Virginia

POSTER 69
Machine Learning-based Classification of Polar Marine Signals Recorded With Distributed Acoustic Sensing
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Distributed acoustic sensing on Arctic seafloor cables has a demonstrated capability to observe an array of environmental and anthropogenic signals, even when entrenched two or more meters below the seafloor. As such, DAS has the potential to provide continuous, high resolution monitoring of Arctic waterways for maritime operations and environmental science with minimal ecological or logistical risk. A major hurdle in implementing this technology is the storage, telemetry, and processing of its enormous data volumes, which may be on the order of terabytes per day. A solution may be found with machine learning classification algorithms trained on in situ signal catalogs and optimized for edge computing hardware to provide near real time analysis. We present a catalog of seafloor DAS-observed seismoacoustic signals generated by coastal oceanic processes in open water, ice bound, and transitional conditions, manually curated from 250 TB of DAS data recorded in the Beaufort Sea, Alaska since 2021. We also present initial results for a self-supervised machine learning classifier trained for pattern-of-life analysis and low latency signal identification.

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POSTER 70
Characterising Low-frequency DAS Behaviour at the Safod Borehole
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Low-frequency distributed acoustic sensing (DAS) enables fiber optic arrays to record long-period strain and deformation signals, in addition to seismic wavefields. We analyze approximately one year of DAS recordings from a 900-m-long fiber optic cable cemented behind casing in the San Andreas Fault Observatory at Depth (SAFOD) within the pilot borehole, Parkfield, California, to assess faulting-related deformation processes and potential noise sources at low-frequency bands. In fault-zone boreholes, such measurements can bring observations closer to seismogenic depths, helping to link phenomena associated with earthquake generation and episodic fault creep with longer-timescale deformation processes.

We examine seven-day windows of SAFOD DAS data containing continuous data coverage, which were recorded from 2024-05 to 2025-05. Focusing on frequencies below 0.01 Hz, we compute time- and frequency-domain measures across roughly 900 channels and analyze the stability of low-frequency amplitudes and spectral shapes along the cable and over time. The records show a clear day–night modulation of low-frequency amplitudes and persistent spatial coherence, with neighbouring channels exhibiting similar amplitude levels over time. We also identify a short data gap followed by a step-like increase in apparent low-frequency amplitude, with no change in gauge length or sampling, as well as several multi-day episodes of low-frequency energy across parts of the array. These preliminary observations suggest distinct regimes of long-period DAS behaviour at SAFOD, including signals potentially relevant to tremor and fault-creep–related deformation, and provide a baseline for interpreting future observations from a planned 3.1-km-long DAS array, enabling improved constraints on the long-term fault-zone mechanical behaviour of the San Andreas Fault system.

POSTER 71
Using Telecom Cable With Ambient-noise Interferometry for Urban Seismic Hazard Assessment: A Case Study in New York City
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The eastern United States is an intraplate region that has under-appreciated seismic risks due to long seismic cycles, high population density, and built infrastructure. However, significant earthquakes close to metropolitan regions, such as the recent April 2024 Mw 4.8 Tewksbury event in New Jersey, remind us of the existing seismic hazard. The seismic waves decay more slowly in the hard crust and can be amplified by shallow sediments. Dormant faults that are often not well-characterized exist. Accurately assessing seismic risks relies on characterizing shallow crustal structure and the fault systems. In busy urban areas, conventional seismic station deployment can be difficult, necessitating a need to leverage the city’s large telecom infrastructure for seismic subsurface characterization and monitoring.

In this study, we explore the potential of using a Columbia University-owned telecom cable with Distributed Acoustic Sensing (DAS) to image the subsurface structure and the active 125th Street Fault in New York City (NYC). This is the first DAS experiment in NYC that used the dense coverage of the telecom infrastructure for urban seismic applications. The cable is ~3 km long, situated beneath Amsterdam Avenue and Broadway on the Upper West Side of Manhattan. The cable crosses the eastern section of the 125th Street Fault. We collected one month of continuous strain data and located the coordinates of the DAS channels using a hammer tap test along the cable. The recorded strain data captures abundant environmental signals from passing pedestrians and vehicles. We apply ambient noise interferometry to the one-month continuous data to extract coherent surface waves. We explore signal processing techniques, such as three-station interferometry, to enhance the target surface waves and use them to image the shallow velocity structure. Coupling of the cable and local, non-coherent noise poses challenges to our ability to extract signals from surface waves. We investigate solutions to those challenges to extend this study to the larger NYC region, and possibly other large, densely developed urban spaces.

POSTER 72
Tracking Hypersonic Re-entering Space Debris Using Distributed Acoustic Sensing
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We face a growing threat from re-entering space debris. This is compounded by the extreme difficulty of tracking objects once they are actively breaking up within the atmosphere, and as such impact and fallout locations are very challenging to predict. Recent studies (e.g. Fernando & Charalambous, 2026) have shown that seismoacoustic data can help alleviate this uncertainty via tracking and characterisation of the sonic booms produced by objects re-entering at hypersonic velocities.

In this work, we will show that the use of distributed acoustic sensing to track re-entering space debris can take us one step further, placing tighter constraints on source altitude and position than is possible from conventional seismic or acoustic data alone. We will demonstrate our results via a case study of the re-entry of Shenzhou-15 in April 2024 across Southern California, which was recorded on the DAS system at the Ridgcrest Fibre. By combining DAS and conventional seismic data, we are able to constrain the object’s trajectory to Mach 25-30 (7-8 km/s), an angle of 64 degrees from north and a descent vector of approximately 1 degree, with a fragment size of approximately 0.5 m. Infrasound propagation modelling was used to evaluate the relative effects of a realistic atmosphere on parameter estimates.

POSTER 73
Characterization of Urban Seismicity Using Multi-fiber Distributed Acoustic Sensing
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Distributed Acoustic Sensing (DAS) enables dense seismic measurements in urban environments by repurposing existing telecommunication infrastructure. Athens presents an ideal setting, as Greece is among Europe’s most seismically active countries, and the Athens metropolitan area lies within a geologically complex basin whose vulnerability was demonstrated by the destructive 1999 Mw 5.9 Parnitha earthquake. We present results from a multi-fiber DAS experiment conducted in Athens, Greece, from 16 May to 30 June 2025, using four telecommunication fibers provided by the Hellenic Telecommunications Organisation (OTE). Two interrogators simultaneously recorded data using the four fibers with lengths of approximately 24, 38, 42, and 48 km, providing extensive azimuthal coverage of Athens, which makes the study one of the largest urban DAS campaigns ever performed.

Data were acquired in two configurations, a lower spatial resolution mode optimized for earthquake recording and a higher resolution mode for ambient noise interferometry. To detect seismic events, we applied bandpass filtering followed by phase-weighted stacking across channels and STA/LTA (short-term average / long-term average) triggering to identify candidate events. During the acquisition period, the National Observatory of Athens recorded 2,645 events across the broader seismic network, of which 548 were detected on at least one fiber. Notably, the DAS array also recorded numerous small events not present in the NOA catalog. For nearby events, we pick P- and S-wave arrivals to constrain body-wave travel times. These picks are also used to locate events in the NOA catalog, which enables us to compare with network-derived hypocenters and allows us to assess potential improvement from the dense DAS coverage, before applying the approach to smaller events detected only by DAS. The travel-time data will also serve as input for 3D eikonal traveltimes tomography to image subsurface velocity structure beneath metropolitan Athens.

POSTER 74
Far-field Tsunami Detection Using Submarine Distributed Acoustic Sensing
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Submarine Distributed Acoustic Sensing (DAS) has recently been proposed as a potential tool for offshore tsunami monitoring and early warning. However, direct observations of earthquake generated low-frequency tsunami waves remain limited due to the infrequent occurrence of trans-ocean tsunamis and sparse long-term offshore DAS deployments.

We present DAS observations of far-field tsunami waves generated by the 2025 Mw 8.8 Kamchatka earthquake, recorded on the SeaFOAM submarine DAS cable in Monterey Bay, California. Continuous DAS strain data reveal coherent signals below 8 mHz propagating along tens of kilometers of the cable, exhibiting clear phase velocity dispersion. We model the tsunami wave propagation from the source region to the U.S. West Coast and compare predicted arrival times and wavefield evolution with both DAS observations and a nearby coastal tide gauge. The agreement confirms the tsunami origin of the observed signals. Our results demonstrate that submarine DAS can directly resolve dispersive, far-field tsunami wavefields from great earthquakes, providing a spatially dense offshore complement to traditional tsunami monitoring systems.

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Enhancing Distributed Acoustic Sensing Sensitivity for Hydroacoustic Monitoring: A Comparative Analysis Using Collocated Hydrophones
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Submarine Distributed Acoustic Sensing (DAS) enables cost-effective hydroacoustic monitoring with dense spatial sampling. However, its broader application is limited by a high intrinsic noise floor and poorly constrained responses between acoustic wave pressure and cable strain. We evaluate the noise characteristics and detection capability of submarine DAS for ocean acoustic signals in the 1–200 Hz band through direct comparison with collocated hydrophones. We analyze three collocated datasets: SeaFOAM DAS in Monterey Bay, OOI DAS offshore Oregon, and MVCO DAS at the Martha’s Vineyard Coastal Observatory. We compare the signal-to-noise ratios (SNRs) of DAS and hydrophones for a range of acoustic sources, including natural T-waves (1–10 Hz), fin whale calls (~20 Hz), wind-farm pile-driving signals (10–200 Hz), and the Kauai Beacon active acoustic transmissions (56–94 Hz). Across all cases, single-channel DAS records consistently exhibit lower SNR than hydrophones. Stacking multiple channels or applying denoising (e.g., f-k filtering) improves SNR, but DAS still exhibits lower SNR than hydrophones for most source types. A key limitation for DAS array stacking is the reduced coherence of target signals across channels. When coherence can be enhanced or effectively recovered for repeating signals (e.g., stacking cross-correlation functions from repeating T-wave sources across channels, rather than the waveforms), DAS can achieve substantially higher SNR than hydrophones. At higher frequencies (>100 Hz), additional challenges arise from DAS gauge length and sampling frequency limitations. Fully resolving high-frequency signals requires shorter gauge lengths and higher sampling rates, substantially increasing already large data volumes and computational demands. Our results highlight the critical challenges associated with submarine DAS data and emphasize that realizing the full potential of DAS for hydroacoustic monitoring will require improved understanding of cable-water-seabed coupling, coherence-enhancing processing strategies, and optimized acquisition parameters.

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Mapping Fault Zone Attenuation Using Midas Downhole Optical Fiber and Borehole Seismic Arrays
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Fault zone architecture provides critical insights into earthquake dynamics. Structural components—fault core, damage zones, and host rocks—influence seismic behavior. The quality factor (Q), representing seismic attenuation (Q⁻¹), is inversely related to fracturing; higher fracture density corresponds to lower Q and greater energy dissipation. Permeability in these zones facilitates fluid migration, altering fault strength and earthquake nucleation. The Milun Fault, an active east-dipping, left-lateral reverse fault in Taiwan’s Longitudinal Valley, caused the 1951 and 2018 earthquakes. The MiDAS (Milun Fault Drilling and All-inclusive Sensing) project initiated scientific drilling in 2021, integrating fiber sensing and borehole seismometers in 2022. Hole-A intersects the slip zone at 520–540m, enabling high-resolution attenuation mapping via DAS and seismometers. We estimate Q along Hole-A using DAS, validated by seismometer data. Before high-resolution mapping (4m spatial resolution), we analyzed six events (~20km away) using paired seismometer and fiber data. Acceleration and strain-rate datasets were integrated into velocity and strain. STA/LTA identified arrivals, raytracing selected events with incidence <30°. Arrival times and effective shaking duration (ESD) defined P, S, and noise windows. Spectral ratios estimated attenuation parameters Q_p and Q_s from t_p and t_s via least-squares fitting. Results showed high consistency between systems. We then scaled to >1,000 local events (2022–2025, M2.0–4.5, incidence <30°) to investigate possible temporal variations, particularly those associated with earthquakes. Using a sliding window on this DAS dataset, we aim to resolve high-resolution Q profiles across Hole-A and characterize depth-dependent variations within the fault zone. Preliminary results show low Q values (in the tens) across Hole-A with a Q_p/Q_s ratio of ~1.5, consistent across sensors. We are currently conducting synthetic waveform modeling via FK analysis with prescribed Q values to compare with observed seismograms, ensuring the methodology accurately reflects the fault zone’s physical properties.

Detection of Atypical Events in Continuous Downhole Distributed Acoustic Sensing (DAS) Monitoring Using Deep Learning

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Distributed Acoustic Sensing (DAS) is an emerging technology that converts standard optical fiber into dense array of virtual sensors, enabling high-resolution detection of acoustic signals along the entire length of optical fiber. An M_w 6.4 earthquake that struck eastern Taiwan on 6 February 2018 highlighted the seismic hazard posed by the Milun Fault, as demonstrated by severe structural damage in Hualien City. To investigate fault structures and seismic activity in this region, the Milun Fault Drilling and All-inclusive Sensing (MiDAS) project drilled a borehole across the fault zone. A downhole fiber-optic cable was deployed and connected to a DAS interrogator for continuous monitoring. The system recorded both earthquakes and a series of atypical signals. These atypical signals distinguished by short durations and rapid attenuation that render them challenging to identify using conventional approaches. To address this challenge and investigate the origin of atypical events, we developed a deep learning framework and applied it to three months of continuous downhole DAS data. The framework successfully detected both earthquakes and atypical signals, with the latter concentrated between 250-360 m depth and cautiously attributed to transient disturbances arising from the early-stage hydration of lower-density cement grout. Their frequency declined markedly following cement solidification, representing the first documented DAS observations of signals linked to this process. More broadly, our findings highlight the potential of integrating deep learning with DAS to detect transient vibration signals, including those generated by fracture processes during gas or fluid injection, underscoring its value for advancing subsurface monitoring and hazard assessment.

First Simultaneous Seismic Event Recordings by DAS and 3-Component Seismometer Arrays at the Low Noise Underground Laboratory (LSBB, Rustrel, France): A Preliminary Analysis

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Array-based methods enhance detection of weak coherent arrivals in low signal-to-noise conditions, enabling detection and localization of low-magnitude seismic events from local to teleseismic scales. Over recent years, optimized array-processing approaches have been developed to address a wide range of configurations, including single- and multi-sources, vertical and three-component recordings, and planar as well as three-dimensional arrays. In parallel, Distributed Acoustic Sensing (DAS) based on fiber-optic technology has emerged as a promising complementary approach, offering continuous spatial coverage and very high spatial sampling. Previous studies have shown that DAS systems can record strong teleseismic events as well as local and regional microseismicity.

At the Low Noise Underground Laboratory (LSBB, Rustrel, southern France, <https://www.lsbb.eu/>), a permanent three-dimensional (3D), three-component (3C) seismometer array is complemented by a DAS array deployed along an underground gallery. Continuous DAS data have been available since mid-December 2025, following earlier discontinuous acquisitions, enabling a direct comparison between the two measurement technologies. The DAS system uses approximately 30 km of fiber distributed along a 3 km gallery, forming a planar array with a 1.6 km aperture co-located with the five deepest permanent stations along the tunnel. The deepest station is located more than 500 m below the top of the mountain.

This work aims to develop array-processing methods adapted to DAS data, evaluate the performance of this emerging technology relative to the seismometer array, and enhance 3D and 3C analyses of seismic observations. We present preliminary results from a limited set of seismic events recorded simultaneously by the DAS and seismometer arrays at LSBB, illustrating differences and complementarity in detection capability and signal characteristics.

Thermal Characteristics of the Milun Fault Using Borehole Optical Fiber Sensing

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Understanding the thermal characteristics of fault zones provides critical insights into earthquake dynamics, fluid transport, and fault mechanics, as temperature anomalies may reflect frictional heating, fluid migration, or variations in lithology. The Milun Fault, an active east-dipping, left-lateral reverse fault, is located in the northern section of Taiwan's Longitudinal Valley. This fault has been responsible for multiple major earthquakes over the past decades. Due to its frequent slip behavior, the Milun Fault Drilling and All-inclusive Sensing Project (MiDAS) initiated a scientific drilling program in 2021 to monitor the fault's thermal and mechanical properties. The MiDAS Hole-A borehole, located on the northwestern edge of the Milun Terrace, directly intersects the fault zone and is equipped with a distributed temperature sensing (DTS) system, enabling high-resolution and continuous temperature monitoring along its depth.

Since September 2022, long-term DTS monitoring has identified a long-lived but decaying temperature anomaly at depths of 540–580 m beneath the fault zone, persisting through August 2025. The origin of this thermal anomaly remained unclear until a recent analysis of DTS data acquired during cementing operations in January 2022, which reveals that the observed anomaly was primarily caused by heat released during the cementing process. However, this finding raises further questions regarding the depth-dependent variation in thermal decay rates, particularly the slower cooling observed below the fault zone. To address these issues, we evaluate the thermal properties of the fault zone using cementing related DTS data and compare the inferred thermal diffusivity with laboratory measurements obtained from retrieved fault core. This approach allows us to map detailed thermal characteristics along Hole-A. After removing cementing induced thermal effects, the results will help in understanding the mechanisms controlling temperature variations near active fault zones and improve the interpretation of thermal signals in earthquake-prone regions.

Deep Learning-based Microseismic Detection using Hybrid DAS and Geophone Arrays: Case Studies in Chiayi and Hualien, Taiwan

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Taiwan is located along the plate boundary between the Eurasian Plate and the Philippine Sea Plate, where ongoing arc continent collision drives intense crustal deformation, frequent seismicity, and numerous damaging earthquakes. Rapid and high-precision earthquake detection and location is therefore essential for constraining seismogenic structure and assessing seismic hazards. In this study, we evaluate the feasibility of integrating Distributed Acoustic Sensing (DAS) with conventional seismic networks for microearthquake detection and location. On September 5, 2023, a magnitude 5.58 earthquake struck the Xingang area in Chiayi. A temporary dense seismic monitoring network was established in the area, and a fiber-optic array utilizing telecommunications cables from Chunghwa Telecom was incorporated into the joint observation to analyze the aftershock sequence. In Hualien area, the MiDAS project constructed a 3-D fiber array for long-term fault zone observations, allowing us to test capability of DAS in detecting local microearthquakes and shallow structure. Building on the recently developed ML-based workflow, AutoQuake (Yang et al., 2025), this study aims to integrate DAS data into a unified workflow to enhance microearthquake detection and location capabilities for the detailed investigation of shallow fault structures.

Automated Multi-source Signal Detection and Classification Applied to Submarine Fiber-optic Cables

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Distributed Acoustic Sensing (DAS) applied to existing submarine telecommunication fiber-optic cables provides high-density spatial sampling and continuous temporal monitoring, enabling the acquisition of diverse offshore dynamic signals. However, DAS data are vast and complex, containing earthquakes, volcanic activity, vessel movements, and various environmental noises, which pose significant challenges for reliable signal identification. This study proposes an integrated DAS signal analysis workflow for submarine

fiber-optic cable observations that combines classical seismological signal detection methods, Density-Based Spatial Clustering of Applications with Noise (DBSCAN), and deep learning image recognition to achieve automated multi-source signal classification. Candidate signals are first extracted from DAS time-series data using the Short-Term Average over Long-Term Average (STA/LTA) method, effectively reducing background noise and constraining the analysis scope. Signal features with spatial continuity are then identified in the time–channel domain, and DBSCAN is applied to cluster coherent energy propagations in high-noise, high-dimensional DAS environments. Differences in spatial extent, temporal persistence, and energy distribution of the resulting clusters are analyzed as the basis for preliminary classification of seismic events, volcanic activity, vessel signals, and others. Based on the clustering results, events are converted into waterfall plot images and classified using deep learning image recognition techniques to improve classification stability and reduce manual workload. In addition, Fourier transform analysis is performed to examine spectral characteristics as supplementary evidence for signal identification. Tests on real DAS data recorded by submarine fiber-optic cables demonstrate that the proposed workflow can stably detect physically consistent events and maintain robust classification performance in complex signal environments, providing an interpretable and extensible framework for multi-source DAS signal analysis.

Avalanche Characteristics With Distributed Acoustic Sensing Near Milford Sound/Piopiotaḥi, New Zealand

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Snow avalanches are a major natural hazard that pose significant risks to alpine environments in terms of safety and infrastructure maintenance, and are often highly unpredictable. Fiordland's Milford Sound/Piopiotaḥi is part of the Southern Alps/Kā Tiritiri o te Moana, and is characterized by heavy precipitation, steep glacier-carved topography, and rapid erosion. Milford Sound/Piopiotaḥi attracts over 800,000 visitors annually, with most arriving by road. State Highway 94, also known as Milford Road, the road connecting Milford Sound/Piopiotaḥi to the rest of New Zealand, is monitored by the Milford Road Alliance, which uses various types of observations (e.g., weather forecasts, meteorological data, webcams, infrasound sensors) to manage avalanche risk. While this system provides valuable information for hazard management, the timing and spatial accuracy of avalanche records can be limited, particularly for events occurring farther from the road or during nighttime hours.

We repurpose a dark telecommunication fiber running along Milford Road, which starts from Milford Sound/Piopiotaḥi and crosses several avalanche-prone regions, as part of the Fiordland Seismological Sounding of Landslides and Earthquakes (FISSLE) project. This results in a 31 km long Distributed Acoustic Sensing (DAS) array. The DAS array recorded 164 avalanches, both natural and triggered, between June and September 2024. We apply signal processing techniques to detect and characterise avalanche events on the recorded data. We analyse the spatio-temporal evolution of the waveforms and frequency content of different types of avalanche signals (e.g., wet slab, storm slabs). Weather data indicate that the natural avalanches examined here occurred during local peaks in precipitation.

Monitoring CO₂ Injection at Svelvik Field Lab With Passive Downhole DAS and Ambient Noise Interferometry

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Continuous monitoring of CO₂ injections is essential for safe and controlled plume migration within CCUS projects and for implementing effective

Measurement, Monitoring and Verification (MMV) plans. While traditional 4D seismic surveys provide high-resolution snapshots of subsurface changes, they are costly, temporally sparse, and logistically demanding. Distributed Acoustic Sensing (DAS), in contrast, provides a dense, permanently deployed surface and downhole array enabling both active and passive measurements with continuous temporal coverage, offering a cost-effective and low-impact alternative for near-well monitoring.

In this study, we present continuous passive downhole DAS monitoring of CO₂ injection at the shallow Svelvik Field Lab (Norway) and assess its potential for near-well plume surveillance. Ambient seismic noise was recorded continuously along a 65 m injection well and four 100 m monitoring wells during a one-week CO₂ injection, framed by pre- and post-injection baseline periods. Spectral analysis revealed three main noise regimes: low-frequency industrial noise (2–30 Hz) associated with nearby quarry activity, injection-related high-frequency energy (50–200 Hz), and persistent electrical/mechanical interference (200–400 Hz). Cross-correlations in the 2–30 Hz band revealed coherent surface-wave arrivals from a repeatable weekday source, providing a stable opportunistic source for interferometric monitoring consistent with MMV objectives.

Preliminary reconstruction of Stoneley waves from ambient noise in the 30–80 Hz band along the downhole array further suggests the potential to track fluid-sensitive guided waves that correlates with CO₂ saturation and plume migration. These results show that passive DAS, combined with ambient-noise interferometry, can deliver high-resolution, continuous monitoring around injection wells. DAS provides a technically robust and economically viable tool for CCUS MMV strategies, supporting safe, controlled, and verifiable CO₂ plume management over extended periods.

Efficient Microseismic Signal Enhancement With Distributed Acoustic Sensing in Borehole Installations

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Distributed Acoustic Sensing (DAS) is a powerful technology for a dense, high-resolution seismic monitoring, providing detailed images of the seismic wavefield. Such features make DAS particularly suitable for challenging environments and deep boreholes, such as those used in Carbon Capture and Storage (CCS) and Enhanced Geothermal Systems (EGS) projects. However, DAS recordings typically exhibit higher noise levels than conventional seismic sensors, limiting the detection and characterization of weak microseismic events. Additionally, large-scale monitoring campaigns generate massive data volumes, making computational efficiency essential for real-time applications. While existing denoising strategies show promising results, many rely on computationally demanding deep learning approaches or require extensive parameter tuning and model training, which limits their use during real-time acquisition.

We introduce a computationally efficient denoising method derived from image-processing techniques and tailored specifically for DAS datasets. The approach is designed to be robust on signals with a low signal-to-noise ratio (SNR) and easy to implement as a “plug-and-play” signal enhancement tool for DAS processing workflows. We evaluate its performance using DAS recordings from the Bedretto Underground Laboratory for Geosciences and Geoenergies, located in Switzerland, where multiple instrumented boreholes surrounding a stimulation well enable high-resolution monitoring of induced seismicity across hundreds of meters.

We first validate the method using synthetic data generated with realistic acquisition geometries and noise conditions based on Bedretto, and then apply it to continuous real DAS recordings from the site, assessing improvements in event detectability and source localization after denoising. Preliminary results show enhanced detectability of events with magnitudes below –2, including events that would otherwise be difficult to detect or analyze due to the low SNR.

Source Inversion Using Synthetic Transmission Sensing Data of the Global Subsea Fibre-optic Telecommunication Network

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Operational submarine telecommunication cables hold immense potential for monitoring global earthquakes and nuclear tests. They improve global coverage especially since only few seismic stations are located in the oceans. Integrated fibre-optic sensing (IFOS), or transmission sensing, offers dual use for telecommunication and strain sensing with optical fibres. IFOS can interrogate over 1000s of km of optical fibre and is, therefore, well suited to leverage the monitoring potential of subsea optical fibre networks. Integration along a fibre condenses all spatial information into a single time series. This prevents the use of established methods that rest on the identification of individual phases of arriving waves, and makes the evaluation of the data non-trivial.

Real fibre-optic data is difficult to acquire on a global scale, which is why we conduct a synthetic test study. In this study, we perform global simulations of wave propagation measured by an IFOS system using the spectral-element solver *Salvus* and the publicly available software package *Pyber*. *Pyber* enables simulations of fibre-optic data and takes into account the arbitrarily-shaped geometry of the cable, crucial for accurate simulations, as the sensitivity of the cable scales with local curvature. We further developed *Pyber* to simulate IFOS data for the global submarine telecommunication network. Here, we present results towards least-squared source inversion using the global subsea telecommunication network, in an effort to evaluate the capabilities of global IFOS data. We quantify the uncertainties in timing, location and moment tensor components for model events scattered across the globe. Further, we discuss results of this study in the context of nuclear and tsunami monitoring, as well as global seismic tomography.

Towards Resolving Phase Wrapping Artefacts in Strong Motion DAS Recordings

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The Milun fault Drilling and All-inclusive Sensing (MiDAS) project in Hualian, Taiwan operates a cross-fault borehole instrumented with distributed acoustic sensing (DAS) and collocated borehole seismometers.

Since DAS uses optical interferometry it would be expected that the DAS recordings exhibit phase wrapping during strong ground motion.

However, our recordings have a notable discrepancy: typical phase wrapping is characterized by instantaneous jumps from $-\pi$ to π , while the jumps in our data are smoothed out in time and only ever reach about three quarters π .

Both could be caused by having initially noisy wrapping data that gets low-pass filtered, which is consistent with the instrument's processing workflow: data is recorded at 10,000 Hz and then denoised and downsampled to 1,000 Hz.

We use synthetic tests to demonstrate that this sort of processing can plausibly reproduce this effect as well as estimate parameters to approximate the wrapping as a completely local function of strain rate.

The general framework for our approach is to first use image-segmentation methods to identify these smoothed wrapping regions and then correct them, after which standard two-dimensional unwrapping methods can be applied.

We verify the effectiveness by comparing the difference in velocity between two seismometers with recovered strain rate integrated over that region for various earthquakes up to the 2024 MW 7.4 Hualien earthquake.

Joint DAS and Nodal Seismic Imaging of Reworked Near-surface Sediments in Open-pit Mine

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Large open-pit lignite mines in western Germany are being closed and rehabilitated as part of the national coal phase-out scheduled for 2038. During mining operations, groundwater levels were artificially lowered by more than 400 m. Their gradual recovery, together with the large dimensions of the pits (up to 85 km² in area and depths reaching 400 m), significantly modifies subsurface stress conditions and may trigger further induced seismicity and

slope instabilities. Therefore, high-resolution seismic monitoring is essential to detect and characterize small-scale processes related to mass redistribution and near-surface deformation.

To evaluate the suitability of distributed acoustic sensing (DAS) for this purpose, a DAS test site with 200 m of fiber-optic cable was installed in an active lignite mine in November 2025. Two days of active seismic refraction experiments were carried out, complemented by five days of continuous recording to analyze ambient seismic noise. DAS data were acquired using a Febus A1 interrogator with gauge lengths down to 1 m and were co-located with 12 three-component SmartSolo IGU-16HR nodal seismometers (5 Hz). The nodal sensors are used to calibrate DAS amplitudes and phase responses and to assess coupling quality and directional sensitivity as a function of fiber position and azimuth. The combined DAS and nodal dataset is used to derive a near-surface velocity model of the recently reworked sediments based on seismic refraction. In addition, automated channel quality assessment, noise reduction, and signal enhancement methods are applied. The results provide a benchmark for DAS performance in an anthropologically modified environment characterized by unconsolidated mining deposits and shallow subsurface imaging in this setting.

Monitoring Rainfall-induced Subsurface Velocity Changes Using Distributed Acoustic Sensing

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Temporal variations in seismic wave velocity provide insights into how the shallow subsurface responds to rainfall, groundwater variations, and near-surface stress changes, which are critical for understanding hazards such as subsidence, landslides, and infrastructure instability. However, conventional seismometers are often spatially sparse and temporally limited, restricting high resolution velocity change monitoring. Here we use distributed acoustic sensing (DAS) on existing dark telecommunication fibre to perform monitoring of rainfall-driven subsurface velocity changes. Our analysis is based on the South Island Seismology at the Speed of Light Experiment (SISSLE), a ~30 km DAS array deployed along State Highway 6 near Haast, New Zealand, where extreme precipitation and recurrent storm events frequently trigger flooding and associated road closures, motivating the need for persistent subsurface velocity monitoring along the transportation corridor.

We apply three-station ambient-noise interferometry and daily stacking to retrieve stable noise correlation functions from 5–25 March 2023, spanning multiple intense late summer rainfall events. Group velocity perturbations are quantified using waveform interferometry and show clear spatial and frequency dependence, indicating depth sensitivity. Group velocity perturbation inversion reveals a pronounced post-rainfall reduction in near-surface velocity, consistent with rainfall-induced softening. The low-velocity anomaly progressively migrates to greater depths with time, suggesting downward propagation in the response. We interpret this behaviour using a one-dimensional hydraulic diffusion model, in which our model reproduces the observed depth-dependent migration of seismic velocity reductions following rainfall, indicating that rainfall infiltration and pore-pressure diffusion dominate the anomalies. These results demonstrate that high-density DAS observations provide a promising capability for environmental monitoring and hazard mitigation.

Assessing Background Noise Effects on Earthquake Detection With Offshore Distributed Acoustic Sensing

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Submarine regions are sparsely instrumented because offshore seismic monitoring is expensive and logistically challenging. Offshore Distributed Acoustic Sensing (DAS) overcomes these limitations by using existing submarine telecommunications cables to continuously record seismic and acoustic signals. Since April 2024, an AP Sensing DAS interrogator has collected continuous data along a 50 km fiber-optic cable offshore Cordova, Alaska. The DAS recordings contain a wide range of natural and anthropogenic signals, as well as pronounced temporal variations in background noise. To investigate how these changing noise conditions affect seismic monitoring, we employ

template matching, which leverages waveform similarity across the dense DAS array to detect repeating and low-signal-to-noise events. This approach provides substantially improved detection sensitivity compared to traditional amplitude-based methods (e.g., short-time-average through long-time-average trigger, STA-LTA). We further analyze channel-by-channel seismic noise levels, quantify their spatial and seasonal variability, and assess how background noise influences the performance of template-based earthquake detection.

A Synthetic Study to Optimize DAS Arrays for Event Detection and Fracture Dynamics in Underground Mines

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Distributed Acoustic Sensing (DAS) offers a promising way to enhance seismic monitoring in underground mines by turning existing and deployable fiber-optic cables into dense strain-rate arrays, even in areas where electronics are not permissible. However, the relationship between DAS wavefields, source representation, and practical deployment constraints still requires further analysis in mining environments. In this work, we aim to develop a numerical framework using 2D and 3D full-waveform elastic simulations to examine how DAS responds to different source types, including explosive-type sources and a range of moment-tensor mechanisms. These mechanisms include deviatoric and double-couple sources, allowing us to explore shear slip and mixed rupture behavior within simplified underground mine geometries that mimic gate-roads, mains, vertical boreholes, headgates, and tailgates found in real mine sites. Initial simulations evaluate how fiber orientation, burial depth, and gauge length affect axial strain-rate responses using horizontal (H), vertical (V), and combined H+V array configurations. In the next stage, we extend these experiments to more realistic conditions with topography by incorporating layered sedimentary structures and representative source depths. We will systematically assess how various array geometries (e.g., gate-road floor lines, borehole fibers, and different apertures) influence detectability and sensitivity to source type. The outcomes of this work will help identify deployment strategies and array designs that improve the understanding of mining-induced seismicity. Moving forward, we aim for such arrays to contribute to the early detection of fracture initiation and evolving rock-mass instabilities, supporting safer mining operations and enabling more reliable seismic hazard assessment.

Toward End-to-end Earthquake Monitoring With Distributed Acoustic Sensing

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Distributed acoustic sensing (DAS) has shown potential for providing spatially dense seismic observations along fiber-optic cables and has recently been incorporated into real-time monitoring workflows for waveform streaming and phase picking. However, the downstream integration of DAS-based picks into earthquake association and location workflows remains an open question. Here we extend an existing real-time DAS processing framework by incorporating phase association and earthquake location, enabling DAS observations to contribute directly to near-real-time seismic catalogs. Real-time DAS data streaming has been implemented and is currently operating

internally, with continuous data processed using a machine-learning phase picker. Building on this foundation, we expand the number of DAS channels used in real time and evaluate automated quality control, event association and location workflows. Application to a 100-km-long DAS array deployed near Ridgecrest, California, demonstrates that DAS phase picks can be successfully associated into coherent events and yield stable hypocenter solutions consistent with cataloged locations, establishing DAS as a potential stand-alone monitoring system. We further discuss how this DAS-only framework is designed to be incorporated into the Southern California Seismic Network alongside conventional seismic stations for regional earthquake monitoring.

Adapting EGF Based Source Analysis for Downhole DAS Data in Enhanced Geothermal Systems

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In the context of the global climate transition, Enhanced Geothermal Systems (EGS) have emerged as a critical component of the renewable energy mix. The successful development of EGS resources relies on the effective creation and management of subsurface fracture networks and flow paths. While micro-earthquake (MEQ) monitoring and seismic moment analysis are primary methods for characterizing these structures.

The dense spatial coverage of DAS channels and tight event clusters associated with discrete fracture networks provide an ideal setting for Empirical-Green's-Function (EGF) approaches, where the event clusters share similar path effects to receivers. In this study, we adapt the EGF-based source parameter inversion workflow to selected event clusters recorded during multi-phase EGF stimulation at Cape station in Utah.

We first performed focal mechanism inversions using SKHASH based on surface seismic data (Mohammadi et al., 2025), then developed cluster-based inversion to retrieve EGF for each station, and obtained moment-tensor solutions using these inverted EGFs. We now adapt this workflow to DAS data, aiming at retrieving DAS-based moment tensor solutions and comparing waveform fitting with seismic data. We also apply EGF-based methods to invert source-time-functions (STF) for the same clusters using seismic and DAS recordings separately and evaluate the performance using surface seismic data and DAS.

The integration of DAS and surface seismometers has the potential to combine the strength of different recording systems, and provide more comprehensive understanding of event source mechanisms, which facilitates a holistic understanding of the EGS stimulation process.

Toward Operational Earthquake Early Warning Using DAS Observations and Finder Algorithm: A Case Study in Southern California

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Earthquake Early Warning (EEW) systems provide critical seconds of advance notice before the arrival of damaging seismic waves by exploiting the fact that electromagnetic signals travel faster than seismic waves. However, existing EEW networks—primarily composed of conventional seismic sensors—often suffer from limited spatial coverage, particularly in harsh and inaccessible regions such as offshore environments. To enhance both accuracy and resilience, it is essential to incorporate additional data sources such as Distributed Acoustic Sensing (DAS), which can cost-effectively repurpose existing onshore and offshore telecommunication fiber-optic cables. Despite its potential, integrating DAS into an operational EEW system presents a key challenge: bridging the fundamental differences between DAS strain or strain-rate measurements and conventional ground acceleration data within a unified framework. In this study, we address this challenge by calibrating a DAS array in Ridgecrest, California, using ShakeMap and co-located seismic

stations from the Southern California Seismic Network (SCSN). Our results demonstrate that DAS strain-rate amplitudes can be converted into ground-motion metrics compatible with the Finite-Fault Rupture Detector (FinDer) algorithm used in existing EEW systems. We are developing a real-time system and evaluating its accuracy and robustness. By integrating DAS with conventional seismic networks, our work advances EEW capabilities toward more robust, large-scale deployment—particularly in fiber-rich yet sensor-sparse regions.

From Drilling to Ground Shaking: Mechanisms, Monitoring and Mitigation of Induced Earthquakes

Oral Session • Friday 17 April • 8:00 AM Local

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Probabilistic Induced Seismic Hazard Analysis in the Western Canada Sedimentary Basin
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We investigate seismic hazard at several locations in the western Canada sedimentary basin from background and induced seismicity through a Monte Carlo-based probabilistic seismic hazard analysis. We develop our background seismicity models based on the sources developed in the 6th generation of national seismic hazard model of Canada. To develop induced seismicity source models, we use the observed seismicity from an earthquake catalogue compiled in this study excluding mining-related seismicity. 100 synthetic sub-catalogues, each with duration of 1000 years, are generated for each alternative in the characteristics of seismic sources and ground motions are estimated from each earthquake using a suite of ground motion models applicable to both active and stable shallow crust earthquakes. Finally, hazard curves are constructed by counting the number of times ground motions are exceeded and dividing by the total duration of synthetic seismicity (i.e., 100,000 years). Results show that, 1) the spatial footprint of induced-seismicity-driven hazard is highly localized to the vicinity of injection operations, 2) the effect of induced seismicity is more pronounced on peak ground acceleration than peak ground velocity, and 3) the contribution of induced seismicity to total seismic hazard (background and induced) is greatest at higher annual exceedance rates, corresponding to the more frequent, smaller ground motions.

Characteristics of Fracture Networks Regularly Activated by Geothermal Production at the Coso Geothermal Field
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The long-term producing Coso Geothermal Field (CGF) in California targets a reservoir characterized by an extensive fracture network and complex fluid pathways, as well as regular natural and induced seismic activity. Located in a transtensional setting, the reservoir is surrounded by active fault systems, allowing for a direct comparison between the characteristics of faults that are routinely reactivated by geothermal operations with those in the surrounding region that are not directly influenced by injection and production. In this study, we analyze more than 97,000 earthquakes (Mw -0.4 to 4.2) occurring within 12 km of the CGF between 1996 and 2010, including approximately 56,000 events from within the field and 18,000 events from the nearby seismically active Rose Valley, to identify and compare seismically active structures. We first relocate the earthquakes using waveform-correlated differential times and compute focal mechanisms. We find that the region is dominated by the expected strike-slip and normal faulting, with the CGF reservoir exhibiting a larger variation in focal mechanisms than the surrounding area – highlighting the structural complexity and heterogeneity of the fracture network

within the field. Moreover, we combine the focal mechanisms, earthquake relocations, and waveform similarity analysis to infer fault planes. By improving the characterization of active structures within and around the CGF, we can gain a clearer understanding of how operational parameters influence the local stress field and seismic response of the reservoir.

Mapping Fracture Growth During the Utah Forge 2024 Extended Circulation
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The latest Utah FORGE 2024 operations saw the successful completion of an extended circulation test between the injection and production wells. The purpose of this test was to evaluate the performance of well-connectivity and overall efficiency of fluid recovery. The microseismic activity induced during the circulation test was monitored by a network of near-surface stations. Preliminary microseismic event locations reveal general patterns in seismic rates and spread and initially suggest a significant southward and upward microseismic cloud migration triggered by the injected fluids progressing after shut-in. In this study, we apply clustering and relocation algorithms to obtain refined relative relocations for the microseismic events induced during and after the circulation test in August 2024. Resulting relocations confirmed large planar fracture growth south of the wells as a continuation of the fracture zones created during the 2024 stimulation. Fault area estimates of the extended feature revealed maximum magnitudes that could potentially be caused by the structure. We compared injection pressure, rate, and total volume with seismic rate and magnitude to identify any causality between the hydraulic characteristics of the circulation and induced microseismicity. The detailed study of the extended growth of the microseismic cloud is valuable to determine how to maintain an efficient enhanced geothermal system (EGS), as injected fluids are increasingly more difficult to recover as they travel farther from the wells. Furthermore, understanding structural dimensions is important for evaluating the potential seismic risks associated with sub-surface structures and for informing future stimulation and circulation activities at the site.

The Bound Growth of Induced Earthquakes Could De-risk Hydraulic Fracturing
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The world's energy supply depends critically on hydraulic fracturing (HF) to access otherwise uneconomical resources. Unfortunately, HF also has the potential to induce larger earthquakes – with some projects being prematurely terminated because of perceived earthquake risks. To de-risk HF, we use a suite of statistical tests to discern if some physical process has restricted the growth of earthquake magnitudes. We show that all stage stimulations at both UK PNR-1z and Helsinki St1 indicate bound fracture growth, implying a more controllable operation. Contrastingly, stimulations at Utah FORGE and UK PNR-2 sequentially transitioned into unbound fault reactivation. The problematic stages (that ultimately led to the termination of PNR-2) are clearly distinguishable. We postulate that our research can discriminate fracture stimulation from fault reactivation, contributing to the de-risking of HF operations worldwide. Our statistical tests provide a framework for model falsification, which can guide physical insights into the bounding processes.

Tremor and Slow Slip in Sedimentary Basins
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The Delaware basin in Texas is an exemplary laboratory for understanding seismicity within sedimentary basins. Though the seismicity has been well studied and can be located precisely, satellite data suggests that energy is

also being released aseismically. Dozens of lineaments have been mapped in the Delaware basin that can be linked to injection and production activities. Complex seismic signals that resemble tremor normally found in subduction zones have also been found. Tremor signals can be identified and distinguished from earthquakes with a machine-learning approach, initially trained on megathrust tremor in Cascadia, using a convolution network followed by a long-short-term memory layer. The ML approach allows for the ternary identification (tremor, earthquake, noise) to function at signal-to-noise ratios as low as 0 dB. For clean tremor signals, a cross-correlation and beamforming approach is used to detect and locate some of these seismic signals and explore the possibility that they could be an example of tremor within a sedimentary basin. Finally, there are also low-frequency anomalies, similar to slow slip, that appear to relate to injection activities within the basin. Though further work is needed to understand these observations, we present a framework for how basement-rooted faults that emerge in the basin can sustain seismicity, aseismic slip, and other complex signals.

Localized Transfer Learning for Detection of Induced Seismicity Across Diverse Monitoring Systems
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Monitoring induced seismicity requires detection systems that are sensitive to low-magnitude events, robust to noise, and adaptable across diverse operational and geological contexts. This study presents a machine learning (ML) detection framework leveraging localized transfer learning. Using a manually curated high-quality Oklahoma dataset (OKLAD) to fine-tune off-the-shelf models, the adapted pretrained models capture local waveform and noise characteristics while remaining generalizable across diverse monitoring configurations. Applied to historical Oklahoma Geological Survey waveforms from 2010 to 2026, the framework enabled re-curation of a seismicity catalog, revealing additional events and improving quality control, including previously underrepresented events.

The framework was further evaluated across multiple scenarios, including conventional seismic networks and dense nodal deployments, such as a 2024 Prague, Oklahoma, nodal array. The model successfully captured after-shock sequences and improved detection relative to conventional approaches. Fine-tuning requires only modest amount of local data, yet the models perform effectively across different platforms, demonstrating the potential regional adaptation. We also explore the potential for extending these models to edge computing devices as small as microcontrollers. Together, these results demonstrate that regionally adapted transfer learning provides a flexible and scalable strategy for enhancing induced seismicity detection, supporting monitoring systems that can adjust to evolving operational conditions, capture previously overlooked events and deliver more detailed insights across diverse geological and operational settings.

A Comprehensive Machine Learning-based Catalog for Effective Monitoring of Induced Seismicity in Southeastern New Mexico
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Energy development across the United States and globally has resulted in increasing seismicity in regions with historically little or no seismic activity. In southeastern New Mexico, the northern Delaware Basin, deep fluid injection coincides with significant seismic activity, including a recent magnitude 4.49 event in February 2024 in the Dagger Draw seismic cluster. The New Mexico Seismological Observatory (NMSO) is expanding its permanent seismic network to establish a reliable statewide network of 43 telemetered stations by 2026. This expansion requires machine learning techniques to automate rapid earthquake detection, improve detection of low-magnitude events, process large volumes of real-time seismic data, and enable analysts to efficiently build complete and precise catalogs.

We present preliminary results of ML implementation for 2-year seismicity in southeastern New Mexico. This region presents challenges for ML pickers, often pretrained on dense local networks, due to predominantly small-magnitude local events recorded by various sensor types, overlapping

signals, and complexities from the sedimentary basin structure. We implement the Pick Aggregator (Aziz Zanjani & DeShon 2026), a multi-model ensemble of ML pickers on SeisBench platform, to address inconsistencies among ML pickers by aggregating detections confirmed by at least two independent models trained on diverse datasets, thus improving catalog completeness. The aggregated catalog contains four times more picks than the maximum single-model catalog, with mean probabilities of 0.4 for P-waves and 0.45 for S-waves. The GaMMA associator performance improves significantly with aggregated picks compared to single-model picks, detecting three orders of magnitude more events than single-model catalogs with a minimum of 8 picks per event. We compare the aggregated ML catalog to single-model ML catalogs and the NMSO catalog developed using standard methods. Overall, the aggregated catalog demonstrates more complete detection capability with additional validation of multi-ML models.

Modulation of Injection Induced Seismicity in Complex Fault Network
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Modeling of injection-induced seismicity plays a significant role in understanding the seismic risks associated with fluid injection in different energy and environmental activities. Here we investigate multi-cycle modeling of induced seismicity in a complex fault zone hosting a primary fault surrounded by multiple secondary faults with different orientations. Fault friction is governed by rate-and-state friction law and the pore pressure diffusion is determined analytically for an injection site away from the fault zone. We use FEBE, a hybrid finite element spectral boundary integral method, to simulate the fracture network with high resolution finite element discretization while accurately modeling the long range elastodynamic interactions using the spectral boundary integral method. We allow for inelastic deformation to accumulate by modeling the fault zone as an elastic-visco-plastic medium governed by pressure-sensitive Drucker-Pragger constitutive law. We used hydraulic and mechanical properties constrained by field observations and laboratory measurements.

The simulation results show spatially heterogeneous distribution of seismicity as well as temporal clustering. While fault criticality remains an important factor, fault network interactions modulate individual fault behavior through stress transfer mechanisms. The complex interplay between pore pressure diffusion, aseismic slip propagation, and elastic stress redistribution creates emergent spatiotemporal patterns that cannot be predicted from single fault models alone. Furthermore, we show that the fault sensitivity to stress perturbations within the network is not universal but varies depending on the rate of change of the pore pressure suggesting that the network collective behavior is a function not only of the pore pressure changes but also the rate of change. Finally, the simulations show that higher confining stress leads to reduced complexity and the seismicity tends to localize on the primary fault. These results may help in assessing induced seismicity hazard and guide safer injection protocols to achieve eco-friendly developments.

Complex Fault Slip Behavior Modulated by Injection Rate With Implications to Hazard Mitigation of Induced Seismicity
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Fluid injection may induce both seismic and aseismic slips on faults, causing significant hazards for subsurface operations. However, how injection rate modulates fault slip behavior remains poorly understood. To address this issue, we directly inject water with controlled rates into biaxially loaded laboratory faults and simultaneously monitor the resulting real-time fluid diffusion and fault slip using optical methods. We find that at low injection rates, fluid diffusion triggers sustained aseismic slip, enabling slip fronts to propagate well beyond the pressurized region through elastic stress redistribution. Conversely, high injection rates drastically reduce the aseismic phase and accelerate the transition of slip behavior to dynamic rupture. While the injection rate controls rupture initiation timing and mechanism, the magnitude of

the induced event is primarily determined by initial fault stress conditions. These findings highlight that effective hazard mitigation should not rely solely on reducing injection rate, but instead should treat injection rate, aseismic fault slip, and fault stress conditions as coupled controls on induced seismicity.

Understanding Rupture and Source Properties of Induced Microearthquakes in the Western Canadian Sedimentary Basin

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The Western Canadian Sedimentary Basin is the second largest intracratonic basin in the world, with natural-gas production averaging 3.15 x 10⁸ m³ per day in 2024 and expected to continue increasing. None of this would be possible without the advancement of horizontal hydraulic fracturing (HF). However, repeated fluid injection significantly increases seismic risk in the region. When earthquakes exhibit rupture directivity, seismic waves are amplified in the direction of fault rupture, resulting in stronger ground motion and increased seismic hazard. While HF-related microseismic events do not typically produce damaging shaking, their rupture characteristics can provide valuable insights into the behavior of larger earthquakes and fundamental questions in earthquake physics, such as source self-similarity.

In this study, we characterize the rupture patterns of HF-related microseismic events (Mw 0.5-2.5) and their relationship to nearby wells using broadband and geophone data from the University of Calgary’s Tony Creek dual Microseismic Experiment (ToC2ME). We apply the Empirical Green’s Function method adapted from Holmgren et al (2019) to identify mainshock-EGF pairs and constrain the corner frequency (f_c) at nearby stations. For each mainshock, we examine the azimuthal variation of f_c and the ratio of maximum to minimum f_c to infer rupture direction and quantify the intensity of the directivity. Preliminary results indicate that microseismicity near the HF wells belong to four major clusters. Of the 224 largest event, 29 exhibit significant directivity (f_{c,max} /f_{c,min} > 2). Events in Clusters 1 and 2, which occurred during the initial well operations, tend to rupture away from the single active well, with average intensities ranging from 1.9 to 2.1. In contrast, events in Clusters 3 and 4 occurred during later, higher intensity of completion, and ruptured toward the three active wells, with slightly higher intensities of 2-3. We also show how these observed rupture patterns correlate with source properties such as stress drop, HF operation parameters (volume, rate, duration), and subsurface stress perturbations.

From Drilling to Ground Shaking: Mechanisms, Monitoring and Mitigation of Induced Earthquakes [Poster]

Poster Session • Friday 17 April

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POSTER 94
Assessing the Potential Bias of Observations From a Single Monitoring Well Within a Local-scale Seismic Array
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The continued advancement of Enhanced Geothermal Systems (EGS) and Carbon Capture and Storage (CCS) relies in part on the ability to provide comprehensive characterizations of microseismicity. High quality seismic catalogs are a crucial component of seismic risk management strategies, yet the financial viability of these projects also depends on the cost-effectiveness

of the seismic monitoring approach. Downhole instrumentation approaches such as distributed acoustic sensing (DAS) can be particularly effective due to low noise levels and improved depth constraint, but the costs associated with drilling monitoring wells and maintaining downhole instruments can be multiple orders of magnitude larger than those of a surface network. As a result, some operators have opted to use a surface network of seismometers in tandem with a single downhole DAS cable in an attempt to provide affordable and effective microseismic monitoring. However, this approach relies on the assumption that downhole observations can be easily integrated into traditional detection and location workflows, a process that is made difficult by the large volumes of data produced by DAS. One way to address this issue is to limit the number of channels outputted by the DAS cable, either through downsampling or aggregation. In this study, we seek to determine the optimal number of observations at reservoir depth from a single monitoring well to be included in a traditional location workflow. To do so, we forward model arrival times from a grid of synthetic sources to a set of receivers on the surface and an increasingly large number of receivers within a single monitoring well. We then generate locations from the synthetic arrival times using NonLinLoc (Lomax et al., 2000) and compare them to the original locations to assess the ability of a wide range of monitoring scenarios to accurately characterize seismicity throughout the study area. Preliminary results indicate that including large numbers of observations from the monitoring well can bias event locations. This effect is exacerbated by the quality of the earth model used in earthquake locations.

POSTER 95
Seismic Velocities and Induced Seismicity at the Utah Forge: How Creating Fractures Helps Us Understand the Spatial and Temporal Evolution of an EGS Reservoir
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The Utah FORGE (Frontier Observatory for Research in Geothermal Energy) is a field-scale laboratory with the goal to enhance our knowledge on how to utilize hot, dry rock for geothermal energy production, which may act as one of the base-load capable components contributing towards the clean energy transition. To transport heat from the underground to the surface, fluids circulate though the reservoir. Considering the low permeability of granite at the targeted depth of ~3km, it is necessary to create fluid pathways through hydraulic stimulation. This process may involve the opening of new fracture or re-activation of existing ones, potentially inducing seismicity.

To better understand where and when stimulation induces seismicity, it is essential to have a comprehensive overview of the seismic activity and potential structures in the larger area. Utah FORGE provides an extensive seismic dataset that includes recordings from a permanent network first emplaced in 2016 and continuously expanded since and multiple temporary nodal arrays and downhole geophone chains. Using this extensive dataset, we: i) utilize machine learning models to create a continuous enhanced event catalogue for the Milford valley, ii) improve the event localization by jointly inverting for the velocity model and earthquake location and iii) utilize ambient noise to investigate relative seismic velocity changes (dv/v) over time.

The three key outcomes - earthquake localization, velocity model, and temporal changes in dv/v – are inherently interdependent. Apart from the location, orientation and evolution of the created fractures or reactivated faults that are highlighted by the seismicity, a combined interpretation of seismic velocities and event occurrence may provide improved insight in the spatial distribution of the physical properties within the reservoir rock and how the fluid injection with the subsequent fracturing might alter those properties. Such knowledge of the underground, together with hydrological and mechanical input, is essential to improve mitigation strategies for induced seismicity in geothermal energy production.

POSTER 96
Earthquake Nucleation Characteristics Driven by Seasonal Stress From Gas Production at the Geysers, California
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The Geysers, California, as the world’s largest commercial geothermal reservoir, has over 400 active injection and steam wells and tens of thousands of earthquakes each year. In this study, we applied a stochastic ETAS model to an enhanced earthquake catalog of this region and identified significant seismicity variations at seasonal periods. We then adopted the FLOW2QUAKE framework which is an integrated model combining multiphase flow, geomechanics, and seismicity forecasting. Using historical injection and steam production data along with a simplified reservoir model based on vertical flow equilibrium, we reconstructed pore pressure changes over time. These were further processed into poroelastic stress changes through a mechanical model. We then model the seismicity response to seasonal gas production to invert for the frictional parameters assuming a nucleation process governed by rate-and-state friction. Our model successfully captures the distinct seismic features at The Geysers, providing new insight into the fault nucleation process and illuminating the characteristics of earthquake nucleation process.

POSTER 97
The Midland Basin Seismic Network: Deployment Overview and Transition to Public Data Access
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The Midland Basin Seismic Network (MBSN) was initiated in 2018 when Hasting Micro-Seismic Consulting, Inc. (HMSC) was contracted by Pioneer Natural Resources (PNR) to construct, operate and maintain a deep-borehole microseismic monitoring array. The original network consisted of 11 deep borehole stations equipped with ASIR AG4.5 geophones installed at depths ranging from 3,480 – 4,500 ft below ground surface. The network was subsequently expanded to include four surface strong-motion stations, three short-period borehole stations installed at ~300 ft, six broadband stations deployed between 10 and 300 ft, and one additional short-period surface station collocated near MBB06 to evaluate surface–borehole signal differences. The completed network now consists of 24 stations.

Between mid-2018 and 1 January 2026, more than 18,000 earthquakes were located within the MBSN by ISTI, the subcontractor responsible for data processing for HMSC. This extensive catalog demonstrates the high sensitivity of the array to both induced and natural seismicity in the Midland Basin. Following ExxonMobil’s acquisition of PNR and the MBSN, the company directed that previously proprietary waveform data be made publicly accessible beginning 1 January 2026. HMSC now provides real-time short-period and strong-motion data to the EarthScope Data Management Center (DMC) under network code HZ, while TexNet contributes real-time broadband data under network code 4O. Station naming conventions include MBB## (deep borehole), MBBB# (broadband), MBNS# (300-ft short-period), MBA## (accelerometer), and MBS## (surface short-period). Metadata for all stations is available through the DMC, and archived miniSEED data from 2018–2025 will be released upon request. These datasets are now incorporated into TexNet’s real-time event detection and notification system, enhancing regional seismic monitoring capabilities.

POSTER 98
Hydrothermal Triggering Revealed Through Periodicity Analysis at the Coso Geothermal Field
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To study the interaction between seismicity and long-term geothermal production, we compare periodicity trends of 15 years of local seismic and daily operational data from the Coso Geothermal Field (CGF). Using nearest neighbor declustering of the local seismic catalog and Schuster tests, we identify a strong correlation between short-term increase in seismicity rates and seasonal variations in injection volume and temperature. Furthermore, the seismic footprint during peak injection of colder fluids reveals a near-instantaneous response up to 2 km away from the injection well, too rapid to be attributed to pore pressure diffusion alone. This short-term and distant response exhibits a clear directional preference, suggesting structural or permeability anisotropy within the reservoir. Moreover, while the seismic response correlates with the initial volumetric increase of colder fluids, it also correlates with temperature decrease during stable injection periods, indicating that thermal effects alone may play a significant role in triggering seismicity at greater distances.

POSTER 99
High-frequency Waveform Simulations for Small Induced Earthquakes in the Near Field
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Geothermal heat extraction often lies directly beneath cities to reduce heat losses during transport, but placing reservoirs under urban areas raises the risk of induced seismicity through thermal, chemical, and pore-pressure changes in the subsurface. In the Munich region such events are typically small (ML<2.4), yet larger events remain plausible: with a structural PGV tolerance of about 5 mm/s, an event of roughly ML≈2.8 at 3.5 km depth would be sufficient to exceed that threshold. Because these small, shallow earthquakes concentrate energy at high frequencies, realistic hazard assessment requires simulations that reach ~40 Hz — a demanding target for numerical models. Full-waveform 3D simulations are computationally expensive and even for a small region only run up to 10 Hz.

To address this, we adapted the open source software MudPy — which combines Green’s-function based low-frequency synthetics with a stochastic high-frequency simulation — to simulate earthquakes and produce ground-motion time series. It was primarily developed for very large earthquakes i.e. subduction zone ruptures, and we therefore had to adapt it to be capable of simulating small local events. Key adaptation included reduction to a single point source and switching from Saragoni & Hart to Cua envelopes. A challenge is matching both vertical and horizontal acceleration amplitudes and reproducing the high energy pulse waveform across the full frequency band. The adapted workflow can provide a relatively fast, computationally efficient way to generate site-specific scenarios where historical records are sparse but subsurface constraints (e.g., from geothermal surveys) are strong, improving local hazard and engineering assessments.

POSTER 100
B-valuation: Linking High B-values at the Edges of EGS Injection Induced Seismicity With Aseismic Slip
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Understanding the mechanisms of inducing seismicity within Enhanced Geothermal Systems (EGS) is important for ensuring the safety of local populations and continued operation of EGS projects. The classically favored dominant mechanism is a direct pore pressure effect, which can induce earthquakes by lowering effective normal stress. However, more indirect mechanisms, like aseismic slip resulting from pore pressure perturbations, may have more a dominant role in inducing seismicity. To better characterize the mechanisms influencing EGS induced seismicity, we conduct spatiotemporal analyses of 9 different EGS injection sequences. We utilize the *b*-value – as a measure of magnitude distribution and a proxy for stress – to examine spatiotemporal variations by splitting earthquakes into equal-event groups or “shells” based on distance from the injection point. Additionally, for the different injection

sequences, we compute and analyze *b*-value variations of their seismicity fronts, defined by the outermost earthquakes from the injection point over time and which can be controlled by fluid pressure diffusion and fluid-induced aseismic slip mechanisms. We find that many sequences exhibit a period of high *b*-values close to the seismicity front, contrary to pore pressure model expectations. Across the different sequences we see the overall seismicity front *b*-values range from coequal to significantly higher than that of the remainder of the respective sequences. We suggest that these extremely high *b*-values are influenced by aseismic slip, and that sequences with extremely high seismic front *b*-values result from a self-sustaining aseismic slip mechanism controlling the seismicity front. This implies that aseismic slip has a crucial influence on EGS injection induced seismicity and should be accounted for in subsequent EGS projects and research.

POSTER 101

Machine Learning Phase Picking and Association Reveals a More Complete Induced Earthquake Catalog for the Fort Worth Basin, Tx
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The North Texas Earthquake Study (NTXES) in the Fort Worth Basin, USA, comprised a heterogeneous network of short-period, strong-motion, broadband, and nodal sensors spanning a large metropolitan area. It was deployed to capture earthquakes associated with oil and gas extraction, primarily wastewater disposal operations. The evolving sensor configurations from 2013-2025, combining velocity and accelerometer data, pose challenges for metadata processing in machine learning (ML) applications, as few training datasets incorporate accelerometer data. This study utilizes SeisBench to implement PhaseNet and EQTransformer (Zhu & Beroza, 2019; Mousavi et al., 2020) for phase picking, and explores traditional and clustering association techniques to decrease the magnitude of completeness of the published NTXES catalog. The original PhaseNet training dataset from Northern California provides the best performance for our induced seismicity detection, as it includes data from different seismic instrument types similar to our heterogeneous network, though some stations require optimized training datasets. Comparing automated detections against the manually curated catalog, only 55.7% (1,238 events) are matched; however, our workflow identifies 4,617 additional events. For matched events, ML-based locations show good agreement with manual picks, with mean differences of 0.77s in origin time, 3.4 km in latitude, 2.6 km in longitude, and 1.8 km in depth. Statistical validation across stations IPD1 (Irving, urban short-period), AZDA (Azle, rural short-period), and VTAX (Venus, NetQuakes accelerometer) reveals high precision in automated phase picking. P-wave arrival time mean residuals are 0.0077s (IPD1), 0.0393s (AZDA), and 0.0045s (VTAX), with S-wave residuals of -0.0385s, 0.0792s, and 0.0363s respectively. S-P time differences show excellent agreement (means: 0.0003s, 0.1097s, 0.0617s). We show that PhaseNet paired with its original training dataset significantly enhances earthquake detection in induced seismicity monitoring networks, providing more complete catalogs essential for hazard assessment.

POSTER 102

Integrating Multiple Seismic Monitoring Systems to Reveal Intense Microseismicity During the 2024 Utah Forge Stimulation
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The 2024 Utah FORGE stimulations and the induced microseismicity have been well captured by multiple seismic monitoring systems, including the regional seismic network, temporary nodal geophones, and downhole geophone and DAS systems. Integrating data from these complementary monitoring systems, each with distinct sensitivities and spatial coverage, enables more complete detection of microseismicity and more accurate characterization of fracture networks. In this study, we applied a machine-learning-based phase picker to the continuous seismic recordings collected over a two-week stimulation period and obtained ~51 million picks. Based on the predicted event origin times, we identified the asynchronous clocking issue among different downhole monitoring systems and corrected it with the cross-correlation method. We further adopted the method proposed in Zhu et al. (2025) for rapid association and incorporated the travel time differences to improve location accuracy. Our results show a clear hierarchy in detection capability among the monitoring systems. The near-surface arrays detected the fewest events, while the DAS cemented behind the production-well casing can detect

approximately an order of magnitude more events. The downhole geophones, despite higher deployment costs, are the most sensitive instruments, producing the most complete catalog roughly ten times larger than that obtained from the DAS system. Near-source downhole geophone monitoring systems help to better constrain locations as they are less affected by shallow velocity heterogeneities, while downhole DAS and surface stations can provide unclipped amplitudes for those events with relatively larger magnitudes. Combining these complementary datasets would improve the completeness and accuracy of the catalog, thereby better resolving the spatial and temporal evolution of the fracture network.

POSTER 103

From Quiescence to Chaos: Triggering of Two M5 Earthquakes in the Weiyuan Shale Gas Field, China
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Understanding how hydraulic fracturing triggers earthquakes—particularly rare but destructive events—is critical for mitigating induced-earthquake hazards. Here, we document a clear transition from fault quiescence to mechanical chaos preceding two $M_L \geq 5$ earthquakes (M_L 5.6 in September and M_L 5.4 in December 2019) in the Weiyuan shale gas field, China, where hydraulic fracturing targeted the Silurian Longmaxi Formation (Shale strata I).

From 2015 to early 2018, extensive hydraulic fracturing was conducted at multiple well pads surrounding the target fault zone. During this phase, the fault zone remained largely quiescent, despite the migration of low-magnitude ($M_L < 3$) seismicity toward the fault. This apparently “lazy” fault behavior fundamentally changed following direct injection into the fault zone at the H39 platform. Fluids migrated downward from shale strata I into the Cambrian Jiulaodong Formation shale (shale strata II, ~460 m thick), ultimately triggering the M_L 5.6 earthquake in September 2019 after a prolonged 11-month preparatory phase, with the rupture occurring beneath the thick shale strata II.

Seismicity induced by injection at the H39 platform also migrated toward the hypocenter of the December M_L 5.4 earthquake but stalled ~1 km from the hypocenter. The M_L 5.4 event occurred during hydraulic fracturing at the nearby H50 platform. We observed linear seismicity migrate towards the M_L 5.4 hypocenter, suggesting elevated pore pressure triggered the second event. Estimated Coulomb stress from previous M_L 5.6 event is -0.18 MPa, indicating limited static stress transfer impact in earthquake initiation. In contrast to the earlier earthquake, the rupture of the M_L 5.4 event occurred above shale strata II, suggesting that this thick shale layer acted as a barrier that inhibited rupture propagation in both events.

A comparison of triggered seismicity within and outside the fault zone reveals distinct diffusion behaviors and bounded/unbounded magnitude growth, underscoring key controls on induced-earthquake hazards and providing important implications for seismic hazard assessment in shale gas fields.

Generating, Calibrating and Validating Multi-Scale Seismic Velocity Models

Oral Session • Friday 17 April • 8:00 AM Local

Conveners: Yehuda Ben-Zion, University of Southern

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Multi-scale Statewide California Seismic Velocity Models: Version 1

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A high-quality multi-scale description of subsurface seismic velocities is foundational for a range of topics including advancing simulations of ground motion and consistent derivation of earthquake source parameters.

In this study, we construct multi-scale statewide P and S velocity models for California by merging existing models with varying spatial extent and resolution. We use the following two-step framework: (1) development of an updated statewide background model targeting frequencies of 0.1-0.5 Hz followed by (2) integration of local high-resolution models validated currently at 0.3-1 Hz. In the first step, we consider three regional subdomains - Southern, Central, and Northern California - and merge the regional-scale models into the starting model CANVAS (Doody et al., 2023). Candidate models are incorporated sequentially using a cosine-taper windowing approach (Ajala and Persaud, 2021). For each iteration, we conduct 3D numerical simulations of ground motion generated by 20-25 earthquakes (M_w 4.1-4.7) per subdomain, using models before and after merging. The simulation results are compared to data using an error function measuring misfits from both waveform envelopes and Fourier amplitude spectra. These results are translated into smooth 2D spatial weighting functions (refinement weights), which preserve portions of candidate models that outperform the reference model. Validation simulations confirm the robustness and effectiveness of the results, which significantly improve the ground motion prediction efficacy in various areas. Building upon the updated statewide background model, we incorporate local high-resolution velocity models. For each local model, we evaluate both the cosine-taper merging strategy and a dictionary learning approach (Zhang and Ben-Zion, 2024) and select the model version that yields the best agreement with observations. Lastly, we implement a low-velocity taper (Ely et al., 2010) with regionally optimized taper depths to improve the shallow seismic structure. The derived models can be improved in future studies by repeating the process for higher frequencies.

Multi-scale Velocity Model Integration for the Los Angeles Basin: A Framework for Continuous Neural Representation
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Ground motion prediction in complex sedimentary basins like Los Angeles relies heavily on accurate 3D velocity models. While standard Community Velocity Models capture basin-scale structures, they often lack high fidelity shallow details necessary for hazard assessment at intermediate periods (0.1–2 Hz). Recent models derived from dense nodal arrays (e.g., LAS1, LB-SB) and community seismic networks (e.g., CSN-LAUDS) offer exceptional local resolution within the basin but remain isolated patches within the broader LA area. In this study, we present a validated workflow to integrate these heterogeneous local models into the broader CVM-S4.26 background. We validate this unified model using 3D finite-difference wavefield simulations of eight M–4 earthquakes (2020–2024) recorded by both traditional broadband stations and the dense Community Seismic Network. Results demonstrate that the merged model outperforms standard CVMs in matching observed waveforms and predicting peak ground motion amplifications, thereby reducing uncertainties in hazard estimation and improving source inversions. Building on this validated volume, we address the limitations of traditional grid-based data fusion by proposing a Neural Velocity Field (NVF) framework. Standard interpolation methods often introduce boundary artifacts and are constrained by fixed grid resolutions. To overcome this, we explore the use of Coordinate-based Neural Networks (Implicit Neural Representations) to parameterize the basin's velocity structure. Unlike discrete voxel grids, this continuous neural representation aims to seamlessly blend the high-wavenumber features of local tomography with the long-wavelength background of the CVM, effectively treating data fusion as a neural fitting task. This data-driven approach could offer a scalable pathway to represent multi-scale earth models with infinite resolution and differentiability.

Constructing Basin Seismic Velocity Structure Constrained by Chronostratigraphy - a Case Study in the Los Angeles Basin

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An accurate seismic representation of a sedimentary basin is essential for reliable prediction of seismic response. Constructing such a model requires detailed descriptions of sedimentary layering, basin geometry, fault systems, and underlying crustal structure, which are commonly constrained by seismic and geological observations. In many densely populated basins, however, these constraints are incomplete or unavailable, posing challenges for seismic hazard analysis. In this study, we use the Los Angeles Basin as a case study where abundant, high-quality seismic and geological models are available for

benchmarking, to construct a basin-scale seismic velocity model constrained by a chronostratigraphic hydrogeologic framework model (Paulinski, 2021) - an independent, non-seismic dataset that describes basin stratigraphy and structure based on depositional history and explicitly representing sedimentary units, major faults, and basin geometry. With the geometry of sedimentary units defined by the chronostratigraphy data, we estimate depth-dependent, shear-wave velocity relationships for each unit based on existing seismic velocity models and generate new candidate basin models. The performance of the chronostratigraphic-based models is evaluated against commonly used seismic models derived from extensive geological and seismic constraints. We conduct 3D numerical wave propagation simulations of the 2019 Mw 7.1 Ridgecrest, California earthquake to assess long-period ground motions (6-8 s), and use smaller events (M_w 4.1-4.7) to validate shorter-period responses (2-3 s). Results show the chronostratigraphic-based model performs comparably to existing models across both period ranges, notably reducing underprediction along the basin's western margin seen in the Statewide California Earthquake Center CVM-S4.26.M01, with mean RotD100 log errors at 8 s reduced by 56%. This study demonstrates the potential for constructing reliable basin seismic velocity models in regions where direct seismic constraints are sparse or unavailable.

Ambient Noise Tomography Across the 2022 Los Angeles Basin Nodal Array

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A detailed 3D model of the Los Angeles Basin (LAB) is crucial for earthquake hazard assessment in the Los Angeles metropolitan area. In 2022, a month-long dense nodal geophone array was deployed in the LAB, consisting of a 185-station distributed sub-array and two ~50-station linear sub-arrays. In this presentation, we show the result of applying ambient noise tomography to study the LAB structure across the nodal array. We calculate multi-component ambient noise cross-correlations using both nodal and regional broadband stations. We measure Rayleigh wave horizontal-to-vertical amplitude (H/V) ratios between 5-9 s period across the nodal array after off-great-circle correction and compare them to the predictions based on SCEC Community Velocity Model S4.26 (CVM). Clear discrepancies are observed near the Central and the West Coast Basins, where the depth velocity gradients of the CVM are likely too low and too high, respectively. We also perform beamforming to determine fundamental (2-13 s period) and higher-mode (2-4.5 s period) phase velocities and H/V ratios across the dense linear sub-arrays. For each location, we jointly invert for multi-mode phase velocities and H/V ratios to get a 1-D Vs model, extending from the surface to a depth of 10 km. All 1-D models are combined to obtain the final 2-D Vs models, which we compared with CVM. In general, our model exhibits a stronger vertical velocity gradient in the top 2 km than the CVM, suggesting that the CVM may underpredict ground motions in earthquake simulations. We will also show and discuss the preliminary 3D LAB model.

Calibration of the Near-surface Seismic Structure in the San Francisco Community Velocity Model (SFCVM)

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We have calibrated the near-surface structure of the San Francisco Community Velocity Model (SFCVM) in the top few kilometers in order to improve its ground motion prediction efficacy. The ability of the reference and calibrated velocity models to predict ground motions is assessed using Fourier Amplitude Spectral (FAS) bias from 0-1 Hz 3D physics-based wave propagation simulations for an ensemble of Mw3.8–4.4 earthquakes. In areas of systematic underprediction, we implement a Vs30-constrained spatially-varying Low-Velocity Taper (LVT), with the optimal station-specific thickness determined from trial-and-error simulations for different taper depths. The optimal spatially-variable LVT reduces the FAS bias for areas outside the basins (defined as sites with surface Vs larger than 1 km/s) by up to 27% for individual events, and by 18% on average for the ensemble of small earthquakes. In the San Francisco East Bay area, the addition of a shallow (25-50 m) low-velocity layer (Vs=125 m/s) further improves the FAS bias by increasing the amplitudes and duration of the synthetics. In areas where the reference model systematically overpredicts amplitudes of the source ensemble, we calibrate the model by removing the near-surface (up to 900 m) decrease in velocities, which further improves the FAS bias by decreasing the amplitudes of the synthetics. The depth to the isosurface of Vs=1.0 km/s (Z1.0) in the

SFCVM is increased by up to about 100 m outside the basins due to the implementation of the optimized LVT, with implications for the depth-dependent basin amplification terms used in Ground Motion Models. The calibrated SFCVM has the potential for improved seismic hazard analysis in the greater San Francisco Bay Area.

Full Waveform Inversion Tomography for Improved Earthquake Ground Motion Simulations in California and Japan
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Simulations of earthquake ground motions are important for seismic hazard analysis, especially to represent large magnitude ($M > 6$), rare and damaging ruptures. Physics-based simulation methods have improved tremendously due to improved numerical methods, more efficient algorithms and codes and inexorable advances in computing power. However, the accuracy of earthquake ground motion simulations is limited by poor knowledge of detailed three-dimensional (3D) seismic wavespeed structure which inhibits reliable simulations of observed waveforms. Full waveform inversion (FWI) tomography provides an attractive alternative to other model-building methods because it solves for 3D wavespeed structure while improving waveform fits – the actual data we seek to model. This study presents a new FWI model of the isotropic shear and compressional wavespeeds (v_s and v_p , respectively) for a ~500 km scale domain of Central and Northern California. The model inverted complete waveforms from 100 moderate (M 4-6) events using a multiscale approach. Waveform fits in the period band 8-40 s were greatly improved relative to the plane-layered starting model, with 76% misfit reduction. Similar performance of the model is found for a set of waveforms from 42 independent validation events provides confidence in the model. The model images low v_s in areas of sedimentary geology in the Central Valley and Livermore Basin with minimum v_s less than 900 m/s in the Sacramento San Joaquin Delta. The Sierra Nevada is underlain by a high v_s root. Wavespeeds are discontinuous across the Calaveras, Hayward and Rodgers Creek Faults with low v_s in the Great Valley Sequence and higher v_s in the Franciscan rocks. The ratio of v_p/v_s traces sedimentary geology in the near-surface and the root of the Clear Lake Volcanic Field in the middle and lower crust. The new model could be used for source studies, such as moment tensor or finite fault inversions or long-period ground motion simulations. Similar methods are being applied to the Kanto Basin and Greater Tokyo region of Japan and will be shown at the meeting.

A New 3D Crustal Velocity Model for Northern Israel: Tomography and Validation
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Strike-slip fault systems in oblique convergence or divergence regimes often develop bends, stepovers, and structural complexities that modulate crustal deformation, stress localization, and seismic wave propagation. Along the Dead Sea Fault (DSF), the active plate boundary between the Sinai and Arabian Plates, these processes produce a heterogeneous crustal environment that remains only partly resolved. Specifically, deep sedimentary basins commonly form within stepovers, where localized transtension promotes long-term subsidence and sediment accumulation. To better characterize the crustal structure along the DSF between the Lebanese Restraining Bend in the north and the intraplate Carmel-Gilboa-Faria Fault (CGFF) system in the south, we develop the first tomographic model for northern Israel using travel-time data from ~1,500 local earthquakes ($M_w > 1.5$). We construct 3D V_p , V_s , and V_p/V_s models together with a relocated seismicity catalog. The resulting images reveal a pronounced bimaterial interface along the DSF, with high-velocity crust to the west and lower velocities to the east. Within the CGFF system, major sedimentary basins display reduced velocities, while anomalously high V_p/V_s values beneath the northern Kinneret basin indicate extensive rock damage, likely associated with sustained seismic activity. A transition zone below 15 km depth, marked by elevated V_p/V_s and increased seismicity, suggests changes in crustal rheology or thermal structure.

We validate the new 3D model using SPECFEM3D simulations of 18 earthquakes ($3 \leq M_w \leq 4.5$), comparing synthetic seismograms with records from the Israel Seismic Network. The 3D model markedly outperforms the standard regional 1D model, yielding higher waveform similarity, near-zero time lags, and a ~35% reduction in median spectral misfit. While shallow low-velocity zones remain under-resolved in narrow basins, this first-generation

integrated tomographic-simulation framework substantially advances our ability to model scenario ground motions and assess seismic hazard along the active DSF plate boundary.

Seismic Interferometry as a Cost-effective Tool for Seismic Velocity-model Validation in Geothermal Fields
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The Netherlands has recognized geothermal energy as a viable solution for reducing greenhouse gas emissions and minimizing reliance on fossil fuels. Geothermal-energy operations can alter local stress conditions, potentially leading to the release of seismic energy in the form of microseismic events. The safety and efficiency of geothermal-energy production depend on the accurate characterization of microseismic activity near operational sites. This characterization is mainly affected by the accuracy of the seismic-velocity model used for hypocentre estimation. Developing a new seismic-velocity model using active sources requires significant investment. Consequently, the geothermal industry seeks innovative and cost-effective approaches to evaluate existing seismic-velocity models.

We present a methodology to validate a seismic-velocity model using seismic interferometry (SI) applied to six microseismic events recorded during geothermal operations in Kwintsheul, the Netherlands. Some of these events exhibit near-vertical incidence angles at specific stations, enabling the retrieval of zero-offset virtual reflection responses beneath the stations. We compare these SI-derived reflections with synthetic responses generated from the available P- and S-wave velocity models. For stations with clear vertical-incidence paths, the P-wave reflections show consistent alignment between observed and synthetic responses. In contrast, neither of the two tested S-wave models reproduces the observed reflection features, indicating a significant mismatch in S-wave velocity structure beneath the stations.

This workflow demonstrates that, under favourable conditions, SI can provide independent, reflection-based validation of seismic-velocity models using microseismic events. In this case, the P-wave velocity model is consistent with the observed reflections, while the tested S-wave models are not. This indicates that SI can serve as a cost-effective tool to identify weaknesses in existing models and guide future velocity-model updates.

Combining Multiple Data Types to Improve or Merge Models in Arrival Time Tomography: Virtual VSP's
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Two of the general limitations of arrival time tomography are inadequate resolution of shear-wave velocity (V_s) structure and poor resolution of near-surface structure. I am developing a new strategy for adding constraints on V_s and near-surface structure from a variety of sources, for which I am borrowing the term virtual vertical seismic profile (virtual VSP). Rather than using interferometry as in the normal definition of virtual VSP, the idea is to use one-way body-wave travel times from points at depth up to the surface through velocity models obtained from one or more sources. There are many potential types of sources for such data, including one-dimensional models from Rayleigh wave ellipticity (H/V) observations or ambient noise autocorrelations, receiver functions and other converted waves, and two- or three-dimensional velocity models. Using the latter data type provides a natural way to merge velocity models. I will describe the strategies involved in producing the one-way travel times from the different sources and present results from applying the approach to the San Bernardino Basin in southern California. Tomographic inversion using P-wave virtual VSP data derived from a Statewide California Earthquake Center community velocity model yields a model with much lower P-wave velocities in the near-surface, consistent with other independent information.

Velocity and Attenuation Models of Mississippi Embayment Sediments Derived From Refraction Wavefields
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We focus on developing quantitative velocity and attenuation models for the ~1 km thick sedimentary column of the Mississippi Embayment to improve understanding of wave propagation, ground-motion amplification, and computation of earthquake wave fields for seismic hazard estimation. The velocity model is constructed by fitting body-wave travel times and surface-wave dis-

persion measurements using precisely timed waveform data from the ~3km ESEE2022 and ~18km USGS piggyback profiles using two 200 lbs explosion sources. A four-layer velocity model, including two linear velocity gradients, the Cretaceous sedimentary layer, and the Paleozoic basement, is constrained using P and converted PS body-wave traveltimes. Surface-wave dispersion provides improved constraints on shallow S-wave structure, allowing subdivision of the upper gradient layers, with inverted V_s values consistent with body-wave constraints at layer boundaries. V_p values for sublayers within the gradient layers are estimated using an empirically derived V_p – V_s relationship for the sedimentary column. Wavenumber-integration synthetic seismograms are used to match observed phase arrivals and amplitude–distance behavior, constraining both velocity structure and anelastic attenuation. Using the inferred velocity model, depth-dependent Q_p and Q_s within the sedimentary column are estimated by modeling the apparent distance–amplitude decay of selected body-wave and surface-wave phases. Attenuation is treated as a material property rather than measured empirically. An iterative least-squares inversion minimizes misfit between observed and synthetic amplitude-decay coefficients. Synthetic tests show good resolution within the sedimentary column but limited sensitivity in the basement. The final velocity model includes a near-surface high-gradient zone where V_p and V_s increase from 1.4–2.0 km/s and 0.21–0.61 km/s, respectively, underlain by a lower-gradient zone where V_p and V_s increase from 2.0–2.2 km/s and 0.61–0.89 km/s. V_p is 2.98 km/s in the Cretaceous layer and 6.24 km/s in the Paleozoic basement.

Generating, Calibrating and Validating Multi-Scale Seismic Velocity Models [Poster]
Poster Session • Friday 17 April
Conveners: Yehuda Ben-Zion, University of Southern California (benzion@usc.edu); Kim B. Olsen, San Diego State University (kbolsen@mail.sdsu.edu); Patricia Persaud, University of Arizona (ppersaud@arizona.edu); Artie Rodgers, Lawrence Livermore National Laboratory (rodgers7@llnl.gov); Te-Yang Yeh, University of Southern California (tyyeh316@gmail.com)

POSTER 56
Comparison of Recorded Ground Motions and Simulations Using Different Three-dimensional Seismic-velocity Models With Implications for the U.S. Geological Survey National Crustal Model
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In this study, we simulate earthquake ground-motions for six earthquakes in New Jersey and California using three-dimensional seismic-velocity models (SVMs). We assess differences in ground motions for a given earthquake using different SVMs and show how improvements to SVMs can yield greater consistency between simulated and observed ground motions. Earthquakes are modeled as point sources with M_w 4.1–5.1. Simulations are run up to 1 Hz using three different wave-propagation solvers. Geophysical structure is assigned using the U.S. Geological Survey (USGS) National Crustal Model (NCM), the USGS San Francisco Bay Area velocity model, and two SVMs for the Los Angeles region (CVMS4.26.M01 and CVMH15.1.0) with an imposed minimum shear-wave velocity down to 200 m/s. In California, the spatial patterns in ground motion amplification are similar between different SVMs for a given earthquake, but the effects of modeling decisions in the construction of the SVMs are apparent in the wavefield. Focusing on the NCM, we note several differences between simulated and observed time series, which include (1) the timing of surface waves relative to body waves, and (2) resonant frequencies for stations above large sedimentary structures. We seek to resolve these differences and improve the NCM using measured horizontal-to-vertical spectral ratios (HVSr) and frequency-dependent Rayleigh-wave phase velocity. For example, with HVSr we find that the modeled seismic velocities of sediments in the Atlantic Coastal Plain need to be decreased to match the resonant periods of surface waves in the observed time series. Upon compari-

son with Rayleigh-wave phase velocity in the western United States, we find that the NCM velocities in the upper crust are too fast. This anomaly appears to be correlated with strain rate, whereby lower shear-wave velocities not associated with changes in composition are correlated with increasing strain rate. After application of revisions to the NCM, we obtain an improved fit to observed time series and ground-motion metrics and demonstrate the utility of such models for predicting earthquake ground motions.

POSTER 57
Constraining Seismic Velocity Structure in Southeastern New Mexico Using Ambient Noise Tomography: Implications for Induced Seismicity Depth Determination
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The northern Delaware Basin in southeastern New Mexico coincides with extensive wastewater disposal from oil and gas extraction and increasing seismic activity, including a recent magnitude 4.49 event in February 2024 in the Dagger Draw seismic cluster. Accurate source characteristics are crucial for assessing the spatiotemporal evolution of induced seismicity and subsurface stress changes. However, constraining depth for predominantly shallow, small-to-moderate magnitude induced events is challenging due to sparse or distant seismic stations and the absence of high-resolution 3D velocity models. Ambient seismic noise interferometry enables the extraction of surface wave dispersion curves from continuous recordings of naturally occurring microseisms, which can then be inverted to constrain shallow subsurface shear-wave velocity structure in the upper few hundred meters without requiring active seismic sources or earthquake recordings.

This study examines the feasibility of this approach using currently operating seismic networks (SC, GM, 4T, NX, and TX) in southeastern New Mexico and surrounding areas. Our data processing workflow consists of: (1) cross-correlation of ambient noise between paired seismic stations with daily stacking, (2) annual stacking of daily cross-correlated signals to increase signal-to-noise ratio, (3) dispersion curve analysis of empirical Green's functions to extract Love and Rayleigh wave group velocities as a function of period, (4) ambient noise tomography to construct 2D phase and group velocity maps at discrete periods for Love and Reyleigh waves. The resolved depth range depends on the frequency bands obtained from varying interstation distances, with sensitivity concentrated in the shallow subsurface critical for characterizing induced seismicity.

POSTER 58
Multi-frequency P-wave Polarization Angle Inversion for Shallow Crustal Structure
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P-wave polarization analysis provides valuable constraints on near-surface S-wave velocity by measuring the polarization angles of P-wave arrivals at seismic stations. However, the depth sensitivity of this method has not been well quantified, limiting its broader application to velocity structure estimation. In this study, we investigate the depth sensitivity of P-wave polarization angles across multiple frequency bands using numerical approaches based on the reflectivity method. Using the resulting frequency-dependent sensitivity kernels, we perform multi-frequency inversion of P-wave polarization angle measurements to estimate the shallow crustal S-wave velocity structure from the near-surface to the mid-crust. We apply this method to three-component seismic data recorded at hundreds of stations across the southern Korean Peninsula. The resulting velocity structures from 1 to 20 km depth show good agreement with receiver function results, while shallow structures within the upper 1 km are consistent with local site survey measurements. These results demonstrate that multi-frequency P-wave polarization angle inversion provides a complementary constraint on near-surface to mid-crustal S-wave velocity structure and can enhance the characterization of near-surface seismic properties.

POSTER 59
Joint Inversion of Rayleigh-wave Phase/Group Velocities Using a 3D Reference Model for Crustal Velocity Structure of Gangwon Province in the Korean Peninsula
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Gangwon Province exhibits strong topographic relief and significant variations in Moho depth, necessitating the use of a 3D reference model for reliable crustal velocity imaging. To construct this model, we incorporated ETOPO1 topography, Moho depth estimates from receiver functions, and near-surface sedimentary layers constrained by P-wave polarization angle inversion essential for improved fitting of short-period dispersion curves. Rayleigh-wave phase and group velocities were measured from ambient-noise cross-correlation functions using data from 101 broadband seismometers and accelerometers for periods of 1–16 s. To extend sensitivity to deeper structures, we also included longer-period (10–40 s) Rayleigh-wave phase velocities derived from regional Helmholtz tomography. These three complementary datasets were jointly inverted to produce a high-resolution 3D S-wave crustal velocity model of Gangwon Province. The resulting model reveals pronounced low-velocity anomalies bounded by the Inje and Geumwang faults, suggesting the presence of compositional heterogeneity and mechanically weak zones. These results provide quantitative 3D constraints on major fault systems and crust–uppermost mantle structure in Gangwon Province.

POSTER 60

A Data-driven Ground Motion Synthesis Framework, with Physics-informed Broadband Time-series and Nonlinear Site Response

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In this study, we develop a non-parametric, data-driven near-surface shear-wave velocity model for Southern California to enhance the basin representation in the SCEC Community Velocity Model (CVM-S4.26). The model is formulated as a conditional random field of residuals relative to CVM-S4.26, expressed using a Gaussian process (GP). The GP employs a composite kernel that combines both stationary and spatially varying components, enabling the model to capture regional geological trends as well as site-specific variations. The stationary kernel provides the average scaling as a function of surface elevation, and depth to a shear-wave velocity of 2500 m/sec (Z2.5), while the spatially varying kernel encodes the location of the local Vs measurements. We train the model on an extensive dataset of geotechnical measurements, derived from both invasive and non-invasive methods, supplemented by a smaller set of deep sonic logs to constrain deeper velocity structure. Our results demonstrate that the integrated kernel, incorporating both local and regional geological information, achieves superior predictive performance compared to models that rely solely on either component. Key strengths of the proposed work are modeling the uncertainty and spatial correlation in addition to the field, as well as the capability of continuous update with the collection of more data. By integrating statistical modeling with shallow geophysical constraints, our approach provides a robust, flexible, and interpretable framework for modeling near-surface velocity structures, with broad implications for engineering and earthquake hazard applications.

POSTER 61

Comparing Piedmont and Coastal Plain Near-surface Substructures Using P-wave Refraction and Surface Wave Dispersion

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The near-surface substructure can inform how land can be used. Groundwater pumping, proximity to the coast, subsidence, and other hazards in the substructure may influence whether land is safe to use. This study utilizes near-surface geophysics to probe the subsurface in regions above and below the Atlantic Seaboard Fall Line to determine their material structures and level of saturation. The Fall Line indicates a transition from stronger rock to unconsolidated sediments and a decrease in elevation from the Piedmont to the Coastal Plain, leading to a possible contrast in substructure and subsurface water storage. A site in the Piedmont, a University of Maryland (UMD) Agricultural Facility in Clarksville, MD, and a site in the Coastal Plain, the United States Geological Survey's West Point Land Motion Observatory in West Point, VA, were considered. Active source data were collected, and the data were processed using a Transdimensional Hierarchical Bayesian (THB)

framework that integrates p-wave refraction and surface wave dispersion to determine the seismic velocity structure over depth. The p-wave velocity (v_p) was constrained using a one-dimensional THB framework and a v_p layered structure was estimated. The s-wave velocity (v_s) was estimated using a v_p/v_s ratio of 1.8, and a script to forward predict a dispersion curve to implement into the THB framework was developed. The dispersion plots from Clarksville and the forward predicted dispersion curves somewhat agree, and the implementation of dispersion in the THB framework will minimize the disagreement. These profiles will be analyzed to identify the depth of the bedrock, depth of the groundwater table, and the porosity of the sediments.

POSTER 62

Hybrid 3D Velocity Model for Southwest Iberia With Improved Ground Motion Prediction Efficacy

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Accurate seismic hazard assessment using physics-based modeling requires a 3D velocity model capable of reproducing observed ground motions. In this study, we evaluate the performance of seven crustal and upper Mantle velocity models for southwest Iberia—five 3D models (PRISM3D, GC3D, EPcrust, Corela et al., 2017, Veludo et al., 2017) and two interpolated 1D models (IGN1D, Attanayake et al., 2017) using physics-based simulations up to 1 Hz. While none of the individual models successfully captures the complete wavefield characteristics, we choose to merge the complementary strengths of PRISM3D and EPcrust using an equal weighting scheme guided by the Fourier Amplitude Spectral (FAS) bias for a 2018 Mw4.3 earthquake from trial-and-error simulations. We have validated the optimized hybrid model against recordings from five Mw 4.1–5.9 earthquakes with varying onshore and offshore source locations. The hybrid model demonstrates a significant improvement in goodness-of-fit, reducing the FAS bias by approximately 50% and 40% relative to PRISM3D and Attanayake et al. (2017), respectively, for both onshore and offshore events. Our optimized hybrid model includes Vs30-constrained near-surface low-velocity material to a depth of 350 m, anelastic attenuation parameterized as Qs = 0.1 × Vs (Vs in m/s), and a statistical model of small-scale heterogeneities with a standard deviation of 5% relative to the background model and a vertical correlation length of 250 m. Specifically, the hybrid model provides improved P- and S-wave arrival times compared to other models and extends the underpredicted coda energy in the Lower Tagus Basin generated from simulations with PRISM3D. The proposed hybrid model provides a foundation for more accurate regional ground motion modeling in southwest Iberia.

POSTER 63

Seismicity and Local Body-wave Tomography of Western Australia Using PyVoroTomo 2.0, a Newly Updated Voronoi-cell Based Tomographic Inversion Code

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Western Australia experiences regular seismicity, presumably due to the accumulation of long-period compressional stress. It also sees thousands of yearly mining blasts reaching magnitudes up to MLa 3. We present an updated seismic catalog of Western Australia (2000-2026; Pickle et al., 2026) showing these events and generated from data from the first three years of data from the ongoing WA Array (WG; 2022), an ambitious project aiming to instrument the entire state at a 40 km grid. We leverage this catalog (30,000+ events) to also introduce PyVoroTomo version 2 (e.g., Fang et al., 2022), a newly enhanced edition of open-source body wave tomography code which iteratively refines stacked random Voronoi cell realizations each derived generated via traditional weighted least squares inversion. PyKonal (White et al., 2020) is used to relocate events and trace raypaths by solving the Eikonal equation. The code has produced new shallow P and S-speed crustal velocity models for Western Australia and has reduced average event residuals by > 50% relative to previous 3D models. The code includes scripts to easily convert QuakeML catalogs, stationXML metadata, and NonLinLoc velocity models to digest and run on datasets featuring millions of event arrivals, and is parallelized to run on Unix, OSX, and cluster environments via MPI and Cython.

POSTER 64

Advancing Seismic Hazard Modeling With the SCEC Unified Community Velocity Model (UCVM) Framework and CVM Explorer

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The Statewide California Earthquake Center (SCEC) Unified Community Velocity Model (UCVM) software framework provides a standardized interface for accessing and integrating multiple seismic velocity models to advance earthquake science and engineering applications. UCVM enables the extraction of high-resolution characterization of Earth's subsurface properties from both fine- and coarse-resolution base models, which are essential for ground-motion modeling, seismic hazard analysis, and wave-propagation simulations. The latest UCVM release (v25.7.1) incorporates Community Velocity Models (CVMs) covering California and portions of the western United States, integrating recent contributions from leading research institutions including the University of Wisconsin, the U.S. Geological Survey, Lawrence Livermore National Laboratory, and SCEC. Current UCVM development efforts focus on incorporating the Multi-Scale Statewide California (MSCAL) velocity model (Yeh, Ben-Zion, and Olsen, this meeting) and expanding collaborations to extend UCVM's spatial coverage.

UCVM is fully integrated in SCEC CVM Explorer, a web-based platform that provides real-time access to seismic velocity data through a simple user-friendly browser interface. CVM Explorer supports the extraction and visualization of 2D horizontal slices, 2D vertical cross sections, 1D profiles, 0D points, and arbitrary point sets from text files. Its visualization tools produce publication-quality plots, offer multiple colormaps, and include options for displaying faults, cities, and standardized data ranges to facilitate rapid model comparisons. Together, UCVM and CVM Explorer streamline data preparation, accelerate model exploration, and enable faster, more precise seismic hazard assessments.

POSTER 65

A Dense Nodal Seismic Experiment Across the Livermore Valley, California

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The Livermore Valley contains a major sedimentary basin underlying the densely populated cities of Pleasanton, Dublin and Livermore in the eastern San Francisco Bay Area. The basin is a low-lying depression filled with thick (up to 600 m) alluvial sedimentary deposits. It is bounded by three faults: Calaveras; Greenville; and Las Positas and possibly shaped by the Mount Diablo Thrust Fault. The last major earthquakes in the region were M 5.6-5.8 ruptures on the Greenville Fault in January 1980, which caused major damage. A temporary network of about 200 three-component nodal geophones was deployed in late 2025 for a two-month period to image detailed basin structure and earthquake site response across the Livermore Valley. The network consisted of a dense west-to-east line (~200 m station spacing) across the Valley, a dense distributed array (150-400 m station spacing) on the Lawrence Livermore and Sandia National Laboratory sites, and a sparse distributed array (~2 km station spacing) scattered across the Valley. During the deployment, a swarm of small earthquakes (M1-4) occurred in the San Ramon area, and additional stations were deployed in this source region to the northwest of the Valley.

This presentation will feature descriptions of the deployment, quality assessments, and preliminary analyses of the data. The intended analysis techniques include: extracting surface wave dispersion and Rayleigh wave ellipticity from multi-component noise cross-correlations, receiver function early lag time analysis, site response analysis, and waveform modeling of local events. We will also investigate the November-December 2025 San Ramon earthquake swarm using local stations deployed in the source region. We are grateful for support from the USGS and the NSF SAGE.

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from UC Berkeley and LLNL who assisted with deploying the nodes, as well as the residents of the Livermore area who agreed to host a geophone for this study.

Geophysical Perspectives on Volcanic Systems: Seismicity, Structure and Dynamics

Oral Session • Friday 17 April • 8:00 AM local

Conveners: Alysha Armstrong, Lawrence Livermore National Laboratory (armstrong52@llnl.gov); Guanning Pang, University of Science and Technology of China (pgn0707@ustc.edu.cn); Brandon Schmandt, Rice University (Brandon.Schmandt@rice.edu); Sin-Mei Wu, University of Hawaii at Manoa (smwu@hawaii.edu)

Arc Magma Migration Inferred at Laguna Del Maule, Chile Using Well Constrained Seismicity and Receiver Function Imaging

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Arc volcanoes are known to have magmatic plumbing networks organized into transcrustal systems. While the geometries of these systems are sometimes well constrained, the links between magma migration and surface unrest remains poorly understood. Dense seismometer deployments around Laguna Del Maule (LdM) in central Chile, where volcanic unrest is being monitored, gives an opportunity to study these connections in detail. Here, we present interpretations using well constrained earthquake locations and high resolution crustal-scale seismic imaging using Receiver Functions (RFs), to infer the magma plumbing and interconnectivity within this modern arc volcano setting.

Over 4300 events were detected within the periods between 2015-2018 and 2022-2024, separated into shallow and deep clusters. Those events occurring within the deep crust (~12-30 km) are a new observation, composed of a mixture of high and low frequency earthquakes. The deep higher frequency events are a pronounced one-day (Feb 14, 2018) swarm of activity with similar magnitudes that is vertically extended between ~21-26 km depth. We interpret this activity to represent a Volcano-Tectonic swarm (VT) related to magma migration. In the RF imagery, the VT swarm is placed within the middle-lower crust between the top of a low velocity zone (LVZ) in the lower crust, and the base of an upper crust LVZ. The lower crust LVZ likely represents an area of deep magma storage that intermittently incubates the upper crust system. Three months following the deep VT swarm, there is accelerated vertical surface uplift as evidenced in the GPS record. We infer that the VT swarm was driven by the delivery of a new batch of magma from lower to upper crustal magma reservoirs. This applied additional pressure to the base of the upper crustal reservoir, leading to a surficial response in a lag-time consistent with the system's hydraulic diffusivity (~20 m2/s). These results indicate that surface volcanic unrest is preceded months in advance by seismic activity occurring within the middle-lower crust, applying bottom-up reservoir pressurization in arc volcanoes.

Dynamic Evolution of the Magmatic-hydrothermal System at Uturuncu Volcano, Bolivia

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Understanding the fine-scale structure and temporal evolution of volcanic systems is essential for constraining magma–hydrothermal processes and assessing volcanic hazards. Seismic imaging provides a powerful window into subsurface properties, yet static images alone are often insufficient to capture transient processes associated with magma intrusion, fluid migration, and pressure redistribution. Here we present results from both three-dimensional (3D) and four-dimensional (time-lapse, 4D) seismic tomography to refine the detailed structure and dynamic evolution of the magmatic-hydrothermal system at Uturuncu volcano, Bolivia.

Uturuncu is located directly above the world’s largest known silicic partial melt body yet has not erupted for ~ 250 ka. Despite this long quiescence, the ongoing non-eruptive activity including surface deformation, degassing, and abundant shallow seismicity, raising fundamental questions about the drivers of ongoing unrest and the role of deep magma reservoirs in sustaining shallow processes.

Using three-years of recordings from two seismic networks, we first characterize the static 3D structure of the magmatic-hydrothermal system through joint seismological and petrophysical analyses. Our results indicate upward migration of fluids and gases through a vertical conduit and shallow accumulation of gases beneath the summit, providing a physical explanation for the observed activity. We track the temporal 4D variations in Vp, Vs, and Vp/Vs by time-lapse tomography, resolving an evolutionary sequence from a sealed, fluid-accumulated state to an intensified active phase, followed by stabilization. Together, these observations provide new insights into the mechanisms driving volcanic unrest and the long-term evolution of magmatic-hydrothermal systems.

Deep-learning-based Monitoring of Volcano-tectonic and Long-period Earthquakes

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The application of deep-learning-based seismic phase pickers has surged in recent years. However, the efficacy of these models when applied to monitoring volcano seismicity has yet to be fully evaluated. Here, we first compile a data set of seismic waveforms from various volcanoes globally. We then show that the performances of two widely used deep-learning pickers deteriorate systematically as the earthquakes’ frequency content decreases. Therefore, the performances are especially poor for long-period earthquakes often associated with fluid/magma movement. Subsequently, we train new models which perform significantly better, including when tested on data sets where no training data were used. Finally, we apply our new model to characterize seismicity at Mount Spurr in Alaska through its 2024-25 unrest episode.

Event Classification Using Seismic Arrays in Volcanic Environments

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In volcanic environments, seismicity can be influenced by different eruption mechanisms, failure of pre-existing faults, magma migration, hydrothermal fluid movement and release of trapped gases. High frequency volcano tectonic events are usually generated by brittle failure of pre-existing faults, while fluid related processes generate low frequency long period seismicity. However, the path and site effects of complex volcanic settings can complicate the seismicity classification. We aim to understand the contribution of array geometry in reducing bias from path and site effects and improve the seismicity classification for real-time application.

We first apply classification to synthetic events where we validate the accuracy by comparing with true labels. We simulate volcano tectonic (VTs) and long period (LPs) events using a Brune type model with two to three orders of lower stress drops for LPs of similar size. We consider source radiation and convolve with distance-based attenuation and station specific site terms for synthetic waveforms at different stations.

We hypothesize multi-station array-based stacking should reduce the bias from path and site effects as well as improve the signal to noise ratio, compared to single-station studies. We compare both time domain and frequency domain stacking and observe time domain stacking can reduce high frequency noise in some cases. We compute energy ratios of low-frequency energy over total energy and apply a Gaussian Mixture model to separate VTs and LPs. We find that with increasing source-receiver distance (i.e.>5 to

10km) the high frequency energy attenuates more rapidly, and classification errors increase. Moreover, the classification of LPs and VTs is complicated for larger magnitudes (i.e. Mw> 4) with corner frequencies that fall outside of the analyzed frequency band of 1-30Hz.

We test the resolved constraints on station distance, magnitude range and spectral stacking by analyzing seismicity from eruptions in Kilauea, Hawaii; Okmok and Akutan, Alaska. Our classification approach using optimized array geometry can improve real time volcano monitoring efforts.

Interconnected Magma Reservoirs at Santorini and Kolumbo: Insights From the Recent Magmatic Crisis

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In January 2025, Santorini and its neighbouring islands experienced an intense earthquake swarm, prompting the Greek authorities to declare a state of emergency followed by the island’s evacuation of the majority of the population. Following a gradual inflation and rise in seismic activity beneath the Santorini caldera, the main seismic swarm began on January 27, close to the submarine volcano Kolumbo, 10 km offshore NE of Santorini at 18 km depth. The Santorini and Kolumbo volcanoes have both produced highly explosive (VEI 5) eruptions in historical times, including the 1650 eruption of Kolumbo, which formed a 2.5 km-wide and 500 m-deep submarine crater and triggered a tsunami that devastated the surrounding islands. Although petrological, seismological, and geodetic analyses identified distinct shallow- and mid-crustal magma reservoirs, there has been debate over whether the two volcanic centres are connected and share a common deep magma source, or whether they result from distinct plumbing systems.

The 2025 seismic crisis provided an unprecedented opportunity to observe the volcanic system and investigate the potential deep coupling. Integrating seismic and geodetic data from onshore and offshore instruments, we observe and model the dynamic emplacement of a 13-km long intrusion with a volume of 0.31 km³ into the upper crust offshore Santorini, reactivating principal regional faults and arresting 3–5 km below the seafloor. We determine a gradual inflation of Santorini’s shallow reservoir 6 months before the crisis, during the intrusion a mid-crustal reservoir beneath Kolumbo at ~7.6 km depth rapidly deflated. This suggests that both volcanoes share, and potentially compete for, a common deep magma supply. In December 2025, we recovered additional ocean-bottom seismometers and pressure sensors, enabling us to refine our seismological catalogues and deformation modelling during and after the seismic crisis. Our analyses highlight the importance of shoreline-crossing monitoring and the need for real-time access to submarine sensor data for a more robust crisis response.

New Focal Mechanism Constraints on the Caldera Ring Fault System at Axial Seamount from an Expanded OBS Network

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Axial Seamount is an active submarine volcano located at the intersection of the Cobb hotspot and the Juan de Fuca Ridge and has experienced well-documented eruptions in 1998, 2011, and 2015. Since late 2014, the Ocean Observatories Initiative Regional Cabled Array has enabled continuous, real-time seismic monitoring, leading to the detection of more than 230,000 earthquakes concentrated primarily within the southern caldera. Previous studies have characterized the outward-dipping ring fault system and its response to

magma chamber inflation and deflation using focal mechanisms. However, seismic constraints on the northern caldera and the intersections with the north and south rift zones have been limited, hindering a comprehensive understanding of the ring fault system and hotspot-ridge interactions.

From September 2022 to September 2024, a dense network of 15 ocean-bottom seismometers was deployed across the entire caldera at Axial Seamount, substantially improving azimuthal coverage and depth control. Using cross-correlation methods to determine first-motion polarities for microearthquakes recorded by at least 10 stations, we obtained 709 high-quality focal mechanisms between September 2022 and September 2023. The results indicate that normal faulting dominates throughout most of the caldera, consistent with motions on the outward dipping ring fault during caldera inflation. In contrast, near the intersection of the northernmost caldera wall and north rift zone, abundant right-lateral strike-slip mechanisms are observed, suggesting a stress regime influenced by overlapping spreading centers. At the southern end of the caldera near and to the south of the International District vent field there are many focal mechanisms that are consistent with right-lateral strike-slip faulting aligned with the fissures of the south rift zone. These may reflect the interactions of caldera inflation with the plate boundary. Further insights can be expected from focal mechanisms for the second year of the experiment which recorded nearly ten times more earthquakes because the caldera was inflating more rapidly.

Transcrustal Anisotropic Imaging of Magmatic Structures Along the Alaska-Aleutian Arc Using Receiver Functions

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The concept of volcanomagmatic systems has evolved from that of a single shallow crustal magma chamber to transcrustal systems. It is therefore of interest to image the entire crustal thickness under a volcano, including depths below volcanotectonic (VT) seismicity. Teleseismic receiver functions offer high resolution at all crustal depths and typically show prominent arrivals with azimuthal polarity flips under volcanoes, which can also interfere with identifying Moho arrivals. We analyze receiver functions at all Aleutian and Alaskan volcanoes using Alaska volcano observatory monitoring network broadband stations. We show that receiver functions are dominated by conversions from contrasts in anisotropy rather than by isotropic heterogeneity. Most of the volcanoes show a conical anisotropic volume extending from the upper to the middle crust. The cone contains concentric fabrics with fast planes that dip outward from the volcanic center and encompasses the bulk of VT seismicity. We propose that the fabric consists of outward dipping faults and dikes.

At Akutan, such a geometry is consistent with geodetic ellipsoidal inflation source models and previous local tomography and relocation work. At Okmok, a previous surface wave radial anisotropy model shows a central horizontal-fast cylinder surrounded by a vertical-fast donut; conical dipping anisotropy as suggested by our results would be consistent with these observations. At Akutan, Aniakhchak, Tanaga, and Westdahl, the lower limit of the anisotropic volume neatly separates VT seismicity from long-period (LP) seismicity below, and we interpret it as the brittle-ductile transition (BDT). The BDT deepens from ~6 km under the volcanic center to below 10 km away from the center at most of the volcanoes. A few volcanoes show arc-parallel instead of concentric fabrics, particularly in the western Aleutians. Similar variations were seen previously in preferential strikes of magma pathways along the arc. Deeper conversions from ~20 km depth and greater at many of the volcanoes may be related to lower crustal magmatic structures.

Seismic Constraints on the Magmatic System Beneath the San Francisco Volcanic Field in Northern Arizona

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Distributed volcanic fields are one of the most common forms of volcanism on Earth and pose significant hazards to population centers around the world. For many of these fields, little is known about the underlying magmatic systems that drive volcanism. The San Francisco Volcanic Field (SFVF) in Northern Arizona is one of the most active cases of distributed volcanism in the western U.S., having produced around 600 volcanic vents over the past 6 Myr. This volcanic field is distinguished by its compositional diversity of eruptive products

which include San Francisco Mountain (SFM), a stratovolcano that was active between 0.9 and 0.4 Ma, and Sunset Crater (SC), one of the best-documented explosive basaltic eruptions on Earth in 1085 CE. To constrain the magmatic system that feeds this volcanism, data from a recent ~600-node seismic experiment are used to detect local seismicity and image seismic velocity contrasts in the crust using a receiver function analysis. Detected seismicity is clustered within several NE/SW- and NW/SE-trending groups that represent the continuation and active deformation of several regional fault systems that have been mapped near the periphery of the volcanic field. The most active region of seismicity observed during the seismic deployment is located directly SE of SFM and extends to depths exceeding 25 km. In adjacent regions, receiver function results show prominent negative conversions between 15 and 18 km depth, indicative of the tops of low velocity zones in the middle crust beneath SFM, SC, and the city of Flagstaff. Given the volcanic context, it is inferred that these low-velocity features represent zones of partial melt that fed volcanism at SFM and possibly nearby basaltic vents in the past. The observed deep crustal seismicity amongst these inferred partial melt zones may highlight a pathway of vertical magmatic fluid transport from a lower crust/mantle source region to mid-crustal storage depths. Combined, these seismic constraints provide critical tools for monitoring the magmatic system beneath the SFVF and the conditions that may promote future volcanic unrest.

Probing the Wairakei-Tauhara Geothermal System, Taupō Volcanic Zone, With a Dense Nodal Seismic Array

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As the world transitions to clean energy and zero-emission technologies, the demand for sustainable subsurface energy resources is steadily increasing. In this study, we utilise a passive seismic approach with a dense nodal seismic array to enhance our understanding of the subsurface at the Wairakei-Tauhara Geothermal System in the Taupōo Volcanic Zone, the first geothermal system for energy extraction in New Zealand. In 2024, 141 nodal seismic sensors supported by the Australian National Seismic Imaging Resource (ANSIR) were deployed across the 20 x 25 km² region centred at the Wairakei geothermal field in two phases, each lasting one month but with slightly different configurations. The array achieved an average station spacing of 3-5 km on a regional scale, with refined inter-station spacing of 200-500 m in several critical areas, such as Te Mihi and Poihipi. To best image the complex subsurface structure with the nodes data we developed an adaptive irregular grid tomography method based on the Poisson-Voronoi approach. This enables multiscale structural resolution while maintaining coverage in sparsely sampled regions with a comprehensive model. The resulting velocity model, jointly constrained by surface wave dispersion and horizontal-vertical-spectral-ratio, offers detailed structural insights from the surface down to a depth of 10 km, revealing features related to the shallow geothermal system, a glimpse of the deeper magmatic systems, and their possible connections. These structures will be evaluated for their potential functions as migration pathways and storage sites for geothermal energy, thereby enhancing our understanding of geothermal energy generation in complex geological settings.

Magmatic Volatile Flux Drives Non-eruptive Volcano-tectonic Seismicity at Mount St. Helens, USA From 2008–2024

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Seismicity during non-eruptive periods is useful for observing stress changes related to magmatic transport and volatile exsolution within active volcanoes. Mount St. Helens in Washington, USA, is the most active volcano in the continental United States and has been in quiescence since 2008. To explore the processes driving seismicity at Mount St. Helens, we create a high-resolution seismicity catalog of non-eruptive seismicity from 2008 through 2023, consisting of 31,133 events. We find persistent shallow seismicity (~2.2 to 2 km below sea level (BSL), 0–4.2 km below the surface) throughout the entire

study period that concentrates beneath the dacite dome complex from the 1980–1986 and 2004–2008 eruptions. Additionally, there is frequent deeper seismicity (2–8 km BSL, 4.2–12.2 km below the surface) beginning in 2016. We examine a selection of deep earthquake swarms and find complex along-depth seismicity patterns. Within swarms, increases in shallow seismicity rates can precede or are concurrent with increases of deep seismicity rates. Lastly, we discover a series of semi-periodic, shallow, burst-like swarms, consisting of low-amplitude, repetitive similar earthquakes, indicating periodic valve-like release of fluid pressure from the conduit. Increased seismic activity beginning in 2016 indicates ongoing repressurization within the magmatic system driven by recharge or crystallization-induced second boiling within the upper-crustal reservoir after 2008. The data indicate that non-eruptive seismicity at Mount St. Helens is controlled by fluid pressure changes from gas flux sourced from the magma reservoir that migrates through crack networks.

Geophysical Perspectives on Volcanic Systems: Seismicity, Structure and Dynamics [Poster]

Poster Session • Friday 17 April

Conveners: Alysha Armstrong, Lawrence Livermore National Laboratory (armstrong52@llnl.gov); Guanning Pang, University of Science and Technology of China (pgn0707@ustc.edu.cn); Brandon Schmandt, Rice University (Brandon.Schmandt@rice.edu); Sin-Mei Wu, University of Hawaii at Manoa (smwu@hawaii.edu)

POSTER 123

A Study of the Volcanic and Tectonic Processes in the Southern Tyrrhenian Sea, Italy

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We aim to study the structure and dynamics of the Aeolian Islands plumbing systems in the southern Tyrrhenian region where active volcanism, intense onshore and offshore hydrothermal activity occur, thus providing the ideal setting to investigate the interplay between tectonic and magmatic processes.

In the Fall 2023 a nodal array of 120 sensors was deployed to investigate the relationship between seismic and volcanic activity in the southernmost islands of the Tyrrhenian sea. This seismic deployment provided a unique dataset that allowed us to analyze seismic signals revealing significant differences in time and frequency domain. In 2024 we deployed 16 broadband stations over the southern Aeolian Islands of Alicudi, Filicudi, Salina, Panarea, Lipari and Vulcano, and in the northern Sicilian coast, yielding high-resolution seismic data over a wide frequency range. Recent low to moderate seismic sequences as well as background seismicity are analyzed and linked to either active faulting or unrest episodes. Seismological analyses allow us to reveal distinct seismic signatures associated with volcanic processes, as also supported by geochemical observations at the surface.

Our study focuses on the importance of dense, multiscale seismic networks that contribute to the understanding of the role of tectonics and volcanism in the Tyrrhenian region.

POSTER 124

Shear-wave Splitting Reveals Stress Evolution Across the 2015 Eruption at Axial Seamount

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Axial Seamount is a hotspot-influenced submarine volcano in the Northeast Pacific Ocean that lies at the intersection of the Juan de Fuca mid-ocean ridge and the Cobb-Eickelberg seamount chain. Its summit is characterized by a 100-m-deep caldera measuring 9 x 3 km³ which has hosted three significant eruptions in the past three decades. Since late 2014, the Ocean Observatories Initiative Regional Cabled Array has supported a real time network that includes bottom pressure gauges and a 7-station seismic network. The geophysical instruments recorded the subsidence and seismic crisis associated with a volcanic eruption in 2015 and subsequent increasing rates of seismicity as the volcano re-inflates through the present day. At volcanoes, shear-wave splitting measurements, specifically the fast polarization orientation and splitting time, are sensitive to microfractures.

Building on unpublished work by Christian Baillard, we are implementing a procedure to analyze more than 240,000 earthquakes in a deep learning-enhanced earthquake catalog for splitting parameters with thorough replication of the previous work and adaptation to more recent open-source software. Seismic waveforms are first processed to select events with a P-wave rectilinearity > 0.7, angle of incidence < 30°, and S-wave signal-to-noise ratio > 2.0 to ensure clean events with S-wave motion in one plane. Shear-wave splitting is performed with the SWSpy package (with parameter adjustments to match the MFAST 2.0 package). This method rotates the three-component seismometer of the S-wave window into the transverse plane and inverts the splitting operator to find measurements of the splitting parameters. This is performed across many S-wave windows with the results clustered to find measurements that are robust. The goal of this study is to interpret splitting parameters in terms of the pattern of crustal anisotropy and stress evolution over a volcanic cycle and determine whether shear-wave splitting provides a useful precursory signal in concert with other seismic observations.

POSTER 125

Toward Comprehensive Catalogs of Volcanic Seismicity: Insights From Template Matching, Machine Learning and Network Coherence at Mount Saint Helens Volcano

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The style and timing of volcanic eruptions are largely controlled by how magma is stored and transported from the mantle through the crust. While shallow magma reservoirs are relatively well constrained, processes occurring in the mid- to lower crust, where melt accumulation, fluid migration, and magma–rock interaction are expected in trans-crustal magmatic systems (TCMS), remain poorly understood. Volcanic seismicity, including volcano-tectonic (VT) earthquakes, long-period (LP), deep long-period (DLP) events, and volcanic tremor, provides a primary window into these processes, making comprehensive seismicity catalogs essential for understanding magmatic system dynamics.

Here we perform a comparative analysis of advanced seismic detection methods using continuous data from the Mount St. Helens (MSH) network during the 2008–2024 non-eruptive period. Starting from the Pacific Northwest Seismic Network (PNSN) VT catalog (4,088 events), Hirao et al. (2025) applied a template-matching (TM) approach yielding a high-resolution catalog with 31,215 VT events and ~10,000 regional tectonic earthquakes. We compare this catalog with a machine-learning (ML) approach using the VolPick model (Zhang et al., 2024), which produces more than 100,000 robust detections after filtering false events, including VT, regional tectonic, and DLP earthquakes. During intense VT swarms, TM provides better event tracking, whereas over the full 15-year period ML significantly improves catalog completeness by detecting earthquakes absent from the initial PNSN-based template database, particularly during quiescent periods. The ML approach detects and locates 43 DLP events, nearly doubling the number reported in the PNSN catalog. We are currently testing an additional method for automated DLP detection using CovSeisNet (CSN), which quantifies the spatial coherence of the seismic wavefield across the network. CSN successfully detects DLP events from the PNSN catalog, and ongoing work aims to combine TM, ML, and CSN to better characterize LP and DLP source processes beneath MSH and to constrain their role in fluid and magma transport within the TCMS.

POSTER 126

Velocity and Attenuation Effects of Magma Beneath Mount Rainier on Regional Differential Pn

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The detailed structure of magma chambers beneath the Cascade Range volcanoes remains incompletely resolved. Seismic wave attenuation is highly sensitive to temperature-dependent anelasticity associated with subsurface thermal anomalies and melt around magma systems, offering a valuable tool for investigating these structures. However, sparse seismic networks and relatively inactive seismicity limits the resolution of local body wave tomography on these magmatic systems. In this study, we extract information about seismic attenuation and seismic velocity from Pn waveforms using earthquakes located approximately 500–1200 km from Mount Rainier in an attempt to investigate the magmatic system beneath Mount Rainier. The use of differential Pn rather than teleseismic P allows imaging of the crust rather than deeper mantle. We analyze relative phase shift and spectral ratio of seismic signals among stations to assess spatial variations in travel-time delays and frequency-dependent attenuation across the volcanic region. The results reveal systematic Pn phase delays of up to ~1.5 s in the vicinity of Mount Rainier, consistent with reduced wave velocities that suggest elevated temperatures and partial melt. Spectral analysis indicates stronger attenuation beneath Mt. Rainier at frequencies below 5 Hz, further indicating the existence of partial melt. Together, these observations validate the Pn wave attenuation could be a valuable tool for investigating subsurface magmatic and thermal structures, particularly in regions where traditional seismic imaging is limited by infrequent seismicity.

POSTER 127

Evolution of the Magmatic System of Nevado del Ruiz Volcano 2017-2025

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A 4D seismic velocity tomographic study was performed for Nevado del Ruiz Volcano (NRV) for the period 2017–205 by using more than 526.238 P-wave and 521.367 S-wave arrival times. Two periods were considered for analysis based on changes in the activity of NRV; 2017–2021 and 2021–2025. The Initial 1D hypocenter locations for both periods were homogenized spatially and removed those earthquakes with considerable difference in hypocenter location in both periods, with the aim to avoid big changes in the illuminated images of the volcano inner structure. The study was focused on changes in the Vp/Vs ratio. The results showed that there was a clear change in the inner structure of NRV during the studied periods. Zones with high-Vp/Vs ratio (H zones) represent possible magma reservoirs and highly fractured and gas-leading zones, while low-Vp/Vs zones (L zones) represent basement and structural stable zones. Three shallow (1km depth) high-Vp/Vs zones (>1.9) towards the E (H1) and W (H2) of the Arenas (current active) crater and below the Olleta crater (H3), as well as two high Vp/Vs zones (>1.8) at 2 km and 3km depth to the S (H4) and W (H5) of the active crater, respectively for the period 2017–2021 were observed. In addition, a zone of low Vp/Vs (<1.6) between 2 and 4 km depth (L1) followed by a high-Vp/Vs zone (>1.9) at 5 km depth (H6) beneath the active crater for the same period were observed. On the other hand, for the period 2021–2025 the configuration of some of these Vp/Vs anomalous zones changed while others persisted; the H1 zone remained at the same position but became shallower while the H2 zone moved closer to the crater. The H3 zone remained in the same position. The H4 zone extended to the active crater, while the H5 zone disappeared. L1 and H6 remained in the same position. Based on these results it is possible to conclude that shallow and small pockets of magma moved toward the active crater between 2017 and 2025 at NRV while the deeper magma chamber (5 km depth) remained stable. A volcanic crisis in 2023 suggests that it was the result of such magma reservoirs reconfiguration beneath the NRV.

POSTER 128

Seismic Velocity and Attenuation Structure of the Mantle Beneath the North Island of New Zealand

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Some volcanic centers occur far from plate boundaries without geophysical or geochemical evidence of a deep mantle plume. While the Taupō Volcanic Zone rifted arc in the North Island of New Zealand shows clear geochemical evidence of subduction related magmas, the magmas of active Northland intraplate volcanic fields (>400 km from the Hikurangi trench), including the Auckland Volcanic Field (AVF), lack the geochemical tracers associated with slab derived fluids. Geochemistry suggests the AVF lavas last equilibrated with fertile asthenosphere at depths greater than ~80 km. This depth matches the approximate thickness of the lithosphere inferred from receiver function studies. To investigate the origin of the enigmatic AVF, a multinational team is deploying a temporary array of broadband seismometers and ocean bottom seismometers, complementing permanent networks. In this study, we use teleseismic waveforms recorded on the initial stations to measure differential travel times and attenuation operators (*) in order to constrain the attenuation structure, utilizing P, S, PKP, SKS, and related phases. This preliminary dataset shows high variability in travel times and * across the array, requiring large upper-mantle seismic anomalies. In particular, results reveal higher attenuation (*) beneath Northland volcanic centers, with the largest * near major volcanic fields. This high attenuation zone is consistent with anomalously high temperatures and/or the presence of melt in the upper mantle. It also coincides with a pronounced reduction in the amplitude of the velocity contrast between lithosphere and asthenosphere, which has been measured by common conversion point stacking of Sp receiver functions. This correlation is consistent with melt infiltration into the base of the lithospheric mantle, which would reduce its velocity contrast with the asthenosphere. Moving forward, we will compare the integrated differential attenuation measurements and velocities to assess whether the magma has a deep intraplate origin.

POSTER 129

New Observations of Volcano-tectonic Events at Mount Erebus, Antarctica

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Mount Erebus, Antarctica, is the southernmost active volcano on Earth, and has been continuously active since it was discovered in 1841. In recent decades the volcano has produced frequent Strombolian explosions originating from a persistent lava lake within its summit crater. Eruptions from the lava lake and icequakes from the highly glaciated volcano dominate previous seismicity catalogues. This contrasts with other active volcanoes which commonly exhibit a wide range of internal seismicity, including Volcano-Tectonic (VT) earthquakes, (deep) long-period events, hybrid events, and volcanic tremor.

We process data from a dense seismic array deployed for about a year starting the austral summer of 2008 using machine learning phase pickers. We associate picks into events using PyOcto, a high-throughput seismic phase associator. Such a procedure results in thousands of events within a single year of data. We apply more strict criteria such as polarization analysis and frequency index analysis to identify relatively impulsive and deeper VT earthquakes. We manually verified the waveforms and found a small subset (n=18) of VT earthquakes. The VT events occur at depths down to 6 km beneath sea level in contrast with superficial icequakes and lava lake eruptions located at the summit 3 km above sea level. Moreover, the spectral character of the VT events rises above the noise for frequencies of about 10 Hz, while the eruptions and icequakes have frequency content restricted to < 10 Hz. The moment magnitudes of these VT events are estimated to be smaller than 1.5. We suggest that the VT earthquakes occur in the vicinity of a melt-related vertical conduit, where thermal contraction enables localized brittle failure.

Spatiotemporal Changes in Seismic Velocity at Axial Seamount

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Ambient-noise interferometry enables continuous monitoring of the subsurface property changes, but its application at submarine magmatic systems remains limited due to the logistical challenges of ocean-bottom deployments and the complexity of seafloor noise. Following the 2015 eruption at Axial Seamount on the Juan de Fuca Ridge, we circumvent these constraints by leveraging the Ocean Observatories Initiative cabled array, which delivers continuous geophysical data streams within an active caldera. We integrate this permanent network (2015-2025) with a dense temporary array (2022-2024) to estimate relative seismic velocity changes (dv/v) from multi-station ambient-noise correlations. By applying coda-wave interferometry across multiple frequency bands, we obtain depth-dependent dv/v constraints. The decadal dv/v time series reveals a four-stage evolution: post-eruption increase (2015-2018), a sharp decrease during rapid inflation (2018-2019), an increase phase through 2019-2023, and a renewed reduction since late 2023, which are consistent with the inflation rate derived from bottom pressure records.

To resolve the spatial variations in the subsurface medium, we invert coda-wave time shifts using coda-wave sensitivity kernels to generate 2-D, time-lapse dv/v maps. These inversions provide a depth-dependent view of how velocity perturbations are localized beneath the edifice and how they evolve over time. Together, the temporal trends and time-lapse imaging across multiple depths constrain the stress evolution beneath Axial Seamount, illuminating the pathways and timing of magma transport during the ongoing deformation cycle.

Cascading Magmatic Unrest and Aseismic Faulting in the Aegean Sea Enabled by Elastic Stress Relay

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Magma reservoirs rarely exist in isolation and are commonly situated near fault networks; however, simultaneous unrest at multiple reservoirs and magma-proximal faults is difficult to observe. We analyze seismic and geodetic data recorded during the 2025 seismic sequence at the Christiana-Santorini-Kolumbo volcanic field in the Aegean Sea. We show that the earthquake swarm is sustained by a cascade of unrest involving two distal magma reservoirs, a >10 km long dike, and two aseismic slip transients. Continuous pressurization of a magma reservoir under Santorini volcano beginning in mid-2024 triggered a dike intrusion sourced from the neighboring Kolumbo volcano in January 2025, which, in turn, triggered a M_W 6.4 dip-slip aseismic transient on a SW-NE trending fault. The dip-slip faulting then facilitated a M_W 5.8 dextral aseismic transient on a W-E trending fault on the island of Amorgos. The dike also interacted with a mid-crustal reservoir along its path and received additional magma in the form of seismically observable buoyancy-driven magma pulses. Our results suggest that unrest in rift zones can propagate over spatial scales much larger than individual magma reservoirs and faults via sequential stressing and failure of individual features in a process we label elastic stress relay.

Seismic Noise Exploration of the Ongoing Episodic Kīlauea Summit Eruption Since December 2024

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Since December 2024, Kīlauea Volcano on the Island of Hawai‘i has undergone a series of episodic eruptions at its summit caldera manifested by hours long lava fountain activity. A total of 40 episodes have occurred to date, during which lava fountain heights reached up to 479 m and eruptive volumes reached as large as 13 million cubic meters from a single episode.

The eruption is consistently evolving, where the lava fountain style, erupted volume, eruption duration, and repose interval vary across individual episodes. Observation of ground tilt at the Kīlauea summit has shown drastic long-term change since the initiation of the eruption and short-term change associated with each eruption episode, implying subsurface properties may have changed significantly related to magma reservoir pressurization beneath the summit caldera. Persistent volcanic tremor can be clearly observed in the 1 to 10 Hz range during both time periods of lava fountain and repose, likely associated with bubbly magma movement within the plumbing system and seismic-acoustic energy from the fountaining phase. In this presentation, we investigate continuous seismic noise recorded around the Kīlauea summit caldera using ~20 permanent broadband stations from the Hawaiian Volcano Observatory network and a ~35-node temporary seismic array deployed since August 2025. We analyze the wavefield characteristics of the seismic tremor in relation to surface and subsurface volcanic activity and apply passive interferometry to perform time-lapse seismic imaging of the crust. These observations may provide insights into the evolving magmatic system, including variations in magma volume, volatile content, reservoir pressurization, hydrological conditions, and caldera boundary processes.

Along-arc Crustal Magma Storage at Alaska-Aleutian Volcanoes Using Novel Teleseismic Receiver Function Analyses

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The Alaska-Aleutian arc varies in volcanic eruptive behavior, frequency, and composition. Likewise, the arc exhibits variability in subduction parameters such as convergence obliquity, regional stress, and a transition from over-riding continental to oceanic crust. How this variability affects transcrustal magma storage and transport remains unclear. Improved seismic velocity constraints at mid- to lower-crustal (>10 km) depths can offer insights. However, limitations in resolution and local seismicity pose barriers, particularly when seeking along-arc comparisons. Teleseismic receiver functions (RFs) address this, as they are sensitive to these depths and independent of local seismicity. However, RFs near volcanoes are typically highly heterogeneous, complicating traditional RF velocity modeling. Here, we introduce a novel, data-driven method to characterize and map RF variability and apply it to 16 volcanoes in the Alaska-Aleutian arc. We use spectral clustering to group RFs at each volcano and then estimate the separation and location of these clusters in the crust via Kernel Logistic Regression. Along arc, we observe three end-member groups. First, at Akutan, Little Sitkin, Kanaga, Cleveland, Gareloi, and Westdahl, we observe successful clustering that reflects RF variability, with spatially distinct clusters that form a volcano-centric pattern. This indicates probable magmatic structure beneath these edifices. Second, at Okmok and Atka, clustering reflects RF variability, but there is no spatial separation of clusters, suggesting complex scattering, shallow crustal heterogeneity, or reverberations. Third, at Pavlof, Aniakhak, Shishaldin, and Veniaminof we observe lower consistency in RF clustering, with spatial separation not centered on the edifice. The remaining volcanoes have characteristics that overlap with multiple groups. These results show significant along-arc variability in crustal magmatic storage. Future RF velocity modeling will provide insights into how subduction parameters relate to magma storage and transport.

Extension Due to Dike Emplacement at Inyo Craters

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Volcanic intrusion accommodates crustal extension to varying degrees at rifts worldwide. This study uses lidar data to quantify the extension that accompanied dike emplacement and phreatomagmatic eruptions at Inyo Craters, California. In total, there are 11 fault-bounded phreatic craters ranging from 40m to 250m in diameter, along with numerous co-eruptive faults. Extension is measured by detailed mapping of fault scarps and topographic offset assessed via serial cross-sections. The results reveal two sets of normal faults, a primary N-S set and a secondary NW-SE set. The average number of faults per cross-section ranges from 4 to 25 faults with a mean of 16. To assess net extension, we sum fault throw with eastward-dipping faults reckoned as positive and westward-dipping faults as negative. The summed fault throw along

each section varies from -14m to +35m, with an average of +16m. Net extension is estimated by assuming a fault dip of 70° and summing the heave values for all faults along each cross-section. We find that net extension ranges from 6m to 39m, with an average of 18m. Net extension along the primary fault set ranges up to 27m, with an average of 9m. Net extension along the secondary fault set ranges up to 26m, with an average of 18m. Maximum extension values occur near the center of the primary fault set at its intersection with the secondary fault set. Based on the net asymmetry evident from summed fault throw, we interpret that the primary dike intruded along a pre-existing 70° east-dipping fault, dilating the fault and extending the region above as the largest phreatomagmatic craters formed. The secondary fault set and related smaller craters formed as the intrusion branched along a NW-striking vertical fracture or a pre-existing strike-slip fault. We estimate a 15m width of the primary dike. This exceeds the 2-8 m width of primary magmatic material measured from a borehole beneath the Inyo Craters but is within the range of dike widths found for other parts of the Inyo-Mono volcanic chain and may reflect a greater width of the dike at depth beneath the Inyo Craters.

Statistical Structure of Repeating Long-period Seismicity at Shishaldin Volcano Across Eruptive Phases

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Long-period (LP) seismic events at Shishaldin Volcano, AK have been recorded for decades, making them important observational targets for understanding changes in the volcanic system state. Here we attempt to characterize the temporal statistical structure and recurrence patterns of LP activity across different eruption stages—before, during, and after eruptions. We analyze continuous seismic data from 2004 to construct an LP-event catalog and examine the amplitude, temporal structure, and waveform similarity of LP activity, to investigate systematic variations and their relation to eruption-related periods.

We utilize a single-station LP analysis workflow, including STA/LTA-based event detection, waveform alignment, manual quality control, and multiplet stacking; we use the event listing to investigate temporal changes in the inter-event time and amplitude distributions and repeating waveform (multiplet) evolution. We initially investigate a time-period from January to June 2004, including an eruption in May 2004, during which time we observe a perturbation in the amplitude–time distribution coincident with eruptive activity.

Global Assessment of Volcanic Responses to Earthquake Caused Dilatational Strain and Normal Stress Changes

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Large earthquakes can alter volcanic activity through static stress transfer and dynamic stress perturbations, but the mechanism(s) and necessary conditions are unclear. We conducted a global investigation of static stress triggering potential to better understand the magnitude of stress necessary to induce a response and the characteristics of volcanoes that respond to these changes. We modeled stress and dilatational strain changes for 415 earthquake-volcano pairs from 2000-2025 at 66 volcanoes within 500 km of M7 and larger earthquakes. Stress and strain modeling used an elastic half space, but included finite fault parameters and resolved normal stress changes on inferred vertical dike-like features oriented parallel to the local maximum horizontal stress direction at each volcano. Because eruption and volcanic activity reports may have a relatively high completeness threshold, we chose to assess volcanic activity using a consistent, satellite-derived thermal radiance algorithm. To assess changes in eruptive activity, we computed the cumulative log of radiative power for a period of 1 year before and after each modeled earthquake. Results were aggregated by summing normalized cumulative power time series in different ways to assess: minimum thresholds for stress and strain changes that resulted in a response, including differences between unclamping and clamping and positive and negative dilatation; variable responses at volcanoes having different compositions; and differences in responses between volcanoes that had varied levels of activity during the observation periods. We found an average increase in thermal power from compressive stress (clamping) 2 weeks after earthquakes, which was more prominent in the volcanoes with andesitic compositions. At basaltic volcanoes, an increase in thermal

emissions was common after an earthquake causing dilatation. We also found a positive correlation between triggering and persistently active volcanoes, suggesting that in most cases, volcanoes must be close to eruption to respond to small changes in stress and strain.

International Collaboration to Advance Earthquake Science and Disaster Response

Oral Session • Thursday 16 April • 8:00 AM Local
Conveners: Michael L. Blanpied, U.S. Geological Survey (mblanpied@usgs.gov); Lindsay A. Davis, U.S. Geological Survey (ldavis@usgs.gov); Sara K. McBride, Seismic Safety Commission (sara.mcbride@caloes.ca.gov); Jenny Riker, U.S. Geological Survey (jriker@usgs.gov)

Global Collaborations for Seismic Resilience: Advancing Seismic Hazard and Risk Modeling Through GEM’s Projects Worldwide

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The Global Earthquake Model (GEM) Foundation is a public-private initiative made of a small secretariat working in concert with a range of governmental, academic and industrial partners. As such, GEM has fostered or participated in many collaborative projects to build seismic hazard and risk models worldwide, from national to continental scales. In this contribution, we discuss how ongoing collaborations are necessary for the continued development of GEM’s global hazard and risk mosaics, and highlight several recent projects that simultaneously developed advanced hazard and risk models, as well as built capacity and connections with (and among) regional partners. For example, the TREQ and FORCE projects, funded by the USAID Bureau of Humanitarian Assistance, were multinational collaborations that involved governmental and scientific partners throughout Latin America and southern Asia, and lead to the innovations on several fronts including the integration of landslide and liquefaction hazard into coupled seismic hazard and risk models, and the use of forecasts of evolving building stock into risk models; several national-scale models were created as well. In addition to these large-scale efforts, tighter partnerships with government agencies in Albania and Bangladesh (the latter sponsored by the UN) yielded advancements in those countries’ models, used for building codes and disaster mitigation, suiting their needs in different ways: producing a state of the art hazard model for Albania, and producing an extensive set of scenarios based on historical earthquakes in Bangladesh, which was more seismically active in the decades before widespread seismic instrumentation. Currently, the CAREC II project is developing a catastrophe bond for Tajikistan and the Kyrgyz Republic that relies on GEM’s updated hazard and risk models for the country; this work has the potential to greatly expand the financial resources available to these governments in response to a damaging earthquake.

Pager 2.0: Next Generation Forecasts to Inform Rapid Global Earthquake Response

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Since its launch in 2010, the U.S. Geological Survey’s (USGS) Prompt Assessment of Global Earthquakes for Response (PAGER) system has provided rapid, publicly accessible alerts that estimate the global impacts of significant earthquakes. By issuing color-coded assessments of likely casualties and economic losses, PAGER enables emergency managers, governments, and humanitarian organizations to quickly gauge the potential scale of a disaster or, more often, to stand down for earthquakes that might be of concern but do not warrant any response. For large and catastrophic earthquakes—those capable of causing more than 100 fatalities or exceeding 100 million dollars in economic losses—decision makers increasingly require information that is not only timely but also more accurate, spatially detailed, and operationally actionable. An effective response depends on understanding not just the magnitude of an event, but also where the most severe shaking occurred, which communities and infrastructure were most affected, and whether impacts are concentrated or distributed across the landscape.

Meeting these expectations calls for a new generation of forecasting tools capable of producing high-resolution geospatial data on shaking intensity, structural damage, and social and economic consequences at local or regional scales (second-level administrative divisions within a country, e.g., at the county level in the United States) for all catastrophic events worldwide. Advancing these capabilities is essential for enabling swift, well-targeted, and effective global earthquake response. Our presentation outlines the scientific vision and a roadmap for developing the PAGER 2.0 products in collaboration with national and international partners. In particular, to operationalize our engineering loss models, we detail our ongoing partnership with the Global Earthquake Model (GEM), leveraging GEM’s global repository of inventory and vulnerability curves, and further testing our in-house alternative damage and loss metrics.

From Source to Impacts: Advances in Real-time Analysis of NZ’s Big Quakes Through the RCET Programme

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The recently concluded RCET programme (Stage 1) has developed, tested and operationalized a suite of new rapid earthquake and tsunami characterisation tools in New Zealand, in collaboration with international partners. Together, these tools significantly enhance situational awareness for responders in the minutes to hours following a major event.

Here, we present an overview of the RCET rapid earthquake characterization framework for New Zealand (tsunami tools covered in the abstract of Fry et al. SSA 2026), including:

- earthquake source: NZ implementations of FinDer (Böse et al. 2012), G-FAST (Crowell et al. 2016), w-phase inversion (Duputel 2012,) and Early-Est (Lomax & Michelini 2009; Bernardi et al. 2015)

- aftershocks: including NZ-developed real-time matched filter detection (RT-EQcorrscan) and machine learning methods built on ED-PAN deep learning phase picker (Liao et al. 2022)

- shaking: NZ implementation of USGS ShakeMap (Wald et al. 1999; Worden et al. 2020)

- impacts: source – shaking - impact pipelines utilizing NZ’s RiskScape framework

- metadata server: message broker interface between characterisation tools

A key achievement is the creation of a rapid analysis pipeline from 3D rupture > shaking > impact. Taking into account first estimates of the spatial extent of rupture critically improves the estimation of impacts from our largest earthquakes, as illustrated through examples from the 2016 Mw 7.8 Kaikōura earthquake, and a simulated M8+ Alpine Fault earthquake.

Many tools are now used routinely in 24/7 operational response. Most run in real-time, and can also be operated by specialist science responders who review, interpret and refine solutions as needed. The combined power of real-time implementation, and on-hand specialist expertise, significantly speeds up and enhances the generation of time-critical bespoke event advice delivered to emergency managers.

Post-earthquake Response Activities and Planning at the Statewide California Earthquake Center (SCEC)

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The Statewide California Earthquake Center (SCEC), in collaboration with USGS and CGS, advances post-earthquake science and response in California and beyond through coordinated research, modeling, and community-based collaboration. SCEC supports rapid scientific response by integrating observational data, physics-based models, and computational workflows to improve situational awareness and inform both scientific and stakeholder communities. Core capabilities include operational aftershock forecasting using UCERF-ETAS models to characterize evolving spatiotemporal aftershock distributions, as well as scenario-driven assessments that place observed events in a broader hazard context.

To ensure resilience and continuity during disasters, SCEC has developed redundancy strategies for computational and human resources. These include priority-queue access at the Texas Advanced Computing Center (TACC) for post-earthquake simulations, geographically distributed computational workflows, and emerging artificial intelligence methods for rapid wavefield generation and ground-motion characterization. Geographic redundancy in scientific coordination is emerging as a priority with the recent center expansion to statewide coverage.

Beyond immediate response, SCEC emphasizes scenario modeling as a preparedness tool not only for estimating shaking and losses, but also for anticipating human and institutional response. Close engagement with different stakeholders strengthens the translation of earthquake science into actionable information. Through sustained collaboration and shared infrastructure, SCEC contributes to a global framework for learning from earthquakes and improving disaster response across diverse tectonic and societal contexts.

The Global Collaboratory for the Study of Earthquake Predictability (CSEP): International Standards, Software, and Benchmarks for Prospective Testing of Earthquake Forecast Models

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The Collaboratory for the Study of Earthquake Predictability (CSEP) is an international, community-driven initiative focused on rigorous, transparent

and reproducible evaluation of earthquake forecasts and hazard source models. For nearly two decades, CSEP has coordinated researchers and institutions worldwide to develop shared testing protocols, open-source software, and standardized datasets that enable meaningful comparisons of competing models across diverse tectonic settings. Recent developments within CSEP reflect a shift toward flexible and reproducible computational experimentation. The latest release of the open-source pyCSEP toolkit provides a unified framework for managing seismicity and forecast data and performing statistically model evaluations using community-vetted tests and metrics. Complementing this, the floatCSEP platform enables fully reproducible forecasting experiments in portable computing environments, facilitating broader participation, version-controlled experiments, and transparent re-analysis of results. While pyCSEP focuses on evaluation routines, floatCSEP provides the workflow needed to define, run, and update complete testing experiments. CSEP has also released and validated a landmark benchmarking database comprising prospective next-day forecasts of $M_w \geq 3.95$ earthquakes in California produced by 27 models under identical experimental conditions. The forecasts span 2007–2018. We find that approximately one-quarter, two-thirds, and 95% of the models produced forecasts consistent with the number, locations, and magnitudes of observed earthquakes, marking an important milestone in earthquake predictability research and building confidence in their use for continuous OEF worldwide. By combining open software, shared data resources, and agreed-upon evaluation standards, CSEP demonstrates how international collaboration can advance earthquake science beyond individual models or regions. As forecasting methods continue to evolve, CSEP provides critical infrastructure to ensure that new approaches are evaluated consistently, reproducibly, and in a globally comparable manner.

International Collaboration to Advance Earthquake

Science and Disaster Response [Poster]

Poster Session • Thursday 16 April

Conveners: Michael L. Blanpied, U.S. Geological Survey

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The NEHRP Post-earthquake Investigations Program

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Post-earthquake scientific and engineering investigations are undertaken to capture critical information to understand the causes and impacts of the event. The four-agency National Seismic Hazard Reduction Program (NEHRP) investigates significant domestic and international earthquakes to learn lessons that can be applied to improve seismic resilience and reduce future earthquake losses. Such investigations involve work of the NEHRP Agencies (NIST, FEMA, NSF and USGS) plus other responding agencies, organizations, and groups. The USGS is the lead agency for activating and coordinating such investigations.

A plan for the coordination of investigations is presented in USGS Circular 1542 “Plan To Coordinate Post-Earthquake Investigations Supported by the National Earthquake Hazards Reduction Program (NEHRP)” <<https://pubs.usgs.gov/publication/cir1542>>. The Plan describes the activation and coordination of the designated NEHRP Agencies, and coordination with other organizations that may participate, including Federal, State, regional, local, Tribal, and territorial agencies; domestic nongovernmental organizations; academic institutions; private companies; and foreign and international agencies and organizations. The Plan delineates the coordination of scientific and engineering investigations to document the direct, indirect, and cascading physical and societal impacts from fault rupture and ground shaking hazards and from secondary hazards such as landslides, liquefaction, and tsunamis. In addition, the Plan identifies pre-event activities to ensure that investigations are executed effectively. When a significant earthquake occurs the NEHRP Agencies determine if full support of NEHRP is warranted, and if so, stand up an ad-hoc Earthquake Investigation Committee (EIC) to coordinate broad-based investigations by engaging with active investigators and creating an opportunity to communicate in real time and to share investigation plans, details about data gathered, and lessons learned. Data, analyses, and key lessons are communicated widely through summary reports, workshops, public messaging, or other means.

POSTER 110

The U.S. Geological Survey’s PAGER System at 15: A Performance Evaluation and Lessons Learned

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The U.S. Geological Survey’s (USGS) Prompt Assessment of Global Earthquakes for Response (PAGER) system has been producing earthquake fatality and economic impact alerts for more than 15 years. Since the system went live in September 2010, we have generated 10,716 alerts, of which 10,275 were green, 326 were yellow, 70 were orange, and 45 were red. We compare median estimates and the corresponding fatality- and economic-based alert levels for both the initial (within the first hour) and final (days to weeks post-event) estimates for events with reported fatalities and/or economic losses. In general, we find relatively good agreement between the estimated and actual alert levels, and crucially, in distinguishing between the “signal” (events that are widely felt, damaging, and/or cause fatalities) from the “noise” (low intensity shaking or no impact on humans). Our long-standing and relatively simple empirical country vulnerability functions have proven robust. Still, they cannot fully capture the range of possible losses at the damage threshold (lower damaging intensity levels), where zero fatalities (green alerts) and a few fatalities (yellow alerts) depend on the collapse (or not) of a few individual buildings. We also provide examples where our operational orange/red level alert embargo prevented unnecessary alerting; several times, early updates (< 30 min) to the magnitude, location, and/or depth of an event significantly affected our early loss estimates, so we have followed a protocol to pause the release of higher-level alerts until such source parameters are considered stable. With rare exception, alerts are typically embargoed for less than an hour after origin time. Because alerting accuracy is categorical, we also provide a confusion matrix, which indicates that a one-alert-level difference occurs occasionally, whereas being off by two alert levels is rare. This comparison of median loss estimates and alert levels over a decade and a half of earthquakes worldwide facilitates more detailed analyses of trends for specific countries and the recalibration of each country’s vulnerability function.

POSTER 111

International Aftershock Forecasting and Products at the U.S. Geological Survey

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The U.S. Geological Survey produces aftershock forecasts to support the coordination of disaster response and public situational awareness following impactful international earthquakes. Forecasts are distributed to U.S. Government agencies and other groups working on immediate response activities and longer-term rebuilding and recovery efforts. We use the Epidemic-Type Aftershock Sequence model to forecast aftershock rates and ground motion models to forecast the resulting shaking hazard from these aftershocks. Our models are run with an interactive software, which outputs the forecasts in a standardized product with a tiered presentation of text, graphics and maps. Forecasts are updated on a regular schedule to calibrate to the aftershocks observed in catalogs. The full product is provided to partners in U.S. disaster response and certain forecasts are also publicly released on the USGS website, currently in a shorter-format product showing temporal forecasts. We have provided forecasts in an operational fashion following impactful earthquakes around the world, including 2021 Haiti, 2023 Turkey and 2025 Kamchatka. Here, we give an overview of our forecasting system and communication products. The AftershockForecaster software was developed to raise the capacity of science agencies worldwide to respond to aftershocks and promote disaster resilience, and agencies in Nepal, Mexico, El Salvador and Türkiye (among others) have been trained on AftershockForecaster. Future work on this downloadable software includes automated solutions for assessing and handling catalog incompleteness. We have also conducted research to improve the forecast products by aligning them to the downstream needs of end-users, including emergency managers, critical infrastructure, public communicators and others. Together with partners in El Salvador and Mexico, we

elicited user needs from a dozen professions and have prototyped new graphs and maps that can meet these varied needs. We present achievements of this forecasting program and opportunities for further development based on ongoing research.

POSTER 112

Improving Seismic Monitoring in the Southwest Pacific

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The Southwest Pacific is among the most seismically active regions on Earth, generating 17 earthquakes of magnitude 8 or greater over the past century. However, seismic monitoring in the region remains sparse due to constrained land area, resource limitations, and infrastructure challenges. The resulting limited open-access real-time seismic station coverage slows detection and response times for monitoring agencies, including the U.S. Geological Survey's (USGS) National Earthquake Information Center. To address these gaps, the USGS, in collaboration with the U.S. State Department, is working to expand and upgrade seismic monitoring capabilities in Fiji, Tonga, Papua New Guinea, the Solomon Islands, and Vanuatu. The project involves collaborating with local partners to identify, install, and operate monitoring sites, and to share data through the Oceania Regional Seismic Network (ORSNET). So far, we have installed a new site in Fiji and plan to install two sites in Tonga in early 2026. An additional six stations in Papua New Guinea, the Solomon Islands, and Vanuatu are planned to be installed by 2027. These nine new or upgraded stations will feature broadband and strong-motion sensors with robust telemetry meeting standards comparable to the Global Seismographic Network. The stations will be co-operated by local monitoring authorities and the USGS Albuquerque Seismological Laboratory. Data will be openly available and archived at the EarthScope Data Management Center for use by the broader research community, with International Federation of Digital Seismograph Networks (FDSN) network code OI (Oceania International). The project also includes training provided by USGS scientists to regional monitoring partners, helping them maintain their existing seismic infrastructure and improve data-sharing practices to meet international standards. Our overarching goal is to establish a high-quality backbone network that fills critical monitoring gaps and strengthens national and regional capabilities. Together, these efforts will improve detection and alerting capabilities for earthquake, tsunami, and volcanic events.

The Landscape Record of Earthquakes and Faulting

Oral Session • Thursday 16 April • 8:00 AM Local

Conveners: Kristen Chيامa, Harvard University (kchيامa@g.harvard.edu); Catherine Hanagan, U.S. Geological Survey (chanagan@usgs.gov); Jessica A. T. Jobe, U.S. Geological Survey (jjobe@usgs.gov); Emerson Lynch, Colgate University (emerson.lynch@gmail.com); Nadine Reitman, U.S. Geological Survey (nreitman@usgs.gov)

Climate Oscillations and Slip Rate Control Channel and Hillslope Responses to Slow Strike-slip Faulting in the Hyper-arid Atacama Desert

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Strike-slip faults act as landscape change agents by offsetting rivers, driving river capture, and triggering hillslope responses. Geomorphic markers near faults, such as offset channels, are widely used to infer slip rates; however, recent numerical models suggest that slip-rate signals are also preserved far upstream as catchments respond to stream lengthening and shortening associated with fault-controlled captures. In these models, slow-moving faults generate dynamic, catchment-wide reorganization, whereas fast faults produce more localized geomorphic responses. Such patterns hold promise for revealing slip rate information, but have yet to be tested across end-member slip rates and climatic environments. Here, we examine the Salar Grande Fault (SGF), a slow strike-slip fault in the hyper-arid core of the Atacama Desert.

We combine InSAR, topographic analysis, and synthetic landscape evolution modeling to investigate the geomorphic response to slow strike-slip faulting under oscillatory climatic conditions. We first provide a geodetic slip rate estimate for the SGF of <0.6 mm/yr and then analyze fault-parallel topographic profiles near and far from the fault using a Profile Relief Ratio (PRR) metric and fault-perpendicular cross-divide metrics that capture ridge mobility linked to erosion and relative slip rate. Our results show that hillslopes and channels respond to slow strike-slip faulting even in a hyper-arid environment. However, low erosion rates dampen the geomorphic signal, producing PRR values more typical of faster-slipping faults. Numerical simulations demonstrate that sediment aggradation during dry periods delays river capture, but the geomorphic adjustment persists under oscillatory climatic conditions in slow-moving faults (<1 mm/yr), as we see with the SGF. In contrast, faster-moving faults show a more profound impact, recorded in steep river profiles and persistent knickzones. This work advances our understanding of the geomorphic response to strike-slip faulting and emphasizes the importance of considering climatic and erosive conditions when assessing relative slip rates.

Reconciling the Paradox of Offshore Fault Slip in the 1906 San Andreas Earthquake

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Observations of the 1906 San Andreas earthquake, including fault offsets, triangulation surveys, and regional and worldwide seismic records, are consistent with a ~250 km onshore strike-slip rupture of the San Andreas fault from San Juan Bautista to Point Arena. Strike-slip rupture is assumed to have continued northward for ~100 km offshore, from Point Arena to Shelter Cove, where surface offsets were recorded. Several observations conflict with this offshore strike-slip interpretation: (1) Pacific-North America plate motions imply substantial extension across a fault following the California coast, which is incompatible with the regional geology; (2) the San Andreas fault through northern California represents a boundary between the Salinian block and Franciscan complex, but the Salinian block ends near Point Arena; and (3) the greatest slip in the 1906 event occurred near Shelter Cove (northern end of the rupture), rather than more centrally in the rupture zone as is typically observed. High-resolution seismic tomographic imagery of the northern San Andreas plate boundary region, combined with geologic, geodetic, and seismicity observations, allows us to resolve the 3-D plate boundary structures. We find a sub-horizontal detachment at ~20 km depth extending ~50 km eastward from offshore to the lithospheric-scale transform plate boundary (defined geodetically). Structures north of Point Arena could include crustal faults terminating at this detachment, as in the region of the 2016 Kaikoura, New Zealand, earthquake. Simultaneous rupture of detachment and crustal faults can lead to slip magnitudes beyond what is expected for individual fault ruptures. Fault slip models for the 1906 event including the detachment produce reasonable fits to coseismic horizontal displacements. Importantly, rupture on the detachment expands the footprint of strong shaking at the northern end of the rupture, consistent with dozens of observations from Humboldt and Mendocino County in 1906. Slip on a detachment would produce larger vertical displacements than a strike-slip fault, potentially leaving a geologic record along the coast.

Surface Ruptures and Near-fault Deformation of the 2025 Mw 7.7 Myanmar Earthquake

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In this study, we document coseismic right-lateral offsets and near-fault deformation of the 2025 Mw 7.7 Mandalay earthquake using post-quake field survey results and the optical remote sensing data. Both results confirmed that the 2025 Mandalay earthquake generated a surface rupture exceeding 470 km in length, extending from the central to southern section of the Sagaing Fault. While the subpixel-correlation result from medium-resolution satellite data shows a continuous and narrow rupture along the fault, and indicating very limited amount of off-fault deformation away from the rupture, the comparison of field-measured cross-fault deformation and optical-image-based offset measurements suggests a varying degree of near-fault deformation occurred along the rupture. The amount of near-fault deformation is minimal along the fault section that cuts through metamorphic rocks with thin or none overlying sediments in the Sagaing Hills, and becomes significant when the fault truncates through the water-saturated unconsolidated Quaternary alluvial deposits. The appearance of the near-fault deformation, however, has a limited impact on the shallow fault slip derivative from the subpixel-correlation inversion result, suggesting that the majority of the near-fault deformation occurred within a short distance of the main rupture during the 2025 Mandalay earthquake.

Post-glacial Surface Faulting Along the East Gallatin-Reese Creek Fault System, Yellowstone National Park

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Glacial landscapes in the central and northern Rocky Mountains hold records of past surface-rupturing earthquakes and provide important insights into regional seismic hazards. In the Greater Yellowstone region, these records are essential to understanding hazard cascades caused by the interaction among tectonic, magmatic, hydrothermal, and mass wasting processes. While 50 years of instrumental seismic monitoring in the region paints a clearer picture of modern seismicity, the longer-term earthquake history and associated hazard of several north-striking normal faults proximal to the Yellowstone Caldera remain understudied. This study focuses on the East Gallatin–Reese Creek fault system (EGRCFS)—a Quaternary-active, 40-km-long, east-dipping normal fault that spans the Wyoming–Montana border in northwest Yellowstone National Park. We present fundamental data on the age of fault-displaced glacial deposits, the vertical offset of geomorphic surfaces, and the rates and spatial variability of fault slip since the late Pleistocene.

New detailed lidar mapping documents a discontinuous network of fault scarps that displace glacial and post-glacial deposits throughout the central 25 km of the EGRCFS from the Gardner River to Obsidian Creek. Samples for ¹⁰Be cosmogenic nuclide exposure dating were collected from boulders at three sites where fault scarps offset glacial deposits. Three initial ¹⁰Be ages on boulders from the northern two sites are clustered between 13.9 and 14.2 ka. Fault scarp topographic profiles from these same two sites yield ground moraine vertical surface offsets of 0.7–3.0 m, which suggests slip rates of approximately 0.1–0.2 mm/yr for the EGRCFS during the latest Pleistocene to Holocene. Additional pending ¹⁰Be ages and scarp profile analyses from the three study sites will provide a detailed record of temporal and along-strike variability in fault displacement. These results will contribute updated fault geometry and slip rate inputs for the National Seismic Hazard Model and inform broader questions about the temporal behavior of seismogenic faults near the Yellowstone Caldera.

How Has the Landscape Affected by the Ridgecrest CA Earthquake Sequence Changed Since 2019? A View From Repeat Lidar and Field Observations

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The M6.4 and M7.1 2019 Ridgecrest Earthquake Sequence caused an extensive surface rupture through a variety of desert landscapes that include playa,

alluvial, and bedrock surfaces. Since then, eolian, fluvial, and mass wasting processes have affected the landscape. The availability of airborne lidar collected in the weeks following the earthquake, and another survey completed in 2024, affords an opportunity to document the initial post-seismic landscape response to a major earthquake by generating a 0.5-meter-resolution map of elevation change. We completed remote mapping of landscape change from the repeat lidar and are in the process of incorporating field assessments of these changes. While many of the observed changes are expected—scarp erosion, fluvial modification of surface ruptures, and eolian erosion and deposition—we can now quantify those changes and observe the details of fault zone modification in a manner that may be useful to paleoseismologists that study past earthquakes using the subtle record of sedimentation and erosion preserved in fault zones. We also observed unanticipated landscape changes such as modification of extant ground fissures that have been present since at least the 1980s, and development of new ground fissures that have appeared since the 2019 lidar was collected. These fissures manifest as elongated narrow zones of material collapse and subsidence with no relative motion across them and are not aligned with earthquake surface ruptures or apparently connected to fluvial channel networks. The temporal lag in fissure development may indicate long-term response to the earthquake on adjacent fault zones that did not appear to change in the coseismic and immediate post-seismic period, or may be a result of non-tectonic processes. This integrated field and remote sensing study will document 5.5–6.5 years of landscape change following a significant surface rupturing earthquake and provide a snapshot in time for future observations of landscape change.

Two Surface-rupturing Earthquakes on the Great Southern Puerto Rico Fault Zone Since ~19 Ka

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Despite high population density and public awareness of earthquakes in Puerto Rico, paleoseismic excavations on the Puerto Rico-Virgin Islands (PRVI) microplate (located within the broad deformation zone of the North Caribbean Plate Boundary) are few, due to logistical and methodological challenges. Active faults onshore Puerto Rico accommodate northeastward PRVI motion, including the Great Southern Puerto Rico fault zone (GSPRFZ). On the southern coastal plain, the GSPRFZ is an active right-lateral normal northwest-trending fault. Quaternary landforms record ~4–8 m of oblique displacement on the GSPRFZ, but the number and timing of individual surface-rupturing earthquakes remain unconstrained. To address this, we excavated a paleoseismic trench across the GSPRFZ where a single, ~1.5-m-tall south-side-down scarp crosses a Quaternary alluvial fan ~200 m along strike from an exposed bedrock fault zone. In the trench exposure, we documented faulted bedrock and fluvial and colluvial deposits and two generations of fissure fill, below unfaulted colluvium. The primary shear zone in the trench was sub-vertical and branched into a ~0.5–2.5-m-wide zone of faults and fissures near the surface. The fault geometries and juxtaposition of deposits across the fault zone suggest substantial strike-slip motion, consistent with the geomorphic expression. We interpret a minimum of two surface-rupturing earthquakes are recorded in the trench. Based on the trench observations, correlations with regional deposit ages, and new luminescence ages, we interpret that the GSPRFZ has hosted at least two surface-rupturing earthquakes since ~19 ka. These results are consistent with previous paleoseismic studies on the GSPRFZ and support the interpretation that active faults on the southern coastal plain accommodate a substantial portion of PRVI motion.

Holocene Fault Activity Near the Oak Grove Fork Clackamas River: Kinematic Linkage of the Clackamas River and Mount Hood Fault Zones

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North-striking extensional fault systems of the Cascade arc in Oregon help accommodate regional clockwise rotation of Oregon crustal blocks. However, the duration of activity and amount of extension is poorly constrained. High-resolution lidar topography (1-m-grid) of the Oak Grove Fork Clackamas River area 75 km SE of Portland revealed previously unmapped faults that lengthen the extent of the Clackamas River fault zone (CRFZ) northward towards the Mount Hood fault zone, potentially providing a kinematic link between these fault systems. From the lidar, we estimate fault offsets at >200 locations across >10 newly mapped fault scarps. Combined with new geologic mapping, and paleoseismic age data we evaluate fault geometry and displacement through time. Offsets range from 0.7 to >100 m across fault scarps that cut Quaternary volcanic bedrock and Late Pleistocene surficial deposits, including at least two generations of glacial deposits. We excavated a paleoseismic trench across the Anvil Lake fault, where the scarp displays 3 m of dip-slip offset. The trench exposed >2 m of glacial deposits in fault contact with pyroclastic bedrock. Colluvial wedge mapping indicates at least two surface-rupturing earthquakes. Radiocarbon ages from detrital charcoal and OxCal modeling constrain the timing of the two most recent surface rupturing earthquakes to 3,110-2,445 and 4,523-3780 cal. yrs BP. Empirical scaling relationships between fault length and magnitude yield ~Mw 6.0 estimate if only the 7.5 km-long Anvil Lake fault ruptured. With the addition of the newly mapped faults, the full CRFZ system is ~42 km-long from N to S and could generate a ~Mw 7.0 earthquake. CRFZ fault strands are spaced ~0.2 to 4 km apart suggesting surface rupturing earthquakes involve complex multi-strand ruptures. We infer subsurface connectivity of CRFZ fault strands, where they likely root into a primary structure at depth. Further consideration of this connectivity is required as we calculate slip rates for the CRFZ structure. These findings have implications for future updates to the National Seismic Hazard Model and for hazard in the region.

Assessing Active Faults in the Cascade Arc: A Case Study of the Blue Ridge Fault, Mount Hood, Oregon

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Extensional faulting is identified near the crest of the Cascade Range, from northern California to southern Washington, that helps accommodate clockwise rotation of the Pacific Northwest region, due to oblique convergence along the Cascadia subduction zone and Pacific-North America plate motion. High topography, steep heavily forested slopes, and recent glaciation obscures surface expressions of Quaternary faulting in this area. Here, we combine geologic and lidar-based geomorphic mapping, fault displacement measurements, and age dating along the Blue Ridge fault (BRF), located north of Mount Hood, to characterize fault activity over the last million years. The Andesite of Laurance Lake flow is offset ~54 m and new 40Ar/39Ar ages for this flow yield a slip rate of ~0.06 ± 0.01 mm/yr for this strand of the BRF. We couple this observation with offsets of ~1 m and ~33 m within undated glacial deposits on the same fault strand, providing evidence for multiple latest-Quaternary surface rupturing earthquakes on the BRF. The 33 m offset is within older glacial deposits, mapped as the Jack Creek glaciation (~140 ka) and suggests a higher slip rate of ~0.2 mm/yr. On another BRF strand, located 4 km west of Laurance Lake, we combine a surface exposure age of 21.3 ± 3.3 ka from 10 boulders along a moraine crest with a ~2.7 m offset, yielding a shorter-term slip rate of 0.13 ± 0.04 mm/yr. An unpublished nearby paleoseismic trench on the BRF reported the most recent earthquake at ~13 ka. This slip rate is calculated for only 1-2 earthquake cycles but the Laurance Lake slip rate suggests a more robust rupture history. Our study reveals that this structure is a Quaternary-active seismic source and activity will likely continue with further Cascade arc rotation.

First Paleoseismic Evidence of Late Quaternary Surface Rupture in the Fraser Canyon of British Columbia, Canada

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The Fraser Canyon of British Columbia (BC) hosts communities and critical infrastructure including the major transportation corridor connecting Metro Vancouver to the rest of Canada. The conspicuously linear canyon follows the >400-km-long, terrane-bounding Fraser Canyon fault that separates the Coast Mountains from the Interior Plateau of BC, which has typically been considered inactive since the Oligocene. No Quaternary-active faults have been definitively identified, partially due to recent glaciation and low strain rates. From lidar images, we identified a 280 m-long, N15°W-trending, uphill-facing scarp 140 m above the canyon floor, opposite the town of Lytton, amongst several generations of glacio-fluvial terraces that post-date the Last Glacial Maximum (LGM). The scarp is adjacent to a landslide scar and is between mapped strands of the Fraser Canyon fault.

Electrical resistivity profiles across the scarp reveal sub-horizontal low-resistivity and high-resistivity zones separated by a steeply-dipping structure. The sharp contrast motivated the excavation of an 8.4-m-long, 1.7-m-deep hand-dug “Nikaia” trench that revealed three sedimentary units. From deepest to shallowest: Unit 1 is a clast-supported gravel; Unit 2 is a pebbly sand; and Unit 3 is a matrix-supported gravelly sand. Two steep, E-dipping structures show vertical separation of the Unit 1–Unit 2 contact by ~0.8 m and ≥0.5 m, respectively, and do not offset the base of Unit 3. The structures are not consistent with gravitational or glacial deformation and instead indicate surface-rupturing faulting with a reverse, east-side-up, component. We interpret Units 1 and 2 to be alluvial deposits constraining rupture to post-LGM (<17 ka), and Unit 3 to be a scarp-derived colluvial unit that caps the faults and post-dates surface rupture. Luminescence and radiocarbon dating samples were collected to refine age bounds. The observed displacement suggests at least one event of M_w ≥6.5. The Nikaia trench provides the first direct evidence for late Quaternary activity of the Fraser Canyon fault, with important implications for seismic hazard in southwestern BC.

Restraining Bend Topography Records Long-term Fault Slip and Fault Strength

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Restraining bends in strike-slip faults reduce long-term fault slip rates and frequently influence the initiation and arrest of fault rupture and associated slip during earthquakes. In these systems, fault slip and off-fault failure accommodate far-field plate motion over many earthquake cycles. Using analytical theory and three-dimensional finite element models, we show that the balance between fault slip and off-fault deformation within restraining bends produces systematic and diagnostic signatures in long-term rock uplift and exhumation patterns. This balance depends on the frictional strength of the fault relative to the surrounding crust, with lower fault strength favoring slip-dominated deformation and higher fault strength favoring distributed off-fault failure. When slip is sustained through a bend over geologic timescales, uplifted crust is advected into and through the restraining bend structure, generating uplift patterns that migrate and extend down-fault. When fault slip is inhibited, however, deformation is accommodated primarily through off-fault failure, leading to rock uplift concentrated within and upwind of the bend relative to strike-slip motion. These contrasting uplift styles persist as fault slip accumulates, providing a durable landscape-scale record that reveals how strain is accumulated and released through repeated earthquake cycles. Applying this framework to natural examples, we interpret uplift patterns in the Santa Cruz Mountains restraining bend along the San Andreas fault (California, USA) as reflecting slip-dominated deformation along a relatively weak fault. In contrast, uplift at the Aksay bend on the Altyn Tagh fault (China) reflects slip-inhibited behavior along a frictionally strong fault. Our models suggest that landscape and geologic records of deformation surrounding restraining bends may provide constraints on long-term slip rates and fault frictional strength within restraining bends along strike-slip faults. This approach may assist in developing physics-based seismic hazard models that require broad characterization of fault frictional properties.

Geology and Geomorphology of the Creeping Central Calaveras Fault

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The Calaveras Fault creeps rapidly at its southern end where it inherits slip from the San Andreas fault around Hollister, California. The creep rate declines to the north until it is essentially zero around San Ramon, California. The central section of the fault has generated several historical M5 - M6 earthquakes in spite of a high rate of continuous to episodic creep. We report new remote mapping and field observations of the central Calaveras fault in the vicinity of Coyote Lake and Anderson Lake. In this section, the Calaveras fault juxtaposes stratified Great Valley Group sediments against unstratified Franciscan Complex rocks of mixed lithology. In the central Calaveras, a single fault strand appears to be accommodating creep. Surface outcrops of the creeping strand reveal a ~10 m-wide zone of weathered and foliated reworked clay-rich gouge, with green serpentinite-rich bands and wider black bands apparently derived from Great Valley shales. The trace of this main strand shows evidence of recent and exhumed carbonation, in the form of travertine terraces in Coyote Creek, exhumed listvenites in ultramafic to mafic host rocks, and carbonate-cemented breccias representing recent seep deposits in the presently dry bed of Anderson Lake.

The current creeping strand is one of several geomorphically young fault strands spanning a zone up to ~1 km wide. Most of the fault strands evident in the geomorphology are west of the current creeping strand, cutting the Franciscan Complex. Following recent work (Adam, et al. 2023 and Scott, et al. 2025), we mapped geomorphic indicators of faulting and their relative confidence and certainty along the central Calaveras. Preliminary statistical analysis indicates that some bedrock compositions exert a strong control on the presence, type, and prominence of some geomorphic indicators. Ongoing investigations will reveal whether the geomorphic signals of bedrock geology dominate, or whether the currently creeping strand has a distinct geomorphic expression relative to nearby recently active fault strands.

Spatiotemporal Trends in Slip Rate and Earthquake Recurrence on the Sierra Madre-Cucamonga Fault Zone, Southern California

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The north-dipping Sierra Madre-Cucamonga reverse fault system (SMdF-CF) in southern California extends for ~100 km east-west along the southern base of the ~1.5- to 3-km-tall San Gabriel Mountains, ~5 km north of the Pasadena Convention Center. Joint rupture of both the SMdF and CF portions would result in a Mw ≥7.5 earthquake adjacent to the major population centers of the Los Angeles metropolitan region. Despite such a major looming seismic threat, the slip rate and paleoseismic histories of these faults remain under-constrained. Previous studies using geomorphic analyses of mountain front sinuosity and low-temperature thermochronology have demonstrated relatively fast long-term uplift rates on the eastern (CF) portion of the San Gabriel mountain front compared to the central and western (SMdF) portions. However, review of the current literature on Quaternary fault slip rates obtained along the SMdF-CF provides an ambiguous result as to whether or not this gradient in uplift along the San Gabriel mountain front persists today. We present newly determined luminescence ages of alluvial fans and, combined with vertical separation measurements extracted from high-resolution lidar data, calculate the slip rate of the CF over two distinct time intervals within the Holocene. Our results suggest that the CF is indeed slipping significantly faster than the SMdF. Additionally, we present three previously unpublished paleoseismic trenches, one on the eastern SMdF and two on the CF, excavated over the past 30 years in order to assess the potential record of previous throughgoing rupture along the entire fault system. We find that ruptures at the eastern and western ends of the SMdF-CF system, such as the 1971 M_w 6.7 San Fernando-Sylmar earthquake, occur more frequently than ruptures within the central part of the system. Large displacements observed in the MRE of several central SMdF trenches suggest occurrence of a large magnitude event, likely involving rupture of the entire SMdF-CF system. Recurrence of such an event, albeit rare, could have devastating consequences for the Los Angeles metropolitan region.

Deep Earthquakes Can Generate Larger and Far-reaching Co-seismic Displacements Than Shallow Events

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In the past several decades, the utilization of geodetic data has enabled remarkable advances in understanding earthquake physics. So far, such seismic studies have mainly focused on shallow (0-60 km) earthquakes, while surface displacements produced by intermediate (100–300 km) and deep (300+ km) earthquakes remaining underexplored since these displacements have been mostly thought to be small. However, recent studies reporting significant co-seismic displacements produced by deeper events—e.g., >1 cm displacements resulting from the 598.1-km deep 2013 M_w8.3 Okhotsk event—challenge this assumption. Yet, the contribution from deep earthquakes to the Earth's surface deformation relative to that from shallower earthquakes is still poorly understood.

Therefore, in this study, we conduct a detailed comparative GNSS analysis to bridge this gap. To achieve this goal, we evaluate the observed co-seismic displacements generated by the 598.1-km deep 2013 M_w8.3 Okhotsk event and the 22.4-km deep 2015 M_w8.3 Illapel event, which have nearly identical seismic moment and focal mechanism. Surprisingly, we find that a deep earthquake can generate larger co-seismic displacements than a shallow earthquake within a broad region. Through modeling tests, we demonstrate that the phenomenon is primarily attributed to the geometry of the 3D displacement fields produced by earthquakes, not from the effect of the Earth's curvature. In addition, we find that the deep earthquake can produce detectable far-field displacements (e.g., larger than 1 mm), sometimes at greater distances than those from the shallow event. For example, GNSS stations in the Hokkaido region (>13° from the earthquake) record clear geodetic signals from the deep Okhotsk earthquake. These results highlight that intermediate and deep earthquakes are important sources of Earth's surface displacements that should be incorporated in our current geodetic framework; furthermore, co-seismic displacement data may bring new insights into the deep rupture process.

Gold Deposits as a Proxy to Identify Paleoseismic Cycles: A Numerical Investigation

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Western Australia's long-lived gold mines may serve as geologic proxies for paleoseismicity in the continental crust. Orogenic gold deposits in stable intraplate terranes have long been linked to seismically driven fluid migration, consistent with the fault-valve paradigm. Cox (2004) proposed that clusters of Archean gold lodes occupy persistent aftershock damage zones at major fault jogs where ruptures repeatedly arrested, implying that ancient ore localization could correlate with recurring seismicity and post-seismic fluid flow. More recently, Cox (2016) demonstrated that injection of overpressured fluids into low-permeability faults induces prolific swarm seismicity and rapid vein emplacement, reinforcing the interpretation that these deposits record repeated seismic cycling rather than single large earthquakes. Furthermore, recent synthesis by Williams et al. (2022) shows that coseismic quartz precipitation only weakly seals fault permeability, allowing fluid pathways to persist across multiple seismic cycles in the brittle crust.

Building on these concepts, this study will integrate regional GIS datasets (bedrock fault maps, geology, and gold mine locations from the Geological Survey of Western Australia) with geomechanical modeling using PyLith to investigate stress transfer, fault reactivation potential, and fluid redistribution through the seismic cycle. Numerical experiments will explore how stress perturbations associated with repeated fault slip, including at the brittle-ductile transition, may localize long-lived permeability and fluid focusing. By testing whether gold deposit distributions align with modeled paleoseismic stress concentrations or cumulative aftershock volumes, this work investigates whether ore systems can be used as spatial proxies for long-term seismogenic behavior in stable continental crust. The results are expected to inform interpretations of fault longevity, intraplate seismicity, and the co-evolution of fluid-fault systems over million-year timescales.

Validating Physics-engine Simulations of Precariously Balanced Rocks for Hazards Applications

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Precariously balanced rocks in the landscape may be used to constrain maximum shaking intensity over timescales at which damaging earthquakes recur. Developing such valuable data requires estimating a precariously balanced rock's fragility, which we define as the probability of toppling as a function of one or more intensity measures. At present, fragilities are typically calculated using empirical equations derived from a combination of shake-table data and numerical modeling results. These equations are limited to a few geometric parameters, rather than a realistic representation of a real rock, but simplified geometric representations have been necessary because of the complexity and computational costs of discrete-element simulations. Recently, Chen et al. (2024) developed the Virtual Shake Robot (VSR), a physics-engine approach for simulating both toppling and large-displacement dynamics of precariously balanced rocks, which promises accuracy and efficiency. Like other models, the VSR requires careful selection of macro-physical parameters. The VSR was designed as the digital twin of a real-world shake table, and the VSR has been tested against a small number of shake-table experiments. Here, we extend the validation of the VSR with a larger ensemble of shake-table data. Klaboe et al. (2018) conducted 312 shake-table experiments, where five concrete blocks were excited by variously scaled waveforms from six earthquakes. For each experiment, displacement was recorded with video and optical image tracking. We reproduce these experiments virtually, using the VSR, and find that 75% of the toppling outcomes agree. Disagreements typically occur at shaking intensities where previously published fragility models indicate an intermediate probability of toppling. We investigate the causes of disagreements by testing parameter sensitivities and dynamic responses of the blocks.

Z. Chen et al., 2024. Virtual Shake Robot: Simulating dynamics of precariously balanced rocks. doi:10.26443/seismica.v3i1.692

K. Klaboe et al., 2018. Seismic response of rocking blocks. Earthquake Spectra, 34(3), pp. 1051-1061.

The Landscape Record of Earthquakes and Faulting

[Poster]

Poster Session • Thursday 16 April

Conveners: Kristen Chيامa, Harvard University (kchيامa@g.harvard.edu); Catherine Hanagan, U.S. Geological Survey (chanagan@usgs.gov); Jessica A. T. Jobe, U.S. Geological Survey (jjobe@usgs.gov); Emerson Lynch, Colgate University (emerson.lynch@gmail.com); Nadine Reitman, U.S.

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POSTER 113

Preliminary Characterization of the Multorpor Mountain Fault: Evidence for Repeated Late Quaternary Faulting on the Mount Hood Fault Zone, North-central Oregon

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The Mount Hood fault zone in north-central Oregon is a ~55 km-long, north-trending zone of active faulting along the western margin of the Hood River graben recently discovered from high-resolution LiDAR. The role that each fault section plays in accommodating Cascade intra-arc extension and regional crustal rotation remains poorly understood and their slip rate and recency of activity are not well constrained. One of the southwestern sections is the Multorpor Mountain fault, an east-dipping, 12 km-long normal fault. We used lidar to identify and map fault traces and extract topographic profiles across suspected fault scarps. We used MATLAB to measure and analyze 27 vertical offsets that range between 1 to 72 meters. The larger offsets cut through glacial deposits and Quaternary volcanic bedrock, while smaller offsets cut through most units such as Quaternary colluvial and alluvial slope deposits. These observations suggest that several surface-rupturing earthquakes have occurred on the Multorpor Mountain fault during late-Quaternary time. We ranked these displacements based on the quality and confidence of the correlative geomorphic surface that is offset across the fault. We then use empirical fault-scaling relationships for fault length, scarp height, and earthquake magnitude, and find that the Multorpor Mountain fault could rupture in ~M6.3 earthquakes. Our findings for the Multorpor Mountain fault

section of the Mount Hood fault zone contribute to improved understanding of displacement along strike, fault characterization, and seismic hazard, offering new insight into how extensional strain is partitioned along active faults in the Cascade arc.

POSTER 115

Middle to Late Pleistocene Faulting on the Puyé Fault Zone, Española Basin, New Mexico

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The Española Basin in the central Rio Grande Rift (RGR) of northern New Mexico is a slowly deforming, 60-km-wide region with low geodetic extension rates (~1 mm/yr), limited observed seismicity, and low-slip-rate (<0.1 mm/yr) Quaternary-active faults. We focus on the Puyé fault, a distributed fault system in the central-western Española Basin, to better characterize the fault for probabilistic seismic hazard analyses and improve our understanding of regional accommodation of strain. We integrate neotectonic and geomorphic mapping on lidar data with field observations and geochronology to characterize the Puyé fault zone. The fault zone has at least four north-south-trending subparallel primary strands that offset the same broad geomorphic surface with a primarily down-to-the-east sense of motion. The mapped scarps extend at least 16 km within a 4- to 7-km-wide zone. The tallest scarp records up to 27 m of net vertical separation. We excavated three 1- to 2-m-deep pits on the faulted surface to collect cosmogenic ¹⁰Be and optically stimulated luminescence (OSL) samples to constrain surface ages, pedogenic character, and calculate a slip rate on the Puyé fault system. From the surface landscape position, regional geomorphic history, soil development, and geochronology, we interpret that the faulted surface has a complicated, multi-stage erosional and depositional history, with the primary surface dating to between ~870 and ~300 ka. These ages yield a total slip rate of <0.1 mm/yr across the fault zone. At a nearby cutbank exposed in a wash that intersects the primary scarp, we observed ~1 m of down-to-the-east offset in late Pleistocene (~24–57 ka) fluvial sand and gravel units. Relatively smaller offsets of younger deposits indicate the Puyé fault system has accommodated several large earthquakes during the middle to late Pleistocene and may currently accommodate RGR extension. These results will be used to characterize the Puyé fault and better quantify uncertainties for site-specific probabilistic seismic hazard analyses at nearby dams and regional seismic hazard models.

POSTER 116

Can Sackungen in Arthur's Pass Record Past Large Earthquakes?

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Earthquake ruptures considered for seismic hazard analyses in Aotearoa New Zealand (ANZ) include >600 km long M_W 8.3–8.5 ruptures that begin on the Alpine Fault and propagate through a complex intersection zone along the Australian–Pacific plate boundary near Arthur's Pass. It is important to determine whether such long ruptures occur (and if so, how often); however, the intersection zone is mountainous, densely vegetated, and has ~5000 mm of precipitation annually, presenting challenges for paleoseismic investigations. In this study, we investigate the viability of using sackungen as off-fault records to constrain past rupture behaviour in the area. Arthur's Pass hosts numerous uphill-facing scarps, <1–2 km in length with apparent normal displacements <10 m that are sub-parallel to topographic contours and ridge crests which we interpret as sackungen. The role of strong earthquake shaking in the formation and/or reactivation of sackungen is unclear. However, significantly higher sackung densities occur within 4 km of mapped active faults, suggesting a causal relationship. If this is the case, other areas with high densities of sackungen could be used to infer the positions of active faults without

surface scarps. As a test, we will extract cores from ponds adjacent to sackungen and date organic material to help constrain the timing of their formation and compare with regional on- and off-fault paleoseismology. If successful, this methodology will provide a widespread record of strong ground motions and help constrain past earthquake behaviour in mountainous parts of ANZ.

POSTER 117

No Apparent Coseismic Surface Rupture in Trench Exposures of the Creeping San Andreas Fault at Topo Creek

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The 150-km-long creeping section of the San Andreas Fault separates two sections that are mostly or entirely interseismically locked and known to host M7+ earthquakes, notably in 1906 and 1857. The creeping section moves gradually at nearly the long-term fault slip rate (~35 mm/yr) and has no historical seismicity greater than M6 except in the vicinity of Parkfield in the southern transition zone. Whether large ruptures could propagate through the creeping section, potentially connecting faults to the north and south in a single M8+ earthquake, is a subject of ongoing debate and has significant implications for earthquake hazard, including the National Seismic Hazard Model. We report results from the Topo Creek site, near the middle of the creeping section, where we excavated trenches to search for evidence of past seismic ruptures. Three of our trenches exposed the entire main fault zone, expressed in well-bedded alluvial sediment. The fault zone is about 10 m wide, generally characterized by a pervasive penetrative shear fabric with few well-defined individual shear planes, and includes a 2-m-wide zone of more intense deformation aligned with a sharp surface trace. Even within the more intensely deformed zone, the apparent offset of units and intensity of shearing gradually decreases towards the surface, lacking clear upward terminations of faults or abrupt contrasts in degree of deformation that would indicate earthquake horizons. In one trench, deformation is expressed as a monoclinal fold with progressive tilting of older strata, without significant discrete faulting in the upper ~1.5 m. None of the exposures revealed features indicative of sudden brittle rupture or strong shaking, such as sand blows, filled fissures, colluvial wedges, or broken blocks. All deformation observed at this site is consistent with gradual creep and does not require high-speed slip. We consider it unlikely that multiple large coseismic surface ruptures occurred since deposition of the oldest exposed strata (>2200 yrs based on radiocarbon) without broadening the intense deformation zones or leaving behind any unequivocal evidence.

POSTER 118

Paleoseismic Investigation of Quaternary Faulting in the Southwest Montezuma Hills, Sacramento – San Joaquin Delta Region, California

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Seismic sources and their associated hazards within the Sacramento-San Joaquin Delta region of California are poorly characterized, in part because fluvial and tidal processes obscure surficial evidence of faulting, and slip rates that combine to no more than ~5 mm/yr of dextral motion across the region. The Montezuma Hills, a ~15 km x ~20 km region bounded by bedrock faults, are uplifted ~100 m above the surrounding Delta, implying that these structures accommodate vertical displacement, but the age and rate of this deformation is not known. Geomorphic analysis of the Montezuma Hills suggests uplift is asymmetric and concentrated toward the southwest, consistent with a discrete topographic escarpment along the southwest margin of the topographic high.

We investigated the southwestern edge of the Montezuma Hills by excavating a trench at the Talbert Lane site, across a break in slope in the escarp-

ment. Preliminary results confirm the presence of a fault at this location, with apparent east-side-up displacement, consistent with geomorphic indicators of uplift. The west-dipping fault juxtaposes coarse-grained fluvial strata to the east against a ~5-m-wide massive finer-grained colluvial zone to the west, which transitions to gently westward-tilted estuarine strata away from the fault. The western end of the trench exposes soil development to at least 3 m depth. Upwarping of hanging wall strata suggests that broader folding accompanies on-fault displacement. Portable luminescence results from a sample grid within the colluvial zone record an abrupt increase in luminescence at depth adjacent to the fault, which we interpret to represent one displacement event of ~2-3m. Luminescence ages from the colluvial zone and estuarine facies are in stratigraphic order and internally consistent, and using a central age model range from ~11 ka at 1 m depth to ~30 ka at ~3 m depth, much younger than expected ages based on extent of soil development. These ages of estuarine facies, now more than 25 m above tidal range, suggest Holocene uplift rates of greater than 1 mm/yr.

POSTER 119

Comparison of Lidar-differencing Fault Displacement Maps With Geomorphic Fault Mapping on the Central San Andreas Fault

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The 150-km-long central section of the San Andreas Fault, from San Juan Bautista to Parkfield, creeps at a nearly continuous rate of up to 35 mm/yr. This creep is measured along the fault at discrete points using alignment arrays and creep meters, while the along strike distribution of creep has been measured with low-resolution, wide-aperture methods such as InSAR. Recent high resolution (0.5 m) displacement maps from ~11-year repeat lidar-derived digital elevation model sub-pixel correlation captures the distribution and rate of active creep along strike at a finer scale than previously measured. These displacement maps have been validated against creepmeter and alignment array data but have not yet been evaluated along strike between these sites. In this study, we compare lidar-based fine-scale geomorphic fault mapping (Powell 2023 and subsequent refinements) to these new displacement maps with two goals in mind. First, we use fault mapping to evaluate the accuracy of the displacement maps against the geomorphic location of the fault. Second, where the displacement gradients are associated with geomorphically-indicated fault traces, we explore how creep propagates through geometric complexities such as stepovers. In areas where the displacement maps and fault mapping disagree on the location of the primary creep, we examine possible causes including influences of fault geometry, possible long-term fault evolution causing the active trace to change through time, interaction with other geomorphic processes (e.g. landsliding), or landscape factors that pose challenges for the lidar differencing measurements. This study provides a framework for understanding how lidar change detection can complement the mapping of surface rupturing faults and to assess the stability of fault traces over the decadal to millennial time scales.

POSTER 120

Late Quaternary Fault Scarps in the Saratoga Valley, Wyoming: A Potential Source for 1882 Colorado Earthquake?

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Quaternary faulting in the Saratoga Valley of south-central WY has been postulated in prior work but has remained an open question. To address this, we performed desktop geomorphic mapping and analysis with lidar, which yielded strong evidence of late Pleistocene to latest (?) Holocene normal faulting in the western and southern parts of the valley. We mapped scarps at 1:10,000 scale or better across two distinct zones separated by the Encampment River. West of the river, NW-trending scarps face NE and SW

within a ~27 km long by ~10 km wide zone over undated alluvial pediments and fluvial terraces that grade to the NE. In general, scarp heights are smaller on younger (lower) surfaces and larger on older (higher) surfaces. For example, at Cow Creek, the modern floodplain is offset ~1.5 m down-to-the-NE across a single scarp, suggestive of latest Holocene rupture, and adjacent fluvial terraces along strike and 14 m and 20 m higher are offset ~1.25 m and ~2 m. A ~25-m-high terrace at Spring Creek is displaced ~4 m down-to-the-SE, suggesting recurrent activity. Other notable scarps include those along the NE base of the Sierra Madre and areas >25 km north of the Encampment River. These scarps displace the Tertiary Browns Park formation; however, we found no geomorphic expression where they cross late Quaternary surfaces. Scarps on the E side of the Encampment River face E to SE and are ~1–2 m high with consistent expression for ~15 km across alluvial fan and colluvial slopes on the E side of the Beaver Creek Hills. A single <1 m high scarp on the Big Creek alluvial fan at the southern end of the valley was the southernmost scarp identified in this study.

These findings have important seismic hazard implications and highlight a possible source for the 1882 M6.6 Colorado earthquake; an event for which a crustal fault source has not been identified. The proximity to strong shaking isoseismals, and possibly the only geomorphic evidence of late Holocene faulting in the area, raise the question of relation to the 1886 earthquake; a theory which may be tested through paleoseismic trenching and geochronologic dating.

Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cascadia, Chile and Beyond

Oral Session • Thursday 16 April • 10:30 AM Local

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Constraining the Shallow Structure of Cook Inlet Basin, Alaska Using P-wave Autocorrelations: Insights Into Subduction Zone and Forearc Structure

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Subduction zones characterized by thick sedimentary basins present complex seismic wavefields that can amplify ground motion, seismic hazard, and risk of cascading natural hazards. The Cook Inlet Basin in southwest-central Alaska overlies the subducting Pacific plate and hosts major population centers, yet its detailed crustal-scale structure remains incompletely resolved due to sparse offshore coverage and strong lateral heterogeneity. In this study, we present autocorrelation functions (ACFs) from vertical-component broadband data that record the P-wave coda from permanent stations surrounding the Cook Inlet to image subsurface impedance contrasts beneath the basin.

We compute P-wave ACFs in 191 stations for a total of 5218 teleseismic earthquake recordings, isolate the causal component, and enhance coherent signals through Phase-Weighted Stacking (PWS). The resulting stacked ACFs reveal robust reflectivity peaks corresponding to the sediment-basement interface, and deeper crustal discontinuities. Comparison with synthetic ACFs generated from layered velocity models demonstrates that the inclusion of low-velocity sedimentary layers is essential to reproduce observed early-time reverberations. Lateral variations in ACF character across stations suggest significant spatial variability in basin thickness and crustal depth, consistent with previous active-source and receiver-function studies. Our results highlight the utility of ACF-PWS methods for imaging sedimentary basins in subduction settings where traditional techniques are limited by resolution of

data. Improved constraints on basin geometry and crustal structure beneath Cook Inlet can improve imaging of properties within the subduction interface, leading to better understanding of the controls on tremor and slow-slip earthquakes, and cascading seismic hazards associated with large megathrust earthquakes in Alaska and analogous subduction zones worldwide.

Razor Sharp Edge – the Yakutat Slab Dissecting South-central Alaska

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The tectonics of south-central Alaska are dominated by subduction of the Pacific plate, the Yakutat oceanic plateau, and evolution of the major continental fault system, the Denali Fault. We use passive seismic data recorded at stations in central Alaska to create a new machine learning (ML) based catalog of seismicity totaling 65,016 events, together with P receiver functions to image velocity discontinuities within the lithosphere, and new images of the lithospheric structure from ambient noise tomography inferring the shear wave velocities down to 50 km depth.

Our new structural images show the razor-sharp edge and extent of the Yakutat slab as it subducts beneath the North American plate with remarkable detail. Thousands of small, previously undetected earthquakes form a prominent linear cluster >3000 earthquakes that occurred between (09/2018-12/2021) that illuminate the precise edge of the subducted Yakutat plate and defines the location of changing slab morphology reflecting the change in stress state. Even more curious is the correlation of these earthquakes with the NE extent of the tectonic tremor epicenters identified by Wech (2016). Our new seismic images and refined locations of down-dipping seismicity further elucidate the lack of mantle wedge below the Denali volcanic gap and the northeastern margin of the Yakutat slab, imaged here to be directly below the curved section of the fault. We infer these features to have controlled the nucleation of the 2002 M7.9 Denali Fault earthquake and the position of recent onset of volcanic fields. Along with the previously recognized modifications to the rock record, surface topography, and lithospheric structure, the on-going seismic activity captured here demonstrates the kinematic and mechanical linkage of various structures involved in oblique subduction zone clogging on the human timescale.

Control of Slab Tearing on Deep-focus Earthquakes and Volcanoes

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It is well known that earthquakes and volcanoes are linked with subduction zones. In addition to seismicity occurring along the plate interface, there are many earthquakes occurring inside the slab. For the intermediate-depth intraslab earthquakes (<350 km), dehydration embrittlement and shear heating instability are two main recognized mechanisms. For deep-focus earthquakes (>350 km), transformational faulting of olivine and adiabatic shear instability are often called to explain their occurrence. However, these two mechanisms cannot well explain the uneven distribution of deep-focus earthquakes globally. For volcanoes along the subduction arc, they are mainly formed by partial melting in the mantle wedge due to fluids released from subducting slab. However, there are volcanoes far away from the subduction arc, such as Changbaishan volcano, which needs different mechanisms to account for such volcanism.

In this presentation, I will report our findings in central Chile subduction zone, Izu-Bonin subduction zone, and northeast Asia. It is found that slab tearing has a major control on deep-focus earthquakes and volcanoes. In the Izu-Bonin, multiscale teleseismic tomography resolves a tear in the slab in the mantle transition zone (MTZ). To the south of the tear, the slab overturns and lies flat at the base of the MTZ. The ~680 km deep 2015 Bonin earthquake (Mw~7.9) is located at the northernmost edge of the overturning part of the slab due to high strains accumulated there (Zhang et al., 2019, NC). For the deep seismicity cluster located to the east of Changbaishan volcano, it is located in the hinge zone of a local slab penetration through the 660 km interface. This local slab penetration at the same time creates a gap for deep hot materials to ascend, providing a deep mantle source for Changbaishan volcanism (Gao et al., 2025, NC). For the central Chile, the transition from normal subduction to flat-slab subduction also creates a tear zone, causing a seismic gap and a volcanic cluster in this region (Gao et al., 2025, EPSL).

Pick Aggregator: A Multi-model Ensemble of Machine Learning Pickers to Detect Offshore Seismic Swarms North of Puerto Rico and the Virgin Islands

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Machine learning (ML) pickers have automated the detection of seismic phases with high fidelity and speed, improving small event detection and catalog completeness by orders of magnitude. However, their performance degrades when analyzing seismic data that significantly differs from their training data, including variations in instrumentation, noise environments, and station density. We present a multi-model ensemble approach with superior detection performance across diverse tectonic environments and varying signal characteristics. Our Pick Aggregator module retains detected picks confirmed by two or more ML models, which helps mitigate inconsistencies among different models and remove false positives, while capturing picks that single ML models may fail to detect. We also test two associators, GaMMA and PyOcta to create an aggregated catalog and use independent differential times from waveform cross-correlation to improve location and timing uncertainties.

We apply this methodology to monitor offshore seismic swarm activity north of Puerto Rico and Virgin Islands using 1-year deployment of USGS Ocean Bottom Seismometers (OBS). The new ML-catalog includes 7,209 events with OBS stations contributing thousands of near-source seismic phases (21% P-wave and 24% S-wave picks), significantly improving azimuthal coverage of offshore events. The ML-relocated catalog with added differential times includes 4969 events (33.6% increase compared to the USGS hypoDD catalog). The relocated catalog reveals a prominent NNW-trending earthquake swarm southeast of the Main Ridge at 20-50 km depth, aligned with a fast shear-wave polarization direction noted in a previous study, suggesting a slab tear near 65°W. We also observe a transition from shallower eastern to deeper western seismicity near this longitude, interpreted as a steeper slab segment west of the tear. This ML-catalog provides direct evidence for complex three-dimensional slab geometry beneath the northeastern Caribbean, with distinct slab segments undergoing differential deformation consistent with heterogeneous subduction along the Puerto Rico Trench.

Low-frequency Earthquakes Track the Motion of a Captured Slab Fragment at the Mendocino Triple Junction

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The transition between the San Andreas Fault and the Cascadia subduction zone at the Mendocino triple junction is critical to understanding the tectonics and seismic hazard associated with these fault systems. Despite its significance, this complex region, where the Pacific, Gorda, and North American plates meet, remains poorly understood. A primary uncertainty is the location and nature of the southern edge of Gorda subduction at depth. Contrasting models propose that the southern edge of the northward-migrating Gorda slab is trailed either by upwelling asthenosphere filling a slab gap or by a fragment of the former Farallon slab now captured by the Pacific plate. No direct constraints on the associated kinematics have been available to distinguish these models. Here, we analyze tidal sensitivity and P-wave motions of a recently identified zone of tectonic tremor and low-frequency earthquakes (LFEs), showing that these events are generated by dipping, strike-slip motion at depth. This slip matches the expected relative motion between the Pacific and Gorda plates, arguing that the LFEs occur on a previously unrecognized, buried extension of the Mendocino transform fault, validating the captured slab hypothesis. A zone of comparatively low seismic velocity between Gorda slab seismicity and the LFEs may represent North American plate accretionary prism material that was progressively subducted at the southernmost edge of Cascadia, with the primary subduction interface ~10 km above the slab at its southern edge near the coast. These findings challenge typical assumptions that subduction faults follow the petrologic slab boundaries and imply the existence of a large detachment fault beneath the northernmost San Andreas system, creating a potential unaccounted earthquake hazard in this region.

Reconstructing Spatial and Temporal Megathrust Rupture History Using Stratigraphy and Microfossils at Sitkinak Island, Alaska

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Rupture variability along the Alaska-Aleutian subduction zone complicates seismic hazard assessments at the western extent of the 1964 Mw 9.2 rupture zone. Sitkinak Island, located in the western Kodiak Island archipelago, is well-positioned to study the variability of slip in this region. Previous work identified five episodes of sudden late-Holocene vertical coseismic deformation marked by laterally extensive peat-mud (subsidence) and mud-peat (uplift) contacts, but questions remain about the site-wide continuity of paleoseismic evidence and the amount of land-level change recorded. A multi-core analysis and quantitative approach across diverse depositional settings is needed to corroborate this unique mixed uplift and subsidence record.

Here, we compare stratigraphic and microfossil data from paired sites in different geomorphic environments on Sitkinak Island. In an east-west transect of seven cores, we identified and dated three sharp stratigraphic contacts that indicate one subsidence event (1964 CE) and two uplift events (520–300 and 1050–790 cal yrs BP). Across earthquake contacts we analyzed fossil diatoms, key indicators of salinity changes, and applied a transfer function to statistically relate diatom assemblages to elevations within the tidal frame. Preliminary paleoelevation reconstructions across sharp contacts indicate subsidence of 0.62 ± 0.26 m at 1964 CE, uplift of 0.44 ± 0.25 m at 520-300 cal yrs BP, and uplift of 0.55 ± 0.25 m at 1050-790 cal yrs BP. We find the timing and direction of coseismic land-level change is consistent between two distinctive geomorphic environments in south Sitkinak Lagoon, strengthening our confidence in a mixed uplift and subsidence signal at the site. Ongoing analysis of an additional sediment core will further constrain 1964 CE land-level change estimates. Our quantitative estimates of paleoearthquake rupture behavior will be integrated into rupture models to define slip variability in this region, improving hazard assessments in Alaska.

Impact of Rough Topography and Seamount Subduction on Near-trench Deformation in the Taltal Seismic Gap, Northern Chile

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North Chile has hosted numerous great earthquakes (Mw > 8.0); however, the Taltal segment (23.5°S–26°S) shows no historical record of major events since at least 1600 CE. This prolonged quiescence, alongside high interseismic coupling and geo-archaeological evidence of tsunamis larger than those recorded historically, characterizes the region as a mature seismic gap. This segment is characterized by the subduction of the Taltal Ridge and rough seafloor topography, which deforms the frontal wedge and influences frictional properties along the plate interface. Thus, it remains unclear whether the resulting structural complexity limits rupture propagation, or if the apparent quiescence is a consequence of the short historical record.

We characterize the offshore structure and plate boundary deformation by integrating reprocessed legacy seismic reflection data (1995 CINCA project), high-resolution bathymetry, local microseismicity, and seafloor geodetic measurements. We identify a highly deformed upper plate featuring extensive subduction erosion and possible collapse structures associated with seamount subduction. At the trench, we find grabens ~1 km of vertical offset and ~10 km wide. This geometry persists in the shallowest section of the plate boundary, but the contact flattens landward, with a broad zone of reflectivity that we interpret as grabens filled with eroded material. Furthermore, recent offshore geodesy data suggest that locking extends to the trench despite these complex features. If, as proposed, tsunami-earthquakes are favored by complex plate contact geometries that might decrease rupture velocity, then this area may be capable of generating such events. Therefore, the lack of historical great earthquakes, despite clear evidence of coupling, suggests either a recurrence interval >400 yr or that the region may be limited in its ability to generate great earthquakes, with the tsunami geo-archaeological record reflecting ≤8.0 M events that included a tsunami-earthquake component. These results offer key structural constraints for modeling the interplay of splay faulting and shallow locking.

Stress, Strain, the Seismic Cycle and Long-Term Forearc Deformation in Northern Chile

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Subduction zone forearcs deform transiently and permanently due to the frictional coupling with the converging lower plate. Transient stresses are mostly the elastic response to the seismic cycle. Permanent deformation is evidenced by forearc topography, upper plate faulting and earthquakes; its relation to the megathrust seismic cycle is debated. Here we study upper plate seismicity, interplate earthquake slip vectors, and the GNSS derived displacement in the northern Chile subduction zone to deduce the stress and strain field and to separate elastic and permanent strain. We find that seismicity is distributed unevenly and that high seismicity rates concur both with a break in the forearc topography and tectonics of the Coastal Cordillera and the onset of a change in subduction obliqueness. Earthquakes in the South American crust under the sea and the Coastal Cordillera show a remarkably homogenous north-south, i.e., trench-parallel, compressional stress field. This stress pattern above the plate coupling zone, almost perpendicular to plate convergence direction, may be explained by strain resulting from a change in subduction obliqueness due to the concave shape of the plate margin, which we demonstrate by investigating inter-plate earthquake slip vectors. From these, we derive a strain rate estimate (-5×10^{-8} /a) and compare it to one derived from upper plate earthquakes (-8×10^{-9} /a). We argue that the dominance of trench-parallel compressive stresses over trench-perpendicular ones is due to canceling of the latter by tensional gravitational stresses due to the topographic gradient between the Andes and the Nazca trench. Based on the distribution of the type of faulting we investigate the trench-perpendicular stress field with a force-balance model. The observed deep strike-slip earthquakes, expression of trench-perpendicular tension, require the deepest extent of the megathrust to be very weak.

Do Coupled Megathrusts Rupture?

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To assess seismic hazard along subduction zones, which host Earth's largest earthquakes, geodesists routinely measure interseismic surface deformation rates and invert them to estimate distributions of slip deficit along the plate interface. The resulting kinematic geodetic coupling models highlight portions of the megathrust that are "locked" and accumulating strain, thus identifying likely candidates for future rupture. However, these models are limited by sparse offshore observations, which lead to large uncertainties in shallow coupling, and by growing evidence that coupling can vary substantially over just a few years, undermining the assumption that coupling remains constant over interseismic periods. Moreover, high coupling is not a prerequisite for earthquake rupture, as dynamic slip can propagate through creeping regions while strongly coupled segments may instead act as rupture barriers.

To evaluate whether, and to what extent, geodetically inferred coupling correlates with coseismic slip, we perform a global comparison of slip deficit models and finite-fault slip distributions. We compile the first unified data-set of coupling models including twelve subduction zones and 61 finite-fault models of megathrust earthquakes that ruptured these margins, with a cumulative moment magnitude of 470. We discretize each slip model into a point cloud reflecting its slip distribution, allowing us to quantitatively link slip with coupling values to evaluate their correlation.

Our slip-coupling analysis reveals consistent global patterns: large megathrust earthquakes ($M_w \geq 7.5$) preferentially rupture highly coupled regions, whereas smaller events show weaker coupling-slip correlations. Comparison with the null hypothesis in which slip-coupling correlation is completely random highlight that observed slip-coupling correlations are statistically significant. These findings highlight the complex interplay between coupling and rupture behavior, demonstrating that strong coupling alone does not unequivocally predict future earthquake slip patterns.

The 2017 Mw 8.2 Mexican Earthquake Jumped From a Normal Outer-rise Fault Onto the Megathrust Interface

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The 2017 Mw 8.2 Tehuantepec earthquake was the largest normal-faulting earthquake ever recorded in Mexico. It occurred offshore on a reactivated outer-rise fault within the Tehuantepec seismic gap, a tectonically complex region within the intersection of the North American, Caribbean, and Cocos plates. Prior to 2017, the Tehuantepec segment was considered a seismic gap, having produced no large megathrust earthquakes for over a century. Previous studies showed that the rupture initiated approximately 100 km offshore, propagated northwestward for ~60 km into the plate boundary zone, then jumped ~10 km inland as it crossed the trench-perpendicular Tehuantepec Ridge before continuing another ~60 km and terminating abruptly.

Using a machine-learning-based earthquake-detection workflow applied to data from a temporary seismic array and permanent Mexican stations, Garcia et al. (2025) produced a high-resolution earthquake catalog that has brought new insights to the evolution of the Tehuantepec earthquake. Here, we interpret these results together with relocated moment tensors in the context of regional plate tectonics. Moment tensor solutions indicate that the offshore rupture segment prior to crossing the Tehuantepec Ridge was mechanically complex, exhibiting a broad mix of faulting styles dominated by normal faulting. After crossing the Ridge only thrust mechanisms were observed. We interpret this as a rupture with two main stages (1) a normal, but significant complex breaking within the rupture before the Tehuantepec Ridge, then (2) a jump onto the megathrust interface. The earthquake stopped at what appears to be a break between the remaining sliver of the Caribbean plate and the North American plate. This suggests that part of the Tehuantepec gap did break in the rupture. To our knowledge, this represents the first documented case of a large normal-faulting earthquake transitioning directly from an outer-rise fault onto a megathrust interface.

2025 Mw 7.0 Hubbard Glacier Earthquake: Seismic Hazard in Fault Corridor

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On 6 December 2025, the Mw 7.0 Hubbard glacier earthquake occurred ~80 km north of Yakutat, Alaska, within a tectonically complex setting. The earthquake was widely felt across Alaska and the Yukon Territory, producing ~700 landslides yet resulting in no reported injuries or structural damage, largely due to its remote location. Preliminary rupture estimates align with the NW-SE trending strands of the Fairweather fault in southeast Alaska based on aftershock distribution and a finite fault model from the United States Geological Survey (USGS). Historically, the Fairweather fault system has produced several destructive earthquakes and triggered landslides, including the 1958 Mw 7.9 Lituya Bay event on its southern segment. The Hubbard glacier earthquake occurred on the northern segment of the Fairweather fault, where fault geometry is complex with hypothesized fault strands connecting it to the Central Denali fault through a connector fault. Therefore, despite the alignment with the regional fault trend, it is presently unclear whether the earthquake occurred on a mapped or an unmapped fault with associated known/unknown seismic hazard.

In this study, we synthesize observations of the earthquake in the context of possible activation along unmapped faults. The vigorous aftershock sequence—2000 aftershocks in the first month >M2—allows us to map the extent and orientation of activated fault strands. We examine the published aftershock distributions as well as versions using several absolute and relative relocation methods. Subsequently, we estimate best-fitting focal mechanisms with associated uncertainties for the mainshock and selected aftershocks using regional waveform moment tensor inversions (MTUQ, Thurin et al., 2025). Finally, we develop Coulomb stress change models for the region using (i) the published USGS finite fault model, and (ii) a new two-fault model based on our relocations and moment tensor analysis. These stress changes are also computed for mapped neighboring faults to assess regional seismic hazard.

Constraining the Coseismic Slip Distribution of a Megathrust Earthquake by Stress-driven Afterslip

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Accurate determination of coseismic slip distributions is crucial for understanding earthquake physics and assessing seismic hazards. However, inversions using only coseismic data often yield highly variable slip models. While these uncertain slip models are routinely used to study postseismic processes, the physical coupling between coseismic stress changes and subsequent afterslip is rarely exploited to constrain the earthquake rupture itself.

Here, we develop an Ensemble Kalman joint inversion method that incorporates stress-driven afterslip to better constrain the coseismic slip distribution. Applied to the 2020 Mw 7.8 Simeonof earthquake using multiple geodetic datasets spanning one year, our method simultaneously solves for both coseismic slip and stress-driven afterslip.

The joint inversion reveals that the Simeonof rupture area is more compact than most previous models suggest, with a distinct velocity-strengthening barrier separating it from the 2021 Mw 8.2 Chignik earthquake rupture zone. This velocity strengthening barrier hosts almost zero coseismic slip but a significant amount of afterslip, and was obscured in coseismic-only models due to its small scale and smoothing constraints. The stress-constrained coseismic slip model together with its afterslip provides a physically consistent relationship with the relocated slab interface aftershocks, which prefer to occur where the afterslip stress is positive.

The Duality of Doublets: Unusually Large Aftershocks or Unusually Strong Fault Interactions?

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Earthquake doublets—large nearby events of similar size striking within a short period—have been a puzzle for over half a century. Is the second event in a doublet pair simply an unusually large aftershock, or do doublets reveal a unique fault interaction process? If all subduction zones exhibit the same percentage of doublets, that would support the first view. But if some subduction zones generate many more doublets than others, that would support the second view.

First, we find that doublets do indeed undergo Omori aftershock decay, reaching the background or steady doublet rate in 4–6 months, although the subsumed decay continues for much longer. However, among the world's twelve major subduction zones, the Solomon–Vanuatu trench hosts ten times more doublets—defined arbitrarily here as $M \geq 6$ pairs within 0.25 M units, 50 km, and 10 years. Whether or not one normalizes by trench length and velocity, this difference cannot be explained by the 2–4 times higher rate of $M \geq 6$ shocks in the Solomon–Vanuatu trench. Here we argue that this extraordinary doublet rate results from abundant (near-vertical) tear faults in the slab and forearc. The trench produces seventeen times more doublets involving strike-slip motion than the mean of the other 11 major trenches. Coulomb stress transfer is as efficient between the subduction interface and adjacent tear faults as between megathrust surfaces offset by these tears. Tear faults segment and roughen the megathrust interface, hampering the along-strike propagation of great earthquakes, and so confine ruptures. As a result, the trench has an exceptionally low rate of $M \geq 8$ shocks despite a very high rate of $M \geq 6$ shocks. The seafloor roughness and tear faulting arise from the recent initiation and reorganization of subduction, and the entrainment of lithospheric fragments and rift-transform systems into the trench. The net impact is a higher post-mainshock hazard due to the abundance of doublets, but a lower rate of great earthquakes and the destructive tsunamis they generate.

Tectonic Pump Closes the Evolutionary Loop for Long-buried Subseafloor Microbes

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Deep marine sediments host one of Earth's largest microbial biospheres, but the vast majority of cells in this environment persist in a non-growth state for thousands to millions of years, trapped underneath many kilometers of sediments. For natural selection to drive adaptation for such extraordinary long-term survival, mechanisms must exist that are sufficiently powerful to exhume these living populations up to surficial sediments where higher quality food sources allow cell proliferation, natural selection for long-lived traits, and dispersal to pass genetic adaptations to populations worldwide. Here, we pro-

pose subduction zone earthquakes as the missing mechanism for deep sediment microbial migration, reactivation, and reproduction. Our models show that slip-driven water circulation in subduction-zone outer wedges produces global fluxes exceeding 1E6 Gt/Myr, sufficient to transport 1E26–1E30 cells/Myr. The tectonic pump is capable of returning microbial communities buried kilometers deep to the surface where they can pass adaptive genetic mutations to the next generation and be dispersed in the overlying water, forming a natural selection loop that selects for extremely long lifespans.

Patterns of Coseismic Landslides in Subduction Zones: Observations From the 2025 M8.8 Kamchatka Peninsula Earthquake and Beyond

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The July 29, 2025, M8.8 Kamchatka Peninsula earthquake is one of the largest instrumentally recorded earthquakes and generated a series of cascading impacts including a tsunami, coastal land-level change, and landslides. Landslides triggered by great subduction zone earthquakes are of particular concern as they can affect people and infrastructure spread over tens of thousands of square kilometers, but there is a paucity of global empirical data from great subduction zone earthquakes to constrain their behavior and estimate future hazards. Evidence of past landslides in the landscape (i.e. paleo-landslides) may provide clues to past subduction zone earthquake behavior, but the quality of those constraints is limited by our understanding of modern subduction zone earthquake-triggered landslides.

Here we present and discuss landslides generated by the Kamchatka Peninsula earthquake and their relationship to other subduction zone coseismic landslide inventories. Landslides were manually mapped over a ~33,000 km² footprint using Sentinel-2 images comparing most recently-available pre-earthquake images to data from July and August, 2025. 346 landslides, with a total area of ~2.5 km² were mapped on the Kamchatka Peninsula and northern Kuril Islands. Mapped slides strongly cluster along the coast and are biased to the south. This suggests shaking may have been more intense in the south, consistent with the U.S. Geological Survey finite fault model which placed the highest slip patch at the southern end of the rupture. We will discuss the apparent 'low' number of mapped landslides relative to other large magnitude events, their distribution as it relates to the earthquake and landscape, and contextualize this event with other subduction and crustal earthquake-triggered landslide inventories. From this case study, we hope to improve our understanding of landslides in subduction zones globally, increasing our ability to forecast future cascading hazards.

Linking Subduction Zone Processes and Cascading Hazards in Alaska, Cascadia, Chile and Beyond [Poster]

Poster Session • Thursday 16 April

Conveners: Geoffrey Abers, Cornell University (abers@cornell.edu); Tiegan E. Hobbs, Geological Survey of Canada (thobbs@eoas.ubc.ca); Andrew Howell, University of Canterbury (andrew.howell@canterbury.ac.nz); Junle Jiang, University of Oklahoma (jiang@ou.edu); Duo Li, Earth Sciences New Zealand (d.li@gns.cri.nz); Camilla Penney, University of Canterbury (camilla.penney@canterbury.ac.nz); Chris Rollins, GNS Science (c.rollins@gns.cri.nz); Ignacio Sepulveda, San Diego State University (isepulveda@sdsu.edu); Lingling Ye, Southern University of Science and Technology (yell@sustech.edu.cn); Iris van Zelst, University of Edinburgh (iris.vanzelst@ed.ac.uk)

POSTER 121

Machine Learning-based High-resolution Earthquake Catalog for the Middle America Trench Using Ocean Bottom and Land Seismometers

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Subduction zones generate Earth’s largest earthquakes along with many low-magnitude events that remain undetected. However, the ability to monitor microseismicity in offshore settings can delineate plate-boundary fault networks and inform coupling and slip patterns. Machine learning (ML) can improve detection of seismic signals over manual picking for sparse offshore sensors, deployed in noisy marine environment. Here, we develop a high-resolution earthquake catalog for the Middle America Trench using ML applied to legacy amphibious CRSEIZE data (1999–2001), including a 2-month Osa aftershock sequence and a 6-month Nicoya deployment following the Mw 6.9, 20 August 1999. We evaluate developed ML catalogs against manually picked catalogs.

Within SeisBench, we run pre-trained phase-picking models optimized for ocean-bottom seismometer (OBS) (PickBlue-PhaseNet and OBSTransformer) and test PhaseNet with several training datasets for land recordings for both the Osa and Nicoya experiments. Picks are aggregated with a conservative cross-domain consensus rule to retain phases detected by at least two distinct OBS–land model combinations (Aziz Zanjani & DeShon 2026). We then associate events with GAMMA and PyOcto. Preliminary results for Osa shows the ML workflow detected 2,202 earthquakes, with only 835 out of 1,557 earthquakes in the manual catalog recovered. Catalogs for both Osa and Nicoya will be presented. These more complete offshore seismic catalogs provide better constraints on the onset and cessation of interplate seismicity, the updip and downdip limits of seismogenic zone, and boundaries linked to a serpentinized forearc mantle wedge. Improved microearthquake distributions should also stabilize statistics such as b-value to constrain temporal and depth distributions of stress.

POSTER 122

Evaluating Seismic Hazards for Carbon Storage on the Scotian Shelf Offshore Nova Scotia

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Geological carbon sequestration is a critical strategy for mitigating global warming by reducing atmospheric CO₂ concentrations. Atlantic Canada has emerged as a promising region for offshore CO₂ storage, with an estimated storage capacity of ~177 Gt beneath the Scotian Shelf offshore NS. Although the Scotian Shelf is a low seismic hazard region, the potential for injection-induced seismicity cannot be overlooked. To quantify background seismicity across the Scotian Shelf, we deployed a temporary network of 19 ocean-bottom seismometers (OBS) from the National Facility for Seismological Investigations during 2024–2025. The OBS array consisted of two linear deployments spanning ~500 km, with an inter-array spacing of ~50 km. The acquired waveform data is subjected to preliminary processing to inspect the clock offset using teleseismic events which found to be insignificant. Subsequently, we performed a machine learning based seismic phase picking, resulting in approximately 1.2 million S- and 0.5 million P-phase picks. Phase association was conducted using a local velocity model and picks with probability ≥ 0.3, yielding ~140 events. Following detailed visual inspection, poorly associated events were discarded, resulting in a high-quality dataset of ~90 events. Our results reveal pronounced spatial heterogeneity in background seismicity, with relatively elevated seismicity concentrated toward the SW termination of the shelf at shallow depths (~5–20 km), whereas relatively low seismicity is observed at the northern termination. This spatial variability suggests the presence of localized active seismogenic sources, while also indicating potentially lower-risk regions for CO₂ storage along the shelf, indicating a need of long-term seismic monitoring.

POSTER 123

PACSAFE LEG2: Investigating Seismicity in the Northern Segment of the Queen Charlotte Triple Junction Using a Year-long OBS Deployment

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The Pacific Coast Seismic Assessment for Faults and Earthquakes (PACSAFE) multi-year OBS program aims to investigate the earthquake hazards offshore BC, with the goal of improving the characterization of seismicity and fault structure in the region. This study examines data from the second leg of the PACSAFE program (LEG2), in which 23 OBS were deployed in the northern segment of the Queen Charlotte Triple Junction, mainly covering the region between the Revere–Dellwood Fault Extension (RDFE) and the south end of the Queen Charlotte Fault (QCF/paleo-QCF), for a one-year period (July 2024–Aug 2025). Of the deployed instruments, two stations self-released prematurely; therefore, our analysis is based on data from the remaining 21 OBS.

We carried out preliminary seismic analyses of the one-year long continuous LEG2 seismic data in the northern segment of the Queen Charlotte Triple Junction . We applied OBSTransformer, a deep learning–based phase picker, to the continuous waveform data. Only high-confidence picks (probability ≥ 0.3) were retained for phase association, yielding 17,500 candidate events. We subsequently conducted both absolute and relative earthquake relocations, producing a final seismicity catalog containing over 14,000 double-difference–relocated events with depths predominantly shallower than 20 km, but extending to ~40 km offshore southern Haida Gwaii. The abundance of earthquakes with high-resolution locations clearly delineates the detailed active fault structure of the region. Lineated seismicity is observed along the RDFE rather than the QCF or paleo-QCF, with a major conjugate shear zone connecting the RDFE to the QCF/paleo-QCF that accommodates most earthquakes observed during the study period, including the aftershocks of the recent 2024 M 6.5 earthquake, whose mainshock hypocenter is located at the intersection of the Tuzo–Wilson Volcanic Field and the QCF. Through further seismological analyses and multidisciplinary integration, the research team anticipates gaining a better understanding of deformation mechanisms and associated seismic hazards in the region.

POSTER 124

Investigating Interseismic Vertical Land Motion Along the Cascadia Subduction Zone Using High-resolution Diatom-based Paleogeodesy and Radiocarbon Chronologies

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Along the Cascadia subduction zone (CSZ), intertidal wetlands preserve distinct stratigraphic evidence of past subduction zone earthquake-driven subsidence. Evidence for subsidence typically consists of a sharp transition from organic-rich peat (pre-earthquake) to a minerogenic tidal mud (post-earthquake), reflecting the rapid relative sea-level rise during great earthquakes. Paleogeodetic approaches using microfossils (e.g. diatoms and foraminifera) have enabled quantitative, high-precision reconstructions of coseismic subsidence that provide essential geologic constraints for modern rupture and tsunami models. However, comparatively little is known about vertical land motion (VLM) in the interseismic period, despite it being preserved within the same sedimentary sequences. In contrast, modern geodetic (GNSS) observations provide insights into present-day interseismic deformation and megathrust locking but are limited in resolution and do not capture long-term variability in coupling behavior.

Here, we aim to extend paleogeodetic reconstructions beyond the coseismic phase to resolve interseismic deformation across multiple earthquake cycles at three sites along the CSZ: Siletz Bay, Coquille River, and Sixes River. We use a diatom-based Bayesian transfer function to reconstruct paleoelevations from the immediate postseismic period through late-stage interseismic strain accumulation to inform patterns of strain accumulation. These VLM reconstructions will be coupled with high-resolution radiocarbon

chronologies to add temporal constraints to VLM though the interseismic period. Together, these data provide new constraints on the evolution of CSZ megathrust locking and improve understanding of long-term vulnerability of coastal environments and communities.

POSTER 125

Machine Learning Detection of Offshore Tremor in the Cascadia Subduction Zone Using Multi-year Continuous Offshore and Onshore Seismic Data

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In the Cascadia Subduction Zone, tectonic tremor provides important constraints on locked-zone geometry and slip processes along subduction plate interfaces. Current catalogs of tremor in Cascadia do not provide reliable detection in offshore regions, possibly due to either the absence of tremor or to the high levels of noise in ocean-bottom seismic (OBS) data. However, in tectonically similar settings such as the Nankai Trough, abundant updip tremor has been observed. Machine-learning techniques have recently revolutionized the search for earthquakes, but application to tremor remains less common. Machine-learning is thus a possible pathway to detecting tremor in challenging environments such as the oceans. This study adopts a machine-learning–based approach and analyzes multi-year continuous seismic records from 2017 to 2025 to investigate a long-standing yet fundamental question: whether tremor activity is present in the offshore region of the Cascadia Subduction Zone. This study integrates labeled onshore tremor records, onshore earthquake events, and offshore noise-only windows from Cascadia to construct and train a machine-learning framework for a ternary classification task (tremor, earthquake, and noise), using fixed-length windows of 150 s sampled at 100 Hz. The model is trained to differentiate tremor, tectonic earthquakes, and multiple types of oceanic and environmental noise based on their distinct signal characteristics. The network combines convolutional and recurrent architectures with time–frequency representations to jointly capture spectral and temporal characteristics of seismic signals. Model performance is evaluated under varying noise conditions to assess robustness and generalization. The trained network will be applied to long-term continuous OBS records in Cascadia to systematically assess the presence, absence, or potential scarcity of tremor in offshore environments, and to inform us as to the locking state of the Cascadia Subduction Zone.

POSTER 126

A 2D and 3D Community Fault Model for the Cascadia Subduction Zone: Release of CRESCENT CFM Version 1.0

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Earthquake hazard in the Cascadia region stems from numerous structures including faults within the upper (North America) and lower (Juan de Fuca) plates and the plate boundary megathrust. Active faults in this system occur throughout southern British Columbia, Washington, Oregon, and northern California. Despite the significant seismic hazard associated with these faults, we lack a regionally comprehensive community fault model for Cascadia. Here we present Version 1.0 of the Cascadia Region Earthquake Science Center (CRESCENT) Community Fault Model (CFM). The CFM is comprised of 2D and 3D representations of faults in both the North America and Juan de Fuca plates, models of the plate interface, and accompanying meta-data for each fault. We include faults that exhibit evidence for nucleating and/or hosting slip during an earthquake since the Late Pleistocene (< 130,000 years) and also those that lack evidence for activity since the Late Pleistocene, but could become active under current stress conditions. The model has been constructed based on information published in peer-reviewed literature and underwent revisions based on evaluations by community members. Onshore faults build upon many sources including the USGS National Seismic Hazard Model 2023 fault sections database and state geological survey fault data-

bases. Offshore, the CFM includes many recently imaged splay faults in the accretionary wedge that are important for understanding megathrust rupture behavior and tsunami hazard. In addition, the CFM is useful for many other applications such as seismic hazard analyses, multi-cycle rupture modeling, and providing constraints in the CRESCENT Community Velocity Model. The CFM can also be used to help identify faults that could be targeted in future studies to improve our understanding of their potential hazard. The CRESCENT CFM will continue to grow and improve through community engagement and feedback leading to future version updates.

POSTER 127

Dynamic Rupture Modeling of the 2010 Mw 7.8 Mentawai Tsunami Earthquake With Self- Similar Stress Drop and Wedge Inelasticity

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We model the 2010 M_w 7.8 Mentawai tsunami earthquake using dynamic rupture simulations with heterogeneous, self-similar stress drop following a 1/k spatial spectrum. Rupture is confined to ~40 km of the deformation front based on high-rate GPS data, with stress and pore-pressure conditions defined by a three-dimensional critical wedge solution, a hypocentral depth of 10 km, and a constant fault dip of 4° from marine geophysical surveys. Random stress drop is implemented through dynamic friction, allowing natural incorporation of inelastic wedge deformation. With minimal tuning, elastic and inelastic models fit the GPS data comparably well, indicating that geodetic observations primarily constrain rupture extent. Inelastic wedge deformation produces >5 m of seafloor uplift despite reduced shallow slip—over three times that of elastic models—and is amplified by shallow slip strengthening via increased fault shear stress. This mechanism explains the disproportionate tsunami generated by the Mentawai earthquake, is consistent with pop-up structures observed in marine reflection data, and highlights the importance of including wedge inelasticity in probabilistic seismic and tsunami hazard assessments in global accretionary margins.

POSTER 128

Comparison of Seismicity Along the Northern and Southern Central Andes and Its Relationship With Along-strike Variations in Andean Deformation

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Two dense arrays of nodal and broadband seismometers were deployed at ~23°–24°S and ~35°–36°S covering from the coast of Chile to the foreland in Argentina to understand the driving processes for the along-strike variations in deformation in the Andes. These two datasets are used to build an earthquake catalog for each of those two regions with a machine-learning-based workflow. Both the catalogs show abundant seismicity along the subducting Nazca slab, but the number of events observed at 23°–24°S is much higher compared to 35°–36°S. Both of these regions show a distinct cluster of events at ~80–120 km depth along the subducting Nazca slab, likely due to dehydration reactions. However, an additional cluster of events is observed at ~180–220 km depth at ~23°–24°S underneath the Puna plateau. Very few earthquakes are observed along the main volcanic arc and the Puna plateau at ~23°S likely due to several factors such as the presence of the Altiplano-Puna magma body, elevated temperatures, and lower crustal flow. However, the main volcanic arc at ~35°S shows abundant seismicity, which is mostly related to the volcanic unrest at the Laguna del Maule volcanic field, where a trans-crustal magma ascent process is observed. In the back-arc, abundant seismicity is observed along the fold-and-thrust belt at ~23°–24°S, where a detachment-involved deformation system is identified and it indicates active

ongoing shortening, and also explains geologically inferred higher magnitude shortening at these latitudes. However, the back-arc at ~35°–36°S shows sparse low-magnitude seismicity in the Malargüe fold-and-thrust belt and Payenia volcanic field, indicating a nearly inactive thrust belt, potential volcanic influence on the seismicity, and also explains the overall low-magnitude shortening along these latitudes. The difference in these two catalogs reflects the variation in deformation processes that resulted in the along strike variations in the Andes.

POSTER 129

A Surface-in-cell Approach to Including Evolving Faults in Geodynamic Models

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Faults play a major role in the dynamic evolution of the crust and mantle. They focus deformation at a spatial and temporal scale that is significantly finer than the large-scale tectonic timescale and it is usually necessary to have a distinct numerical strategy to include them in a geodynamic model.

A classical strategy is to create a mesh that respects the fault locations and attribute fault properties (or additional degrees of freedom) to the nodes or edges of the mesh that lie on the fault. This approach has a high setup cost but it provides accurate and efficient solutions.

When faults evolve their shape or position time (for example a plate-boundary in a global convection model), a fault-conforming mesh can be overly expensive to compute.

We examine some simple alternatives to remeshing of the faults and compare their ability to accurately represent fault behaviour in large-scale models. Our preferred model is one in which fault-segments are treated as unique, triangulated surfaces which map information to their embedding mesh such as perpendicular distance, surface normal, material properties, history variables. The surfaces move through the mesh in a manner comparable to the particles of a particle-in-cell method. The properties on the mesh are smoothed, but the smoothing is not cumulative as the fault moves. The mesh can be adaptively refined close to the fault but there is no requirement for the fault surfaces / edges to be included in the mesh.

We will show benchmarks comparing this approach with fault-conforming meshes and applications to tectonic deformation and fluid flow problems.

POSTER 130

Low Frequency Earthquakes in the Alaska Subduction Zone

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The Alaska, Cascadia, and Southern Chile subduction zones share several key features including Low-Frequency Earthquakes (LFEs) which occur along the subduction interface and provide important information on local slip. We analyzed publicly available seismic records from Alaska between 2013 and 2018 to identify repeating seismic signatures during tremor-active periods, allowing us to construct LFE templates (stacks of multiple events from the same region which improve the signal-to-noise ratio). In total, we added 45 new templates to the six previously published for the region (Chuang et al., 2017). The new templates are distributed throughout most of the previously defined tremorgenic zone (Wech, 2016) and cover a larger area than previous LFE catalogs for the Alaska subduction zone. Owing to stacking, several P- and S-wave arrivals are clearly observable above the noise level significantly improving hypocentral constraints. Estimated depths range from 35 to 50 km, with location uncertainties of 0.4–2.1 km horizontally and 0.8–3.3 km vertically.

We applied a novel technique that incorporates S-wave polarization directions to better constrain the focal mechanisms of these events. Preliminary results provide new insights into the regional tectonic deformation, particularly in the complex corner where double-verging subduction has been proposed. Our observations indicate that the deformation cannot be explained by a single process. Instead, we identify: (1) thrust events aligned with the NW-dipping Alaska subduction zone; and (2) events that could differ from expected NE thrust along the eastern edge of the tremor-genic zone. Overall, this work advances understanding of slow-slip processes in Alaska and their role in accommodating the complex subduction geometry. These findings may also have important implications for similar geometries along the margins of the Cascadia and Southern Chile subduction zones.

POSTER 131

Forearc Seismic Structure at the Alaska Peninsula Revealed From AACSE Receiver Functions

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The Alaska Amphibious Community Seismic Experiment (AACSE) deployed 75 ocean-bottom seismometers (OBS) and 30 land stations across a 700 km × 250 km region along the Alaska Peninsula portion of the Alaska-Aleutian subduction zone. Including permanent seismic networks, over 130 stations are available for analysis. This region encompasses the Shumagin, Semidi, and Kodiak segments, defined by their along-strike variability in coupling, seismicity, and megathrust rupture, as well as a history of terrane accretion in the overriding North American plate, and uneven plate fabric orientation on the incoming Pacific plate. Here, we use receiver function (RF) analysis of teleseismic earthquakes to provide novel constraints on the seismic velocity structure of the subducting plate, overriding plate, and plate interface offshore.

We calculate RFs for 141 teleseismic events ($M \geq 6.0$, distance 30° – 100°) using time-domain iterative deconvolution. We visually identify arrivals that are likely due to either the overriding or subducting plate Moho, or plate interface based on comparisons of their arrival times to expectations from regional models. Furthermore, similarity of RFs between proximal stations supports interpretations that these arrivals indicate crustal structure, even in traditionally noisy offshore areas. A primary challenge for OBS-derived RFs is contamination by complex reverberations from the water column and sediment layers. Our study area ranges from sites near the trench with varying thickness of unconsolidated sediment atop basement crust, to the forearc shelf composed of thicker accreted material that has more gradational increases in velocity with depth, spanning depths from ~100–5000 m. Understanding the effects of these varying site structures on RFs still is relatively underexplored. Thus, we investigate the predicted reverberations of these expected structures, and explore the reverberation waveform inversion method of Kim et al. (2024) to mitigate these effects, and recover the underlying crustal signal. We expect this approach to yield new, high-resolution constraints on the forearc seismic structure.

POSTER 132

Revisiting the Tectonic Geomorphology of the Nicaragua Segment of the Middle America Trench Using Newly Collected High-resolution Bathymetry and Reprocessed Marine Seismic Reflection Data

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The Nicaragua segment of the Middle America Trench hosted a devastating tsunami earthquake in 1992, but land-based geodetic studies have not identified an associated locked patch along the megathrust. Because modeled slip varies across studies, understanding fault geometries near the trench and their lateral continuity can add important context to understanding tsunami generation at the margin. Here, we present tectonic and geomorphic analysis of new high-resolution bathymetric data collected in 2025 aboard the R/V *Atlantis*. Combined with reprocessed multichannel seismic reflection data collected in 2000 aboard the R/V *Ewing*, these data allow us to better constrain lateral continuity of structural features. Using a high-pass spatial filter on the bathymetry, we identify a change in the wavelength of structures from the lower to mid slope and correlate these geomorphic structures with their subsurface expressions along strike. The lower slope structure is comprised of laterally continuous slope and bench pairs, that appear to mimic the incoming plate structure. The upper and mid slopes are characterized by shorter wavelength structures that appear less laterally continuous and are likely related to overriding plate structures. Understanding the lateral continuity of these subsurface features is an important step toward understanding the seismic and tsunami hazard along this margin, and it will provide important context for seafloor geodetic observations currently being collected in this region.

POSTER 133

Crustal Stress and Faulting in the Pacific Northwest: Insights From an Updated Focal Mechanism Catalog

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Characterizing seismic hazard in the Pacific Northwest (PNW) is complicated by a lack of observed moderate magnitude seismicity. This makes it difficult to understand the relationship between mapped crustal faults and the present-day stress field. To address this, we use deep-learning-derived first-motion polarities and S/P amplitude ratios to build an updated catalog of over 10,000 high-quality focal mechanisms from regional microearthquakes. This catalog, spanning Washington, Oregon, and southern British Columbia, reveals several distinct tectonic domains with diverse faulting styles. We use these mechanisms to invert for regional stress orientation, developing high-resolution maps of the crustal stress field along the Cascadia margin. These new maps align with sparse stress observations and GPS-derived strain fields from previous studies. They demonstrate that transpression, characterized by abundant reverse and strike-slip faulting, dominates the stress field in the North American crust. Although the maximum compressive stress is generally oriented north-south, local variability suggests complex interactions between crustal blocks along known structures, such as the southern Whidbey Island fault in Washington State. Finally, comparisons between the focal-mechanism-derived stress and GPS-derived strain fields indicate that locking of the Cascadia subduction zone exerts little influence on contemporary crustal seismicity. These findings clarify how mapped crustal faults accommodate tectonic deformation and provide new insights into the interplay between PNW crustal faults and the Cascadia subduction zone, which is critical for understanding regional seismic hazard.

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The Cascadia Offshore Subduction Zone Observatory Infrastructure Project

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This summer, the Cascadia Offshore Subduction Zone Observatory (COSZO), an NSF-funded infrastructure project, will add seismic and geodetic instruments to the Ocean Observatories Initiative (OOI) Regional Cabled Array (RCA) off Newport, Oregon. In Cascadia, geophysical observations show that the megathrust is mostly locked from the coastline to the deformation front, but off central Oregon they are consistent with a locked megathrust near the deformation front that transitions to creeping behavior beneath the shelf where there are two sustained clusters of earthquakes. We are constructing new science junction boxes, with updates to the RCA design, to connect to three primary nodes on the continental slope and shelf that currently do not support seafloor geophysical observations. At each new junction box and a fourth site on the shelf, we will install a Nanometrics Atlantis Cabled Observatory ocean bottom seismic package comprising a buried broadband seismometer, a strong-motion accelerometer, a low-frequency hydrophone, and a differential pressure gauge. We are building two types of calibrated absolute pressure gauges that utilize Paroscientific resonant quartz crystal sensors. The Geodetic and Seismic Sensor Module combines a triaxial accelerometer with two pressure gauges that are periodically calibrated against the internal pressure of the housing measured by a barometer. The Self-Calibrating Pressure Recorder also includes two pressure gauges but performs calibrations with a reference pressure close to ambient generated by a piston gauge. COSZO will also include uncalibrated absolute pressure gauges, Nortek Vector 3-component

ocean current meters, and open ports for more sensors. Together with sensors already on the OOI RCA at the Slope Base and Hydrate Ridge sites, the infrastructure will enable studies of fault coupling and deformation of the Cascadia megathrust and the overlying accretionary prism and support efforts to prototype offshore earthquake and tsunami early warning. COSZO will stream data into EarthScope Data Services and a workshop is planned for spring 2027 to engage early career scientists.

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Monitoring Seafloor Deformation in Taiwan via Ocean-bottom Geodetic Instrumentation

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Taiwan is situated at the complex junction of the Ryukyu and Manila subduction zones, where intense seismic activity is driven by rapid plate convergence. Based on regional geodetic data and tectonic models, the convergence rate along the southern Ryukyu margin exhibits a significant eastward increase, from 92 mm/yr offshore Hualien to 123 mm/yr near the Gagua Ridge, suggesting a high potential for M_w 7.5–8.4 earthquakes. To directly monitor these offshore processes and quantify long-term strain accumulation, we established a GNSS-Acoustic (GNSS-A) network, including six sites along the southern Ryukyu subduction zone. During this continuous monitoring period, the 2024 M_w 7.3 Hualien earthquake occurred, providing a rare opportunity to capture seafloor coseismic signals. At site ORY2, located 40 km east of the epicenter, we recorded a significant coseismic uplift of 52.9 ± 13.5 cm. These observations align with coseismic dislocation modeling and underscore the vital role of offshore fault systems in regional strain release. Furthermore, our long-term monitoring identified multiple slow slip events (SSEs) that preceded the 2024 Hualien earthquake, suggesting a potential mechanical link between transient slip and major rupture initiation.

Offshore southern Taiwan, where three additional GNSS-A sites were established near the northern tip of the Manila Trench, the geodetic data reveal N-S-oriented extension in the Tainan Basin and NE-SW extension between the Manila Trench and the North Luzon Trough. We also observe a distinct shift in deformation patterns across the continent-ocean boundary near 20°N. By integrating these seafloor observations with terrestrial geodesy, this research provides new insights into fault segmentation and plate boundary processes in the Western Pacific. Our results demonstrate that sustained ocean-bottom instrumentation is indispensable for accurately characterizing subduction dynamics and assessing regional seismic and associated hazards.

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Using Seafloor Geodesy to Constrain Gorda Plate Kinematics and Shallow Megathrust Locking in Southern Cascadia

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Uncertainty regarding the kinematics of the Gorda oceanic plate limits our understanding of regional tectonics and our ability to estimate the earthquake and tsunami hazard along the southern Cascadia subduction zone. Here we describe ongoing efforts to constrain plate motions, rates of convergence, and shallow strain accumulation across the southern Cascadia subduction zone using an array of four GNSS-Acoustic sites surveyed since 2022. Three sites are located on the North American plate along the deformation front between 42.2°N and 41°N, and one site is located on the Gorda plate. All sites were surveyed with a GNSS-Acoustic equipped Wave Glider. Three of the four sites have enough data to resolve preliminary velocities, including site GCC1 on the Gorda plate. Comparison of our measured velocity at GCC1 to that estimated based on the MORVEL 2010 plate model shows that the observed GCC1 velocity is ~10 mm/yr slower than expected. We are using finite element modeling to explore implications of this slower than expected Gorda plate velocity for regional tectonics and shallow megathrust locking.

Subduction, Faulting and Earthquake Interaction Across the Cook Strait of New Zealand
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The Southern Hikurangi Subduction margin in New Zealand intersects the Cook Strait and the surrounding Wellington and Marlborough regions. Together, these regions form a tectonically diverse and active part of New Zealand monitored by a relatively dense seismic network. The study area has hosted several large earthquakes in recorded history and acted as the termination of the 2016 Kaikoura earthquake. Despite these earthquakes and the availability of good long-duration seismic data, there remains significant uncertainty in our understanding of the drivers of seismicity in the region, in particular, the mechanisms of earthquake triggering and nucleation. Studies in other regions around the world have shown that small, previously undetected earthquakes can provide key insights into understanding fault geometry at depth, foreshock and swarm processes as well as triggering and earthquake nucleation.

We have extended a nationwide machine learning earthquake catalogue to detect and locate earthquakes in the Southern Hikurangi Margin between 2011 and 2018. Our catalogue contains 69,152 earthquakes, 32,620 of these being newly detected events, as well as high quality locations with reduced uncertainties and an improved magnitude of completeness. Our self-consistent cataloguing methods allow us to investigate spatial and temporal variability in earthquake occurrence in the region. We first present the key structural features illuminated by this catalogue including subduction interface geometry, upper plate faulting and the presence of a double Wadatti-Benioff Zone. We then investigate fault reactivation between the 2013 Cook Strait and 2016 Kaikoura Sequences, as well as other key temporal features of seismicity. Finally, we discuss the results of our dynamic triggering study in the region, identifying triggering from local, national and global events and the discussing implications this has on the temporal variations in seismicity.

Seismic Patterns of the Luzon Arc South of Taiwan
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Arc-continent collision is an important tectonic process along convergent margins, yet how crustal deformation and seismogenic structures evolve from intra-oceanic subduction through an incipient transition to mature collision remains incompletely resolved. We use the Luzon Arc south of Taiwan as a natural along-strike that spans (from south to north) an active subduction domain, a transition zone, and the northern arc-continent collision zone. We analyze continuous waveforms from seven onshore stations and nineteen ocean-bottom seismometers (OBS) deployed for three years (2007–2009), totaling 36,180 waveforms. We apply machine-learning phase detection followed by stacking-migration event localization, using the regional 1D velocity model of Huang et al. (2014). It yields 4,855 well-located events—more than the 381 events reported for the offshore and period in the standard local catalog—substantially improving offshore-to-onshore seismicity continuity. Then, we integrate the very preliminary relocated seismicity with bathymetry, Bouguer gravity, and magnetic anomaly maps to relate earthquake distributions to along-arc structural segmentation. In the southern subduction domain, seismicity tracks a N–S-trending arc expressed by NE–SW en échelon bathymetric lineaments. North of 20.71°N, this pattern terminates within the transition zone, where the arc narrows and shifts to an overall NW–SE trend; seismicity there is comparatively sparse during the deployment, consistent with spatially localized and possible rapidly varying slab-related processes. In the collision domain, where the arc impinges on the Eurasian continental shelf, we identify a NW–SE-trending crustal-scale structure extending at least ~100 km from the transition into the collision zone, coincident with gravity and magnetic anomalies, and with seismicity suggestive of conjugate faulting. Our preliminary results demonstrate that integrating OBS observations with modern detection and location methods can help to resolve along-strike changes in seismogenic architecture of the arc across the subduction-to-collision transition south of Taiwan.

Ensemble Analysis of Large Megathrust Earthquakes: From Rupture Heterogeneity to Stress Changes and Ground Motion
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Inferences about offshore megathrust earthquake processes are notoriously uncertain and sensitive to data choices and ad hoc regularization schemes, hampering quantitative interpretation. Here, we characterize the similarities and differences between several large earthquake models derived from unregularized Bayesian kinematic inference methods, including the 2011 M9.0 Tohoku, 2014 M8.1 Iquique, 2015 M8.3 Illapel, 2016 M7.8 Pedernales, and 2015 M7.8 Gorkha. Through finite-fault models derived from joint datasets and consistent inversion schemes, we assess relationships between kinematic rupture parameters, including slip, rupture speed, rise time, and average slip rate, locally and within and across events. We use posterior model ensembles to compute static surface deformation and on-fault stress changes, dynamic ground motion, and their spatiotemporal covariances. For posteriors, patch-level correlations are robust across some parameters, given expected trade-offs, but intra-event correlations between most parameters are variable across events. The discrepancies with theoretical predictions imply limitations in adopted physics and/or inversion approaches for heterogeneous rupture scenarios. Our analysis reveals characteristic deformation and stress change patterns over the megathrust, with uncertainty influenced by station coverage, fault slip patterns, and data-model error structure. Despite significant spatial variability in source properties, the static elastic strain drop is tightly constrained to ~100–300 microstrain, while the static stress drop spans ~5–25 MPa. Predicted peak ground displacements (PGD) exhibit near-field discrepancies with empirical scaling laws due to finite-source and directivity effects. Our findings inform physics-based earthquake modeling and improve quantification of rupture complexity and hazard impacts.

Mechanisms and Seismogenic Structure for Large Continental Earthquakes

Oral Session • Thursday 16 April • 8:00 AM Local
Conveners: Qinghui Cui, China Earthquake Administration (qhcu@ief.ac.cn); Yuanyuan Fu, China Earthquake Administration (fuyuanies@163.com); Guohui Li, China Earthquake Administration (lgh@ief.ac.cn); Zhigang Shao, China Earthquake Administration (shaozg@seis.ac.cn); Lingling Ye, Southern University of Science and Technology (yell@sustech.edu.cn)

Progressive Eastward Rupture of the Main Marmara Fault Toward Istanbul
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The Main Marmara fault (MMF) in northwestern Türkiye poses the highest seismic risk in broader Europe. The 2025 MW 6.2 was the largest earthquake along the MMF in >60 years. We integrated observations from multiple temporal scales including the decade-long evolution of M > 5 earthquakes, their rupture dynamics and aftershock patterns. We show a series of eastward propagating M>5 events and a gradual eastward partial rupture of the MMF over the last ~15 years. The seismically active portion of the fault includes creeping and transitional segments with some of the most recent seismicity

located near the presumably locked Princes Islands segment south of Istanbul that has the potential to generate a M~7 earthquake. Our analysis highlights the necessity of real-time monitoring of this part of the MMF.

Hierarchical Architecture of the 2025 Mw7.1 Dingri, Southern Tibet Normal Earthquake

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We present rapid and dense observations of the 2025 Mw7.1 Dingri normal earthquake sequence in southern Tibet. By applying machine-learning techniques to dense seismic array data around the epicenter, we constructed a high-resolution aftershock catalog with ~137k relocated aftershocks. We then obtained well-resolved focal solutions of ~350 M_L>=2.5 aftershocks using the P wave first motion polarity measurements. Together with 3D fault model construction, surface displacement measurements, we reported a strong spatial correlation between the shallow dipping angle of the main fault plane, surface deformation pattern and lithology. Relatively low dipping angles were observed around the Dingmucuo Lake, with widespread distribution of lacustrine sedimentary rocks, accompanying low shallow aftershock density and broad diffusive deformation zone. To the contrary, high dipping angles were associated with Laguigangri metamorphic core complexes, together with high aftershock density and large vertical offsets. 3D fault model further illuminates hierarchical fault geometry around the mainshock epicenter, with both east-dipping and west-dipping faults. We suggest that the mainshock rupture initiated where fault exhibits strong complexity and favors stress concentration. Resolved focal solutions indicate an increasing fraction of strike-slip component with depth. We suggest that such strain-partition scenario might reflect considerable amount of strike-slip stress condition resulted from the slab tear in the Indian lithosphere.

Seismic Reflection Imaging of the Source Zone of the 2024 Mw4.8 Tewksbury, New Jersey, Earthquake, and the Relation of Eastern U.S. Seismicity to Crustal Structure
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The 2024 Tewksbury, New Jersey, M_w4.8 earthquake was one of the most widely felt earthquakes in eastern U.S. history because of its proximity to major urban areas like New York City, Newark, and Philadelphia. The earthquake occurred near the southern limit of the northeast-southwest trending Ramapo seismic zone, which lies just west of the Ramapo fault that forms the western border of the Mesozoic Newark rift basin. Here we present a reprocessed seismic reflection profile, acquired in 1984, that images the source zone for the 2024 earthquake sequence. The profile was collected in a southeast-northwest orientation approximately perpendicular to geologic strike and above the 2024 earthquake and its aftershocks. Strata in the Newark basin are imaged as a series of gently dipping and deformed reflectors, with the bottom of the rift basin being imaged as discontinuous reflectors dipping about 25° to 30° to the southeast. Below the basin are strong, southeast-dipping reflectors with about the same dip, originating from the downdip portions of the strata and thrust faults exposed west of the basin. The aftershocks appear to be almost entirely within the allochthonous thrust sheets beneath the Newark basin. The aftershocks form a plane that cuts across the thrust fault reflectors, suggesting that the earthquake occurred on a younger fault formed since the Mesozoic. The earthquake sequence and the other earthquakes in the Ramapo seismic zone are located where the thrust faults deepen eastward and where footwall uplift presumably occurred in the Mesozoic in response to basin downdrop. The area is geologically on strike with the central Virginia seismic zone to the southwest, which exhibits similar relations between seismicity, crustal structure and Moho depth. This area correlates with the Appalachian Gravity Gradient and points to a zone of earthquakes resulting from stress concentration coincident with changes in crustal thickness and structure at the buried Laurentian rift margin.

Why Do Large Earthquakes Occur in the New Madrid Seismic Zone, Central United States?
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A comprehensive seismotectonic model for the New Madrid seismic zone (NMSZ) addresses why large earthquakes occur in this midcontinent setting. At least three >7M earthquakes occurred in 1811-1812 and paleoseismology evidence indicates several large earthquakes occurred over the last ~4000 years. NMSZ faults in the Mississippi Valley graben (MVG) are part of a broader, northeast trending system of strike-slip basement faults. The northwest trending Reelfoot fault occurs within an axial ring dike intrusion, necessitating reverse faulting. Ongoing strain accumulation in the NMSZ is driven by perturbations to a low viscosity upper mantle below the MVG produced by heat and metasomatizing fluids emanating from a thick segment of the Farallon slab located in the mantle transition zone. A similar situation exists for the North China Craton where the lithosphere is undergoing thermochemical erosion by fluids released by the Pacific flat slab. The NMSZ is covered by hundreds of meters of unconsolidated sediments in the Mississippi Embayment, but potential field studies reveal the presence of the MVG and intrusions that influence earthquake locations. Seismic reflection studies indicate the presence of numerous northeast trending, near-vertical faults in the crust. A new set of focal mechanisms reveals that strike-slip faulting is as prevalent as reverse faulting on the Reelfoot fault. Significant strike-slip motion may occur on the Reelfoot fault during large earthquakes, explaining the lack of expected topography due to reverse faulting. The portion of the flat Farallon slab below the MVG contains the Hess plateau. Metasomatizing fluids emanating from the plateau rise below the thinned Embayment lithosphere markedly reduce mantle strength below the NMSZ. The presence of a low strength region lends strong support to previously proposed models for the NMSZ that account for the generation of repeated large earthquakes and small surface strain rates. An implication of the model is that large earthquakes will continue to occur in the NMSZ.

A Tale of Three Events: Systematic Comparison of Mainshock Rupture Properties, Sequence Behaviors and Fault Zone Structures for Recent Major Continental Earthquake Sequences
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Continental earthquakes occur within continents, rupturing along shallow crustal faults that are either located at major plate boundaries or within a plate. They can be especially damaging when occurring beneath populated land areas. Several major continental earthquakes have struck at different tectonic regions since 2023, including the 2023 M7.8/7.6 Kahramanmaraş, Turkey doublet, the 2024 M7.5 Noto Peninsula, Japan earthquake and the 2025 M7.7 Sagaing Fault, Myanmar earthquake. Each event involved ruptures of hundreds of kilometers of crustal faults, and are followed by numerous aftershocks and remotely triggered seismicity. Yet they also behaved quite differently in terms of their rupture speeds, foreshock activities, aftershock productivities, and their relationships with fault zone properties and deep fluid movements and deep Earth structures. In this presentation, we attempt to compare these events and try to identify similarities and differences among them. We find that: 1) while their foreshock sequences behave quite differently, each mainshock appears to initiate at either a branching fault or a subsidiary segment before jumping onto the main fault; 2) there is a general anti-correlation between mainshock slip patches and aftershock locations, and regions with supershear ruptures appear to have delayed and deficient aftershock activities; 3) 3D fault geometry and crustal structures control the mainshock rupture process, including breaking of asperities and the occurrence of sub- vs supershear rupture speeds; 4) deep crustal and upper mantle structures likely control the tectonic loading of the upper crustal faults and hence the general locations of future large earthquakes. Updated results will be presented at the meeting.

Mechanisms and Seismogenic Structure for Large Continental Earthquakes [Poster]

Poster Session • Thursday 16 April

Conveners: Qinghui Cui, China Earthquake Administration (qhcai@ief.ac.cn); Yuanyuan Fu, China Earthquake Administration (fuyuanies@163.com); Guohui Li, China Earthquake Administration (lgh@ief.ac.cn); Zhigang Shao, China Earthquake Administration (shaozg@seis.ac.cn); Lingling Ye, Southern University of Science and Technology (yell@sustech.edu.cn)

POSTER 154
An Evaluation of Factors that Influence Earthquake Event Magnitudes
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Earthquake magnitudes are almost always an average of magnitudes calculated at many stations. How these magnitudes should be calculated at individual stations is not the focus of this presentation. There is a significant body of literature on this topic. There is considerably less on how magnitudes calculated at individual stations should be treated and combined to determine the earthquake magnitude. This research explores many aspects of how handling and combing individual station magnitudes affects the final event magnitude. Factors considered include precision, how average is defined, site corrections and azimuthal and regional effects. Earthquakes recorded in eastern Canada from 2006 through 2025 were analyzed. The dataset was restricted to earthquakes with magnitudes calculated at five or more stations for most analyses and ten or more for azimuthal effects. It was found that how average is defined has very little effect on the final magnitude. The precision to which amplitudes were measured and magnitudes calculated did not effect the outcome. The effect of including site corrections in this region is small as considerable effort was made to situate stations on bedrock. Site corrections, however, had a greater impact than all other factors studied. Averaging the data over azimuthal windows rather than treating all station magnitudes equally was less significant than site corrections but somewhat more than the other factors explored. Most of the azimuthal effects, however, could be attributed to site responses. Correcting for site response and then azimuthally averaging appears to overcorrect the data. Applying regionally appropriate attenuation relations reduced the uncertainty but did not have a significant impact on the event magnitude for the events analyzed. The effect could be greater for small events where all recording stations are within a single region with significantly different attenuation from adjacent regions. Although the study focused on eastern Canada, the results should be broadly applicable elsewhere with some factors exhibiting greater regional variations than others.

POSTER 155
The Stagnant Pacific Slab in the Lower Mantle Transition Zone Beneath Northeast Asia Continental Margin and Large Deep Outboard Earthquakes
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The mantle transition zone (MTZ), bounded by the 410-km and 660-km discontinuities (410 and 660), is crucial for understanding the material and energy exchange between the upper and lower mantle. The MTZ plays an important role in the global material circulation, slab dynamics, and seismogenesis of deep earthquakes in subduction zones. Here we construct fine MTZ structures of both P and SH waves beneath the northeast Asia continental margin using improved grid-search waveform modelings, based on high-quality triplicated waveforms of three deep Kuril earthquakes recorded by the China Digital Seismograph Network (CDSN). We find a high-velocity anomaly (HVA, average 3.3% δV_p and 2.3% δV_s) with a thickness of 130-138 km in the lower MTZ. The HVA hosts a top interface with positive velocity contrasts (δV_p : 4.3%, δV_s :3.2%), while the 660-km discontinuity (660) shows reduced velocity contrasts (δV_p : 3.6%, δV_s : 5.1%) and negligible depressions of less than 10 km. The HVA we detected likely implies the thickened stagnant Pacific slab that may alter localized heat exchanges

between the MTZ and lower mantle. The increased V_p/V_s ratio (~1.85) indicates a water-rich state (~0.42 wt%) inside the stagnant slab, evidencing the deep water transportation by the slab subduction. We infer that the interior localized dehydration of hydrous minerals within the stagnant slab may trigger the large outboard 1990 M_w 7.2 Sakhalin (Kuye) earthquake. Our results can provide more insight into slab dynamics and seismogenesis of deep earthquakes in northeast Asia.

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POSTER 156
Slab Morphology Change and Subduction-zone Dynamics Beneath the Kuril-Kamchatka From Topographies of the 410-Km and 660-Km Discontinuities
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The mantle transition zone (MTZ), bounded by transition zone discontinuities such as 410-km and 660-km discontinuities (410 and 660) generally accepted as the olivine-associated phase transformations, plays an important role in global material circulations and slab behaviors in subduction zones.

Here we collect near-source SdP waves using several dense seismic networks and image the topography of the 660 around the Pacific slab beneath the Kuril-Kamchatka. The 660 exhibits broad depressions up to 32–63 km with apparent downward deflections beneath the Kamchatka Peninsula and northern Kuril (region I), supporting slab penetration into the lower mantle; in contrast, the 660 depressions beneath southern Kuril (region II) are less than 21–28 km with a relatively flat configuration, implying a stagnating slab with possible hot entrained mantle materials and/or partial melts below it. We interpret these regional variations in the 660 topography as reflecting local low-temperature anomalies due to different slab morphologies associated with contrasting subduction modes. We suggest compound effects of pressure-driven mantle flow and trench retreat for inducing the inferred subduction mode change of the Pacific slab from region I to region II.

Then, we also further image the 410 and 660 beneath the Kamchatka using more dataset. We confirm a thickened MTZ with a thickness of 325–345 km around the cold descending Pacific slab. The 410 exhibits apparent uplifts of 45–65 km with an average of 55 km in a horizontal width of ~130 km. In contrast, the 660 shows depressions of 15–37 km with an average of 25 km. The topographic patterns may imply a Pacific slab significantly heated in the MTZ. We infer that the slab is possibly heated by hot mantle flows around the torn slab window extended to at least the MTZ range.

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POSTER 157
Earthquake Nucleation Along Paleotectonic Weak Zones in Stable Intraplate Regions
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Earthquakes in stable intraplate regions pose significant seismic hazards because they can occur close to populated areas, despite their generally low seismicity. Large intraplate earthquakes typically have long recurrence intervals, making it difficult to identify potential source regions in advance. Understanding the mechanisms of earthquake nucleation is therefore essential for seismic hazard assessment in low-seismicity regions. Historical earthquakes may provide important constraints. We present the source properties of the largest instrumentally recorded earthquake (magnitude ~6.3) on the Korean Peninsula that occurred in December 1952 in the southwestern suburban area of Pyongyang, North Korea. The event is identified as a normal-faulting earthquake with a moment magnitude of M_w 6.3 and a focal depth of approximately 28 km. The source region is located along the eastern margin of the paleo-collision zone between the North China and South China blocks, where crustal-scale inherited seismogenic structures are inferred. We find seismicity associated with other paleotectonic structures across the Korean Peninsula. Persistent seismic activity is observed within reactivated paleo-rift structures in the East Sea (Sea of Japan). The systematic lateral variation in

focal depths suggest ongoing neotectonic thrust development across inherited rift-related structures. Also, the 14 December 2021 M_w 4.9 Jeju offshore earthquake ruptured an aseismic paleovolcanic structure that responded sensitively to regional stress changes and crustal heterogeneity. This mid-crustal event generated strong ground motions and local stress perturbations. These observations indicate that paleotectonic inheritance exerts a first-order control on earthquake nucleation in intraplate regions. We suggest that systematic monitoring and characterization of seismicity associated with paleotectonic structures are critical for assessing the potential for future large intraplate earthquakes. This study provides seismic evidence for preferential earthquake nucleation along inherited tectonic structures surrounding the Korean Peninsula.

POSTER 158
Unveiling the Pre-rupture Seismicity of the 2022 Ferndale Fault: A 15-year Template Matching Analysis
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The 20 December 2022 M_w 6.4 Ferndale earthquake highlighted the significant seismic hazard posed by intraslab faults within the subducting Gorda Plate, near the complex Mendocino Triple Junction (MTJ). While the mainshock occurred on a distinct strike-slip structure, this fault was largely unrecognizable in standard earthquake catalogs prior to the rupture. The Gorda Plate in this region is severely internally deformed, creating a chaotic background of seismicity that often obscures individual fault planes. This raises a critical question regarding the pre-rupture phase of this fault: Was it completely locked and aseismic for decades, or did it host low-magnitude microseismicity that went undetected by routine network monitoring?

In this study, we reconstruct the seismicity history of the Ferndale source zone for approximately 15 years prior to the mainshock (2008–2022). We leverage a high-resolution catalog of aftershocks from Yoon and Shelly (2024), originally detected using machine learning algorithms. To optimize detection sensitivity, we apply hierarchical clustering algorithms to the aftershock waveforms, identifying families of highly similar events (multiplets). From each cluster, we select representative “master templates” with high signal-to-noise ratios. These high-quality templates are used in a matched-filter (template matching) cross-correlation search against continuous seismic data to recover missing micro-earthquakes hidden in the noise.

Following detection, we employ precise double-difference relative relocation methods to sharpen the spatial resolution of the pre-mainshock seismicity. We analyze the resulting catalog for fine-scale spatio-temporal patterns, specifically searching for linear alignments (“streaks”) that may indicate rheological boundaries or creeping sections, as well as seismic gaps that may delineate the locked asperities responsible for the 2022 nucleation. By characterizing the architecture of this hidden fault zone prior to its failure, this study provides critical constraints on stress accumulation and fault segmentation within the deforming Gorda Plate.

POSTER 159
Corrosion of Rupture Barriers Through Rock Damage Induced by Aftershocks
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Rock damage represents degradation of material integrity through the creation and coalescence of micro-fractures, which significantly alter the mechanical properties and stress distribution within the Earth’s crust. Earthquake-induced damage leads to regional rock weakening, facilitating the occurrence of moderate and large ruptures by reducing the fracture toughness in connected fault zone regions. This study focuses on “doublet earthquakes”, where a moderate or large earthquake is followed by a subsequent large event, such as the 2019 M_w 6.4 and M_w 7.1 Ridgecrest and 1992 Joshua Tree-Landers earthquakes in California, and the 1999 $M > 7$ Izmit-Düzce and 2023 $MW > 7.5$ earthquakes in Turkey. We consider several such pairs and estimate the rock damage evolution by converting earthquake catalog data to fracture volume using scaling relations from seismology and fracture mechanics. We examine how the evolving seismicity and rock damage corrode structural barriers that stop the first earthquake in a pair, overcoming geometric/mechanical obstacles, and facilitate the occurrence of the second event. We perform a quantitative analysis of the spatio-temporal connectivity of the evolving damage zones, using several geometric and statistical seismology parameters, with special attention to rock volumes around fault junctions. Our current findings indicate that the generation of damage across major geometrical irregularities such as orthogonal faults and the total area of interconnected damage are important factors in

the preparation process leading to the subsequent large event. Updated results will be presented in the meeting.

POSTER 160
Microseismicity and Upper-crustal Anisotropy in the Southern Sichuan-Yunnan Block, SE Tibetan Plateau
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The southern Sichuan-Yunnan block at the intersection of the Honghe faults (HHF) and the Xiaojiang faults (XJF) is of complex tectonics and pronounced crustal anisotropy. With machine-learning technique in waveforms analysis to a dense temporary array and permanent stations around, we investigate spatial fine-scale variations in upper-crustal anisotropy and microseismicity. The distribution of microearthquakes coincides with crustal velocity gradients, effectively delineating strain zones. S-wave splitting reveals structurally controlled anisotropy in the upper crust. Within the Yimen region, where microseismicity is particularly intense, *dual* fast directions and large time-delays indicate a broad heterogeneous crustal deformation zone. The spatial correlation between seismic anisotropy and strong microseismicity highlights seismogenesis controlled by heterogeneous structures and localized stress. Notably, the middle segment of the HHF shows consistent anisotropy, low delay times, and an isolated steeply-dipping earthquake swarm, attributed to joint sinistral strike-slip and compressional movement. Significant contrasts in anisotropy between the upper crust and the whole crust across the block boundary faults seems to be related to the inner-intermediate zone boundary of the Emeishan large igneous province (LIP). Fine-scale crustal anisotropy illuminated by microseismicity could provide critical information to the tectonic preparation background of large continental earthquakes [supported by NSFC Projects 42494863 & 42330311].

POSTER 161
Advancing Earthquake Catalog Completeness and Slab Imaging in Hispaniola Using Deep-learning Phase Pickers and Fine-Tuned Machine-learning Workflows
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Hispaniola is located along the complex boundary between the North American (NOAM) and Caribbean plates, where subduction, collision, and strike-slip processes generate high rates of microseismicity as well as destructive earthquakes ($M > 7.0$) that have struck the island over the past centuries. Existing local seismic networks have limited access to real-time station data, which restricts catalog completeness and resolution to resolve subducting slab geometries and limits seismic hazard assessment. To address these limitations, we applied three deep-learning pickers (EQTransformer, GPD, and PhaseNet) to continuous data recorded by multiple seismic networks in the region from 2013 to 2023. After phase association using PyOcto, absolute event location with Hypoinverse, and applying cutoff filters to reduce poorly located events, the resulting picker-specific catalogs were merged into an aggregated catalog containing over 190,000 earthquakes. After clipping to the study region and comparing with local Dominican Republic (DR) network catalogs, the aggregated catalog contains nearly three times more earthquakes while showing strong agreement in event location and phase picking with the network catalogs.

Double-difference relocations using HypoDD further refined event locations and enabled high-resolution imaging of slab-scale seismicity. The results suggest that the NOAM slab extends farther west toward the Haiti–Dominican Republic border than indicated by previous tectonic models and support a collision zone between the south-dipping NOAM slab and the north-dipping Caribbean slab beneath the Mona Passage. To overcome the limitation of using pre-trained models, we are fine-tuning these pickers using manually reviewed seismic phases from DR networks. Initial PhaseNet results show a doubling of P-phase recall and more than a fourfold increase in S-phase recall, along with improved picking accuracy, even when using only a subset of the training data. These results demonstrate the effectiveness of

machine-learning workflows for improving our understanding of complex tectonic regions such as Hispaniola.

POSTER 162

Assessing the Sensitivity of Recurrence Parameters to Completeness Choices

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The determination of the completeness period of a seismic catalog is a key factor in estimating recurrence parameters and, consequently, in the derivation of annual frequency curves used in probabilistic seismic hazard analysis (PSHA). Nonetheless, no consensus exists on how completeness should be defined or applied, resulting in substantial methodological differences across models. In Peru, Roncal (2017) employs a uniform completeness period for the entire catalog, applying identical temporal thresholds to interface, intraslab, and crustal events. While this simplifies the workflow, it risks introducing biases by overlooking variations in detectability and recording conditions across tectonic environments. In contrast, Aguilar and Tarazona (2024) adopt a tectonic setting–specific completeness scheme, adjusting completeness years by magnitude ranges and focal mechanisms. This methodology yields a more realistic representation of seismicity and reduces the likelihood of underestimating or overestimating recurrence rates. Pagani et al. (2020) assign distinct completeness periods to each seismic source, guided by tectonic segmentation and the varying quality of local records.

The choice of completeness criterion directly affects the Gutenberg–Richter parameters (a and b), which influence annual exceedance rates and hazard maps. Models based on a single completeness period may oversmooth regional variations, underestimating hazard in areas with robust coverage or overestimating it where seismic records are sparse. Conversely, differentiated completeness approaches better capture the spatial and tectonic variability but demand more detailed analyses and introduce computational effort and epistemic uncertainty in threshold selection.

Overall, defining completeness is not trivial. It requires balancing physical representativeness, statistical robustness, and consistency with source models and recurrence formulations. Current trends increasingly favor mechanism or source specific completeness to improve recurrence parameter estimation and enhance the accuracy and practical value of PSHA for seismic risk management.

POSTER 163

Exploring New Statistical Metrics to Evaluate the Magnitude Distribution of Earthquake Forecasting Models

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Evaluating earthquake forecasts requires diagnostic metrics that isolate specific aspects of seismicity without being confounded by inconsistencies in others. Within the Collaboratory for the Study of Earthquake Predictability (CSEP), tests such as the N-test and M-test are designed to assess consistency in event counts and magnitude distributions, respectively. We show that the recently proposed M-test for catalog-based forecasts depends on the N-test, limiting its ability to assess magnitude distributions independently. Using simulated data, we demonstrate this limitation and propose a modified M-test based on resampling synthetic catalogs, which removes this dependence. The resampled M-test is implemented in the pyCSEP toolkit and we apply it to earthquake forecasts for Switzerland (1933–2022) and Europe (1990–2015) for which the M-test without resampling was used. We find that most models that passed the M-test while providing an inconsistent number of events are instead considered inconsistent with the observations when resampling is applied, and that this does not happen when the number of events is consistent. We then compare the resampled M-test against alternative metrics - including chi-square formulations, the Hellinger distance, the Brier score, and a novel Multinomial Log-Likelihood (MLL) score - finding that the MLL consistently outperforms the M-test and other metrics. We study how the power of the test changes with the number of observations and cutoff magni-

tude, comparing the MLL and M-test against classical statistical tests such as Kolmogorov–Smirnov (KS) and Anderson–Darling (AD). Overall, our results show that previously used magnitude tests can be misleading when event counts are inconsistent, and that the Multinomial Log-Likelihood test with resampling offers a more reliable and powerful metric for evaluating magnitude distributions in earthquake forecasts

POSTER 164

Fault Branching, Slip Partitioning, and Tectonic Implications of the 2021 Mw 7.4 Maduo Earthquake, Northern Tibet

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The 2021 Mw 7.4 Maduo earthquake ruptured a previously unrecognized fault system along the northeastern margin of the Tibetan Plateau, providing a valuable opportunity to investigate how earthquake rupture geometry, slip partitioning, and stress evolution are recorded in the landscape. The rupture propagated eastward along a relatively linear strike-slip fault before bifurcating into northern and southern splay structures near its eastern terminus, producing distinct surface displacement patterns and distributed deformation.

We integrate relocated aftershocks, focal mechanism solutions, and Sentinel-1 ascending and descending InSAR data to characterize the spatial variability of faulting style, stress regime, and coseismic slip distribution. Aftershock focal mechanisms reveal a systematic transition from dominantly left-lateral strike-slip faulting to transpressional deformation toward the rupture termination, indicating increasing resistance from pre-existing structural barriers. InSAR-derived displacement fields show pronounced slip partitioning between the main fault and secondary branches, with contrasting horizontal and vertical deformation patterns across the splays and adjacent inherited faults.

Our results demonstrate that coseismic strain release was not confined to a single mature fault but was distributed across newly developed and inherited structures, producing a heterogeneous landscape record of rupture geometry and deformation. Comparison with nearby large earthquakes along the East Kunlun fault system suggests that relatively linear, newly formed faults may exhibit higher mechanical efficiency than older, geometrically complex fault segments. These findings highlight the importance of fault branching and off-fault deformation in shaping earthquake landscapes and emphasize the value of integrating geodetic and seismological observations to interpret strain accumulation and release across multiple structural levels.

POSTER 165

Pulse-like Ground Motion Observed During the 6 February 2023 Mw 7.8 Pazarcık Earthquake, Türkiye

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We analyzed 100 three-component strong ground motion records within 200 km of the causative fault of the 6 February 2023 Mw 7.8 Pazarcık (Kahramanmaraş) earthquake in southeastern Türkiye. Using a wavelet-based method, we identified and characterized near-fault pulse-like ground motions while accounting for pulse orientation uncertainty. Our analysis focused on how the focal mechanism and rupture process influenced the spatial distribution, orientation, and predominant direction of the observed pulses. We also examined pulse amplitudes and periods, as well as the effect of long-period amplification on ground motion response spectra. The main findings are as follows: (1) A total of 21 distinct ground velocity pulses were identified, showing complex features attributable to the strike-slip mechanism and rupture directivity. Most pulses (17 out of 21) were recorded within 20 km of the fault, with orientations ranging from normal to parallel relative to the fault strike. These waveforms exhibited unidirectional characteristics consistent with left-lateral slip. Pulses observed beyond 20 km were primarily normal to the fault and displayed bidirectional, multi-cycle waveforms resulting from rupture directivity. (2) Pulse amplitudes ranged from 30.5 to 220.0 cm/s, with the peak velocity of 220.0 cm/s recorded at Station 3138. Pulse periods varied from 2.3 to 14.5 s. The amplitude and period ranges are comparable to those of global earthquakes of similar magnitude. While amplitude decreased markedly with fault distance, period showed no clear distance dependence. (3) Compared to non-pulse records, velocity pulses significantly amplified acceleration response spectra near the pulse period, with factors between 2.1 and 5.8. Larger velocity pulses also strongly amplified velocity response spectra,

especially at long periods. This pulse-induced amplification leads to underestimation of long-period ground motion by empirical models.

POSTER 166

An Intraplate Long-lasting Earthquake Sequence Near Feidong County, Hefei, East China (2024-2025)

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On 18 September 2024, an M4.7 earthquake occurred at the southern end of the Tanlu Fault in East China, near Feidong County in Hefei. This area had not experienced a destructive earthquake since the 1673 M5 event. The M4.7 mainshock caused strong ground shaking and raised widespread public concern. Before the M4.7 earthquake, there were three M3+ events: M3.5 on 24 February, M3.1 on 1 May, and M3.9 on 14 September 2024. Following the main shock, extensive aftershocks occurred, including magnitudes of 3.8 on 25 September and 1 October 2024, 3.9 on 16 January 2025, 3.8 on 27 January 2025, 3.0 on 2 March 2025, and 3.0 on 8 November 2025. Here, we present the rupture evolution model of the M4.7 Feidong earthquake, using the apparent moment-rate function (AMRF) inversion based on near-source recordings from dense regional networks. Our results indicate that the rupture initially propagated southward but was subsequently hindered by a strong structural barrier, resulting in a stopping phase characterized by backward rupture propagation. The resolved high stress drop and slip rate suggest an energetic rupture, likely contributing to the intense shaking experienced in the Hefei basin.

Network Seismology: Recent Developments, Challenges

and Lessons Learned

Oral Session • Wednesday 15 April • 8:00 AM Local

Conveners: Blaine Bockholt, Idaho National Laboratory

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Evaluation of Distributed Acoustic Sensing Phase Pick Quality and Performance for Operational Earthquake Monitoring

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Over the past several years, distributed acoustic sensing (DAS) has been gaining use in seismological research and even seismic monitoring. The Southern California Seismic Network (SCSN) recently started incorporating DAS data into routine regional seismic monitoring operations. We present an analysis of the expected and observed effects of adding DAS data to monitoring. Prior to adding DAS data to real-time operations, we conducted a test on 228 events from 28 May to 1 August 2023 to evaluate the number and quality of phase picks from DAS data and the potential effects of those additional picks on earthquake locations. We also compared automatic picks from the machine learning picker PhaseNet-DAS to analyst picks to assess its accuracy, although it is not yet being used in operations. We then repeated this analysis for 331 events from 6 May to 8 July 2025, after 7 DAS channels were added to the real-time systems, to assess whether the performance was as expected. PhaseNet-DAS generated about twice as many picks as the analysts. The arrival times of the PhaseNet-DAS picks were similar to those of the analysts, mostly within ~0.5 s, with P picks having a smaller deviation than S picks. The STA/LTA picker in the real-time system generated about half as many P picks as the analysts, though they were typically accurate. The detection threshold of PhaseNet-DAS was a little better than that of the analysts. For the event locations and depths, we found little difference in the accuracy compared to a reference hypocenter with or without DAS picks included; however, the depths of hypocenters that included PhaseNet-DAS picks were systematically

deeper by ~1 km than those without. Overall, we found that adding DAS into our monitoring systems can provide more picks, especially in areas with poor seismic station coverage, with potential benefit to earthquake parameter quality. PhaseNet-DAS may be able to provide accurate automatic picks to reduce additional analyst work from the extra stations.

Optimizing Station and Source Graphs for Graph-based Earthquake Phase Association

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Constructing earthquake catalogs is an essential task in seismology. Graph neural networks applied to Cartesian product graphs between station and source graphs have been shown to be a promising approach to earthquake detection and phase association. To date the graphs used in the constructions of the source, station, and (sub)graph of the Cartesian product graph have relied on simple distance relationships, such as K-NN or radius-graphs, which are likely to be sub-optimal. Here, we show improvements for both selecting the initial source graph node distribution and creating the station graph for arbitrary station geometries. For the initial source nodes, we establish a sampling and filtering workflow to create well-packed, highly uniform, and volume-preserving distributions of monitoring nodes over arbitrary 3D (or 4D space-time) domains, and over arbitrary shells of the WGS84 ellipsoid.

For the station graph, we describe a sequential, greedy-optimization procedure that can grow a station graph from a seed graph (e.g., a Delaunay Triangulation), into a well-connected and stable graph that improves upon standard K-NN or radius-graph constructions. This growth process is achieved by iteratively ranking and selecting from candidate (new) edges with weights that account for the global connectivity and expansion, pairwise graph resistance, station distances, and the local graph ‘curvature’ (e.g., using discrete Ricci graph curvature). This results in station graphs that are significantly improved compared to K-NN or radius-graphs in many metrics of graph health. We implement a similar form of this optimization to select the subgraph of the Cartesian product graph, where we extract an optimal subset of source-station pairs that promote coverage and minimize azimuthal gaps, while maintaining sparsity and focusing on essential interactions. We assess the newly designed graph construction schemes in their effect on the accuracy of down-stream earthquake location and phase association tasks.

Source Type Classification of Non-earthquake Signals Commonly Recorded on Regional Seismic Networks: Implementation and Pipeline Development

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Surficial mass movements, such as landslides and debris flows, have seismic signatures distinct from other routinely-recorded seismic sources like earthquakes and explosions. However, visual similarities between the characteristics of these signals can still make it difficult to practically discriminate between source types during operational seismic monitoring. This ambiguity motivates the development of automated techniques for seismic signal classification, which can lessen the load on earthquake-focused seismic analysts and expand opportunities for non-earthquake event cataloging. Here, we present a machine learning classification scheme for differentiating between regional (<200 km) seismic signals generated by shallow earthquakes, rock falls, landslides/avalanches, anthropogenic blasts, and glacial events. These source types are commonly recorded on regional seismic networks and therefore present the most useful target for automated classification.

Our signals derive from the Exotic Seismic Events Catalog (ESEC) — a diverse, manually-created database of seismogenic surface events — and the U.S. ANSS Comprehensive Earthquake Catalog. We select earthquake signals such that the source–receiver distance distribution and number of signals are balanced with respect to the ~300 ESEC events. We implement a feature-based approach to classification using statistical metrics — e.g., “rise time”, the time duration from signal onset to signal maximum — extracted from waveforms. We test feature extraction approaches including both large, generalized sets as well as specific, manually-engineered (and thus highly interpretable) features. Feature importance metrics provide insight into the machine learning algorithms we use, which include support vector machines and a random forest classifier. We test our classification method on real-time seismic data in the context of the USGS National Earthquake Information Center’s operational systems. We picture our classification workflow as one modular element of

a larger non-earthquake identification pipeline that includes detection and location as preliminary (or concurrent) steps.

Phase Picking Beyond Local Distances: Where Waveform Filtering Still Matters

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In routine seismic monitoring, analysts typically filter waveforms before picking phase arrival times, as arrivals can be obscured by unwanted signals with dominant frequencies. Despite its importance in manual processing, waveform filtering has generally been regarded as inconsequential when training deep learning models for phase picking. This perception may stem from the assumption that neural networks can inherently learn to filter relevant features during the training process. As a result, a common practice is to either use unfiltered waveforms or apply a 1 Hz high-pass filter. This approach has yielded satisfactory results to date, primarily because most models have been trained on waveform data recorded at local epicentral distances (typically within 100 km) and deployed for cataloging events within similar ranges. However, for waveform data recorded at regional and teleseismic distances, where signal attenuation is more pronounced, such assumptions may no longer hold, and appropriate filtering becomes substantially more important. Here, we show that using unfiltered or 1 Hz high-pass filtered waveforms can lead to suboptimal model performance beyond local distances. We propose two straightforward strategies that incorporate waveforms pre-filtered across multiple frequency bands during both training and inference. Our results show that, by carefully selecting a set of filter bands, substantial performance improvements can be achieved across a broad range of distances.

Background Seismicity, Swarms and Fluid-injection Induced Earthquakes in New Mexico: New Constraints from USArray Data

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We investigated intraplate seismicity in New Mexico using waveform data from 87 broadband TA stations and 21 short-period SC stations for the period 2007-2010. Applying a deep-learning phase picker and a grid-search associator, we identified 9,514 earthquakes and 5,567 non-tectonic events, achieving a completeness magnitude of M_L 0.8, significantly lower than the values in the ANF (1.8) and ComCat (3.0) catalogs. Most seismicity forms clusters around the Socorro Magma Body, Raton Basin, and Dagger Draw, where fluid processes, either natural or anthropogenic, can enhance pore-pressure diffusion and fault reactivation. Background seismicity, which accounts for 36% of events above the completeness level, is more diffusely distributed across tectonic province boundaries, with elevated activity along the West Jemez Lineament but little correlation with the Rio Grande Rift. Focal mechanisms inverted from waveform modeling indicate that moderate events ($ML \geq 3.3$) predominantly occur at depths shallower than 10 km, while earthquakes in Raton Basin and Dagger Draw occur within the basement rocks. While background seismicity rates in individual tectonic provinces remain constant, clustered events exhibit intense temporal seismic activity, indicating the strong influence of fluid processes. We emphasize the importance of continuous seismic monitoring in regions of active or planned energy development, particularly in the Permian Basin.

SCSN Live: A Realtime View of the Network

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SCSN Live is an application to visualize how the Southern California Seismic Network (SCSN) detects earthquakes in real time. As the waveforms from the SCSN stations come into Pasadena, they run through real time picking and associator algorithms to detect an earthquake. This information is visualized in a fast, continuously updating web-based display that is built on infrastructure that is independent of the underlying processing platform.

In this presentation we will describe the challenges of gathering data from different sources and how we overcame them to combine the information in a meaningful, integrated display. Users can select stations and see their real time seismograms. If there are picks on the channel, they are overlaid as time marked flags. The station locations are rendered on a map along with

recent events in the area. Global events with magnitude over 5.0 are shown on a separate map. These maps help users identify what events may have signals in the current waveform view. The application uses common data sources and standard formats so it can be implemented by any network easily. SCSN Live establishes a connection to a SeedLink server to receive the streaming waveform data. It gets the event information through a client that is continuously listening to the PDL service. The station locations and picks are fetched from the FDSN Station and Event web service endpoints. The result is a comprehensive view of seismic network waveform data, observed phase arrivals, metadata, and the resulting earthquake catalog.

Webservices of the Italian National Accelerometric Network - RAN

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The mission-critical Italian National Accelerometric Network, RAN (*Rete Accelerometrica Nazionale*), informs the Italian Civil Protection Department, DPC (*Dipartimento della Protezione Civile*), about destructive and felt earthquakes. It consists of more than 700 stations, of which about 440 are closely monitored. Typically, the network identifies about 1800 events per year. Earthquakes with an M4 or larger magnitude trigger a temporary 10-station array deployment around the epicenter. These stations telemeter acceleration measurements in real time to the data center, and the data streams are immediately incorporated into the automated processing flow, providing valuable information on the aftershock sequence. DPC shares data with other government agencies and academic institutions in real time and on request. The automatic processing results include, among others, PGA, PGV, PGD, PSAs, Housner and Arias intensity, and response spectra. Web services are essential to maintaining a robust, efficient real-time flow from data to information.

Web services are an integral part of the network's operations and information dissemination. They provide both public and restricted access. Public access includes in-depth event information tailored to the needs of the emergency officers, a station map with station details, and FDSN web services. The restricted area grants access to the network maintenance dashboard. It includes live information on station availability, SOH for network devices, and station history. We are currently restyling the website with updated branding in compliance with the public administration-coordinated image guidelines. Also, new features include enhanced event and station filtering, enabling in-depth catalogue searches. The internal dashboard will incorporate field service operations logging and station inventory management. In the future, this will lead to a web UI that updates metadata.

The GRMT Project: Global Real-time Centroid Moment Tensor Analysis for Significant Earthquakes

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The seismic moment tensor is a mathematical representation that characterizes the size of an earthquake and its source geometry. It can help identify which fractures are contributing to the event and determine where the main seismic-moment release occurs. The centroid moment tensor (CMT) inversion is a standard procedure for extracting CMT information from seismic waveforms. It is triggered by a rapid earthquake report, and the hypocentral information is used as initial input to the CMT inversion. This two-step analysis typically requires time and does not yield accurate centroid information.

To address timeliness and accuracy issues, this project proposes a Global Real-time Moment Tensor (GRMT) to obtain rapid CMTs for large earthquakes worldwide. It integrates CMT inversion and global grid search into a single system. High-performance computing is applied to deal with the massive inversion and large-scale grid search problems. With this approach, all point-source information, including centroid time/location, moment magnitude, and the full moment tensor, can be obtained simultaneously.

The goal of the GRMT project is to provide the world's first CMT report in less than 20 minutes for $M_w > 6.0$ earthquakes. Unlike conventional earthquake reports, the GRMT will provide the complete CMT, determined from a global grid search, rather than the moment tensor determined at or near the hypocenter. Precise CMT is key to the rapid determination of source characteristics, such as the fault mechanism, rupture type, and directivity of a

large event. More importantly, the GRMT can provide crucial information for global earthquake/tsunami early warning and hazard assessment.

ISC: Collaborating with Seismic Networks Worldwide

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The main mission of the International Seismological Centre (ISC) is to produce the most long-term, complete and comprehensive Bulletin of instrumentally recorded seismicity on a global scale by utilizing seismic event data exchange with ~150 seismic networks in ~100 countries. We also take additional, not regularly reported measurements from openly available waveforms to improve event source parametrization. For instance, we aim to better constrain the depths of moderate to large seismic events in poorly instrumented regions by taking the depth phase arrival time measurements. For large events, we calculate Probabilistic Point Source Model solutions (ISC-PPSM) that helps to constrain event depths, source time functions and moment tensors. We are also taking automated IASPEI-compliant amplitude and period body/surface wave measurements to complement similar measurements supplied by networks in order to calculate more robust ISC mb/MS.

In addition, we produce a set of data products that stem from the ISC Bulletin and allow the ISC to assist several areas of research. These include the ISC-EHB dataset (1964-2022), ISC-GEM catalogue (1904-2021), IASPEI Reference Event List (GT, 1959-2022) and ISC Event Bibliography (1904-2026). We also maintain supplementary services: the Electronic Archive of Printed Station/Network bulletins, the International Seismological Contacts, and the ISC Dataset Repository. We look forward to further extending our collaboration with both permanent and temporary networks worldwide.

How Not to Be Fooled by Seismicity Depth Distribution: Lessons From the 2023 Kahramanmaraş (Se Türkiye) Aftershock Sequence

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The seismogenic depth and asperity width along major fault zones are critical for seismic hazard assessments and are typically inferred from the depth distribution of microseismicity. However, accurately determining seismicity depth remains challenging, particularly under sparse station coverage. Most existing location algorithms underestimate location errors, and few criteria exist for depth-specific quality control. Following the 2023 Kahramanmaraş earthquake doublet in Türkiye, discrepancies of ~5 km in aftershock depth distributions along the Savrun-Çardak-Doğanşehir fault system (SCDF) were reported by different catalogs, raising debate over the actual extent of the seismogenic zone. In this study, we evaluate the depth accuracy of three absolute location methods, HypoInverse, NonLinLoc, and a newly developed two-step grid search algorithm that incorporates equal differential time (EDT) surfaces. We use location stability under controlled perturbations as an indicator of accuracy and systematically evaluate the sensitivity of depth distributions to three key factors: station geometry, velocity model, and phase-picking errors. Our results show that removing the nearest station can cause deviations of ~5 km in depth distributions, often exceeding variations introduced by velocity model uncertainties and picking or association errors. Sparse networks tend to be more sensitive to all tested factors, amplifying depth instability under perturbations. Under these perturbations, we demonstrate that the two-step grid search behaves more stable, thus renders less bias in seismicity depth distribution. Based on these findings, we also propose a quality control strategy to identify well-located events and retrieve correct depth distribution. Applying the above approaches to the 2023 Kahramanmaraş aftershock sequence, we confirm the presence of stable deep events (~30 km) and transient deepening of early aftershocks in the eastern SCDF segment and southwestern East Anatolian Fault (EAF).

Evidence-based Seismic Impact of Wind Farms and Borehole Sensor Performance at the EKA Array

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Mitigating seismic ground vibrations (SGV) at the Eskdalemuir (EKA) array is increasingly important as Scotland expands wind farm (WF) development to meet 2045 Net Zero goals. The UK MoD currently restricts WF development within 50 km of the array based on an empirical model that assumes a single point source and simplified attenuation. A 2004 student paper also set a limit of 0.336 nm rms ground displacement, though background noise has risen significantly due to forestry and other human activity.

Two independent studies were commissioned to reassess these assumptions. The first deployed a linear array of seismic sensors up to 10 km from an operating WF, measuring SGV across wind speeds from 0 to >20 m/s. Results show no detectable turbine-related seismic noise beyond ~5 km, demonstrating that real-world propagation differs substantially from the MoD model.

The second study drilled a 200m borehole near the EKR4 element of the array and installed a broadband seismometer with surface sensors for comparison. Borehole installations—standard at many CTBT stations—significantly reduce SGV. Data shows reductions of ~10 dB on calm days and up to 25 dB on windy days within the MoD's 2–8 Hz bandwidth. The borehole sensor provides clearer P-wave arrivals and improved SNR. Importantly, the original 0.336 nm threshold is routinely exceeded by forestry and other anthropogenic sources, indicating it is no longer a meaningful constraint.

These findings show that WFs have minimal seismic impact beyond ~5 km at EKA and that borehole sensors can substantially enhance the array's resilience to environmental noise. This evidence supports revising the MoD moratorium to allow WF development at distances greater than ~5 km. The wind industry has offered to fund borehole installations, strengthening CTBT monitoring capability while enabling renewable energy expansion.

Measurements of the Magnetic Sensitivity of Geophysical Instruments

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Recent studies as well as those from past decades have shown that inertial seismometers respond to magnetic fields. For some seismometers the response is strong and can result in the noise floor of the sensor being limited by the magnetic wavefield instead of the seismic wavefield, potentially preventing the sensor from detecting signals of interest. This magnetic sensitivity is typically not specified by manufacturers and can vary widely even for sensors of the same design installed in close proximity. Previous studies have measured the magnetic sensitivity of seismometers by collocating them with magnetometers, an effective approach but one that requires fielding the equipment in a suitable location and waiting for sufficiently large magnetic fields. In this study, we examine magnetic sensitivity measurements for seismometers and other geophysical sensors made in a controlled laboratory environment. The testbed is described and the results of using it to evaluate the magnetic sensitivity of a large set of seismometers are presented. The measurements quantify the magnetic response of the seismometer across a large bandwidth and allow researchers to understand the magnetic sensitivity of a sensor before it is installed at a field site. Such quantifications are particularly important for sensors used in seismic monitoring networks since it is critical to understand how their performance and noise floor can be impacted by transitory events like solar storms or other causes of magnetic field variations.

A Frequency Response Model for Passive Seismometers With Complex Impedance Damping

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Frequency response models for passive seismometers, such as the Geotech GS13, are typically provided as a simplified geophone model of a damped spring-mass system with an electromagnetic transducer. These models can work well at low frequencies, provided the seismometer free period and damping coefficient are properly adjusted. However, these frequency response models were devised for geophones, which have a relatively small coil inductance that was often assumed to have negligible impact within the frequency passband of interest. Larger, passive seismometers have proportionally larger inductances, which can significantly impact the seismometer's response at frequencies above a few Hz. In addition, some data recorders have a measur-

able channel capacitance, due to the need for input surge suppression. The influence of these complex impedances in parallel with the seismometer's electromagnetic transducer result in damping of the seismometer proof mass motion that is no longer purely resistive. A complex impedance term should be included in the electromagnetic damping portion of the seismometer frequency response model. Here we provide a mathematical model for including these terms in the frequency response and the results of testing a Geotech GS13 seismometer to validate the revised response models.

Scoring the Quality of Ground Motion Records

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We propose a new quality assurance (QA) workflow to improve the accuracy of automatically processed earthquake ground motions. These improvements extend existing QA checks in the U.S. Geological Survey (USGS) automated ground motion processing software, *gmprocess*. These methods also support manual review, because automatic identification of problematic records increases reviewer efficiency. As part of this QA workflow, we define a plausibility score based on intensity measures (IMs), such as peak ground acceleration, significant duration, and ratios of IMs from different components. The score is a taper function based on the physically plausible range of these values and on the expected values given magnitude and distance. Defining plausibility is challenging because there is no strict threshold at which an IM abruptly switches from plausible to implausible. Thus, we use a fuzzy-logic approach that combines scores across IMs, capturing the gradual transition from plausible to implausible. We apply this approach to a dataset of over 1.2 million records throughout the United States. The results have identified numerous problematic records; the most common examples are erroneous sensitivity reported in the metadata and velocity sensor components that are clipped or require centering, leading to inaccurate records and IMs. The score inputs include standardized IM residuals relative to ground motion models, and model selection uses the USGS seismotectonic regime earthquake calculator software (*STREC*). A drawback of this approach is the potential to remove accurate records that are atypical for legitimate reasons. We avoid this by including membership functions that are not based on IM models and by defining the taper function so that only extreme outliers receive low scores. Furthermore, including the score with the dataset allows users to select an appropriate threshold for their application and to investigate unusual records and potential instrumentation issues.

Revolutionizing Borehole/Posthole Installations: Self-orienting Seismic System

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Orientation of a seismic sensor is a key item of metadata required for analysis, however this is often inaccurate or missing from stations where the operator cannot directly access the sensor to see its orientation, for example, in boreholes or on the ocean bottom. Nanometrics has developed a unique, patented system incorporating a miniature MEMS gyrocompass in the seismometer to determine its orientation with an accuracy of +/-0.5 degrees, which is generally not achievable by other methods. Software in the data recorder automatically queries this orientation and incorporates it in the channel metadata. Seismometers incorporating this gyrocompass also have self-leveling functionality, so the tilt of the data is known as well as the orientation. This North-finding capability was initially developed for ocean bottom use and is now being integrated into down-hole systems using the Trillium 120 Borehole or Posthole seismometer with the Centaur data recorder.

This self-orienting seismic system requires only a single software command to find its orientation and automatically incorporate it in the metadata. It removes any concern about the accuracy of the orientation, since the gyrocompass measures the direction of the Earth's axis of rotation, which is the definition of geographic North. This is an improvement over a magnetic compass, which measures magnetic, not geographic, North and may not accurately measure magnetic North due to disturbances from nearby magnetic material, such as the borehole casing. Furthermore, this North-finding

capability eliminates the complex operations currently used to control the orientation of borehole sensors, such as installing a "bishop's hat" fixture with expensive equipment or cross-correlating seismic data between the borehole sensor and a surface sensor. The orientation determined by the gyrocompass will automatically accompany the seismic data to the data center, so it will always be available to the user. Optionally, a rotation transform can be applied in the Centaur data recorder, to supply data that is already aligned to North.

Network Seismology: Recent Developments, Challenges and Lessons Learned [Poster]

Poster Session • Wednesday 15 April

Conveners: **Blaine Bockholt**, Idaho National Laboratory (blaine.bockholt@inl.gov); **Dara E. Goldberg**, U.S. Geological Survey (degoldberg@usgs.gov); **Renate Hartog**, University of Washington (jrhartog@uw.edu); **Kristine Pankow**, University of Utah (kris.pankow@utah.edu); **Dmitry Storchak**, International Seismological Centre (dmitry@isc.ac.uk)

POSTER 6

Earthquake Detection, Classification and Location in the Wabash Valley Seismic Zone

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The Wabash Valley Seismic Zone (WVSZ) is located along the lower Wabash River valley near the border between southeastern Illinois and southwestern Indiana. Most mapped faults in the region strike NNE–SSW and have been identified through seismic imaging and mining-related investigations. On April 18, 2008, a magnitude 5.4 strike-slip earthquake occurred on an ESE–WNW–striking fault northwest of Mt. Carmel, Illinois, and was widely felt across several Midwestern states. This event demonstrates that the WVSZ is capable of producing damaging earthquakes and highlights the seismic hazard posed to a region that is not traditionally considered highly active.

Despite this potential hazard, seismicity in the WVSZ is poorly characterized due to sparse and uneven station coverage. Since 2000, only 69 earthquakes have been reported in the USGS ComCat catalog, suggesting that many small to moderate events likely remain undetected or poorly located. As a result, the true level of seismic activity, its spatial distribution, and its relationship to mapped and unmapped faults remain uncertain.

In this study, we leverage all available seismic stations within 100 km of the WVSZ and apply modern machine-learning–based workflows to improve earthquake detection, classification, and location from 2000 to the present. We use automated phase pickers and event associators to build a more complete earthquake catalog. The resulting catalog will allow us to better resolve active fault structures, identify seismic clusters, and evaluate temporal variations in seismicity. Our results will provide a more accurate assessment of seismic hazard in the WVSZ and offer new insights into intraplate earthquake processes in the central United States.

POSTER 7

ANSS Station Information System: A Centralized Station Metadata Repository for Populating, Managing and Distributing Seismic and GNSS Station Metadata

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The Station Information System (SIS) is a multi-faceted metadata management application used by 58 networks to manage seismic sites, GNSS sites, telemetry hubs, equipment and instrument responses. SIS is an inventory management system for field operators who can track the history of individual pieces of equipment, a metadata management system for researchers interested in the channel and instrument response, and a reporting tool for field operators and network managers. This shared data repository has created a knowledge base leading to improved metadata quality and adoption of standardized practices across the ANSS community.

We will present key features and recent developments in SIS. SIS enables field operators to document their site visits by supporting field actions like install/swap/uninstall equipment, change logger configuration, recalibrate

instruments, track telemetry and store field notes. SIS allows the user to publish metadata in standard formats such as FDSN StationXML, dataless SEED and IGS Site Logs thus bridging the gap between field operations and network operations. Because SIS is a shared database repository, SIS users can build off each other's knowledge and expertise. SIS provides a close integration with the EarthScope Nominal Response Library (NRL). This reduces the amount of time a user needs to research the response when a new equipment model is introduced into their regional seismic network (RSN). Field and Network managers can use SIS reporting capabilities to better plan and maintain their networks with reports that filter by equipment age or equipment model or what equipment have active problem reports. SIS also has visualizations like station maps, and amplitude phase plots for instrument response. SIS also integrates with external FDSN dataset web services to display seismograms. SIS provides Web Service API endpoints enabling scripted access to the database.

POSTER 8

Using Version Control to Manage Seismic Software Configurations

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Building and maintaining computer systems is an important part of operating a seismic network. The real-time data flow is complex - acquisition, processing, distribution, storage, visualization, etc., and the variability from network to network is similarly complex - sensors, stations, geometry, telemetry, metadata, models, software, hardware, personnel, collaborators, etc. Given these challenges, solutions that simplify and streamline the work efforts are not just helpful, but critical to the networks operation and success.

In this presentation we explore the concept of using a well known tool in the field of software development - git version control - as a solution to a long standing problem in the field of network seismology - configuration management. We look at some real world scenarios using examples from ISTI and NCSN.

A git version control project forms the basis of this method, with a project for each software application that requires significant configuration. We enlist a resource that typically exists for a short time - the branch - and reimagine it as a resource that exists for the long term. We see how configurations change over time, and how version control provides tools to track, distribute and even revert these changes. We examine how configurations compare from system to system and network to network, and the tools used to highlight those similarities and differences. We discuss the additional benefits of using version control - as a centralized platform where users can collaborate, resources are securely stored remotely, and creating new systems can quickly be accomplished using automation, virtualization and cloud frameworks.

POSTER 9

Combining Strong and Weak Motion Data, with Amplitude Ratio as a New State of Health Metric

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Co-locating weak-motion seismometers with strong-motion accelerometers enables monitoring of seismicity at all scales, from the largest earthquakes to background-level microtremors. However, a combined analysis depends on having comparable data from both instruments, installed at the same depth, accurately aligned in the same package, and precisely calibrated so they can produce equivalent data, i.e. the same ground motion velocity or acceleration signals after response correction.

We present data from recent earthquake sequences in the Hualien region of Taiwan, captured by dual downhole sensors (Cascadia Slim Posthole) in the Downhole Seismic Observation Network of Taiwan CWA. In this example the seismometer and accelerometer signals match within 0.5% on average after response correction, allowing for the synthesis of a combined data stream with an unprecedented dynamic range of 220 dB. Algorithms for optimal combination of the data are discussed and demonstrated.

This processing also enables a new quality assurance metric for calibration accuracy. Previously, it has only been possible to verify this by running a calibration test procedure, typically no more often than once a year, since the test process is laborious and interrupts normal data collection. However,

in analyzing data from a dual instrument, the response-corrected amplitude ratio of the strong and weak-motion data streams can be continuously measured and reported as a state-of-health metric, to verify that the two instruments are operating correctly and measuring ground motion with the same accuracy in terms of sensitivity and frequency response.

POSTER 10

Earthquake Source Depth Refinement in France and Nearby Regions

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Although France and its nearby regions are characterized primarily by small to moderate seismicity, the associated seismic risk cannot be overlooked, particularly given the presence of numerous nuclear power plants. Accurate earthquake source-depth determination provides a critical constraint for seismic hazard assessment and plays an essential role in Probabilistic Seismic Hazard Assessment (PSHA) modeling, which underpins long-term evaluations of seismic risk. Owing to imperfect station coverage in the study region, traditional earthquake location methods generally yield poorly constrained source-depth estimates. In this study, we improve the SMAC method (stacking multiple-station autocorrelograms; Zhang et al., GJI, 2014) to evaluate source depths of over 500 moderate-magnitude earthquakes ($M \geq 3$) that occurred in mainland France and its nearby regions between 2010 and 2025. The SMAC method extracts and enhances coherent surface-reflected signals from either the main S wave or its coda through autocorrelation and stacking. We improve the SMAC method in two key aspects: (1) incorporating local velocity structure and topography rather than assuming a uniform one-dimensional velocity model, and (2) introducing prior information on Moho depth to better constrain earthquake source depths when using the main S wave. The two approaches depend differently and complementarily on station distribution: near-field stations yield more accurate main-S-phase depth estimates ($< \sim 1$ deg), whereas far-field stations ($> \sim 1$ deg) improve coda-based depth determinations. In this study, both the main-S-wave-based and coda-based SMAC approaches are applied and evaluated. Taken together, these results suggest that reliable earthquake source-depth estimates can provide critical inputs for seismic hazard assessments and related studies.

POSTER 11

Building a Stronger Seismic Network for Statewide Earthquake Monitoring in New Mexico

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The New Mexico Tech Seismological Observatory (NMTSO) has been monitoring seismic activity in New Mexico since the 1990s, with a particular emphasis on the Socorro Magma Body and southeastern New Mexico. In recent years, the number of earthquakes in the state has increased significantly, primarily in the northeast (Raton basin) and southeast (Permian Basin) due to anthropogenic causes. Due to the increased seismic risk, the seismic network faced an immediate need to upgrade its daily earthquake monitoring workflows, existing instrumentation, and statewide network coverage. Since 2023, the network has integrated Seiscomp (Scanloc) into the daily earthquake detection and monitoring workflow, along with machine learning tools, to develop a comprehensive earthquake catalog. However, despite improvements in detection workflows, the precise locations of earthquakes in the northern Delaware Basin remain unavailable due to sparse and uneven seismic network coverage, a key concern for state agencies, regulators, and operators. To address this issue, we plan to expand the existing seismic network with an additional ten new stations in the southeastern part of the state, thereby developing a denser network with uniform coverage in the Delaware Basin. Additionally, several regions in New Mexico experience natural seismic activity and have very few or no permanent seismic monitoring stations. Our goal is to build a statewide, permanent seismic network, expanding our coverage from fifteen to more than forty seismic stations statewide, with a focus on the Valles Caldera, the Rio Grande Rift, the Raton Basin, and the modernization of the Socorro magma body network. Furthermore, our current research goals include further improving our catalog in the Permian Basin with ongoing studies for relocation (Growclust), ambient noise studies to enhance the Delaware basin crustal velocity model, and the implementation of machine learning in real-time earthquake monitoring.

Incorporating Machine Learning to Improve Monitoring at the Southern California Seismic Network (SCSN)

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The Southern California Seismic Network (SCSN) is in the process of incorporating Machine Learning (ML) to enhance the quality and timeliness of its earthquake products. At most regional seismic networks, including the SCSN, earthquake monitoring systems depend on CPU-based local servers to process continuous seismic data in real time, generating earthquake information such as event origin time, location, and magnitude. Implementing machine learning algorithms for real-time event characterization across a large-scale regional seismic network of approximately 560 continuous stations presents distinct challenges related to the accuracy and quality of automatic event solutions, system reliability, and scalability. Previous studies have typically applied ML-based phase pickers and event detectors on smaller seismic networks covering a limited spatial region, often using archived data in batch or post-processing modes rather than operating in real time. At the SCSN, machine learning is currently used in post-processing - after an event has been detected by the real-time system - to refine earthquake origin times, locations, and magnitudes.

In this presentation, we will discuss how the SCSN has been exploring utilizing ML for automatic and continuous phase picking and event detection, as well as the use of GPU-based local servers. We will also discuss the different approaches we have explored and describe the systems currently operating in the development, testing, and production stages.

Recent Innovations and Improvements for Real-time Operations at the Southern California Seismic Network (SCSN)

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The Southern California Seismic Network (SCSN) is an Advanced National Seismic System (ANSS) Tier 1 digital seismic network that monitors ground motion and seismicity and delivers real-time earthquake information, including origin time, hypocenter, magnitude, and ShakeMap products. The network operates approximately 377 real-time strong-motion and broadband seismic stations and incorporates real-time data from an additional 178 partner-operated stations. Seismic data are transmitted using a diverse set of communication technologies, including cellular modems, USGS and CalOES Public Safety Communications microwave links, digital radio, multiple VSAT satellite systems, and the Internet. On average, the SCSN records roughly 355 earthquakes of magnitude 3.0 or greater each year and one magnitude 6.0 or larger event every three years. Products are distributed to agencies such as the USGS and CalOES via the Product Distribution Layer (PDL), email, and SMS, and are made available to researchers and the public through the Southern California Earthquake Data Center (SCEDC) and SCSN web services.

In this presentation, we describe recent and ongoing efforts to improve the redundancy, reliability, and resiliency of SCSN real-time operations. We focus on network and systems engineering approaches that enhance data delivery robustness and operational continuity. These include the deployment of dynamic routing and redundant VPN tunnels for field communications, allowing automatic path optimization, rapid failover, and increased resilience to communication outages while maintaining secure data transport. We also discuss the application of industry-standard cybersecurity practices, including encryption and authentication, along with planned enhancements to fur-

ther strengthen network security. Finally, we present strategies for providing server-level redundancy across geographically distributed data centers to support uninterrupted real-time processing and product generation during large earthquakes and infrastructure disruptions.

Architecture and Infrastructure of the Southern California Earthquake Data Center (SCEDC)

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As the primary archive for the Southern California Seismic Network (SCSN), the Southern California Earthquake Data Center (SCEDC) hosts an earthquake catalog from 1932 to the present, earthquake data products, and an ever-growing waveform archive critical to earthquake early warning services and the research community. To meet growing user demand, the SCEDC has uploaded its archive to the cloud as part of Amazon's Open Data program. The SCEDC is also involved in ongoing efforts to integrate distributed acoustic sensing (DAS) data into existing workflows.

Managing complexity has become ever more important as the SCEDC integrates data from more sources and serves out an increasing number of data products. In this poster, we present the infrastructure of the SCEDC, highlighting the adoption of infrastructure as code (IaC) and containerization technologies, such as Puppet, Terraform, and Docker, to deploy software with complex dependencies in a scalable and reproducible manner. We also highlight the flow of data from multicast sources into distributed local archives and the cloud archive, and the integration of data sources from the cloud for redundancy. Additionally, we discuss the SCEDC's role in the hosting of a DAS hub that will include DAS data sets for earthquakes in the SCSN catalog and enable researchers in the broader seismological community to access and process DAS data.

Phase Associator Comparison for Small Scale Seismic Networks

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Phase association, linking picks to an earthquake, is a critical step in earthquake location analysis, both in real-time and in post-processing studies. A widely used real-time earthquake associator is the Earthworm module known as binder (Johnson, 1997). Binder employs a grid search based algorithm for earthquake association using only P arrivals. Because S-wave arrivals are included only after the nucleation of the event using P arrivals, the performance of Binder is limited by the need for clear P arrivals. This constraint is particularly disadvantageous for induced seismic monitoring, where P picks are often sparse due to the low amplitude signal of smaller magnitude earthquakes. In contrast, the post-processing algorithm known as GaMMA uses a new Gaussian Mixture Model approach to phase association using both P and S arrivals. PyOcto, another promising new associator, employs an Oct Tree sorting algorithm that uses both P and S arrivals.

In this study, we compare the results and parameter adjustments of the three association approaches for small scale monitoring arrays (5x5km) as well as explore a new version of binder, named SBinder, that also nucleates on S arrivals. We use analyst-curated catalogs from these small-scale arrays (8-12 stations) as a benchmark, complete with combined sets of picks from a STA/LTA picker, a filter-based picker, and a custom-trained PhaseNet model. We test and present the performance of these associators against these pick sets.

Initial results show that GaMMA performs better with tuned PhaseNet picks than with phase arrivals from traditional pickers. We find that GaMMA generates new events that were previously missed in the curated catalog when used in tandem with PhaseNet picks, but additional tuning was required in the location phase to prevent the inclusion of a significant number of false detections.

Ultra Low Power, High Resolution Standalone Seismic Digitizer

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This work presents a novel, state-of-the-art standalone digitizer designed for seismic monitoring applications. The device is based on three 32-bit analog-to-digital converters, providing a dynamic range of up to 143 dB and selectable sampling rates from 50 sps to 800 sps. Data acquisition and control are managed by a high-performance, low-power RISC processor running the proprietary GEObit operating system.

Seismic data are stored as GBT files format on a removable microSD card with a capacity of up to 64 GB, which is directly readable on both Linux and Windows operating systems. Data retrieval is straightforward, requiring only file transfer from the microSD card. Data can also be accessed via Bluetooth or USB interfaces, if the instrument is deployed underground.

In addition to the three high-resolution seismic channels, the digitizer supports three auxiliary 16-bit channels for seismometer state-of-health (SOH) monitoring, such as mass position. The device provides three command lines for locking, unlocking, and centering broadband seismometers, supporting both active-high and active-low logic, ensuring compatibility with a wide range of commercial broadband and wideband seismometers, as well as geophones. The analog front-end supports multiple gain configurations. The digitizer integrates one 3-axis MEMS accelerometer with a dynamic range of 97 dB, allowing simultaneous recording of seismic and acceleration data. Precise timing is ensured through a 32-channel GNSS receiver and a TCVCXO clock with 0.2ppm frequency stability.

Power consumption is extremely low, approximately 0.22 W, allowing continuous operation for up to six months when powered by a 170 Ah zinc-air battery. User interaction is supported via Bluetooth and USB connections, with dedicated iOS and Android applications providing real-time data visualization, instrument configuration, SOH monitoring, and seismometer control.

The device has a diameter of 110mm, a height of 30mm, and a weight of only 150g. It is housed in an IP68-rated enclosure made of hard-anodized aluminum, making it suitable for harsh environments and underground deployment.

Ultra Low Power, Standalone Wide-band Miniature Seismometer

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This work presents a novel, state-of-the-art standalone digital seismometer designed for seismic monitoring applications. The instrument integrates a tri-axial wide-band response sensor with a flat response from 10 s to 100 Hz and a, high quality MEMS accelerometer, and a high-dynamic-range digitizer (143 dB) based on 32-bit analog-to-digital converters (ADCs). The system supports selectable sampling rates ranging from 50 to 800 samples per second (sps). Data acquisition and instrument control are managed by a high-performance, low-power RISC processor running the proprietary GEObit operating system.

Seismic data are stored in GBT file format on a removable microSD card with a capacity of up to 64 GB. The storage medium is directly readable on both Linux and Windows operating systems, enabling straightforward data retrieval via simple file transfer. In addition, data can be accessed through Bluetooth or USB interfaces, which is particularly advantageous when the instrument is deployed in underground environments.

The onboard three-axis MEMS accelerometer with a dynamic range of 97 dB, allowing simultaneous recording of seismic and acceleration data. Precise time synchronization is ensured by a 32-channel GNSS receiver and a TCVCXO clock with 0.2ppm frequency stability.

The instrument is optimized for ultra-low power consumption, operating at approximately 0.29 W. This enables continuous operation for up to six months when powered by a 9 V, 170 Ah zinc-air battery. User interaction and system management are supported via Bluetooth and USB connections, with dedicated iOS and Android applications providing real-time data visualization, instrument configuration, state-of-health (SOH) monitoring, and full seismometer control.

The device has a compact form factor, with a diameter of 110 mm, a height of 65 mm, and a total weight of 450 g. It is housed in an IP68-rated enclosure fabricated from hard-anodized aluminum, ensuring robustness and suitability for operation in harsh environments, including underground deployments

A New Local Magnitude Scale for Alaska

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We developed a new local magnitude (M_L) scale for Alaska, along with station corrections, using 27,598 normalized Wood-Anderson peak amplitude measurements from 394 seismic stations. This was motivated by the need to replace a legacy M_L formulation that had not been updated in many years and was based on vertical-component amplitudes, coincident with the Alaska Earthquake Center (AEC)'s transition to SeisComP for real-time seismic processing. The scale is based on a representative catalog of 681 reviewed earthquake solutions from 2015-2024, spanning magnitudes 1.6-6.2. Events were selected to ensure balanced magnitude-depth sampling and broad spatial coverage in and around Alaska. All amplitudes were reprocessed consistently within SeisComP to avoid bias from external tools. Amplitude measurements represent the peak amplitude averaged from the two horizontal components of each waveform. To calibrate the new scale, we simultaneously inverted for M_L , attenuation parameters n and K , and station corrections using an iterative least-squares regression. The newly calibrated amplitude attenuation function was used to compute a new M_L for each event, along with updated station corrections.

The new attenuation model provides an improved fit to the amplitude decay with distance relative to the previous model, reflecting a steeper near-field spreading and reduced far-field attenuation. The recalibrated M_L values are systematically higher for small earthquakes, while differences between the two scales decrease with increasing magnitude. Station corrections are centered near zero, showing no systematic biases, but reveal coherent geographic patterns that likely reflect regional differences in tectonic and geologic conditions. Residual analysis guided the removal of outlier stations and confirmed that the final model is unbiased, with residuals centered near zero and an RMS scatter of ~0.46 magnitude units. The new M_L scale provides a more accurate and regionally appropriate representation of seismic wave attenuation in Alaska while establishing a framework for future regional refinements.

Architecture of Generation 3 Real-time System at the Alaska Earthquake Center

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Operating within one of the world's most seismically active plate boundary zones, the Alaska Earthquake Center (AEC) provides real-time seismic monitoring across Alaska, spanning the full range from local to global distances. The AEC upgraded its real-time system in 2025 to what we are referring to as our Gen 3 system. This upgrade was driven by a number of needs and challenges, including public expectation for nearly instantaneous high-quality information, changing computing and information landscape, such as cloud and mobile technologies, as well as the evolution of seismological software and services, while also improving our ability to reliably detect, characterize, and monitor seismic activity in this complex tectonic environment.

We present our Gen 3 processing structure and system architecture, which at its core has a fundamental tenet of redundancy to ensure continuity of operations under a number of real-world scenarios. A critical component in the Gen 3 system is the inclusion of SeisComP software. This software includes a core open-source set of packages and functionality, and licensed modules to extend the functionality of the software. The Gen 3 architecture also takes advantage of modern computing infrastructure capabilities, including cloud computing. We have implemented versioning, staging, and other systems to ensure operations and consistency across redundant systems. We operate multiple processing pipelines, including global and local processing, with the ability to add new pipelines to support the unique and diverse nature of seismicity and earthquake monitoring in Alaska. This transition also provided an opportunity to systematically revisit foundational seismological frameworks of AEC operations, including 1-D velocity models and Alaska-specific magnitude calibration, expand routine products such as moment tensors, and revise duty and analysis workflows through an all-hands, center-

wide effort. Our Gen 3 software and architecture positions the AEC to incorporate new monitoring technologies and techniques more efficiently.

POSTER 20
Monitoring Network and Station State of Health with Grafana
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The Caltech/USGS Southern California Seismic Network (SCSN) is one of the largest seismic networks in the United States responsible for over five hundred seismic stations throughout Southern California. These stations must deliver high quality seismic data in real time for continuous earthquake monitoring. While the network has dedicated staff for station maintenance, earthquake analysis, and data archival, it has limited resources to monitor all stations for all times of the day. SCSN thus stands to benefit from further automation and data visualization tools to manage the large number of stations and processes it operates.

We will present on how SCSN is developing dashboards to monitor network and station state of health using Grafana, an open-source analytics and interactive visualization web application. With Grafana, SCSN can quickly visualize network and station state of health in many formats. SCSN takes advantage of our high resolution data that has been archived for years, real-time data streamed directly from dataloggers, and other data sources to allow users to examine both seasonal trends and active short-term issues across various state of health channels. The dashboards and accompanying software developed by SCSN are designed to be easily extendable and maintainable in order to accommodate the growing network.

POSTER 21
Shaking Intensity Parameters Computed at Seismic Sensor Sites for Real-time Monitoring: Application to the Community Seismic Network
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The Community Seismic Network (CSN) continues to expand in southern and northern California and consists of over 1200 permanent, three-component accelerometers that report in near-real-time to the Amazon cloud. We present comparisons of efficiency and accuracy of several recursive algorithms that solve the SDOF differential equation in real time to compute spectral accelerations (SAs) in-situ at the individual stations, i.e. at the edge on the sensor-microcomputer sites. Each CSN station is a low-cost MEMS sensor coupled to a microcomputer (Raspberry Pi) that is connected to the Internet. As real-time seismic networks become denser with large numbers of sensors, current processing methods in which waveforms are transmitted to a central server for processing may not be computationally efficient or reliable in the face of infrastructure failure during a large earthquake. The SA methods that were tested include algorithms developed by Newmark (1959), Nigam and Jennings (1969), Kanamori et al. (1999), and for Matlab. Tests performed with two recent, felt earthquake datasets illustrate the robustness of the estimates computed with these methods. A key motivator for implementing this architecture at the edge (at the sensor site) is to prevent the large time latencies that can arise when each seismic station is required to send finite-duration full waveform datasets to a centralized processing site distant from the sensor site, where the SAs are then computed. Computations of PGA, PGV and SAs at 0.3 s, 1 s, and 3 s are now being carried out over the entire CSN network, and these shaking intensity parameters are formatted into ShakeMap message packets. ShakeMaps using this method for the 8/12/2024 M4.4 Highland Park earthquake indicate an order of magnitude improvement in spatial resolution when the high-density CSN data are added. Specifically, the CSN data elucidate the ground motion amplification that occurs in the parts of the basin that contain the CSN stations - a region marked by deep sediments occurring near the center of the central Los Angeles basin.

POSTER 22
Multidisciplinary Stations: A Next Generation Tool Kit for Geoscience
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As cross-disciplinary science becomes increasingly critical to understanding geophysical phenomena, a multidisciplinary approach is essential for integrating instrumentation and ensuring reliable and efficient data acquisition for successful scientific outcomes.

The scientific community requires adaptable solutions for the co-location of diverse sensor types. Deploying such instruments in remote, volatile environments while ensuring reliable, continuous data acquisition presents additional challenges. The complexity and cost associated with deploying, operating and maintaining remote stations are significantly increased if using multiple independent sensors, each with dedicated acquisition infrastructure. Recent efforts, such as the European Plate Observing System, aim to address this by integrating multidisciplinary geophysical applications into unified and efficient deployments.

Modern seismic data loggers, such as the Nanometrics Centaur Gen5, support integration of a wide range of sensing elements, while maintaining ultra-low power consumption, precise timing, local data storage and reliable real-time data transmission. Enhanced capabilities regarding customization and edge computing allow the implementation of functionality tailored to meet specific monitoring objectives for unique station configurations.

A case study is presented for a multidisciplinary geophysical monitoring station that leverages these capabilities to enable comprehensive, reliable and efficient data collection. The multidisciplinary station configuration and end-to-end data pipeline, from remote sensing to science doorstep in the data center, are discussed.

POSTER 23
Practical Digitizer Testing: The Albuquerque Seismological Laboratory Digitizer Test Suite
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Testing seismic instrumentation in the lab prior to deployment can help ensure the equipment operates as expected in the field. When verifying digitizer performance, one can input a standardized signal of a known voltage and frequency into the digitizer and assess the output of the digitizer compared to what is expected. Here we present several tests used by the Albuquerque Seismological Laboratory (ASL) of the United States Geological Survey (USGS) to verify the correct operation of digitizers deployed in approximately 350 seismic installations managed by ASL across the United States and around the world, as well as networks supported by the Advanced National Seismic System (ANSS) depot. These tests estimate the sensitivity, timing, self-noise, clip level, and crosstalk between channels of the digitizer to ensure it matches manufacturer specifications. While the tests are not exhaustive, they are designed to capture the most common specifications, and most of them can be performed with a simple signal generator and/or reference digitizer. The results of the tests are analyzed using a Java software package called the ASL Digitizer Test Suite, which has been under development at ASL. This software package is publicly available to the community to help with digitizer testing in a variety of applications.

POSTER 24
A Seismic Network Assessment for Prioritizing Analog Upgrades Based on Pick-ability and Location Performance
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The University of Utah Seismograph Stations (UUSS) regional seismic network includes legacy short-period analog stations that continue to contribute data for earthquake location and magnitude estimation but are outdated. Since 2020 UUSS has upgraded 19 analog seismic stations to 6-channel digital weak and strong motion stations, enabling expanded recording capabilities, onsite data storage, and elimination of costly radio frequencies. We perform two independent network analyses that evaluate the Utah seismic network and the contribution of the remaining 21 analog stations, focusing on earthquake detectability and location quality. We use these assessments to determine analog upgrade priority and if any analog stations could be decommissioned, but they could also be applied to determining the most impactful locations of new installations, prioritizing station maintenance, and evaluating the impact of station and telemetry outages.

We assessed station quality and localized magnitude completeness using a data-driven approach that accounts for individual station noise and phase pick history to develop a Utah-specific attenuation model, following Wilson et al. (2021). The model is then used to estimate the minimum locatable magnitude distribution across the region and the maximum distance to which a given earthquake magnitude can reliably be manually picked on any station. Earthquake epicentral and depth uncertainty are tracked standards that are dependent on network coverage, so we further evaluate earthquake location quality throughout the region based on the network configuration. We re-tooled the Upgrade Score method (Hotovec-Ellis et al., 2017) to evaluate the analog stations' effect on constraining depth and providing azimuthal coverage for Utah events. The resulting Modified Upgrade Scores highlight the most impactful locations of stations and account for station density and the seismic hazard distribution in the state. We combined the results of the two analyses to establish tiers of short-period, analog stations for prioritizing upgrades and identifying stations where upgrade is unnecessary.

POSTER 25
Training and Performance of Machine Learning Pickers With Alaska-specific Data
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Globally pre-trained machine learning (ML) earthquake phase-detection algorithms continue to gain research popularity and are routinely used to generate earthquake catalogs with thousands of additional events. These pre-trained algorithms promise broadscale regional transferability and application in real-time monitoring. In Alaska, however, we find that while globally pre-trained ML models offer improvements over traditional detection methods, these ML models underperform our performance measures when compared to seismic data analysts (Noel & West, 2025). To address observed underperformance, we develop a location-specific training dataset for Alaska. We curate signals from 2019 through 2023 from permanent installation, real-time, seismic stations operating in Alaska and western Canada. We retrain ML architectures and apply our resulting models to the full 2024 calendar year of network data. Additionally, we prepare catalogs using models pre-trained on community datasets. We compare each 2024 catalog to our benchmark Alaska Earthquake Center analyst-reviewed catalog through a binary classification framework. Lastly, we apply a minimum catalog inclusion criteria based on Alaska Earthquake Center analyst review standards, establishing a one-to-one performance comparison. Our approach aims to evaluate the performance differences between training datasets and established ML architectures to develop an earthquake detection approach with appreciable benefits for Alaska.

POSTER 26
The RAII-UABC Urban Accelerometric Network: Real-time Seismic Monitoring and Ground-shaking Products for Emergency Response
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The Accelerometric Network of the Institute of Engineering of the Universidad Autónoma de Baja California (RAII-UABC) is a recently established urban seismic network, installed and put into operation in 2025 to strengthen seismic monitoring and response capabilities in the city of Mexicali, Mexico, a region of high tectonic activity associated with the Imperial–Cerro Prieto fault system. In its initial phase, the network consists of 15 triaxial accelerometric stations based on low-cost, high-performance MEMS sensors, installed on the UABC campus and at high schools, leveraging existing infrastructure for power, security, and network connectivity. Data are transmitted continuously via the SeedLink protocol to the II-UABC operations center, where SeisComp is used for real-time acquisition, operational monitoring, quality control, and data exchange with external networks, including the National Strong Motion Program and the Southern California Seismic Network.

Accelerometric waveforms are processed automatically and in near real time to compute peak ground acceleration (PGA) and Modified Mercalli Intensity (MMI), enabling the generation of high-resolution ground-shaking maps for earthquakes with magnitude $M \geq 3.5$. These maps constitute a key operational product of the RAII-UABC, as they are transmitted to civil protection authorities to support rapid situational awareness and decision-making during seismic emergencies. For each event, the system generates a database including acceleration, velocity, and displacement time series in physical units, as well as station-specific reports with response and Fourier spectra. As part of the network's evolution, an expansion is planned for 2026, including the installation of approximately 70 additional stations and the deployment of a public web portal for data access and product dissemination. Through inter-institutional coordination and the integration of seismic products into civil protection workflows, the RAII-UABC strengthens local seismic monitoring infrastructure, contributing to improved urban resilience and more effective, timely disaster response.

POSTER 27
Human-centered AI for Seismic Phase Picking in Operational Monitoring
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Deep learning based seismic phase pickers have advanced rapidly and are beginning to support near-real-time automated phase identification. Yet for seismic monitoring operations, where tolerance for error is minimal, their reliability and limited interpretability remain persistent concerns. To address this, I explore a human-centered AI framework designed to integrate machine-learning models into analysts' workflows in a way that enhances, rather than replaces, expert judgment. The framework is motivated by the two-step nature of manual phase picking. Analysts first make a rapid visual decision about whether an arrival is present. They then perform a detailed refinement step to identify the precise onset sample, a process that often involves zooming in, adjusting filters, and applying subjective judgment. The proposed system automates this second step. Analysts verify the presence of an arrival and supply a coarse timing estimate from a zoomed-out view, and the model generates a probability distribution over possible onset time. The refined pick is taken as the most likely sample. By centering the analyst's role and delegating only the most time-consuming and subjective component to the model, this approach reduces variability, increases throughput, and maintains human oversight. I present a prototype interface demonstrating this workflow and invite feedback from seismic network operators to eventually integrate this into existing operational monitoring systems.

POSTER 28
Güralp Data Centre: Cloud-based Data Acquisition and State-of-health Monitoring for Seismic Networks
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Operational seismic networks are required to deliver reliable, low-latency data and timely earthquake information while managing heterogeneous instrumentation, long-term data archiving, and evolving network and operational demands. Beyond waveform acquisition, network operators require comprehensive visibility of network state-of-health (SOH), latency, and data continuity in order to maintain catalogue completeness and rapid response capabilities.

We present the Güralp Data Centre (GDC), a data acquisition and archiving platform designed to support operational network monitoring by providing centralized access to real-time and archived seismic data alongside

integrated SOH analysis tools. GDC aggregates SEEDlink data streams from distributed stations and provides time-based data interrogation, long-term performance metrics, and automated SOH reporting to support both day-to-day operations and long-term network assessment. GDC can be deployed either on Gralp-hosted cloud infrastructure or within a customer-managed cloud environment, allowing users to balance redundancy, scalability, and data control requirements. When accessed through the Gralp Discovery platform, GDC enables automated instrument registration, remote firmware and configuration updates across networks, and traffic-light dashboards for rapid assessment of station health, latency, and outages. We discuss how these capabilities address common challenges in network seismology, including remote station management, near-real-time data availability, and long-term network performance monitoring, and consider lessons learned for improving the reliability and responsiveness of seismic monitoring systems.

POSTER 29

Generalized, Automated Mapping of High-impact Regions for Seismic Station Deployment

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Seismic networks must adapt as seismicity evolves, yet decisions about where to install new stations are often based on subjective judgment rather than objective criteria. This work addresses where new stations would deliver the greatest operational benefit and how to identify those areas using an automated and reproducible approach. This project is grounded in well-established seismological principles linking detection sensitivity and location accuracy to network geometry. Using source-to-station distance and azimuthal coverage, we encode these constraints in a generalized, open-source Python workflow with a simple GUI. This workflow integrates recency-weighted seismicity, existing network geometry, and a monitoring contextual layer. Four metrics are computed in the AOI grid: near-field event coverage at 4 and at 10 km, azimuthal gap improvement toward $\leq 90^\circ$, and cumulative saltwater disposal volume as the contextual layer. These are combined via user weights into a composite index and grouped using automatic clustering into discrete priority regions. Applied to the Midland Basin (2017–2025 TexNet catalog), the workflow identified four priority regions where additional stations would reduce near-field gaps, improve azimuthal coverage, and align with operational goals. The results support objective, reproducible planning, and the adaptable contextual layer (e.g., fault zones, geothermal energy production, population areas) enables straightforward transfer to other monitoring environments.

POSTER 30

Comparing Verizon and AT&T FirstNet Latency During the 2026 Rose Parade

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Many stations in the Southern California Seismic Network (SCSN) transmit real-time seismic data using commercial cellular networks operated by multiple providers. Verizon connections use standard commercial service plans, while AT&T connections operate on FirstNet, a priority network intended to ensure reliable data delivery for public safety applications during earthquakes and other large-scale emergencies. Evaluating the performance of these services under realistic congestion conditions is critical for assessing network resilience during major seismic events. The Rose Parade in Pasadena, CA that runs every January 1st, provides a unique opportunity to test cellular performance under extreme but controlled demand conditions that approximate post-earthquake network congestion.

To compare cellular data delivery performance, multiple mobile seismic stations are deployed near Colorado Boulevard, where cellular demand is

expected to be highest during the parade, with additional stations installed at less congested locations closer to Del Mar Boulevard and Caltech. Seismic data are transmitted simultaneously over Verizon and AT&T cellular modems, and packet delivery latency is measured and compared during the event, as well as during periods before and after peak congestion. This experiment provides a realistic assessment of cellular network behavior during a large seismic event, as temporary cell infrastructure commonly deployed for concerts and sporting events may be limited or absent along the parade route. As a result, the observed network conditions may better represent the congestion levels experienced following a major earthquake, allowing for a meaningful evaluation of the effectiveness of priority cellular services for seismic data transmission.

POSTER 31

Do You See What I See? Comparing Operational Shakemap Products in Northern California

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Four operational instances of ShakeMap exist within Northern California: the Northern California Seismic System (NCSS) produces the “NC” ShakeMap (supported by active and standby instances within the U.S. Geological Survey (USGS) Earthquake Monitoring Project and UCB), the California Geological Survey (CGS) produces the “CGS” ShakeMap; and the USGS National Earthquake Information Center produces the “US” or Global, ShakeMap. Operational redundancies are important for ensuring ShakeMap products remain available during system upgrades, system failures, or in the event of damaging earthquakes. Consistency between these ShakeMap instances is important for both producing agencies and downstream applications. The University of California, Berkeley (UCB) Grafana-based state-of-health monitoring platform (BATS) has become a valuable tool for visualizing the functionality of Northern California seismic instrumentation. Here, we combine Python-based scripts to acquire ShakeMap products from each instance to produce comparison products for incorporation into the BATS visualization system, improving situational awareness during event response by highlighting key differences. We examine differences in ShakeMap outputs, including metadata, ground-motion characteristics, and participation of individual stations. Major differences in ShakeMaps from recent test events include: (1) missing stations, especially along state boundaries; (2) variability of calculated ground motions at individual stations; (3) configuration-driven differences in outlier flagging; and (4) variability in the number of “Did You Feel It?” reports (DYFI) used. Earthquakes examined highlighted different aspects of these inconsistencies, which allowed us to correct configurations, resulting in improved consistency between ShakeMap instances. Longer-term data quality analytics, including routine revisiting of significant California earthquakes to ensure inclusion of all available records, are currently being implemented as we aim to visualize and quantify operational issues in real-time.

POSTER 32

Integration of MEMS Accelerometers in Regional Seismological Networks: Piloting A Low-cost Edge Computing Approach

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We deployed low-cost MEMS accelerometer nodes integrated with the SeisComP monitoring system to evaluate whether distributed, cost-effective sensors can augment traditional regional seismic networks. The system architecture consists of WiFi-enabled ESP32-S3 microcontrollers equipped with high-resolution ADXL345 accelerometers, sampling 3-axis acceleration at 100 Hz with adaptive gravity subtraction for seismic signal isolation. Each node implements TensorFlow Lite Micro inference (25ms latency, 45KB model size) trained to classify noise, P-waves, and S-waves from 4-second sliding windows. We combined deep learning classification with classical STA/LTA algorithms to provide robust fallback capabilities.

Edge processing enables intelligent event filtering before network transmission—only seismic phases exceeding confidence thresholds (>0.5) trigger MQTT message publication to a server running the SeisComP infrastructure.

Published picks include NTP-synchronized UTC timestamps, signal-to-noise ratios, classification confidence, and optionally the full waveform window (400 samples $\times$ 3 channels) for analyst review. A local storage mechanism captures events during network outages with automatic synchronization upon reconnection, ensuring data integrity. The complete system including utilizing off-the-shelf developer boards, power management, and weatherproof enclosure costs about \$50 per node, enabling dense spatial deployment previously infeasible with traditional instrumentation. Custom PCBs would lower these per-unit costs.

Initial beta testing focuses on evaluating MEMS sensor performance against traditional seismometers in detecting local and regional events ($M>2.0$). Key metrics under evaluation include detection latency compared to network stations, false alarm rates in urban noise environments, P-wave pick accuracy relative to analyst picks, and network bandwidth efficiency achieved through edge filtering. This deployment represents an important step toward understanding whether distributed, intelligent sensor networks can effectively complement traditional seismological infrastructure.

POSTER 33

Variability in Seismic Sensor Calibrations

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The United States Geological Survey (USGS) Albuquerque Seismological Laboratory (ASL) operates approximately 350 seismic stations worldwide and conducts annual electronic calibrations on these stations. Characterizing and calibrating seismometers is critical for seismic network operations because inaccuracies in the reported instrument response directly propagate into errors in recovering true ground motion. This, in turn, leads to amplitude and timing errors (often several times greater than those typical in automated or analyst picking methods) that can affect a wide range of studies including tomographic studies, earthquake timing and location, surface wave studies, and ambient noise cross correlation and can have a profound impact on regional and global models.

The response of a seismic sensor is commonly described by a finite number of poles and zeros. Estimating these poles and zeros for an individual sensor can be difficult in practice as it requires exciting the seismometer over a wide band of frequencies using the calibration coil of the instrument. Vendors often provide a nominal response for a seismic sensor, but typically the high frequency end of that response is theoretically modelled and not always empirically verified. There is an added complexity that some sensors have a calibration coil response that is frequency dependent, so the curve obtained from running an electronic calibration does not reflect the true ground motion response of that sensor. In this study, we examine the variability in electronic calibrations for several different types of seismometers and compare this variability to ground motion calibration using co-located sensors.

POSTER 34

Seismology as a Service: Portable Product Generation at the Southern California Seismic Network (SCSN) Using Service-oriented Architecture and Cloud Computing

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Seismic networks create catalogs through a set of operations for each event, such as seismic phase detection and origin calculation. Researchers often perform the same operations using different algorithms. Implementing these and other basic processes as scalable and portable modules would enable robust network-scale operations, and provide a framework for rapid experimentation to develop or improve new techniques. A service-oriented architecture, where each operation is a url end point, provides these capabilities. The SCSN has

adopted its automated origin refinement process, “hypoPN”, to a service-oriented architecture that uses a cloud hosted machine learning picker, PhaseNet (Zhu and Beroza, 2018). Tepp et. al. (2025) describes how the SCSN had created another pipeline, “ST-Proc”, to do event detection using GaMMA (Zhu et. al. 2021) on unassociated phase picks and how the hypoPN and ST-Proc pipelines improved automated solutions and streamlined analyst workflow.

This presentation will describe the current state of seismic processing services in operation at the SCSN, focusing on new developments. We describe recently created services such as an associator service that uses the GaMMA algorithm and a locator service that uses the hypoinverse algorithm. We describe our efforts to create a new pipeline to help analysts with “clones”, which are undetected events close in time and space to a detected event. We also have started using software libraries to manage our formats. These libraries and formats are collaboratively designed with other members in ANSS. (<https://gitlab.com/anss-netops/anss-data-formats>). To promote community use and collaboration, we are in the process of releasing the code for these services, starting with our picker and associator. (<https://github.com/SCEDC/seismo-service>). Additionally, we discuss the costs required for maintaining these systems. Our work illustrates how a distributed service-oriented architecture allows networks to re-use existing services in multiple pipelines as well as reduce the time to introduce new algorithms.

POSTER 35

STATION: A Scalable Platform for Cross-regional Seismic Station and Site Characterization

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STATION (*Seismic sTATION and SIt e amplificatiON* – <https://distav.unige.it/rsni/station2025.php>; Tarchini et al., 2024) is a web-based service and data infrastructure designed for the dissemination and exchange of seismological products related to seismic stations. Originally developed for Italy and neighboring regions, STATION has evolved into a scalable platform that currently integrates data from more than 5,000 seismic stations distributed across Italy, adjacent areas, Türkiye, and Northern Europe, and exploits recordings from over 200,000 earthquakes acquired since 2005. The seismological data available in STATION include products derived from seismic waveform processing that are relevant for station and site characterization, such as horizontal-to-vertical spectral ratios (HVSr) computed from both S-wave and noise windows, as well as local magnitude (Ml) residuals. Data processing is performed through a quasi-automatic workflow that includes: selection of recordings within a predefined epicentral distance range; automatic picking of P and S phases; computation of HVSr curves (average, and NS and EW components separately) for both signal and noise windows; and estimation of station Ml and corresponding residuals.

The resulting database includes several million individual measurements of HVSr curves and Ml residuals, together with additional ground-motion parameters such as peak ground acceleration and velocity, providing a dense dataset for large-scale analyses. For each station, a dedicated webpage provides access to metadata, interactive maps, summary tables describing data coverage and temporal ranges, and graphical visualizations of the derived products. STATION can support a wide range of scientific and operational applications, including cross-regional site response studies and rapid post-event analyses. Future developments of the service will focus on enabling temporal analyses of the data to investigate time-dependent variations in site response and ground-motion characteristics.

New Developments in Earthquake Rupture Physics For Source Characterization and Ground Motion Modeling

Oral Session • Thursday 16 April • 2:15 PM Local

Conveners: Ruth Harris, U.S. Geological Survey (harris@usgs.gov); Camilo Pinilla-Ramos, University of Southern California (camilo.pinilla@berkeley.edu); Arben Pitarka,

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Dynamic Branching and Surface Rupture in the Signal Hill Stepper on the Newport-Inglewood Fault, Southern California

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The right-lateral Newport-Inglewood fault (NIF) system cuts across the densely populated Los Angeles (LA) metropolitan area and sourced the destructive 1933 M_w 6.4 Long Beach earthquake, demonstrating its significant seismic hazard. The fault is highly segmented in its surface expression. At Long Beach, it manifests as a complex system of splay faults and linking reverse faults, leading to uplift of Signal Hill and Reservoir Hill. Oil industry logs and other data sets help to precisely define the fault geometry. Offset geological markers and topographic evidence aid in determining the slip history across the multiple splays [Toghradjian and Shaw, 2024].

We use the 3D discontinuous Galerkin method [Zhang *et al.*, 2023] to model the dynamics of potential earthquakes on the NIF in the Signal Hill region. Our goal is to explain the complex rupture paths implied by observational data. We find that the ability of rupture to propagate on the various fault segments depends strongly on the rupture propagation direction and the vertical velocity structure in the region. Using a homogeneous velocity structure, we show that activation of the splay faults and uplift of Signal Hill and Reservoir Hill require “forward branching” from southeast to northwest on the fault system [e.g., Kame *et al.*, 2003]. However, using a 1D velocity structure that increases wavespeed with depth (derived from the SCEC Community Velocity Model [Shaw *et al.*, 2015]), we find that this directional dependence becomes more complicated, with rupture in the backwards direction allowing slip on the splay faults via their connection at depth. In addition, we find that rupture through the stepper is facilitated by slip on the splay faults and inhibited when the splay faults do not participate. The latter effect could help explain the termination of the 1933 Long Beach earthquake at this location [Hough and Graves, 2020]. These observations emphasize the importance of subsurface fault connectivity on rupture propagation, particularly in the presence of depth-dependent wavespeeds.

Complex Rupture Behavior of the 2023 Mw 7.8 Kahramanmaraş, Türkiye Earthquake Revealed by Broadband Ground-motion Simulations

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The Mw 7.8 Kahramanmaraş earthquake exhibited highly complex rupture behavior, and caused more severe damage than anticipated based on the historical seismic record of Türkiye. This event raised fundamental questions about rupture initiation, propagation, and the interaction among multiple irregular fault segments. To better understand the observed variability in ground motions, we perform broadband simulations using a frequency–wavenumber (FK) Green’s function approach coupled with the Graves and Pitarka (2016; GP16) kinematic rupture model, assuming a regional one-dimensional velocity structure. The modeling strategy combines deterministic rupture features at low frequencies with stochastic rupture processes at high frequencies, following the GP16. The rupture is represented by three distinct planar fault segments to capture the complex fault geometry, while the slip distribution is constrained using available seismic and geodetic data.

Near-fault ground-acceleration records are used to investigate the rupture velocities along the Narlı splay fault and the Amanos fault, where station coverage is particularly dense. A range of rupture scenarios is explored, including fully stochastic models in addition to hybrid models that combine large-slip patches with smaller-scale random heterogeneity. Additional analyses investigated how variations in key rupture parameters, such as rupture velocity, rise time, and the size and spatial distribution of slip patches, affect

near-fault ground motions, as reflected in spatial PGV maps and in fault-normal (FN) and fault-parallel (FP) velocity waveforms.

The simulated ground motions are evaluated through direct comparison with recorded data. The results show that this modeling framework provides valuable insight into how rupture kinematics control regional ground-motion amplitudes and near-fault effects during the Kahramanmaraş earthquake sequence. More broadly, the approach offers a useful basis for rapid, physics-based ground-motion modeling and simulations of large earthquakes on multi-segment strike-slip faults.

A Physics-informed Probabilistic Approach to Forecast Large Earthquake Ruptures

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The elastic energy that drives earthquakes accumulates heterogeneously along faults, resulting in complex earthquake occurrence patterns. Although earthquake cycle simulations help capture such complexity in seismic hazard models, their high computational cost prevents widespread use and comprehensive uncertainty quantification. Here, we propose a physics-based probabilistic method to forecast the timing and magnitude of large earthquakes. The theoretical underpinning of the method is an extension of fracture dynamics theory to elongated ruptures that have saturated the seismicogenic depth. This theory yields a closed-form equation of motion for very large ruptures that allows to determine their evolution, from initiation to arrest, without requiring computationally demanding 3D dynamic rupture simulations. Combining this theoretical tool with observational constraints on seismic coupling, historical seismicity and fracture energy, the method forecasts the rupture arrest locations of very large earthquakes. We apply this approach to estimate the time-dependent probability of earthquakes exceeding Mw 8.5 across the entire Chilean subduction zone. Sensitivity analysis shows that the most critical model parameter relates to the scaling between fracture energy and slip. We constrain the model parameters by matching the time between mega-earthquakes on the Valdivia segment, validate the constrained model based on the seismicity of other segments, and then apply it prospectively over the whole Chile megathrust. Our results highlight how earthquake potential on a given megathrust segment can be altered by earthquakes on neighboring segments, which reduce the energy available for multi-segment ruptures. The sensitivity analysis to model assumptions and parameter values points to aspects of subduction megathrusts that should be a priority for future developments, including seismic coupling and fracture energy scaling. The proposed physics-informed framework constitutes a new approach for time-dependent seismic hazard analysis on large faults.

When and Where Does Aseismic Creep Stop Rupture Propagation?

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Aseismic creep on faults is characterized by rate-strengthening friction, which means that the fault actively resists movement as slip rates increase. This resistance to coseismic rupture velocities approaching from adjacent locked fault sections suggests that frictional behaviors associated with creep can, in and of themselves, be barriers to rupture. Because creeping sections of faults are in motion during the interseismic period, they also consistently release at least some of the shear stress from tectonic loading. This may mean that creeping areas also have low enough shear stress to cause a rupture to stop, even independently of frictional conditions. Thus, understanding which combinations of frictional resistance and shear stress retention, over what length of fault patch, are able to stop throughgoing coseismic rupture is critical for evaluating hazard from partially-creeping faults. Here, I conduct a suite of dynamic rupture simulations on partially-creeping strike-slip faults under a range of stress conditions, varying frictional resistance and stress release in creeping patches of different lengths, and looking at the length and amount of surface

slip of the resulting earthquake. My results so far are unsurprising: creeping areas that are longer and have more stress release are more likely to prevent rupture from reaching the end of the fault. The frictional properties of the creeping patch have less of an effect on rupture length, though they still affect slip patterns. More energetic ruptures can also overcome larger and more resistant creeping patches. I have run over 3000 models at the time of abstract submission; my goal is to explore how this balance of factors affects rupture length over a wide enough parameter space that I can develop physics-based passing probabilities for partially-creeping faults. These probabilities will be useful for a range of applications, including interpreting evidence of past ruptures, probabilistic rupture forecasting, and source scenario development for both probabilistic and deterministic hazard modeling.

The “Finite Volume” Effects of Faults in Dynamic Earthquake Rupture and Sequence Simulations

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Faults are not pure planes but instead contain finite volumes of fractured rocks that accommodate fast and slow deformation, which in turn significantly modulate fault stresses and earthquake source processes. I will present an overview of the effects of “finite volume” faults in dynamic rupture and earthquake sequence simulations. At short timescales relevant to earthquake rupture propagation, such “finite volume” fault zones can introduce stress perturbations at short length scales corresponding to dynamic waves within the fault zones. These dynamic stress perturbations can significantly interfere with both rupture fronts and healing fronts, providing vital mechanisms for the generation of slip pulses, supershear ruptures, and high-frequency ground motions. At long timescales relevant to earthquake sequences, the diffusive deformation of fault zones can redistribute fault stresses through energy dissipation, promoting complex seismicity patterns and seismicity migration through alternation of small and large earthquakes. I will also demonstrate how the early development of fault zones can significantly alter the behavior of subsequent earthquakes and aseismic slip migration in earthquake sequence simulations. Together, our simulations show that the “finite volume” effects of faults provide natural sources of stress heterogeneity that can not be ignored in earthquake simulations. The geological structures of fault zones and their evolution contain vital information about the mechanisms of earthquakes that can be deciphered through numerical simulations.

Constraining Rupture-generator Scaling Using Measured Surface Offsets, Near-fault Ground Motions and Rupture Dynamic Simulations

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This study shows evidence based on observations of near-fault ground motions and surface offset that regions with larger-than-average surface offset exhibit weaker ground motions for frequencies above 0.5 Hz. This negative correlation of surface offset and high-frequency ground motion is inconsistent with current scaling in kinematic rupture generators. Using rupture dynamic simulations with a linear slip-weakening rheology model combined with observed data enables us to define an input parameter space that is consistent with the observations. Given the multi-parameter nature of rupture dynamics, we focus on just two parameters: stress drop and the slip-weakening distance, Dc. Under this framework, the observed scaling can be explained if the stress drop is positively correlated with the slip-weakening distance. We explore the implications of our findings in kinematic source modeling constrained by our rupture dynamic simulations. We conclude that the ratio between the time of positive acceleration and the total rise time is negatively correlated with the total rise time, which contrasts with the current assumption of keeping this percentage fixed. Moreover, this study shows that regions with larger-than-average static stress drops tend to radiate weaker high-frequency energy and stronger low-frequency energy.

Realistic Representation of the Complex Dynamic Rupture Process to Simultaneously Account for Asperity Pulses and High-frequency Radiation: Syncro-shock Hypothesis

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As a quantitative investigation of the effectiveness of dynamic rupture simulations with complex source representation, we performed dynamic rupture simulations of the 2016 Kumamoto earthquake Mw 7.0 using a simple slip-weakening friction law, together with a complex stress-drop and strength-excess parametrization on the fault surface (Pitarka et al., 2009). By referring to the asperities of previous kinematic inversions, we searched for optimal

locations and sizes of three rectangular asperities on the causative Futagawa and Hinagu faults with specified high stress drops. After about 1,500 trials, we identified the optimal case with near-fault velocity pulses, as observed, due to high slip rates and forward rupture directivity in the assumed asperities.

However, we also found that any strong but rapid stress drop fluctuations in space do not contribute to generating randomly arriving high-frequency pulses as observed. All the fluctuations would be smoothed out by the forward rupture directivity, and we see only asperity pulses from the main fault surface. We assume all the complexities of observed strong-motions should come from a single fault plane; however, it is unlikely to have the same complexities with two or three orders in size on the same fault plane. Moreover, in dynamic rupture simulations, we need to add strong barriers abundantly within asperities in order to generate high-frequency pulses due to variations in rupture speed. If we assume as such, the rupture will readily stop before it reaches the entire fault surface.

Thus, as a logical consequence, we should assume that the high-frequency component is generated by numerous small, independent faults (“syncro-shocks”) in a zone around the main fault surface, the same zone in which aftershocks occur. This “syncro-shock” hypothesis means that different-sized faults are randomly (fractal in size) distributed and simultaneously ruptured, associated with the rupture on the main fault surface. The observed source spectra of omega-2 characteristics should be obtained as the result of the summation of waves from the main fault and many syncro-shocks.

Characterizing Rupture Speed Through Near-fault Particle Motions in Large Strike-slip Earthquakes

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Earthquake rupture propagation speed is a critical source parameter that strongly influences seismic hazard and risk. Yet, measuring rupture speeds in natural earthquakes often remains ambiguous, particularly for transient supershear ruptures. Near-fault seismic waveforms, recorded within a few kilometers of the fault, offer unique potential for resolving rupture processes. Here we present near-fault data signatures to directly infer rupture speeds in continental strike-slip earthquakes.

We first synthesize near-fault seismic waves from kinematic source models under varying rupture speeds, and identify systematic dependencies of velocity waveforms and particle motions on rupture speed in both amplitude and shape. Comparisons with analytical solutions for steady-state rupture reveal discrepancies that highlight the contributions of seismic radiation from different source configurations. We then conduct analysis of near-fault datasets from eight $M \geq 7$ strike-slip earthquakes and demonstrate that particle motion features, rather than complex velocity waveforms with multiple high-frequency spikes, provide clearer diagnostic signatures. Applying a particle-motion-based criterion, we identify rupture speed signatures associated with supershear and subshear propagation, as well as complexities such as multiple rupture fronts and initial-stage rupture phases.

Our findings underscore the value of near-fault seismic data for advancing source characterization and provide a framework for more robust inference of rupture dynamics in large strike-slip earthquakes.

Neural Operator Augmented Earthquake Sequence Simulations with Elastic Heterogeneities

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Simulating earthquake sequences with evolving elastic heterogeneities in 3D remains computationally prohibitive due to the need to repeatedly computing the elasticity kernel, which relates fault slip with traction changes on the fault. Here we introduce a computational framework combining 3D boundary element (BEM)-based quasi-dynamic earthquake sequence simulations with a Fourier Neural Operator (FNO). The FNO is trained to specifically provide rapid mapping from slip distributions to elasto-static traction changes (with relative L2 error within 3 percent and computational time < 0.01 seconds on a single GPU), given arbitrary isotropic elastic heterogeneity, while the balance equation equating shear stress with fault strength is solved numerically with adaptive time stepping. We show that for SCEC Benchmark Problem 5 and a case with fractal initial conditions on the fault, BEM-FNO hybrid framework

produces earthquake sequences that are visually indistinguishable from those done with conventional, Okada-based BEM. We will also show preliminary results of earthquake sequence simulations in the presence of strong elastic heterogeneities with the BEM-FNO hybrid approach.

Unified Nucleation Mode and Mechanics Model for All Earthquake Rupture Speeds

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Earthquakes are destructive natural hazards with damage capacity dictated by rupture speeds. Traditional dynamic rupture models predict that earthquake ruptures gradually accelerate to the Rayleigh wave speed with some of them further jumping to stable supershear speeds with a transition mechanism. We show that spontaneous shear ruptures on laboratory faults can attain steady sub-Rayleigh or supershear propagation speeds immediately following nucleation, illustrating a unified rupture nucleation mode across all possible rupture speeds. A self-similar analysis of dynamic rupture then leads to a unified mechanics model where the rupture speed is uniquely determined by a driving load regardless of the speed. Our results reproduce and explain a number of enigmatic field observations on earthquake speeds, including the early onset of supershear ruptures, stable sub-Eshelby supershear ruptures, and the dictating role of fault loading on the rupture speed.

New Developments in Earthquake Rupture Physics For Source Characterization and Ground Motion Modeling [Poster]

Poster Session • Thursday 16 April

Conveners: Ruth Harris, U.S. Geological Survey (harris@usgs.gov); Camilo Pinilla-Ramos, University of Southern California (camilo.pinilla@berkeley.edu); Arben Pitarka, Lawrence Livermore National Laboratory (pitarka1@llnl.gov); David D. Oglesby, University of California, Riverside (david.oglesby@ucr.edu)

POSTER 167

Improving Parallel Scalability and Solver Performance in the PyLith Crustal Deformation Modeling Software

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We provide an overview of recent enhancements to the open-source crustal deformation finite-element modeling code PyLith. PyLith uses a multiphysics formulation to solve the governing equations of quasi-static or dynamic elasticity, poroelasticity, or incompressible elasticity, with various bulk rheologies and prescribed quasi-static fault slip. The recent changes improve parallel scalability by adopting a modular approach for loading finite-element meshes in serial or parallel, reordering and refining meshes, and inserting cohesive cells for faults. We also improve solver performance by fine-tuning the default parameters of the algebraic multigrid preconditioner and by incorporating both length and displacement scales in the nondimensionalization of the governing equations. Updated examples distributed with PyLith demonstrate the improved solver performance; in solving the two- or three-dimensional quasi-static elasticity equation with prescribed fault slip, the number of iterations in the linear solve is relatively insensitive to the number of unknowns across four orders of magnitude.

Current development focuses on (1) updating the code to use the latest version of the Pyre Python simulation framework, which PyLith uses to specify simulation parameters; (2) implementation of dynamic prescribed slip using an implicit-explicit time integration scheme; and (3) implementation of fault friction and a multi-grid nonlinear solver. PyLith is developed and distributed through the Computational Infrastructure for Geodynamics (https://geodynamics.org/resources/pylith).

POSTER 168

Identify Transient Supershear Rupture Through Deciphering Near-fault data

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Near-fault data are essential in studying earthquake source physics due to their high sensitivity to rupture propagation on faults. The 2023 Mw 7.8 Kahramanmaraş, Türkiye earthquake was well-recorded by a dozen of local strong motion stations located within 3 km to the Amanos segment of the East-Anatolian fault (EAF), providing a great opportunity to explore the application of near-fault data in resolving source dynamics. In this study, we explore the features of velocity waveforms at these stations and develop a new approach to investigate the rupture speed.

The velocity waveforms display large pulses in both fault-parallel (FP) and fault-normal (FN) components. FN components usually feature a single several-seconds-long pulse, while FP components display varying number of pulses among different stations. We conduct dynamic rupture simulations and note that the number of FP pulses is related to off-fault distance and rupture speed. In the subshear rupture zone, stations locating within 1 km off fault display a single FP pulse, while stations locating between 1 to 3 km off fault show double FP pulses. Tripple FP pulses appear when the station locates between 1 to 3 km and in the transient supershear rupture zone. Besides the waveform shape, we also note that the onset timing difference (OTD) between FP and FN pulses can be an indicator of the rupture speed. The onset timing of the first FP pulse for stations within 1 km off fault and of the second FP pulse for stations between 1 to 3 km off fault can represent the arrival of shallow rupture front, while the onset timing of FN pulse represents the arrival of shear wave energy. Then OTD exhibits the relative speed between the rupture and the shear wave. We apply the new approach of OTD calculation to the dataset along the Amanos segment and suggest that supershear transition exists between stations #2718 and #3143 during the Kahramanmaraş earthquake. We further apply the OTD method to other near-fault records with well verified subshear or supersehar rupture speeds to examine and the reliability of the new approach.

POSTER 169

Analysis of Energy Budgets as a Means of Comparing Modeled Earthquakes Along the Cascadia and Sumatra Subduction Zones

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Understanding the energy dynamics of megathrust earthquakes is vital to assessing their impact and constraining non-unique models. Earthquake energy budgets, defined as sums of frictional, fracture, and seismic energies, are not fully understood. Simulations on high-performance computing (HPC) platforms are one way to visualize ruptures and study how energy is dissipated by a fault, and through seismic waves, under different initial conditions. The HPC-enabled tool, SeisSol, solves for dynamic rupture on complex, three-dimensional faults and seismic wave propagation through heterogeneous media. We present energy budgets from models based on the 2004 Mw9.1 Sumatra-Andaman earthquake and compare them with seismological observations. Overall, the models produce realistic energy components relative to seismological estimates. For example, Kanamori (2006) reports radiated energy of 3E17 J and the preferred Sumatra model produces radiated energy of 5.6E17 J. This preferred model produces a larger ratio of radiated energy to seismic moment of 1.14E-05, relative to the estimate of 4.6E-6 (Kanamori 2006). Across the suite of models, which vary in earthquake magnitude and distributions of stress drop and peak slip rate along the megathrust interface, we find that total energy scales with magnitude. But, these model earthquakes partition energy equally, with 12.3% going into radiated energy and the remaining 87.7% dissipated into work against friction and fracturing. We also share results for models with varying megathrust interface geometries along the Cascadia subduction zone, where the last megathrust earthquake was in 1700. We report how earthquake characteristics control the energy budgets of these potential megathrust earthquakes and compare these results with the results from the Sumatra models. The results for the Cascadia models help constrain megathrust geometry at Cascadia and allow for quantification of the influence of different geometries on energy partitioning in megathrust

events. Energy budget comparisons yield another way to compare and contrast seismic events across Sumatra and Cascadia.

POSTER 170

Mitigating Geometry-induced Stress Singularities in Three-dimensional Boundary Element Method Simulations of Rough Faults

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Physics-based computational models are essential for understanding and predicting fault slip behavior across a wide range of spatial and temporal scales. A realistic representation of earthquake physics requires incorporating complex fault geometry, which plays a critical role in controlling rupture initiation, propagation, and arrest. The Boundary Element Method (BEM) is widely adopted for quasi-dynamic earthquake simulations due to its ability to model geometrically complex faults using boundary-only discretization. However, conventional BEM implementations rely on analytical dislocation solutions with piecewise constant slip on flat rectangular or triangular elements, introducing unphysical stress singularities at element boundaries. These artifacts are further amplified in simulations of 3D rough faults, where discretized geometry and slip heterogeneity jointly produce nonphysical stress concentrations. As a result, such singular stress fields compromise the accuracy of on-fault stress calculations and pose challenges for earthquake cycle modeling.

To address these geometry-induced singularities, we introduce a strategy that more faithfully approximates the mechanical behavior of smoothly curved fault surfaces. Rather than directly evaluating stresses due to, and resolved on, flat elements, each element is subdivided into smaller sub-elements that better capture the local curvature of the fault surface. Moreover, we test different choices of receiver location and orientation, and demonstrate that small differences in the orientation of the local normal vector, introduced by discretization, play a critical role in controlling normal stress distributions along the fault. The resulting composite representation, together with a consistent definition of local normals, bridges the gap between discretized and smoothly curved geometries, reducing geometric discontinuities and resulting in a smoother stress field that closely matches analytical approximations. This approach improves the physical consistency of on-fault stress estimates and provides a more robust framework for BEM simulations of rough fault surfaces.

POSTER 171

Rich Rupture Dynamics of the 2025 Mw 7.7 Mandalay Earthquake Revealed by Unprecedented Near-fault and High-resolution Observations

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Resolving earthquake rupture complexity depends critically on near-fault observations, which remain exceedingly rare. Often, a single key observation can reshape our understanding of rupture processes. The 2025 Mw 7.7 Mandalay earthquake along the geometrically simple Sagaing Fault provided an unprecedented dataset, including the first near-fault video capturing rupture, strong-motion recordings, field surveys, and satellite imagery. By combining computer vision, image analysis, and dynamic rupture modeling, we reconstructed high-resolution coseismic slip, ground motion, and distributed deformation, revealing remarkably rich rupture dynamics. Near Thazi, video captured a shallow subshear rupture underlain by a deeper supershear rupture, indicating a subshear-to-supershear transition controlled by depth-dependent friction. The footage also revealed off-fault dynamic tensile cracks forming ahead of the rupture, oriented ~37.5° to the fault strike on the com-

pressional side—overturning the conventional view that such cracks develop only under static stress or on the extensional side. Field surveys confirmed abundant similar cracks invisible to optical or SAR satellite imagery. Near Nay Pyi Taw, strong-motion recordings revealed a northward back-propagating supershear rupture dynamically triggered by the earthquake's own P-waves on a critically prestressed southern segment. These observations demonstrate that even geometrically simple faults can host rich rupture behaviors. The methods developed here could enable low-cost near-fault video monitoring of rupture processes in resource-limited regions. The growing availability of high-resolution near-fault data provides an unprecedented opportunity to address fundamental questions in earthquake physics, including rupture speed diversity, depth-dependent rupture behavior, off-fault crack generation, and dynamically triggered rupture—challenging conventional interpretations based solely on far-field observations.

New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets

Oral Session • Friday 17 April • 10:30 AM Local

Conveners: Tariq Alkhalifah, King Abdullah University of Science and Technology (tariq.alkhalifah@kaust.edu.sa); Ebru Bozdag, Colorado School of Mines (bozdag@mines.edu); Lori Dengler, California State Polytechnic University, Humboldt (Retired) (lori.dengler@humboldt.edu); Arash Fathi, ExxonMobil Technology and Engineering (arash.fathi@exxonmobil.com); Peggy Hellweg, University of California, Berkeley (Retired) (hellweg@berkeley.edu); Susan E. Hough, U.S. Geological Survey (hough@usgs.go); Kami Mohammadi, University of Utah (kami.mohammadi@utah.edu); Jack Muir, Fleet Space Technologies (jack.muir@earth.ox.ac.uk); Jeroen Ritsema, University of Michigan (jritsema@umich.edu)

Widespread Urban Seismic Quietening During the 2024 Total Solar Eclipse

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Solar eclipses are hugely significant cultural events. Although not often discussed, they also have a substantial seismic impact as wind speeds drop and anthropogenic activity decreases. We explore these phenomena by examining data from across Canada and United States during the 2024 April 8 total solar eclipse. We compute relative noise levels in more than 10,000,000 time windows across the month for several hundred seismic stations.

A clear pattern of urban seismic quietening is observed for many cities within the totality line; wherein noise levels peak slightly before the start of totality before fading significantly during the total obscuration of the Sun by the Moon and then rising back to above-average levels for the month. Such a pattern is not observed for cities even slightly outside the path of totality or rural areas within it, suggesting that this is a localised phenomenon associated with modified anthropogenic activity.

Additionally, our results present (another) piece of evidence to show that the exact Earth-Moon-Sun syzygy does not cause enhanced seismic activity, i.e. eclipses do not cause earthquakes.

Seafloor Topography Controls Primary Microseism Generation: New Insights From Cyclone-forced Seismic Observations in Northeastern Australia

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Primary microseisms are long-period seismic waves generated by the interaction of ocean surface gravity waves with the seafloor, yet the spatial distribution and excitation mechanisms of their sources remain poorly resolved. Here, we investigate the heterogeneous generation of primary microseisms associated

with seasonal tropical cyclone activity and Cyclone Ita in North-east Australia (2014). Combining continuous seismic data from a regional network with high-resolution (30 m) bathymetric maps, we show that primary microseism excitation is highly localized in both time and space, and critically dependent on fine-scale seafloor roughness. Our analysis reveals that the most energetic Rayleigh wave bursts originate from regions with pronounced bathymetric variability, where coupling between ocean waves and the solid Earth is most efficient. The finding provides observational evidence supporting the theoretical conjecture that topographic undulations at scales comparable to ocean-wave wavelengths govern the strength of microseismic sources in the 10–20 s period band. Our findings highlight the critical role of nearshore bathymetric roughness in shaping the spatial coherence of primary microseism excitation. These understandings are essential for guiding the future applications of persistent seismic sources in seismic imaging of Earth’s near-surface structures and for monitoring the evolution of the seismic wavefield.

Earthquake Observations From Moored Vertical Hydrophone Array in Arctic Ocean

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Six hydrophone moorings were deployed in the Arctic Ocean during the 2019-2020 Coordinated Arctic Acoustic Thermometry Experiment (CAATEX) to study ocean water temperature variations throughout the year by using sound-speed profiles inferred from the arrival times of signals from known active sources. The six moorings were grouped into two sets of three: one north of Canada and one north of Svalbard, Norway, forming a line across the North Pole. Each mooring was equipped with a distributed vertical line array (DVLA), containing 25-40 hydrophones on a vertical cable with a 30-40 m spacing, measuring the hydroacoustic pressure from depths of 50-1200 m. One of the three moorings in each group had a transducer positioned directly above the DVLA, which transmitted an 875-s-long signal, centered at 35 Hz, every 3 days. The hydrophones recorded twice a day for a total of 90 minutes (from 11:59:50 or 23:59:50 UTC to 12:45:00 or 00:45:00 UTC) with a sampling rate of 976.5625 Hz. Over a year of deployment, these moorings passively listened to sounds in the ocean, including earthquakes, in addition to the active sources. This deployment allowed us to observe seismic activities in the Arctic Ocean from their signals in the water column. We present a catalog of earthquakes recorded by these moored vertical hydrophone arrays, together with incident angles inferred from the acoustic wave propagation speed along the cable from both P waves and oceanic T phases. These observations are useful for studying the seismic activity as well as the physical structure of the ocean and the solid Earth along the source-receiver paths. We explore using earthquake signals to infer the sound speed profile and model the effects of ocean bathymetry and possible sound speed changes on the acoustic waves generated by these earthquakes. We hope that our findings will contribute to the understanding of the acoustic environment of the Arctic Ocean and show the possibility of using ocean acoustic observations to study the Earth.

Tremor-like Signals Along the San Jacinto Fault: Observations From a Long-term Dense Seismic Array (Faultscan)

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Since their identification in the early 21st century, tectonic tremors have attracted considerable interest as they provide a unique window into the mechanisms and activity of fault systems. However, their emergent character and lack of clear phase onsets make them difficult to detect and to distinguish from anthropogenic noise. In the San Jacinto Fault region, recent observations of tremor-like signals have fueled debate within the seismological community

as to whether these signals originate from deep tectonic processes or from human activity.

In this study, we investigate the presence and characteristics of tremor-like signals along the San Jacinto Fault in Southern California. Our approach relies on slant-stacking applied to data from the long-term FaultScan dense nodal array, composed of 300 stations deployed at the Piñon Flat Observatory between mid-April 2022 and mid-October 2024. We perform beamforming at crustal P- and S-wave velocities, typically associated with tremor propagation, and develop a detection proxy based on slant-stacked waveform envelopes. To minimize contamination from anthropogenic sources (e.g., train-induced signals from the Coachella Valley) and wind-generated noise, we focus on coherent body-wave energy and azimuths oriented toward the fault zone.

Our search for tectonic tremors along the San Jacinto Fault turns up empty. Instead, we observe a variety of tremor-like signals, dominated by acoustic T-phases from large offshore earthquakes in the Tonga subduction zone, as well as well-resolved earthquake sequences and spectral-line signals. We also identify one intriguing T-phase-like sequence associated with the October 2023 offshore Japan volcanic crisis.

Extremely Shallow Semi-repeating Tremor Caused by Water Hammers in a Sewer Pipe in Social Circle, Georgia

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Repeating earthquakes are mostly generated by small asperities that are loaded by continuous creep surrounding them, and their recurrence times are inversely proportional to the loading rates. However, sometimes anthropogenic activities can also produce repeated seismic shakings with shorter recurrence intervals, and their source mechanisms can vary. Here we reported semi-repeating ground vibrations recorded in Social Circle, Georgia starting on August 14th 2025. Ten tremor-like events were captured by sixteen three-component SmartSolo sensors during one hour on August 15th 2025, followed by four days of continuous observation by three stations. The signals recur nearly every six minutes with similar but not truly repeating waveforms and clear diurnal amplitude variations that are stronger during daytime. Clustering analysis reveals several sub-event types with distinct coda durations. Their timing correlates with expected residential water-use patterns, suggesting a shallow anthropogenic source. Later excavations revealed that a forced main pipe connected to a local pump station vibrated nearly every six minutes, likely caused by the water hammer effect due to a faulty check valve. These findings demonstrate that human activities in the shallow subsurface can generate semi-repeating seismic waves, exhibiting recurrence behavior analogous to natural fault or volcanic systems. Correctly identifying their causes help to better distinguish them from naturally occurring events.

Railroad Buckling in Earthquakes

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Photographs of railroad tracks buckled by earthquakes have been invoked as evidence of severe epicentral strain. Buckling is anticipated because near-surface strain above shallow earthquakes can locally far exceed the 10⁻⁴ strain known to cause thermoelastic instability in rails. However, the stress pathways responsible for these two processes are fundamentally different. Thermoelastic stress develops within the steel rails and is locally resisted by track infrastructure, whereas transient dynamic strain associated with seismic waves is transmitted to track infrastructure but resisted by the rails. Weak coupling between the rails and track infrastructure allows dynamic strain to be distributed over hundreds of meters, thereby reducing the likelihood of buckling. Recent examples from Türkiye show railroads crossing surface ruptures, creeping faults, or zones of lateral spreading to be primarily buckled by static strain. In contrast, documented railroad buckling during the 1886 Charleston earthquake has been attributed to transient dynamic strain (Bilham and Hough, 2024). This apparent inconsistency can be explained by changes in track construction. Twentieth-century rails have greater height, width, and thickness than 19th-century rails, resulting in a moment of inertia approximately four times larger. Modern track therefore requires more than twice the longitudinal compressive stress to initiate elastic instability; this exceeds the forces that can be mobilized through track infrastructure. As a result, while documented buckling of tracks may shed new light on near-field strain in historical earthquakes, modern railroads are largely resistant to buckling from dynamic strain in earthquakes, with the notable exception of locations where dynamic strain nucleates lateral spreading and localized static strain.

Potential Abiotic Methane Hydrate in Earth’s Deepest Subduction Zone

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Methane hydrate is widely observed along continental margins where biotic carbon and hydrogen are rich. In contrast, abiotic origin methane hydrate was rarely reported despite that serpentinization in the mantle generated hydrogen and methane pervasively. Here we reported for the first time the Bottom Simulating Reflector (BSR), an indicator of methane hydrate, beneath a pelagic ocean that is far away from continental margins. We image the shallowest velocity interfaces below seafloor (bsf) in the southern Mariana subduction zone by applying a new active-source receiver function (RF) technique to an Ocean Bottom Seismometer profile across the trench. Our results indicate a sharp velocity-reduction interface, i.e. BSR, ~0.2-0.3 km bsf for stations located ~20-50 km from the trench on the overriding plate. This location coincides with a high-velocity crustal anomaly and the serpentinized peridotites sampled at comparable distance perpendicular to the trench. These evidence suggests that the BSR resulted from abiotic H₂ and CH₄ released during peridotite hydration in the overriding mantle. We propose that this process may be widespread in global subduction zones, representing a critical source of methane hydrate.

The Martian Crust Outside Elysium Planitia From Joint Probabilistic Inversion of PP/SS Precursors and Rayleigh Waves

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Seismic observations from the InSight mission have revealed a stratified Martian crust beneath the landing site, while surface-wave studies have provided long-wavelength constraints on global crustal thickness. However, the fine-scale internal structure of the crust away from the lander remains poorly resolved, and there are limited constraints on the extent to which intracrustal layering persists across the Martian crust. In this study, we analyze distant seismic event data, specifically their PP and SS reflections, to investigate crustal structure at the bounce points located midway between the InSight lander and the event sources. We use SHARP-SS, a recently developed seismic method that employs Bayesian probabilistic inversion with a reversible-jump Markov chain Monte Carlo framework, to reliably identifies and characterizes underside- and topside-reflection signals that arrive before and after the PP and SS reflections. By jointly inverting both PP and SS waveforms, we leverage the complementary sensitivity of the two wave types and link their travel times through layer specific, variable velocity ratios, thereby yielding improved constraints on Mars’s crustal wave speeds. Our analysis of event S0976a confirms previously reported PP and SS precursor signals (Li et al., 2022). For event S1000a, we perform a joint inversion of the PP precursor waveform and Rayleigh-wave dispersion measurements reported by Kim et al. (2022), allowing us to better constrain both absolute velocities and crustal thickness. The resulting model indicates a shear-wave velocity increase at depths of approximately 30–40 km, accompanied by an increase in vp/vs ratio near ~20 km depth. These results demonstrate that joint probabilistic inversion of body-wave precursors and surface waves provides new constraints on the lateral variability and internal stratification of the Martian crust beyond the InSight landing region.

Earth Balloons Sensors as Precursors of Venus Seismology Missions

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Our understanding of the formation, evolution, and interior structure of Venus remains critically limited by the inability of conventional seismic instrumentation to survive the planet’s extreme surface conditions (about 460°C, 90 bars). While seismology has been fundamental to characterizing the interiors of Earth, the Moon, and Mars, a new approach is required for Venus. Despite the lack of plate tectonics, Venus likely experiences frequent intraplate seismicity, active volcanism, and atmospheric-surface coupling that could serve as detectable seismic sources.

Crucially, theoretical models indicate that acoustic waves from seismic events couple significantly more efficiently into the dense Venusian atmosphere than into Earth’s. To exploit this strong atmosphere-surface coupling, we propose the use of aerial platforms equipped with infrasonic sensors as a viable alternative to short-lived surface landers.

We report on the development of this work through our analysis of terrestrial measurements, with a focus on Earth analogue campaign, specifically measuring seismic activity using infrasonic sensors deployed in the stratosphere. Preliminary demonstrations have successfully validated the detection concept and our ability to measure quakes from the stratosphere. Consequently, this work is now advancing toward a comprehensive, end-to-end analysis of infrasonic balloons , with a focus on instrumentation but also event detection, to establish a robust framework for the remote geophysical exploration of the Venusian interior.

Distributed Acoustic Sensing Without Burial: Implications for Seismic Studies of the Moon and Earth

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Advances in seismic sensing on Earth are opening new possibilities for observing seismic processes on planetary bodies. On the Moon, much of our current understanding of internal structure is derived from a small number of Apollo-era seismic sensors sparsely distributed on the lunar surface. Distributed Acoustic Sensing (DAS), which transforms fiber-optic cables into dense, large-N seismic arrays, offers a fundamentally different approach to sensing seismicity, enabling scalable deployments with minimal surface operations. However, the feasibility of DAS on the lunar surface hinges on whether an effective coupling between the fiber cable and regolith can be achieved without burial.

We conducted earthquake detection and controlled-source experiments in a lunar regolith simulant to evaluate the performance of surface-deployed DAS. Earthquake recordings from regional and local events were obtained using fiber deployed at varying burial depths, while controlled shaker experiments systematically isolated the effects of burial, cable mechanical properties, free-hanging segments, and atmospheric noise on signal fidelity.

We find that, in a low-noise environment, surface-draped DAS can reliably detect remote seismic signals, with attenuation not consistently correlated with burial depth. Controlled-source experiments show that while burial improves amplitude and phase stability, mechanically stiff, thicker unburied cables can achieve comparable coupling when continuous ground contact is maintained. We also find that free-hanging cable sections significantly degrade performance, and wind-induced noise is shown to be a primary limitation for unburied terrestrial deployments—an effect absent on the Moon.

Our experiments clearly demonstrate that surface-deployed DAS is a viable and potentially transformative tool for future lunar seismic sensing and suggest a broader role for DAS in enabling new observational paradigms in both planetary and terrestrial seismology.

The Distributional Finite Difference Method: An Efficient Approach for High-resolution Global Wavefield Simulations

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As seismologists seek increasingly higher spatial resolution to investigate small-scale objects in Earth’s mantle, traditional numerical methods face sig-

nificant bottlenecks. The complexity of meshing, wavefield accuracy requirements, and escalating computational costs at high frequencies necessitate a new generation of wave propagation codes. Specifically, there is a demand for flexible methodologies that can handle variable resolution across 3D models and maintain accuracy at fluid-solid boundaries while remaining computationally competitive with established tools like the Spectral Element Method (SEM).

In this study, we evaluate the Distributional Finite Difference (DFD) method as a promising approach for global seismology. DFD combines the structural simplicity of pseudo-spectral and finite-difference methods with the rigorous boundary condition treatment characteristic of spectral element techniques. DFD accounts for material discontinuities and non-conformal interfaces via an element-wise domain decomposition. A key advantage of this approach is that numerical accuracy is independent of element size. Consequently, elements can be very large in smooth regions of a model and refined only where required by the geometry. We are developing a portable, high-performance C++ implementation of the DFD solver designed to leverage the power of different modern high-performance computing (HPC) systems.

Preliminary benchmarks in the framework of acoustic 2D simulations indicate that DFD is computationally faster than SpecFEM2D in AK135 earth model for equivalent levels of accuracy. When optimized for parallel architectures and integrated with hybrid modeling approaches, DFD represents a powerful tool for imaging remote targets in the deep mantle.

Building Local sP and PmP Phase Datasets for Precise Earthquake Location and Whole-crust Imaging Using AI-assisted Methods

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Later seismic phases, such as sP depth phases and Moho-reflected PmP waves, provide critical constraints on earthquake source parameters and crustal structure, yet they are rarely used in routine earthquake studies. For instance, accurate focal depth is often difficult to determine due to trade-offs with origin time, especially in regions with sparse near-source stations. The sP phase offers a powerful constraint on depth, but its systematic use has been limited by identification challenges.

We develop an integrated workflow that combines expert phase analysis with artificial intelligence tools to build high-quality local sP and PmP phase datasets. Key characteristics of sP and PmP waves are first identified through careful analyst review to generate reliable training datasets. Based on these expert-labeled data, deep-learning models, including PmPNet for PmP identification and sPNet for sP detection, are trained to automatically identify these later phases from large seismic datasets.

Our primary goal is to construct comprehensive local sP and PmP datasets in seismically active regions such as California and Sumatra, enabling broader use of these phases in earthquake studies. Initial applications in California demonstrate that incorporating sP phases reduces focal-depth uncertainties by a factor of five for most crustal events. These expanded datasets will provide a robust foundation for improved earthquake relocation and high-resolution imaging of Moho topography and lower-crustal structure.

Full Waveform Inversion of the Los Angeles Basin Using Neural Operators

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Full waveform inversion using conventional numerical methods is computationally expensive for large 3D problems. Neural operators offer a data-driven alternative that can approximate solutions to wave equations orders of magnitude faster while remaining reasonably accurate. Building on recent advances in neural operators for elastic wave modeling and inversion, we apply the machine learning approach to the LAB2022 data set, a nodal seismic array spanning the Los Angeles Basin. We use a transformer-based Helmholtz neural operator as the forward modeling engine and automatic differentiation for full waveform inversion, enabling extensive parameter search that is prohibitive with conventional methods. Our results demonstrate the feasibility of large-scale neural-operator-based full waveform inversion using real

seismic data and highlight its potential to refine velocity structures in regions with comparable spatial footprints, which is important for earthquake hazard assessment and tectonic studies.

From Physics to Scale: Building Foundation Models for Seismic Full-waveform Inversion

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Seismic full-waveform inversion (FWI) is a central tool for high-resolution subsurface imaging in energy, resource, and Earth science applications. By exploiting the full information content of seismic wavefields, FWI enables detailed recovery of subsurface properties, but it remains computationally expensive, highly nonlinear, and severely ill-posed. Recent advances in artificial intelligence offer new opportunities to address these challenges, while raising a fundamental question: how can learning-based approaches respect wave physics while scaling to realistic seismic problems?

In this talk, I will present our recent progress in applying AI to seismic FWI through two complementary directions that together motivate the development of seismic foundation models. The first direction focuses on physics-informed learning, where wave equations and physical constraints are embedded into model architectures or training objectives to improve stability, interpretability, and data efficiency. The second direction explores large-scale, data-driven learning, including auto-regressive and foundation-style models trained on extensive seismic simulations, which learn transferable representations of wave propagation across acquisition settings and geological regimes. By contrasting physics-guided and data-scaled approaches, I will discuss their strengths, limitations, and emerging hybrid strategies. Through examples in seismic velocity model building and waveform inversion, I will illustrate how these ideas improve robustness, scalability, and imaging fidelity. I will conclude with a perspective on building physics-aware foundation models for seismic inversion as a pathway toward reliable and trustworthy subsurface characterization.

Red-DiffEq: Regularization by Denoising Diffusion Models for Solving Inverse PDE Problems With Application to Full Waveform Inversion

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Partial differential equation (PDE)-governed inverse problems are fundamental across various scientific and engineering applications; yet they face significant challenges due to nonlinearity, ill-posedness, and sensitivity to noise. Here, we introduce a new computational framework, RED-DiffEq, by integrating physics-driven inversion and data-driven learning. RED-DiffEq leverages pretrained diffusion models as a regularization mechanism for PDE-governed inverse problems. We apply RED-DiffEq to solve the full waveform inversion problem in geophysics, a challenging seismic imaging technique that seeks to reconstruct high-resolution subsurface velocity models from seismic measurement data. Our method shows enhanced accuracy and robustness compared to conventional methods. Additionally, it exhibits strong generalization ability to more complex velocity models that the diffusion model is not trained on. Our framework can also be directly applied to diverse PDE-governed inverse problems.

New Frontiers in Seismic Observations and Modeling with Innovative Methods and Emerging Data on Earth and Other Planets [Poster]

Poster Session • Friday 17 April

Conveners: Tariq Alkhalifah, King Abdullah University of Science and Technology (tariq.alkhalifah@kaust.edu.sa); Ebru Bozdag, Colorado School of Mines (bozdag@mines.edu); Lori Dengler, California State Polytechnic University, Humboldt (Retired) (lori.dengler@humboldt.edu); Arash Fathi, ExxonMobil Technology and Engineering (arash.fathi@exxonmobil.com); Peggy Hellweg, University of California, Berkeley (Retired) (hellweg@berkeley.edu); Susan

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POSTER 104

Retrospective and Near-fault Constraints for High-resolution Earthquake Relocation

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Accurate earthquake locations are fundamental for resolving fault geometry, rupture processes, and earthquake physics. Although improved seismic network coverage and double-difference relocation techniques have substantially enhanced location precision, two challenges remain: improving earthquake locations during periods of sparse network coverage, and robustly constraining mainshock hypocenters as they were in short of S picks and cross-correlation constrained differential times.

We present a set of practical strategies for earthquake location refinement, including a retrospective relocation framework, grid-search-based relative relocation for mainshocks, and hypocenter depth refinement using near-epicentral observations. These methods are applied to the Weiyuan shale gas field, where seismic monitoring evolved from a sparse network with ~27 km station spacing during 2015–2018 to a dense near-fault network with ~5 km spacing since 2019. By first relocating earthquakes using the dense network and then retrospectively constraining earlier events, location uncertainties in the sparse-network stage are reduced from kilometer-scale to <100 m, representing an improvement of approximately one order. We further implement a grid-search relative location approach to refine the largest two M5 earthquakes, which significantly improved earthquake locations that were biased during double-difference relocation.

We further examine how station distance affects mainshock depth determination using the 2008 M_w 7.9 Wenchuan earthquake as a case study. While previous studies reported hypocenter depths of ~15 km based on mixed near and far observations, our analysis demonstrates that inclusion of distant stations introduces systematic depth bias. Using near constraints that are sensitive to depths, we obtain a robust hypocenter depth of ~8 km. Combined with first-motion polarity analysis, these results indicate rupture initiation on a low-dip fault (<30°), rather than a high-angle reverse fault.

POSTER 105

Infrasound Analysis of the Osiris-Rex Re-Entry: Examining Shock Wave Behavior

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The OSIRIS-REX sample return capsule re-entry provided a unique, controlled opportunity to study atmospheric shock wave propagation from a high-altitude source. Unlike natural meteoroids, which often undergo complex fragmentation and ablation, the capsule offered a stable source for characterizing specific acoustic generation mechanisms. We utilize infrasound data recorded by a regional network of ground-based sensors to analyze the acoustic signature associated with the descent. This study employs a semi-analytical weak-shock approach developed for a cylindrical line source to evaluate signal evolution as the wavefront propagates through the atmosphere. We examine the applicability of established shock theories to the recorded data, comparing theoretical predictions with the observed waveforms. The analysis explores the relationship between source characteristics and observations, providing a framework for better understanding the physics of non-fragmenting and non-ablating entries. These findings have broader implications for the monitoring and characterization of space debris, artificial re-entries, and meteoroids using infrasound stations.

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POSTER 106

Low-angle Subduction of the Indian Plate and Megathrust Geometry Below the Eastern Himalayas

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Complex Faulting in the Eastern Himalayas

The Eastern Himalayas are a region of both intercontinental convergence and strike-slip faulting. The area produces large earthquakes that threaten population centers of millions of people. However, there is no accepted explanation for the combined strike-slip and thrust faults that cause the frequent earthquakes.

New Seismic Data

In a recent study by Bai et al. (2025), new data recorded on a recently deployed broadband seismic array in the region was analyzed. Installing instruments in this largely inaccessible area is often difficult so there are few previous data from this area. Using earthquake focal mechanisms, the regional stress field is found to be dominantly north-south horizontal compression, which is consistent with both the thrust and strike-slip faulting. Also, details of the structure of the Moho and the geometry of subducting Indian plate are clarified from earthquake relocation and receiver function analyses of the seismic data.

Proposed Tectonic Model

Using the results from the new seismic data, a tectonic model was proposed for the region. The model shows that the generation of earthquakes and the uplift of the broad mountains beneath the Eastern Himalayas region can be explained by the dominant north-south compression and a gentle under-thrusting of the Indian plate. The subduction interface is well recognized in the Western and Central Himalayas but more complicated in the Eastern Himalayas.

References

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POSTER 107

Subduction Zone Flow From Global Anisotropic Full-waveform Inversion

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Anisotropy is a key parameter for elucidating subduction-related mantle flow mechanisms, yet it remains poorly understood. Current seismic models exhibit significant discrepancies, and there is no consensus on anisotropic structure inferred from different data sets (e.g., shear-wave splitting versus surface-wave-based anisotropic models). Previous studies have suggested a correlation between trench velocity and mantle flow patterns at subduction zones based on shear-wave splitting observations. In this study, we investigate subduction-zone flow using the azimuthally and radially anisotropic full-waveform inversion model, GLAD-AZI-M28 (in prep.). The model is constructed using minor- and major-arc surface waves after 28 iterations. We systematically compare the resulting anisotropic patterns with a global compilation of SKS splitting measurements and trench velocity data. Our initial results reveal a global-scale correlation at subduction zones below 200 km depth between trench retreat and fast anisotropic directions, consistent with flow-induced anisotropy. The pattern is distinctly different in regions characterized by trench advance.

POSTER 108

Azimuthal and Radial Anisotropy of the Middle East

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Azimuthal anisotropy is a key parameter for understanding lithospheric deformation and mantle flow, and properly accounting for anisotropy can be helpful for accurately estimating seismic source parameters. We present MEAD-AZI, an azimuthally and radially anisotropic full-waveform inversion (FWI) model of the Middle East. The model builds upon MEAD-M20 (Orsvuran et al., in revision), which results from 20 conjugate-gradient iterations including transverse isotropy in the upper mantle. Starting from MEAD-M20, we have performed 15 more iterations, sequentially updating radial anisotropy and Rayleigh-wave azimuthal anisotropy. The inversion incorporates publicly available seismic data from global and regional networks, as well as data from the Saudi Geological Survey and the Iranian Seismological Center. We employ multitaper phase measurements for Rayleigh and Love waves in 30–60 s and 50–100 s period bands. We will discuss our observations in the context of regional tectonics and mantle geodynamics, and assess their impact on improved estimation of seismic source parameters.

POSTER 109

Earth's Mid-mantle via Probabilistic Array Imaging

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The Earth's mid-mantle (800–1200 km depth) hosts enigmatic seismic discontinuities whose physical origins remain debated. Competing hypotheses attribute these features to either thermal anomalies, such as partial melting due to volatile transport, or compositional heterogeneities associated with ancient subducted crust. However, distinguishing between these scenarios remains a challenge; standard imaging techniques often fail to robustly resolve the polarity of weak seismic reflections amidst noise and reverberations that contaminate mid-mantle reflections. Consequently, previous global surveys relying on linear time-domain stacking have yielded only a fragmented perspective, where the global connectivity, topography, and distinct physical origin of mid-mantle discontinuities remain debated. To address these limitations, we present a new global imaging framework that integrates curvelet-based wavefield separation and deconvolution, with probabilistic array processing. Rather than relying on traditional linear stacking, we develop “probabilistic vespagrams” that rigorously account for uncertainties in signal coherence and wavelet estimation. This approach allows us to distinguish robust structural features from processing artifacts. We apply this workflow to a global dataset of SS and PP precursors to construct a probability map of mid-mantle discontinuities. By systematically quantifying the likelihood of positive (eclogitic/compositional) versus negative (thermal/melt) impedance contrasts globally, we aim to resolve the global distribution of mid-mantle heterogeneities and determine the relative dominance of compositional stratification versus partial melting by water transport in controlling deep-Earth dynamics

POSTER 110

Receiver Function Migration Imaging of Sedimentary Structures in the Qaidam Basin

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Qaidam basin, situated on the northeastern margin of the Tibetan Plateau, hosts a massive Cenozoic sedimentary sequence reaching thicknesses of approximately 15 km. While the architecture of the basin has been constrained by active-source seismic profiles from hydrocarbon exploration, the high attenuation inherent in thick sedimentary cover often limits the penetration depth of such surveys. Passive seismic methods, taking advantage of high-energy earthquakes, offer superior penetration capabilities. Furthermore, recent advancements in nodal array technology allow for recording passive seismic data at unprecedented spatial density, providing new opportunities to image deep basin structures.

In this study, we investigate the feasibility of utilizing passive seismic data to resolve internal basin architectures. We analyzed one month of earthquake data recorded by 84 nodal stations deployed across the western margin of the Qaidam Basin with an average spacing of 4 km. By calculating high-frequency receiver functions (RFs) of up to 2.5 Hz, we applied array-based denoising techniques to suppress the strong ambient noise and improve the signal-to-noise ratio. Subsequently, a recently developed least-squares migration technique was employed to improve the imaging resolution. Our results

reveal significant variation in the basement topography, reaching a maximum depth of 10 km and shallowing toward the basin margins. Beyond the basement, we successfully imaged a distinct intra-sedimentary interface at about 3 km depth, potentially representing the transition from unconsolidated to consolidated sediments. The RF-derived structures show excellent agreement with a nearby active-source reflection profile. This study demonstrates that the passive seismic method is a robust, cost-effective approach for delineating first-order basin architecture, serving as a powerful complement to traditional active source seismic surveys.

POSTER 111

Glitch Finder General: Building a Glitch Detection Scheme Using the Matrix Profile

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Seismic data is a valuable tool that can be used to sample a planetary body's interior and reveal information about its tectonic activity. However, factors such as a limited number of seismic stations, noise, and even anomalous signals can complicate the task of seismic event detection. Factors such as noise or glitch-like signals can conceal or disrupt event waveforms, making it difficult to identify and characterize potential seismic events. In this work, we attempt to build a framework for “glitch” detection using the Matrix Profile (MP). The MP is a fast template matching method that does not require a priori templates, can be more efficient than traditional autocorrelation approaches, and unlike machine learning approaches, does not require training. Furthermore, previous work (Shakibay Senobari 2024) has shown that the MP is capable of detecting events below the noise level. For this reason, we apply the MP to the InSight seismic dataset to build a catalog of glitches for the martian seismic dataset.

The InSight seismic data set has a high signal-to-noise ratio that severely inhibits the detection of both seismic events and glitches, leading to the spatial and temporal clustering of these signals. Glitches can be concealed within true event waveforms and can even be misinterpreted as seismic signals, making their identification important. Before applying the MP to the full dataset, we applied the MP to the time periods between sols 246-259, 1009-1043, and 1211-1241. We use the Pan Matrix Profile (PMP) to select a set of subwindow lengths, which allows us to detect a variety of different signals. Preliminary results show we are able to identify glitches based on their high degree of similarity (MP correlation coefficient $r \geq 0.99$) and their “boxcar” shape in the resulting MP, even during noisier periods. As part of our future work, we will continue to curate this glitch catalog and refine our glitch detecting framework for application to other seismic datasets. Lastly, we will finetune the MP for seismic event detection in the martian seismic dataset.

POSTER 112

Revisiting Visible Ground Roll

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Observations of seeing the ground undulate during earthquakes goes back to the earliest days of earthquake observations. Visible ground roll (VGR) was included in early descriptions of earthquake intensity scales. Wood and Newman's Modified Mercalli Scale of 1931 has the wording “Waves seen on ground surfaces” as an indicator of intensity XII shaking. In more recent renditions of macrointensity, ground roll has fallen by the wayside as a strong motion indicator. It did not make it into the Coast and Geodetic Survey's postal questionnaire developed in 1928 or the subsequent version used by the USGS when they took over compiling U.S. earthquake data in the 1970s. The “Did You Feel It?” questionnaire currently used to collect and tabulate felt reports does not include a VGR question and some scientists have questioned the validity of such reports. We became interested in VGR in our re-examination of the M6.4 1954 Fickle Hill earthquake. As part of that study, we requested reminiscences of the earthquake in local newspapers and social media. We received over 40 reports from people who were between the ages of 3 and 14 when the earthquake occurred. Their descriptions of chimneys toppling and other strong motion indicators were used along with newspaper reports to revise the location and depth of the earthquake. An unexpected outcome of these reports was the prevalence of VGR observations. More than half of our observers who were outside at the time of the earthquake recalled

seeing the ground move like “waves on the ocean” and one person who was indoors saw the hallway of her home undulate. In this study we compile a partial catalog of credible reports of VGR, examine how VGR relates to other macroseismic indicators, and whether source characteristics such as depth and focal mechanism may influence these observations.

POSTER 113

An Hybrid High-order Method for the Elasto-Acoustic Wave Propagation on General Meshes

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Because of the complex geometry of some geological features, the simulation of elasto-acoustic wave propagation in the Earth is challenging. To handle efficiently this difficulty, we consider hybrid high-order (HHO) methods, which offer several attractive assets such as local conservativity, geometric flexibility through the support of polyhedral grids, and high-order precision. As HDG methods, HHO relies on a pair of unknowns, combining polynomialals attached to the mesh faces and the mesh cells. Here, HHO methods are studied for the space semi-discretization of coupled elasto-acoustic waves in the time domain using a first-order formulation. Explicit and singly diagonal implicit Runge–Kutta (ERK & SDIRK) schemes are used for the time discretization. We show that an efficient implementation of explicit (respectively implicit) time schemes calls for a static condensation of the face (resp. cell) unknowns. Our findings indicate that implicit time schemes remain competitive in many situations, at least in 2D. Simulations in a 2D realistic geophysical configuration (wave propagation in a sedimentary basin and coupling with the atmosphere) are performed, illustrating the geometrical flexibility of the HHO method: both hybrid (triangular and quadrilateral) and nonconforming (with hanging nodes) meshes are easily handled, delivering results of comparable accuracy to those of a reference spectral element solver.

POSTER 114

Using Fourier Neural Operator for Seismic Forward and Inverse Problems

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We are presenting our work on using the Fourier Neural Operator to solve the wave equation to simulate the 3D ground motion simulations from earthquakes and use it in both forward and inverse problems. We use the U-Shaped Neural Operator (U-NO) to solve the Helmholtz equation to forward simulate the 3D seismic ground motions and use the trained model to invert the seismic source. The inversion results from synthetic data show promising results; we are currently working on the real-data inversion. We set up the physical domain in San Francisco Bay Area and use the past earthquakes for the inversion. We will report our preliminary inversion results in this presentation.

POSTER 115

Ocean-bottom Seismology: Next-generation Technology Solutions for Marine Monitoring

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Researchers continue to intensify their focus on the seafloor to gain a deeper understanding of the Earth's structure, tectonic processes, and potential hazards through the acquisition of ocean-bottom seismic (OBS) data. However, the unique challenges of deep-sea environments require innovative, purpose-built engineering solutions and robust manufacturing techniques to safeguard

data quality, data completeness and system reliability, while meeting scientific objectives and optimizing ease of deployment. A range of cabled and autonomous ocean bottom sensing solutions are now available, supporting the global community's study of underwater ground motion, its dynamic properties, and natural or triggered events on the seafloor.

This poster presentation provides a comprehensive overview of the engineering challenges in the domain of OBS platforms, highlighting the advancements in technology and capability solutions that the Nanometrics team has developed to address those challenges for various configurations and use cases. With proven technologies such as integrated kinematic gimbals for levelling at all landing tilt angles, an integrated MEMS gyrocompass for precise orientation, and designs certified for deployment depths of up to 6000m, this poster will demonstrate that seamless multidisciplinary data collection across diverse marine environments is now more accessible than ever before. Recent technological advances include customer deliveries of both SMART cable seismic instrumentation and an integrated Cabled OBS observatory, expanding options to support a wide range of application-driven sensing instruments and dataloggers. This continuous innovation aims to facilitate further understanding of the dynamic properties in these challenging deep ocean environments.

POSTER 116

Earthquake Infrasound Recorded in the Maryland Piedmont

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The USGS reported an otherwise unremarkable 2.5 MLg earthquake October 27, 2025 21:17 UTC, in the mid-Atlantic Piedmont (4 km above the fall-line) near the Baltimore-Washington DC suburb of Columbia MD. “Did You Feel It?” registered 1227 responses with peak intensities of IV. The USGS network is sparse in this suburban area with the closest station 95 km distant. However, the 2.5 MLg event was recorded on 21 Raspberry Shake (RS) recorders within 51 km and a Raspberry Boom (RB) near the epicenter. Relocation moved 2.8 km westward within 2 km of the dual seismic-infrasound (RS,RB) station, R6CAF. The 0.3 second S-P at the site and 8 second Acoustic-P time locates significantly shallower than the USGS 8 km depth. Additionally, 0.5-3 Hz Rg waveforms, on 31 RS recorders out to 137 km, are inconsistent with a 8 km depth. Correlation processing (10 days before and 30 days after) detected two small aftershocks (ML <1) with no detectable infrasound. The Rg dispersion is consistent with measured dispersion from two 2021 shallow events 21 km NW consistent within the high velocity Piedmont metamorphics. The seismic-to-acoustic conversion event is very well recorded on the RS-RB station. The P and S wave arrivals on the microbarometer are linearly related to the vertical velocity at ~800Pa/(m/s). The first arrival of the pure infrasound signal (I1) at P+5 seconds is consistent with generation at the immediate epicenter, but large acoustic arrivals (I2) at P+8 and P+10 sec suggest more complicated conversions in the epicentral area. And, not correlated with shaking the instrument or the building structure. The record affords a rare opportunity to explore seismic generated infrasound at near epicentral distance. In historic context, in 1993 a series of magnitude 1 - 2.7 earthquakes were felt in close proximity to the 2025 event. Additional felt events occurred in 1996, 2001 and 2002.

POSTER 117

Physics-informed Neural Networks for P–SV Wave Propagation and Diffraction in Wedge-shaped Media

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Wedge-shaped discontinuities provide canonical models for continental margins, mountain roots, crustal offsets, and surface topography. Predicting scattered in-plane (P–SV) wavefields in wedges remains challenging because traction-free boundaries enforce P–SV coupling and mode conversion, while the wedge tip introduces a geometric singularity that generates diffraction and highly complex post-tip wavefield patterns. In contrast to the scalar out-of-plane (SH) wedge problems, closed-form solutions for the in-plane vector wedge problem exist only for a few special cases (e.g., diffraction-free 90° wedges and 120° wedges for specific Poisson ratios). Numerical methods can extend beyond these cases, but typically demand aggressive mesh refinement near the tip, rigorous stability constraints, and carefully designed radiation/absorbing boundaries to represent an effectively unbounded domain. We use Physics-Informed Neural Networks (PINNs) to investigate the response of a wedge subjected to a vertically propagating SV wave. The proposed PINNs is trained by minimizing residuals of the elastodynamic equations, together with traction-free boundary conditions, radiation conditions, and a small set of early-time incident-wave constraints. These incident constraints are imposed

through a data-misfit term built from two snapshots of the prescribed incoming field inside the wedge, constructed by superposing analytical inclined-plane-wave half-space solutions associated with the wedge faces. Despite this minimal labeled data, embedding the governing physics in the loss function enables accurate extrapolation beyond the training window. Before the incident wave reaches the tip, predicted displacements match the analytical solution to within 1% error. More importantly, after tip interaction, the framework resolves the full scattered response, capturing the post-tip wavefield structure, including mode-converted reflections from the traction-free faces and tip-diffracted waves, without requiring additional labeled data. The resulting mesh-free surrogate yields the full spatiotemporal wavefield for various wedge angles.

POSTER 118

Seismic Characterization of Medicanes and Mediterranean Storms Through Microseism Analysis
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Microseism is the most continuous seismic signal on Earth and is generated by interactions among the hydrosphere, atmosphere, and solid Earth. As a result of its strong relationship with sea state and storm activity, it represents a valuable tool for investigating meteorological phenomena in a climate change context. In this study, supported by the Interreg VI-A Italia–Malta project WAVEGUARD, we analyze the microseism generated by intense meteorological events that occurred in the Mediterranean Sea between November 2011 and February 2023, including 9 Medicanes (Mediterranean tropical-like cyclones) and 4 common storms. Despite their different dynamics, all events produced heavy rainfall, strong wind gusts, storm surges, significant wave heights generally exceeding 3 m, and widespread coastal damage.

The analysis is based on continuous seismic recordings from 104 coastal stations located in Italy, Malta, Greece, and France, together with 15 Etnean stations used for array analysis. We investigate microseism characteristics in terms of spectral content, spatio-temporal amplitude variations, and source locations, tracked using two independent approaches: a grid-search method based on seismic amplitude decay and array techniques. The inferred microseism source locations are compared with storm surge areas derived from hindcast wave data and are consistent for 10 out of 12 analyzed events; the remaining two correspond to weak Medicanes showing no significant microseism amplitude increase. We further characterize the seismic signature of these events using a coherence-based noise analysis and estimate their seismic strength through the Microseism Reduced Amplitude parameter, allowing a clear seismic distinction between Medicanes and common storms. These results demonstrate the potential of microseism as a complementary tool for monitoring Mediterranean meteorological events and highlight the value of historical seismic archives for investigating past extreme weather in a climate change scenario.

POSTER 119

Investigation of Artifacts in MTZ Receiver Functions Using Spectral-element Method Synthetics
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Estimates of the depths of the 400-km and 670-km mantle discontinuities and the thickness H of the mantle transition zone rely on traveltime corrections for wave speed variations in the mantle. With a focus on North America, we explore how well topography of the 400-km and 670-km can be constrained using waveforms, receiver functions, and common-conversion-point (CCP) images computed with the spectral-element method. In 3D input models, the

400-km and 670-km are horizontal boundaries. P-wave and S-wave velocities in the mantle are taken from global or regional-scale tomographic models.

If we calculate CCP images and make traveltime corrections using the same model, we obtain 5-km high topography of the 400-km and 670-km and 5-km variations of H due to inaccurate ray theory. If we calculate traveltime corrections using a different model than assumed in the input model, the 400-km and 670-km have residual topography of about 10 km. This is large compared to topography inferred from USArray data. It is difficult to predict the artifacts because the spatial correlation between the undulations and the assumed velocity structures of the tomographic models is low.

We will present experiments and statistical analyses to illustrate that CCP images must be interpreted carefully given the inaccuracies of ray theory and uncertainties in the velocity structure of the mantle.

POSTER 120

Güralp Ocean Bottom Monitoring Solutions: Autonomous Nodes, Cabled Observatories and Smart Cables
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Autonomous free-fall ocean-bottom seismometers (OBS) offer flexible deployment and redeployment options. The Güralp Aquarius operates at any orientation without a gimbal and can wirelessly transmit state-of-health (SOH) and seismic data to the surface via an integrated acoustic modem. This enables monitoring and partial real-time data transmission without offshore cabling, reducing logistical complexity while maintaining data accessibility. These capabilities make Aquarius well suited to OBS pool operations, including the National Facility for Seismic Imaging in Canada, one of the most recent large-scale OBS pools to become operational worldwide. In contrast, cabled observatory systems provide continuous, high-resolution real-time data via direct connections to onshore infrastructure. The Güralp Orcus is a compact underwater seismic station integrating a broadband seismometer and strong-motion accelerometer in a single package. The slimline Güralp Maris offers additional flexibility, using the same omnidirectional sensor as Aquarius and supporting deployment on the seabed or within narrow-diameter subsea boreholes. Both systems are deployed globally within multidisciplinary observatories, including the Neptune array operated by Ocean Networks Canada.

SMART Cables represent a promising pathway to expanding cabled ocean observatory networks at significantly reduced cost. By combining seismology, oceanography, and telecommunications within a single system, large-scale monitoring networks can be developed through shared logistics and funding across industries. Güralp has demonstrated this approach through a successful wet demonstration in the Ionian Sea, conducted in collaboration with the Istituto Nazionale di Geofisica e Vulcanologia (INGV), representing the first practical deployment of this technology. Future projects will leverage low-power, low-volume sensor and data acquisition designs to support both commercial SMART cable initiatives and science-driven observatories.

POSTER 121

Absolute Compressional-wave Speed of the Earth's Outer Core Constrained by Global Correlation Wavefields
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The compressional-wave (P-wave) speed of the Earth's outer core provides a fundamental constraint on its composition and thermodynamic state. While numerous seismological and geophysical studies have been foundational in investigating the P-wave velocity structure of the outer core, resolving its entire profile, particularly regarding absolute velocity estimates, remains a significant and ongoing challenge. In this study, we introduce a new class of observations that constrain the P-wave speed of the outer core over a wide range of depths. We utilize the global correlation wavefield, derived from the stack of earthquake late-coda cross-correlations, which has recently emerged as a novel dataset and also a powerful tool for studying the Earth's deep interior. We identified new and prominent correlation features which exhibits significant sensitivity to the absolute compressional-wave speed of the outer core across a broad range of depths, and we quantify the sensitivities. Further analyses yeild absolute measurement of the P-wave velocity profile of the outer core, which offers new insights into the structure and dynamics of the entire liquid core and also demonstrates the power of global correlation wavefields for probing the deep- planetary and Earth interiors.

POSTER 122

High-resolution Imaging of the Floridan Karst Aquifer System With Full-wave Ambient Noise Tomography
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Subsurface structural heterogeneities affect hydraulic properties, storage, and connectivity. Therefore, a detailed understanding of shallow subsurface structure is essential for groundwater availability, planning, and contamination management in groundwater aquifer systems. We investigate the Floridan Aquifer System, a karst aquifer, using full-wave ambient noise tomography (FWANT). We reprocess openly available dense seismic nodal array data from the River Rise seismic array, which covers part of the Floridan Aquifer System with an aperture of ~500 m. The array, with 70 nodal stations spaced at 40–50 m, provides high spatial sampling suitable for resolving fine-scale heterogeneity in the shallow subsurface. FWANT exploits Rayleigh-wave empirical Green's functions extracted from ambient noise cross-correlations and incorporates full-wave simulations to jointly constrain three-dimensional P- and S-wave velocity structures. From preliminary data processing, we successfully extracted high-quality Rayleigh-wave signals over a broad frequency range of 2–30 Hz, with dominant energy between 5 and 30 Hz. The expected structural sensitivity ranges from the near surface to approximately 200–250 m depth, covering the unconsolidated sediments and the upper part of the aquifer. We will construct high-resolution Vp, Vs, and Vp/Vs models and assess the lithology, porosity, bulk connectivity, and fluid saturation, offering insights into the distribution of permeable zones and hydraulically active karst features within the aquifer. This study will examine the feasibility of FWANT for high-resolution aquifer characterization in karst environments and other complex shallow groundwater systems.

New Possibilities for InSAR in Earthquake Science: the NISAR Mission and OPERA Displacement Maps

Oral Session • Wednesday 15 April • 8:00 AM Local

Conveners: Eric Fielding, Jet Propulsion Laboratory

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A GNSS-based Time-variable Surface Displacement Product for OPERA DISP InSAR Corrections

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The “Observational Products for End-Users from Remote Sensing Analysis” (OPERA) project provides accessible Earth surface displacement data from ESA Sentinel-1 and the newly launched NASA-ISRO NISAR SAR satellites. Based on advanced InSAR time series methods, the OPERA Surface Displacement products enable research in active solid Earth deformation. OPERA's coverage is broad, reaching all U.S. States and Territories, Canada (within 200 km of the U.S. border), and Central America. While InSAR has high spatial resolution and broad coverage, it has long-range error sources that can be mitigated via alignment to data from GNSS ground networks. GNSS-estimated displacements are more precise, are aligned to a global reference (e.g., the International Terrestrial Reference Frame), maintain stability over time, account for tropospheric and ionospheric effects, and have higher temporal sampling rate than InSAR. Thus, InSAR applications benefit greatly from integration with GNSS data.

Data products from the Nevada Geodetic Laboratory include precise position time series in global and plate-fixed reference frames (e.g., North America, Pacific) for >9,800 stations in the OPERA footprint. These openly available products can be used to reduce errors and to provide information on

3D displacement. To ease and enhance their utility for InSAR we have developed a prototype gridded product with ~28,000 points and mean spacing of ~17 km. At each grid point we construct a three-component displacement time series from 2012 to the present using robust spatial filtering and temporal gap-filling with data from the nearby stations. The gridded time series are corrected for known equipment changes, outlier positions, and badly performing sites. Aligning InSAR to GNSS time series reduces errors associated with orbit uncertainty and atmosphere, while preserving deformation signals of interest from e.g., earthquake cycle, active tectonic movement and strain, surface loading, seasonality, GIA, ground stability, and subsidence. We will present our methodology and examples of using the gridded position time series for solid Earth studies.

New Fringes: Earthquake Monitoring in Vegetated Regions With NISAR

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Interferometric Synthetic Aperture Radar (InSAR) data have been critical for advances in earthquake science by providing high-resolution surface deformation measurements throughout the earthquake cycle over many regions of the world. However, in vegetated regions, the current generation of C-band InSAR measurements decorrelate, therefore cannot be used, so earthquake studies are limited to ground measurements (e.g., GPS, seismometers, strainmeters, etc.). NASA-ISRO's new NISAR mission uses an L-band radar, whose longer wavelength better penetrates through vegetation and maintains coherence in densely vegetated regions. This new dataset will provide high-resolution SAR images every 12 days globally. Additionally, in combination with other satellites, multiple viewing geometries of fault systems will enable more accurate derivation of 3-D displacement measurements (east, north, and vertical), which can be used to constrain fault slip solutions.

One new potential monitoring region is the Cascadia Subduction Zone, where InSAR monitoring of long-term tectonic and transient events has been challenging due to the dense vegetation that covers the region. We use all the available L-band NISAR and present some of the first NISAR images and surface deformation time series of the region. We perform a coherence analysis of the NISAR images and compare with the other available satellite data (e.g., ALOS-2 and Sentinel-1). We further compute phase statistics to determine the impact of residual noise on future derived time series. We demonstrate the potential for long-term monitoring using NISAR in the region and that more deformation measurements over time will improve our current understanding of the earthquake cycle and preparedness for hazards in the region.

NISAR Urgent Response Products for Earthquakes

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Synthetic aperture radar (SAR) data is now a well-known source of surface displacement data for earthquakes under or near land. The NASA-ISRO SAR (NISAR) mission is a new SAR satellite with two radar systems, the L-band

(24 cm wavelength) SAR provided by NASA and the S-band (12 cm wavelength) SAR provided by ISRO and has a 12-day repeat cycle. The L-band SAR is operated over all land areas reachable by the radar beam which is looking to the left of the 240 km wide satellite track (southward), while the S-band SAR is operated over South Asia and a few other locations. NISAR entered the science operations phase at the beginning of January 2026. NISAR is the first SAR satellite to provide the standard products that include level 2 geocoded unwrapped interferograms (GUNW) for the adjacent-in-time pairs of NISAR scenes with 80-meter pixel spacing. The GUNW products include an estimate of the ionospheric correction (phase screen). The analysis-ready data (HDF5) files for the GUNW products also include geocoded wrapped interferograms with 20-meter pixel spacing. The NISAR L-band SAR data products will be available soon through the NASA EarthData system, easily searchable through the Alaska Satellite Facility graphical search tool or through applications programming interfaces. The NISAR S-band products will be available through the ISRO data portal. The standard product latency provides the processed L2_L_GUNW data within two days after acquisition by the satellite, when the most accurate satellite orbits are available. The NISAR mission has a special urgent response system that can give higher priority to the data downlink from the satellite and expedited L-band processing using preliminary orbits with a goal of products available, including GUNW, within 5 hours after satellite acquisition. The NISAR urgent response is triggered from the USGS earthquake feed based on magnitude (near USA or India magnitude 7.0 with depth less than 50 km) or on the PAGER estimate (yellow in USA and India or orange/red in rest of the world).

Mapping Creep Along the Central San Andreas Fault Using NISAR and ALOS-2

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Measurements of aseismic creep along active faults inform estimates of strain accumulation, leading to an improved understanding of tectonic processes and seismic hazard. The Central San Andreas Fault (CSAF) is one of the most well-instrumented and studied areas in the world, but cutting-edge studies using a variety of geodetic data continue to explore the localization, spatial patterns, slip rates, geometry, and cadence of the slow slip along the fault. Satellite remote sensing such as Interferometric Synthetic Aperture Radar (InSAR) provide improved capability to constrain and understand aseismic creep and its variations along the strike of the CSAF. The NASA-ISRO Synthetic Aperture Radar (NISAR) satellite was launched successfully on July 30, 2025, and promises to provide unprecedented coverage, measurement accuracy, and consistency of observations, which will help to evaluate the spatiotemporal characteristics of surface creep on active faults. In our presentation, we will take a first look at measurements of creep on the CSAF with L-band NISAR data. We will use a stack of NISAR interferograms from November 2025 to April 2026 to reduce the impact of atmospheric and other noise sources. We will also present our results from the analysis of JAXA L-band ALOS-2 ScanSAR data since 2015 to map spatiotemporal variation of creep along the fault. We will compare the NISAR measurements with satellite InSAR results from ALOS-2 for the calibration and validation of the NISAR measurements in meeting science requirements. These will be combined with in situ GNSS measurements to provide early assessment of the potential of the NISAR data towards understanding of aseismic surface creep on tectonically active faults.

Incorporating NISAR to Resolve Three-dimensional Fault and Landslide Deformation

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Satellite remote sensing of ground displacements has been an essential tool that enables better understanding of fault and landslide slip processes. However, presently available satellite SAR (Synthetic Aperture Radar) systems dominantly use a right-looking design on polar orbits, limiting the capability for directly obtaining 3D (three-dimensional) ground movements, which are

needed for accurate geophysical modeling. The scarcity of frequently acquired L-band data, which typically retain higher coherence than the short-wavelength C- and X-band acquisitions, presents another key challenge for imaging densely vegetated terrain and for resolving spatially high-gradient displacements. The successful launch of the NISAR mission in July 2025 marks the beginning of a new era for SAR observation. NISAR's L-band, left-looking SAR acquisitions with 12-day repeat interval offer an unprecedented opportunity for resolving high-gradient deformation features in vegetated areas, and for obtaining 3D ground displacements by incorporating right-looking and left-looking SAR acquisitions to advance earthquake and landslide science. Here we explore using the limited amount of available NISAR data, covering creeping faults and slow-moving landslides in California, to showcase NISAR's capabilities and potential in resolving 3D ground deformation over challenging terrains through data integration of multiple satellite SAR systems.

New Possibilities for InSAR in Earthquake Science: the NISAR Mission and OPERA Displacement Maps [Poster]

Poster Session • Wednesday 15 April

Conveners: Eric Fielding, Jet Propulsion Laboratory

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POSTER 128

Identification of Potential Slow-moving Landslides Using ICA on InSAR Time Series and Terrain Analysis

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Slow-moving landslides (SMLs) have the potential to transition into catastrophic events with little warning, posing a significant risk to communities in mountainous areas. Their low deformation rates (millimeters to a few meters per year in scale) make them difficult to detect, especially in regions without active monitoring networks. Interferometric Synthetic Aperture Radar (InSAR) has been a useful tool to identify suspected SMLs across broad areas through the analysis of temporal and spatial deformation variations. However, separating SMLs from other deformation signals is still challenging. In this study, we employ InSAR and terrain analysis to identify SMLs in remote cities in La Paz (Bolivia), San Cristobal (Venezuela), and Medellín (Colombia). We apply Independent Component Analysis (ICA) on Sentinel-1 InSAR time series to identify long-term and periodic surface deformation signals. We additionally conduct terrain analysis to map regions with greater slopes and higher contributing drainage area. By comparing InSAR velocity with terrain data, most SMLs occur in regions with higher long-term and annual periodic velocities and higher slope and catchment area products. We aim to further test this approach by incorporating multispectral data and regional precipitation history to refine the detection of rainfall-triggered SMLs temporally and spatially. This work is part of a broader effort to automatically map SMLs in urban areas and to improve our understanding of rainfall as an influence on their velocity.

POSTER 129

Leveraging Multitemporal InSAR Products for Geohazards and Geomechanics Research: Characterizing Data Quality and Lessons Learned

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Many problems in solid-earth hazards and mechanics require observations and understanding of spatially variable, time-dependent crustal deformation. Multitemporal InSAR data meet critical observational needs, but the advanced processing and interpretation required can pose a steep learning curve for new users, limiting faster adoption and broader reach. Here, we report our experience of using primary InSAR data and/or analysis-ready products in sev-

eral student-led research projects at the University of Oklahoma. Our efforts focus on time-series analysis of openly accessible Sentinel-1 data, including co-registered SLC products from ASF's HyP3 processing platform and, where feasible, OPERA products. Our applications target time-varying InSAR deformation signals associated with a wide range of phenomena, including shallow fault creep, injection-induced earthquakes, postseismic fault relaxation, geothermal reservoir operations, and fault-bounded aquifers, as well as slow-moving landslides, in selected regions in California, Utah, and Oklahoma. In these case studies across various scales, we develop metrics to characterize the rates and timescales of deformation, along with their associated confidence levels. While analysis-ready InSAR products are of reasonable quality for some of our problems, we summarize best practices for quality control and interpretation and assess situations where tailored processing is warranted, e.g., where complex atmospheric and/or land-surface conditions obscure fine-scale or subtle signals. These examples and lessons may help maximize the scientific value of NISAR's systematic observations for broader communities.

POSTER 130

Mapping Surface Deformation at Scale: A Look at the Opera Displacement Products for Earthquake Science and Hazards Applications

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Remote sensing satellites provide critical observations for understanding Earth processes and responding to natural hazards, yet transforming raw radar data into actionable information—particularly for non-specialists—remains a significant challenge. To address this challenge, initiatives such as the European Ground Motion Service (EGMS) and NASA's Observational Products for End-Users from Remote Sensing Analysis (OPERA) leverage advanced cloud-based processing environments to deliver standardized, continental-scale InSAR products over Europe and North America, respectively.

Here we present results from the OPERA Surface Displacement (DISP) product suite, highlighting applications relevant to tectonic faults and landslides, and describe how users can get started with OPERA data. OPERA systematically generates analysis-ready InSAR displacement time series from Copernicus Sentinel-1 data, beginning in 2016, with processing of the full archive through the present currently underway. Products are generated from both ascending and descending orbits, enabling investigation of fault motion and related deformation signals at continental scale without the burden of large-scale InSAR processing. All OPERA products are freely available through the Alaska Satellite Facility Distributed Active Archive Center (ASF DAAC), supporting rapid use in both research and operational contexts. OPERA will soon start its integration of data from the NASA-ISRO Synthetic Aperture Radar (NISAR) mission into the OPERA DISP product suite, further expanding spatial coverage and revisit capabilities. We conclude by briefly describing upcoming OPERA products, including the Vertical Land Motion (VLM) suite, which will further support interpretation of fault slip and vertical deformation signals.

POSTER 131

Triggered Aseismic Creep Following the 2023 Ocotillo Swarm Constrained by 3D InSAR Observations

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On December 1, 2023, a M4.8 earthquake occurred as part of an earthquake swarm 11km east of Ocotillo, CA in the Yuha Desert. This region is primarily underlain by strike-slip faults and north-south trending normal faults that accommodate the distributed strain between the Elsinore Fault to the

northwest and Laguna Salada Fault to the southeast. The 2023 Ocotillo swarm occurred at a depth of about 8.7 km. Nonetheless, shallow aseismic slip is clearly observed in the Yuha Well Fault Zone in week-long, month-long, and seven year-long interferograms following this event. As a result, this sequence provides a rare opportunity to probe the spatial and temporal relationships between earthquake swarms, seismic slip at depth, and aseismic creep in the shallowest portions of the crust.

To investigate creep related to the December 2023 event, we use Interferometric Synthetic Aperture Radar (InSAR) data from Sentinel-1 and UAVSAR to perform 3D displacement decomposition using three independent viewing geometries. We validate the InSAR observations and remove contributions of interseismic strain using OPERA displacement products. We then model the depth of aseismic creep from the compiled InSAR observations and compare with seismicity catalogs. Understanding creep on faults in this region provides insight into the drivers of microseismicity, and has implications for stress transfer to other faults and earthquake hazard in this region.

Observation and Analysis of Topography and Deformation: Relating Earthquakes to Cascading Hazards

Oral Session • Friday 17 April • 8:00 AM Local

Conveners: Stephen B. DeLong, U.S. Geological Survey

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The Center for Land Surface Hazards (Clash): A Community Effort to Understand Cascading Land Surface Hazards

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Greater understanding of the connections between geohazards is helping to elucidate how many catastrophic events are not isolated, but rather part of complex “hazard cascades.” These cascades involve sequences of events in which one geohazard — like an earthquake — triggers others, like landslides, and those in turn can propagate to further hazards, such as fluvial aggradation and flooding. With cumulative impacts that are more severe than the sum of the individual events, cascading hazards have a widespread impact on society, and their pace is rapidly increasing in the face of global change and population growth. Yet quantitative understanding of these cascading effects remains in its infancy, with most research focused on individual hazards. Basic questions — including the magnitude and duration of “follow-on” hazards following an event like an earthquake — remain to be resolved. The recently-formed Center for Land Surface Hazards (CLaSH) is a community initiative with a primary goal of developing the scientific understanding needed to forecast hazard cascades, while promoting awareness of their importance and training a future workforce capable of addressing their impacts. Forecasting the impact of hazard cascades requires integrating and modeling processes to predict interactions that amplify hazardous conditions. This presentation will provide an overview of CLaSH and its activities, with an emphasis on potential connections to the earthquake science community as part of better understanding and forecasting the role of large earthquakes in hazard cascades.

Gravity Modulates Earthquake-triggered Sliding During the 2025 Dingri Normal-fault Earthquake on the Tibetan Plateau

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Normal-fault earthquakes in high-elevation mountain belts occur in landscapes with extreme relief, yet the role of gravity in controlling earthquake-triggered deformation remains unclear. Using high-resolution InSAR observations of the 2025 Mw 7.1 Dingri earthquake in southern Tibet, we identify multiple localized aseismic sliding features that initiate immediately after the mainshock and decay rapidly over months. The deformation is strongly selective in space and remains highly localized. Sliding concentrates on steep, high-relief slopes rather than in regions predicted to experience the largest coseismic static stress changes. These observations indicate that seismic stress perturbations act as the transient trigger, whereas topography-related

gravitational pre-stress controls where shallow materials fail by preconditioning them close to their frictional threshold. This coupled earthquake-gravity mechanism provides a physical pathway by which repeated earthquakes can preferentially weaken and mobilize the steepest slopes, promoting long-term topographic flattening across the Tibetan Plateau.

Active Stress Pattern Investigations and Earthquake Probabilities in North Pakistan: Implications for Seismic Hazard
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The Northern parts of Pakistan, coinciding with the Himalayan collisional zone, are regarded as one of the most seismically active regions in the world. The area is experiencing crustal compression since the Eocene due to the ongoing India-Eurasia collision. The ongoing N-S compressional stress regime in the region is well established, but local variations in seismicity patterns and stress conditions do exist in the area, and encompassing these variations in the hazard-related studies is crucial for better characterization of the area. The scope of the current study covers the western margin of Himalayas with special emphasis on Hazara Kashmir Syntax, Nanga Parbat Syntax and Hindu Kush seismic zone. The objective is to carry out seismicity analysis by utilizing the available earthquake record. For this purpose, a regional seismicity catalogue is acquired from the Micro-seismic network operated by WAPDA in the region. The catalogue is processed and evaluated for temporal and spatial homogeneity in ZMAP software package. The analysis showed that the whole region has a recurrence interval of ~20 years for a magnitude Mw= 7.5 earthquake and ~60 years for Mw= 8.0 earthquake. The b-value maps showed that the area is characterized by significant spatial variations in b-values. The prominent high b-value regions identified in the study are along the Nanga Parbat syntax, Hazara Kashmir Syntaxis and Hindu Kush seismic zones suggesting heterogeneous stress conditions due to fault pattern complexity in these regions. The study area is subdivided into various subregions based on variations in seismicity patterns, fault gaps, variations in trends of major faults, and tectonic settings. Moreover, the focal mechanism solution catalogue is used to investigate the stress patterns and determine the principal stress orientations in the area using Michael's method. The result for stress tensor inversion indicate that although the region is dominated by compressional tectonics, considerable strike-slip deformation is prevalent along the Nanga Parbat and Hazara Kashmir Syntax.

A GNSS-derived Strain Rate Map of North America and Implications for Continental Deformation
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This study presents a geodetic strain-rate model for the North American Continent derived from Global Navigation Satellite System (GNSS) velocity measurements. The model incorporates horizontal GNSS velocities compiled by Zeng (2022) for the western United States and Median Interannual Difference Adjusted for Skewness (MIDAS) (Blewitt et al., 2016) velocities from Nevada Geodetic Lab for the remainder of the continent. Strain rates are calculated using the methodology of Shen et al. (2015). The resulting model reveals distinct spatial patterns of crustal deformation across North America. High shear strain rates are observed along the entire western margin of the continent, particularly along the San Andreas Fault system. Elevated compressional strain rates are evident along major subduction zones, including the Alaska, the Cascadia, and the Cocos (at the southern margin of the continent) subduction zones. Regions of pronounced dilatational strain are identified along the Gulf of California rift zone, across the Yakutat Block, and within the Central Nevada Seismic Belt and Intermountain West Seismic Belt. Broad extensional strain is also evident across eastern Canada, consistent with post-glacial rebound processes. In contrast, low strain rates characterize much of the Basin and Range Province and most of the central and eastern United States. Overall, the spatial distribution of high strain rates correlates well with regions of elevated seismicity across the continent. This strain-rate model provides important constraints on continental deformation, supports improved seismic hazard assessments, and contributes to ongoing efforts to refine and update the North America stress map (e.g., Lund Snee and Zoback, 2020).

Coseismic Landslides and Their Cascading Hazards: Improving Modeling, Assessment and Communication
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Following major landslide-triggering earthquakes, damaged slopes, landslide-dammed rivers, and mobilized sediment can lead to elevated landslide, debris flow, and flooding hazards for years to come. In recognition of the importance of the ground failure hazard cascade initiated by earthquakes, several U.S. Geological Survey (USGS) initiatives aim to provide situational awareness information more quickly and effectively. The USGS Ground Failure Product (GFP) has been providing summary alert levels and spatial estimates of coseismic ground failure hazard within minutes of major earthquakes worldwide since 2018. To augment the GFP, we present a prototype of a new “Post-earthquake Ground Failure Hazards” product that aims to provide public information on the types of cascading hazards to expect in the days, months, and years following a major ground-failure-triggering earthquake.

In addition to these automated products, the USGS has recently advanced its ability to provide rapid, event-specific assessments of ground failure locations, impacts, and ongoing hazards through a cross-disciplinary project called “Landslide Assessments, Situational awareness, and Event response Research (LASER).” The LASER project trains and maintains a landslide event response corps with streamlined remote sensing and field capabilities and protocols for rapid information release. Since late 2023, LASER teams have conducted rapid assessments and/or provided partner agency support for over two dozen landslide events, including several landslide-triggering earthquakes. In this presentation, we summarize these three USGS initiatives related to coseismic landslides and highlight results for several earthquakes, including the recent M7.0 Hubbard Glacier earthquake, which triggered widespread ground failure in Alaska and Canada.

Observation and Analysis of Topography and Deformation: Relating Earthquakes to Cascading Hazards [Poster]

Poster Session • Friday 17 April

Conveners: Stephen B. DeLong, U.S. Geological Survey (sdelong@usgs.gov); Andrea Donnellan, Purdue University (andread@purdue.edu)

POSTER 137
Effect of 3D Fault Geometry on Surface Deformation and Implications for Segmentation Along the Hayward and Calaveras Faults
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Geologists can map faults and collect geologic slip rates at the surface, but they cannot directly map fault shape at depth. Fault shape at depth exerts a first-order control on how slip is distributed along a fault and how plate motions are accommodated as along-fault slip and off-fault deformation. Because three-dimensional (3D) fault geometry is the basis for seismic hazard models, uncertainty in fault dip and whether faults link or remain segmented complicates methods to determine slip rates from quasistatic forward-modeling. This study aims to refine the 3D geometry of segmented faults, focusing on potential connection between the Hayward and Calaveras faults, two major right-lateral strike-slip faults in the high seismic hazard region in the San Francisco Bay Area of Northern California. We do so by integrated field-based and modeling methods. First, we present physics-based numerical models of surface deformation due to right-lateral slip along dipping, bent and interacting fault segments. When subjected to a remote stress, dipping faults of 89.9°, 75°, and 60° show that steeper dip angles exhibit higher strike-slip motion and less off-fault deformation. Left-bending and left-stepping segmented faults result in regions of compression that cause uplift. In contrast, right-bending and right-stepping segmented faults result in extension that causes depression. Second, we apply these insights to interpret hidden subsurface fault geometry from high resolution Light Detection and Ranging (LiDAR) data along the Hayward and Calaveras faults near Monument Peak. Two minor reverse faults, the Mission Fault and the Arroyo Aguague Fault, sit between

the Hayward and Calaveras faults in this region. The Quaternary Fault and Fold Database shows how the Mission Fault does not connect to the Calaveras fault, but does link to the Hayward Fault. Using LiDAR datasets, we identify signatures that suggest linkage between the Mission Fault and the Calaveras Fault, resulting in hard-linkage between the Hayward and Calaveras faults. Determining whether these two major Bay Area faults link is crucial for seismic hazard assessments.

POSTER 138
Understanding Earthquakes and Related Hazards With NASA's Surface Topography and Vegetation (STV) Observing System
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NASA's Surface Topography and Vegetation (STV) incubation study is developing an observing system to measure global and targeted high-resolution topography and vegetation structure for launch in the mid-2030s. STV address four of NASA's Science Spheres including Biosphere, Cryosphere, Geosphere, and Hydrosphere. Each of these are related to cascading hazards associated with earthquakes. Topography can be used to identify faults through their expression at the surface. STV will provide bare Earth topography, which will enable clearer identification of surface expressions of faults. Earthquake cause changes in topography that can cause damage but also inform better understanding of earthquake processes. Knowledge of overlying vegetation structure is needed to assess fuel loading associated with wildfires, which can be triggered by earthquakes. Earthquakes can also trigger landslides, and heavy rains can exacerbate landslides and debris flows after earthquakes and wildfires. The overarching STV question, “How does Earth's changing surface structure inform us about natural hazards, vegetation, and water resources,” relates directly to cascading hazards. We will discuss the STV observing system and measurements needed to improve understanding of earthquakes and related cascading hazards.

POSTER 139
Cascading Fluvial Hazards After a Large Earthquake Revealed by Decadal Sediment Budgets
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Cascading land surface hazards triggered by earthquakes (i.e., landsliding, channel aggradation, and flooding) can persist for decades and pose sustained risks to downstream infrastructure and communities. Among these processes, earthquake-induced landslide sediment delivery to river networks plays a central role in amplifying and prolonging post-seismic hazard conditions. Quantifying the magnitude and persistence of post-seismic sediment transfer is therefore critical for assessing how seismic events generate long-lived hazards and compound infrastructure vulnerability. Here we construct a decadal sediment budget following the 2008 Mw 7.9 Wenchuan earthquake. This extreme event triggered more than 60,000 landslides in the steep mountains along the eastern margin of the Tibetan Plateau, supplying vast volumes of erodible material to downstream river systems. Post-seismic sediment transport was quantified using repeated acoustic surveys conducted between 2008 and 2018 in a downstream reservoir that trapped landslide-derived sediment exported by the Min Jiang River. These observations were integrated with hydrological gauging and grain-size analyses to develop a decadal-scale post-earthquake sediment budget. Our results show that total riverine sediment flux increased by approximately sixfold relative to pre-earthquake conditions, with bedload contributing a substantial fraction of the export. Elevated sediment and bedload fluxes persisted throughout the decade following the earthquake, exporting ~10% of the coseismic landslide material stored in upstream catchments. These findings demonstrate that sustained, earthquake-driven sediment pulses can maintain fluvial hazards long after seismic shaking ceases, highlighting the importance of post-seismic sediment dynamics in seismic hazard assessment and infrastructure planning in tectonically active regions.

POSTER 140
Mapping the Creeping Section of Bartlett Springs Fault to Better Understand Fault Geometry's Control on Creep Rates
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Differences in fault slip rate control how faults accommodate deformation and the nature of the hazards they pose. Coseismic slip produces earthquakes that can generate shaking-induced damage and surface rupture, while aseismic creep produces continuous ground deformation. The Bartlett Springs fault in northern California is part of the distributed San Andreas fault system along the boundary between the Pacific and North American plates and may slip both coseismically and aseismically. It has a slip rate of 7.5 mm/yr compared to the San Andreas fault rate at similar latitudes of 11-20 mm/yr. The creep rate on the Bartlett Springs fault at Lake Pillsbury is 3.4 ± 0.1 mm/yr measured on an alignment array and up to 8 mm/yr measured from geodetic data. Understanding coseismic and aseismic slip distribution along the Bartlett Springs fault, and how these fit with the broader San Andreas fault system, is key to understand the overall hazard.

This study explores if a right stepover on a right lateral strike slip fault may be conducive to creep because it is a region of extension. Lake Pillsbury sits in a basin, likely caused by a right step over on the right lateral Bartlett Springs fault at a location that is experiencing creep. These site characteristics make Lake Pillsbury a good spot to explore fault geometric controls on creep rates. Previous mapping efforts of Bartlett Springs fault include mapping using aerial photos of the creeping portions where the fault crosses Lake Pillsbury and has not been mapped since lidar has become available. There have been few trenching studies in the past, and the earthquake history at this site is not well understood. We present new results from recent mapping efforts on the Bartlett Springs fault from traditional field mapping, airborne and terrestrial lidar, and drone surveys. We also quantify fault displacement using topographic differencing and alignment array measurements using total stations. Fault geometry will be used to inform future fault models studying the relationship between coseismic slip rates, creep rates, and fault geometry.

POSTER 141
Investigating Dynamic Triggering in Cascadia Volcanic Systems Using Seismic Network Data
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Dynamic stress from large, distant earthquakes can influence seismicity in tectonic regions, but its effect on volcanic systems in the Cascadia subduction zone remains less understood. This study investigates whether surface waves from large (M > 7.0) teleseismic earthquakes dynamically trigger microseismicity at major Cascadia volcanoes. The focus is on three primary volcanic centers: Mount Rainer, Mount St. Helens, and Mount Hood using catalog and waveform data from the Pacific Northwest Seismic Network (PNSN). Catalog analysis was conducted for events between January and August 2025 to identify changes in seismicity rates following global earthquakes. Station level analysis supported by basemaps of seismic network coverage highlights the spatial distribution of detections and network sensitivity. Python-based workflows, including short-term average/long-term average (STA/LTA) event detection and waveform visualization are applied to assess changes in seismicity rate following the amplitude and timing relative to Rayleigh wave arrivals. Preliminary results, over 7-month time window, suggest that distant large earthquakes do not trigger increases in microseismicity. These findings provide an initial framework for evaluating volcano specific stress sensitivity in Cascadia and lay the groundwork for extending analysis to longer time periods and additional volcanic systems. This work represents an early step toward improving eruption hazard assessments in subduction zone environments.

POSTER 142
An Updated Geospatial Liquefaction Model for California
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Global geospatial liquefaction models developed using logistic regression are used to quantify the extent of liquefaction and aid in rapid response (Zhu et al., 2015, 2017; Rashidian and Baise, 2020). Prior work has demonstrated that these global models can be biased and updating the models for regional application is beneficial (Zhan et al., 2023). In order to update the global geospatial model for use in California, we have assembled an observational liquefaction database from 19 historical earthquakes in California. The observational database is compiled from the literature and includes existing digital datasets

and additional georeferenced and digitized data from historic maps. In addition to the observational liquefaction database, we have also sampled a large set of potential geospatial variables (e.g. Zhu et al. 2017) with the addition of sand fraction, Maximum multiscale deviation (MMD), Maximum multiscale roughness (MMR), scale of the MMD, scale of the MMR, tangential curvature and depth to bedrock which were not tested in Zhu et al. (2017) but have been included in other geospatial liquefaction efforts (Sanger and Mauer, 2025). In addition to continuous variables, we also include categorical variables related to surficial geology. A regional liquefaction susceptibility map is prepared using the existing Vs30-based geologic map from Wills et al. (2015) using a hierarchical classification methodology. We will present an updated geospatial liquefaction model for California and a web-based interactive GIS platform for sharing the model and the observational liquefaction database.

POSTER 143
Bidirectional Interactions Between Surface Hazard Cascades and Earthquake Triggering
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Earthquakes are widely recognized as triggers of surface hazards and cascading processes, yet the potential for surface hazards to modulate or trigger seismicity remains poorly constrained. Following two large landslides on the Tibetan Plateau in 2018, landslide-dammed lakes formed and evolved toward catastrophic outburst flooding. Using a combination of machine-learning detection and waveform cross-correlation, we construct a local earthquake catalog and identify a statistically significant increase in seismicity as lake levels approached their maximum, followed by a return to background activity after dam breach.

Coulomb stress modeling indicates that the majority of detected earthquakes occurred in regions experiencing positive stress changes due to the combined effects of surface loading and pore-pressure diffusion. The close spatial and temporal correspondence between modeled stress perturbations and observed seismicity supports a triggering relationship associated with the landslide-driven hazard cascade. Extending this analysis using generalized lake and reservoir parameters suggests that earthquake triggering by landslide-dammed lakes and similar transient surface loads may be more widespread than previously recognized. These results highlight the importance of considering bidirectional interactions between earthquakes and surface hazards when assessing seismic risk and managing cascading hazards in tectonically active mountain regions.

On the State of Knowledge/Art/Practice for mHVS

Analyses; A Prelude to the ESG7-COSMOS mHVS Pre-Event Forum

Oral Session • Friday 17 April • 8:00 AM Local
Conveners: Cécile Cornou, University of Grenoble Alpes (cecile.cornou@univ-grenoble-alpes.fr); Shinichi Matsushima, Kyoto University (matsushima@sds.dpri.kyoto-u.ac.jp); Alexandros Savvaidis, Consortium of Organizations for Strong Motion Observation Systems (alexandros.savvaidis@beg.utexas.edu); Alan Yong, U.S. Geological Survey (yong@usgs.gov)

Perspectives on the State of Knowledge and Practice About Single-station Microtremor Horizontal-to-vertical Spectral Ratio (mHVS) Analysis for Evaluating Seismic Site Response
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Several analytical methods have been developed to estimate frequency-dependent site response. Most methods are based on spectral analyses (e.g., standard spectral ratio (SSR) techniques) and do not require supplementary data beyond an earthquake observed from at least two recording locations (i.e., SSR multi-station method). Nevertheless, sufficient earthquake recordings are not always readily available for robust analyses. Other site-specific approaches

(e.g., one-dimensional frequency-domain linear or equivalent-linear ground response analysis) require several downhole body- or surface-wave measurements from in situ seismic recordings. This field data acquisition portion of site characterization can be cost, as well as environmentally, prohibitive. To address these challenges, the single-station microtremor (i.e., ambient noise) horizontal-to-vertical spectral ratio (mHVS) analysis method is gaining traction as a stopgap when earthquake data is unavailable or scarce. The mHVS method, however, still lacks consensus toward standardized guidelines and commercial use. The greatest challenges to an international standardization of mHVS acquisition and analysis are two-fold: (1) The underlying composition of the microtremor wavefield is site dependent and therefore, the appropriate theoretical (forward) model for inversion is strongly debated; and (2) There are many user-defined choices involved in the data acquisition, processing, and interpretation stages that remain inconsistently applied.

I present briefly an update of the historical development of the mHVS technique and the physical basis of mHVS. I then propose preliminary recommendations for developing guidelines for mHVS acquisition and analysis. My perspectives are motivated to highlight presentations in this session as a prelude to the 18 October 2026 7th Effects of Surface Geology (ESG7) pre-event session entitled ESG7-COSMOS mHVS Forum (Grenoble, France), where a main topic of interest is the definition of a roadmap for updating existing guidelines, e.g., the Site EffectS assessment using AMbient Excitions guidelines (SESAME, 2004).

H/V Processing of Seismic Noise Recordings: A Retrospective and Roadmap for Updating the SESAME Guidelines

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Introduced about 4 decades ago in Japan, the H/V spectral ratio method applied to seismic noise has undergone successive waves of geographical expansion—from Japan to Mexico and Latin/ Southern America, Europe and the Mediterranean, South-Western Pacific, central and southern Asia, and, more recently, North America. Each expansion phase has not only spurred a wide range of applications in subsurface imaging, site effect mapping, sometimes in relation with observed building damages, but also driven fundamental research into the origin, nature, and composition of seismic noise. These efforts have been accompanied by the development of regional guidelines and/or reviews on data measurement, processing, and interpretation. Notably, early 2000s European initiatives produced the SESAME H/V guidelines, which have remained a widely accepted reference to this day. This presentation shortly reviews the evolution of H/V research and applications from its inception to the present. It highlights recent scientific advances on H/V curve modeling, the relationship with the composition of noise wavefield, and observations and numerical modeling of seismic noise in complex geological settings, as well as today's needs in seismic code updates and empirical ground motion prediction models. The developments over the last 20 years reveal some important gaps in the current SESAME guidelines, providing a roadmap for their necessary evolution.

Characteristics of Microtremor Horizontal-to-Vertical Spectral Ratios and Resulting Subsurface Structures in Japan and Taiwan

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Characterizing spatial variations in subsurface structures is essential for accurate seismic hazard assessment. This study investigates microtremor horizontal-to-vertical spectral ratios (MHVRs) to elucidate heterogeneous subsurface structures in the Shonai and Miyazaki Plains in Japan, and the Dawan Lowland in Taiwan. In the Shonai Plain, site characteristics were analyzed to correlate historical damage from the 1894 Shonai earthquake with ground conditions using 19 arrays and 132 single-station measurements. The results reveal indistinct MHVR peaks across a broad area, with complex spatial distributions of peak frequency and amplitude, suggesting significant lateral variations in shallow sedimentary layers and an irregular basin configuration.

In the Miyazaki Plain, a region vulnerable to Nankai Trough and Hyuga-Nada earthquakes, subsurface structures were investigated using 51 single-station and 4 array measurements. Most sites exhibit prominent MHVR peaks, where high-frequency peaks in northwest and southeast correlate well with geomorphological classifications, providing a basis for mapping the sediment-bed-rock interface.

In the Dawan Lowland of Tainan, Taiwan, situated between the Tainan and Napalin Anticlines, 93 observation points were utilized to investigate the subsurface structure in a tectonically active zone. The analysis revealed significant differences of directional dependence of MHVRs between different geomorphic features in the area, where the orientations of the maximum discrepancy of MHVRs of most stations are consistent with the strike of topographical boundaries. This indicates that the MHVRs are strongly affected by 2D or 3D structural effects, such as dipping layers or basin-edge geometry, rather than simple 1D stratification. The results demonstrate that while MHVR is an efficient tool for site characterization, the clarity and directional stability of peaks are highly sensitive to local topographic features. These findings emphasize the necessity of integrating dense single-station grids with array data to resolve complex subsurface heterogeneities in diverse geological environments.

The New Sesame Criteria: Why Not Ai?
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Microtremor H/V measurements are widely used in several fields of earthquake engineering and exploration geophysics. A single measurement takes only a few minutes; however, a large number of measurements is required to image the subsurface in detail. As for all geophysical techniques, the ability to assess data quality, recognize potential issues, and correctly interpret the information contained in a microtremor recording requires training and experience.

Twenty years ago, the SESAME (2004) guidelines attempted to provide criteria to assess the reliability of H/V curves and the clarity of H/V peaks. However, two decades of subsequent research suggest that a new generation of criteria is possibly needed, particularly with regard to peak clarity.

We will summarize the main limitations of the current criteria from our perspective. We will then present a proposal for the development of new criteria, based on one artificial neural network specifically trained on thousands of examples, with particular emphasis on the identification of the following features:

- 1) normal H/V curves,
- 2) 1D H/V peaks,
- 3) 2D H/V peaks,
- 4) artefacts,
- 5) velocity inversions,
- 6) recordings requiring cleaning,
- 7) malfunctioning sensors.

This neural network serves three main purposes. First, it enables automatic quality control by distinguishing high-quality records from potentially problematic ones, which is particularly useful when processing large datasets or when field operations are carried out by non-geophysicists. Second, it allows the rapid extraction of H/V curves exhibiting common patterns from large databases. Third, given the complexity and variability of H/V curves, a neural-network-based classifier can be more effective than fixed-threshold criteria such as those proposed by SESAME.

Estimating Regional Shallow 3D S-Wave Velocity Model From Active and Passive Surface Wave Methods and Horizontal-to-Vertical Spectral Ratios Based on Neural Networks

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We developed a method that spatially interpolates 1D Vs profiles to a 3D Vs model based on neural networks to develop regional shallow 3D subsurface models. The method uses dispersion curves obtained from active and passive surface wave measurements, and horizontal-to-vertical spectral ratio (H/V) obtained from single station 3C microtremor measurements. Since the number of sites with dispersion curves is smaller than those with H/V measurements, the neural network consists of two stages. The first stage (A)

predicts Vs profiles from H/V using training data of Vs profiles obtained from dispersion curves, and the second stage (B) predicts Vs profiles from surface topography and geomorphological classification etc. using training data of Vs profiles obtained from the first stage. Estimation procedure for a regional shallow 3D Vs model can be summarized as four steps and two stage neural networks. The first step estimated 1D Vs profiles by the inversion of dispersion curves at sites where both dispersion curve and H/V were observed. The second step predicts 1D Vs profiles from H/V spectra based on the first stage network (A) trained by H/V spectrum-1D velocity profiles together with other regional information including coordinate, surface elevation, geomorphology, and bedrock depths in community velocity model. The first stage (A) network predicted 1D Vs profiles from H/V spectra measured at sites without surface wave methods. The third step applied non-linear inversion to 1D Vs profiles predicted in the second step to finalize 1D Vs profiles. The last step applied the second stage network (B) trained by the geological information-1D Vs profile pairs, to predict 1D Vs profiles in the investigation area from geological and other regional information. We applied the proposed method to the Tokyo Metropolitan area, using dispersion curves, H/V and Vs profiles open to public as digital data, and predicted Vs profiles to 90 m deep with 200 m grid intervals. The predicted Vs model was reasonably consistent with surface topography, surface geology, and geomorphological classification.

The Physical Basis for the Modeling of HVS Under the Diffuse Fields Assumption

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The Horizontal to Vertical Spectral Ratio (HVS) for Ambient Seismic Noise (ASN) is a popular measurement that typically determines the dominant period at a given soil site. Proposed by Nakamura in 1989, quickly gained adept practitioners around the world. The measurement is easy and economical and the results allow for microzonation with unprecedented resolution. The ideas of receiver functions seemed to be the basis of this method but the proposed explanations were not convincing. Arai and Tokimatsu (2004) proposed to compute HVS as the ratio of averages that, using the concept of diffuse fields in dynamic elasticity firmly established by Weaver (1982), can be seen as ratios of directional energy densities. Within a diffuse field, occupying a half-space, composed of equipartitioned sets of plane P, S and Rayleigh waves, the Green's function of dynamic elasticity is *exactly* retrieved from correlations. The full space with a circular cylindrical inclusion allowed to demonstrate *exactly* the Green's function retrieval within a heterogeneous medium. In all these results, a common relationship was the proportionality of the average autocorrelation (the directional energy density) with the imaginary part of the system Green's function.

Consequently, Sánchez-Sesma et al. (2011) proposed to model HVS in terms of the imaginary part of system's Green's function and applied it to layered media. The approach has been extended to borehole measurements with and without a liquid layer. Lateral irregularities have been studied in pioneering test cases, but still they are the next frontier as the numerical burden requires further scrutiny. On the other hand, we rely on multiple scattering as a primary factor for field equilibration but the search for reliable indicators of a diffuse nature of ASN is part of our quest. This research is partially supported by DGAPA-UNAM grants IN105523 and IG100626. J. G. González is supported by the UNAM Postdoctoral Program (POSDOC).

Basics of Double-correction Method for mHVS Based on the Diffuse-field Concept as a Replacement for “Nakamura Method”

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In the development history of the microtremor technique for site effect studies, the contribution of the Nakamura method (Nakamura, 1989) based on the Horizontal-to-Vertical Spectral Ratio of microtremors (mHVSr) could not be underestimated, even though his interpretation had created more debates than solutions, where mHVSr was assumed to correspond to the Horizontal Site Amplification Factor (HSAF) of earthquakes. Because of the fundamental difficulty of using mHVSr as a direct substitute for HSAF, numerous schemes have been proposed, with only partial success (See reviews in Molnar et al., 2022).

After the advent of the theoretical solutions based on the Diffuse-Field Concept (DFC) on mHVSr by Sanchez-Sesma et al. (2011), as well as on the Horizontal-to-Vertical Spectral Ratio of earthquakes (eHVSr) by Kawase et al. (2011), however, we developed inversion schemes of velocity structures underneath using either mHVSr (Garcia-Jerez et al., 2016) and eHVSr (Nagashima et al., 2014). Once we invert the velocity structure, we can calculate a theoretical HSAF to support physics-based strong-motion prediction.

The DFC for eHVSr tells us that HSAF can be derived from eHVSr by multiplying the vertical site amplification factor, VSAF*, derived from the Generalized Inversion Technique (Nakano et al., 2015). Here, * denotes the correction for the 1/eHVSr on the seismological bedrock. Ito et al. (2020) proposed the Vertical Amplification Correction Function (VACF), defined as the average VSAF* across all sites in Japan, to empirically obtain HSAF from eHVSr.

Since earthquake observations are much more costly than microtremor observations, it is meaningful to transform mHVSr into eHVSr, if possible. To that end, Kawase et al. (2018) proposed earthquake-to-microtremor ratios (EMRs) for five categories, based on the fundamental predominant frequency of mHVSrs, as determined from 100 collocated observations in Japan. Thus, the double correction method for HSAF means

HSAF=mHVSr*EMR*VACF.

This is considered to be a direct replacement for the Nakamura method, although EMR and VACF may be region-specific.

3D Numerical Modeling of Ambient Seismic Noise: Assessing the Impact of Noise Source Directivity and 3D Basin Structure on Ambient Seismic mHVSr Ratios

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The mHVSr technique is widely used for site characterization, but its interpretation is challenging in complex geological settings where both lateral heterogeneities and variations in noise source distributions influence the observations. We investigate the sensitivity of mHVSr amplitude and polarization of these coupled effects using direct 3D numerical simulations. The study is motivated by strong temporal variability observed at station in the Mygdonian sedimentary basin (northern Greece), where large changes in mHVSr amplitude, polarization, and occasional shifts in the dominant frequency were observed. The station was located above a blind fault separating shallow northern basin from a deeper southern basin, suggesting that both structural complexity and variations of noise sources contribute to the observed variability.

We compute realistic 3D viscoelastic Green functions for a simplified but geologically meaningful basin model and use reciprocity to synthesize ambient noise wavefields for different source distributions. This approach allows us to systematically explore the influence of noise source distributions on mHVSr measurements at receivers located on either side of the blind fault. Our results show that strong lateral heterogeneities significantly affect mHVSr amplitude and polarization, particularly near the fault and toward the deep basin. Uneven source distributions exert first-order control and can produce apparent spatial or temporal variations that mimic structural effects. Sources within the shallow basin generate surface waves trapped in the upper layers that propagate toward the deep basin, imprinting the shallow-basin signature on deep-basin mHVSr, while the reverse effect is not observed. Polarization depends on receiver position, being generally parallel to the fault on the deep-basin side and perpendicular in the shallow basin, although directive sources can partially mask this pattern. Comparison with elastic

Diffuse Field Theory shows reasonable agreement near the mHVSr peak for isotropic sources, but notable deviations arise when attenuation and strong lateral contrasts are present.

Review of Site Response Modeling Conditional on HVSR STEWART, J. P., University of California, Los Angeles, California, USA, jstewart@seas.ucla.edu

Frequency-dependent horizontal-to-vertical spectral ratios (HVSRs) of three-component recordings can provide useful information on site resonant frequencies, which are potentially useful for predicting site response. Despite this potential, HVSR-conditioned site response models have not been adopted in the ground motion models most often employed for ground motion prediction in the United States and most global regions. I suggest that this stems from HVSR data resources being unavailable to support model development until recently, ongoing questions related to how HVSR should be measured and interpreted, and lack of consensus on how HVSR data should be utilized for site response prediction.

This presentation will briefly outline these implementation challenges. As part of that discussion, I will review recently compiled data archives, issues related to the measurement of HVSR from earthquake or microtremor signals (eHVSr vs. mHVSr), and peak identification strategies focusing on applications to western United States sites. I will also describe site response modeling approaches including non-parametric models conditioned on mHVSr ordinates and parametric models conditioned on attributes of mHVSr peaks (i.e., peak frequency, amplitude, and width). I will discuss the statistical performance of available models and describe considerations related to the potential future practical application of HVSR models.

Examples of Microtremor Horizontal-to-Vertical Spectral Ratios as a Useful Tool for Geotechnical Site Characterization

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The Horizontal-to-Vertical Spectral Ratio (HVSR) method, utilizing ambient seismic noise or microtremors, has emerged as a non-invasive and cost-effective tool for geotechnical site characterization. This presentation explores practical examples of HVSR applications in assessing subsurface properties, such as soil resonance frequencies, site amplification, and stratigraphic characterization, critical for geotechnical engineering and seismic hazard analysis. By analyzing the spectral ratio of horizontal to vertical ground motion components, HVSR reveals key geotechnical parameters, including sediment thickness and shear-wave velocity profiles. Case studies from urban settings demonstrate how HVSR effectively identifies site-specific characteristics, aiding in the design of resilient infrastructure. The discussion highlights the method's advantages, limitations, and integration with other geophysical techniques, underscoring its value in geotechnical investigations.

On the State of Knowledge/Art/Practice for mHVSr Analyses; A Prelude to the ESG7-COSMOS mHVSr Pre-Event Forum [Poster]

Poster Session • Friday 17 April

Conveners: Cécile Cornou, University of Grenoble Alpes (cecile.cornou@univ-grenoble-alpes.fr); Shinichi Matsushima, Kyoto University (matsushima@sds.dpri.kyoto-u.ac.jp); Alexandros Savvaidis, Consortium of Organizations for Strong Motion Observation Systems (alexandros.savvaidis@beg.utexas.edu); Alan Yong, U.S. Geological Survey (yong@usgs.gov)

POSTER 144

The Role of F0 in Eurocode 8 Site Classification: A New Pathway for Site Effect Assessment Using Single-station Ambient Vibration

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The European seismic regulation will soon transition to a new Eurocode 8. In the first chapter, seismic actions are revised, introducing the anchoring acceleration for rock sites with a 475-year return period, representing the plateau of the rock regulatory response spectra, and the acceleration at a 1-second period. In addition, the soil classification system, previously based on V_{s30} , N_{SPT} , and the approximate thickness of the rock substratum, has been updated. In the main body of the text, it now depends on the time-average shear wave velocity down to (the depth at which exceeds 800 m/s), denoted as $V_{s,H800}$. If H_{800} is less than 30 m, then $V_{s,H800}=V_{s30}$.

The appendix proposes alternative classifications if H_{800} is unavailable. One of these is based on the fundamental resonance frequency of the soil (f_0) with V_{SZ} , the average shear wave velocity obtained for an investigation depth between 10 and 30 m without reaching bedrock. If unavailable, V_{SZ} can be estimated using empirical correlations with geotechnical parameters.

While the fundamental resonance frequency or the fundamental resonance period is already used in several international regulatory codes (e.g., NZS 1170.5 in New Zealand and Seismic Design Codes for Buildings in Japan), it was not applicable in Eurocode 8. This revision introduces its use for site classification, allowing the combination of geophysical measurements (e.g., single-station ambient vibration recordings).

In this context, we propose first to compare the site classifications proposed in the regulatory codes that use f_0 and then to compare the response spectra for different site classes based on f_0 and V_{SZ} with alternative definitions of site response spectra based on V_{s30} and f_0 , as proposed by Cadet et al. (2012).

The use of these new site classifications in combination with single-station ambient vibration measurements, often employed in large-scale studies for site effects due to their cost-effectiveness, could provide new insights for seismic microzonation.

POSTER 145

Evaluation of Ambient Noise HVSR Measurements for Urban Site Characterization in Anchorage, Alaska

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Anchorage, Alaska, is one of the most seismically active urban centers in North America, exhibiting pronounced spatial variability in near-surface soil stiffness, making the accurate estimation of fundamental site frequency essential for resilient infrastructure design and seismic hazard mitigation. This study evaluates the effectiveness of the Horizontal-to-Vertical Spectral Ratio (HVSR) technique using ambient vibration data acquired from two complementary sources: continuous recordings from permanent strong-motion stations operated by the U.S. Geological Survey and the University of Alaska, and targeted deployments of portable Smart Solo broadband three-component seismographs. Ambient noise measurements were conducted at multiple sites, with each portable deployment co-located with a permanent station to enable direct comparison of mHVSr between data collected in the free field and in indoor sensor installations. Results demonstrate that mHVSr-derived fundamental frequencies are consistent with expected V_{s30} -based site classifications, confirming the reliability of mHVSr for rapid site characterization in complex urban environments. When adequately shielded from wind, portable sensors yield stable and well-defined HVSR peaks that closely match those obtained from permanent stations, despite the additional damping and anthropogenic noise associated with building installations. In contrast, unshielded outdoor measurements exhibit significant wind-induced amplification of HVSR amplitudes, highlighting the critical role of proper field procedures. Overall, this study shows that low-cost portable instrumentation, combined with robust HVSR analysis, provides a practical, accurate, and scalable framework for evaluating site conditions in seismically active regions. Ongoing work focuses on optimizing sensor placement and shielding strategies and expanding spatial coverage across Anchorage to support refined, citywide seismic hazard assessments.

POSTER 146

Preliminary Results From Two Months of Continuous Recording of Ambient Vibration on a Dense Array of SmartSolo 3C Seismic Instruments Deployed in the Metropolitan Area of San Juan, Puerto Rico

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Seismic data from ambient vibrations were recorded in a continuous mode for a two-month time span by an array of 35 SmartSolo 3C seismic station instruments (35SS3CSSI) deployed in the San Juan Metropolitan Area of Puerto Rico. In addition to the temporary instruments, twelve permanent strong motion stations of the Puerto Rico Strong Motion Program (PRSMF) are located within the SmartSolo array. The sites of the 35SS3CSSI were located, as much as possible, on different surface geology geologic units. The array covered an area of 141.0 km^2 (perimeter of 46.2 km) with interstation distances between 0.71 km and 5.7 km . Data were collected at 250 sps . From the center of the 35SS3CSSI array, the Great Northern Puerto Rico Fault Zone (GNPRFZ) is located E-SE to W-NW with the main branch perpendicular distance being approximately 16 km .

Ambient vibration HVSR shows apparent good correlation of site fundamental vibration frequency (FVF) with the site surface geological conditions, in which small values of FVF are dominated by shallow soft layers, while large values of FVF are associated to hard layers. Site SS57 of the 35SS3CSSI, located on surface geological conditions of Quaternary-Holocene (Quartz sand, thickness ranges from 1-4 m) deposits grading downward into older alluvial deposits (QTT), shows a FVF of about 1.7 Hz . On the other hand, Site SS97 is on surface deposits of Cretaceous-Upper Cretaceous, poorly indurated volcanic conglomerate (predominant clasts of andesite lava) and mudstone interstratified with thinly-bedded siltstone and sandstone, and apparent maximum exposed thickness of 400 m shows a FVF of about 4.5 Hz . These results were compared with HVSR computed from data of the strong motion stations SJ05, and BY01 of PRSMF, which are in the same geological unit as SS57, and SS97, respectively, showing good agreement between the estimated FVFs. More results of the FVF distribution will be presented.

POSTER 147

Horizontal-to-Vertical Spectral Ratio and Surface Wave Dispersion Inversions to Determine the 1D Velocity Structure Beneath Foulness Island, UK

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In 2021 an instrumentation suite was deployed across Foulness Island, Essex, UK, to record the seismoacoustic wavefield generated by a set of eight near-surface explosions (Green et al., 2025). Foulness Island, an area of reclaimed coastal marshland, is located on the northern shore of the Thames Estuary, 70 km east of London. The upper 20 m of the subsurface at Foulness Island consists of unconsolidated marine and estuarine alluvium deposits, predominantly formed of clays, silts and sands. Below this are layers of London Clay, Lower London Tertiaries, Chalk, Upper Greensand and Gault Clay underlain by Palaeozoic Basement Sandstones. The near-surface explosions generated a complex set of surface waves that necessitate numerical waveform modelling to simulate their dispersion characteristics. However, the development of a simple 1-D subsurface velocity model for Foulness is required to undertake such waveform modelling.

Using the seismic ambient noise recorded on 12 broadband seismic stations deployed for the experiment we measure single-station Horizontal-to-Vertical Spectral Ratio (HVSR). We explore the sensitivity of the HVSR curves to various parameters including window length, window selection, spectral smoothing and combining horizontal components. The HVSR observations at Foulness display a dominant peak at 0.55 Hz and secondary peak at 3 Hz . To invert the HSr curves for the 1-D velocity structure we use ModelHVSR (Herak, 2008; Albarello et al., 2023). We also developed a tool that jointly inverts both surface wave dispersion observations with HVSR observations. The inverted three-layer 1-D velocity model consists of a thin (~40 m), low velocity layer (V_s of ~200 m/s) overlying a thicker, faster layer, over a half space. Such low shear-wave velocities at the near-surface are required to generate the unique set of surface waves observed at Foulness.

A Framework for Quantifying the Time-dependent Evolution of HVSR Features for Basin Site Response Modeling

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The horizontal-to-vertical spectral ratio (HVSR) is widely used to estimate fundamental site periods from ambient vibrations, providing a cost-effective means to characterize subsurface impedance contrasts and sediment thickness. Conventional applications typically reduce HVSR to a single stationary parameter (the peak frequency) implicitly assuming one-dimensional layering and a temporally diffuse wavefield. However, deviations in HVSR shape across time windows, including secondary peaks, masked or muted resonances, and amplitude variability, reflect the influence of lateral heterogeneity, basin-edge effects, and transient ambient sources that are not captured by static metrics. To advance HVSR toward basin-scale (or intra-basin scale) site response modeling, we develop a framework that jointly quantifies stationary and time-dependent HVSR features. Frequency-domain descriptors, including peak frequency, bandwidth, and number of spectral peaks, provide baseline measures of resonance strength and dimensionality. Building on this, Stockwell transform-based time-frequency analysis is used to evaluate the temporal persistence and stability of HVSR features. Persistent frequency ridges are interpreted as robust site-controlled resonance, while intermittent (short-lived) peaks are associated with source variability or localized scattering. Application to 300 sites across Southern California demonstrates that time-dependent HVSR metrics highlight differences basin interiors, basin edges, and transition zones, even when peak frequencies are similar. These results show that incorporating time-frequency structure and component-wise assessments enable HVSR to move beyond static proxies, providing a suite of physically interpretable, direction sensitive features that capture basin complexity and support improved site condition classification and seismic site response prediction.

Site Response Characterization of California's Geomorphic Basin Categories Using Microtremor-based HVSR

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Ground motion models (GMM) developed for active tectonic regions such as California incorporate site response components that are commonly parameterized using simplified site descriptors, including the time-averaged shear-wave velocity in the upper 30 m (V_{S30}) and depths to shear-wave velocity isosurfaces (e.g., $z_{1.0}$). While adequate for well-represented sites, these parameters may bias predictions at sites with complex subsurface conditions. Such biases can arise from site-specific resonances and frequency-dependent site effects associated with geological features, including deep or laterally extensive sedimentary basins. In recent decades, the microtremor-based horizontal-to-vertical spectral ratio (mHVSR) method has gained attention as a tool for identifying site resonance, with the lowest spectral peak commonly interpreted as an indicator of the fundamental site frequency (f_0). Moreover, the overall shape of the mHVSR spectrum has also been shown to resemble site response in response spectral space, highlighting its potential for capturing frequency-dependent amplification.

In this study, we use ground-motion data from 685 strong-motion stations with co-located mHVSR measurements to develop site response models to explicitly capture site-specific resonance and frequency-dependent site effects within each of four geomorphic categories (i.e., basin, mountain/hill, valley, and shelf) across California. Geomorphic categories are evaluated statewide using geological units, information from shear-wave velocity models (e.g., National Crustal Model), and surface topography. Two complementary models are proposed: (1) a peak-based model that is conditioned on mHVSR peak attributes, including fundamental frequency and amplitude, to corresponding peak features in site response, and (2) a similar model that would utilize mHVSR peak attributes to relate to broader, ramp-like amplification behavior using a logistic functional form. The results suggest that mHVSR has potential for characterizing site response and improving site-specific ground motion estimates.

Analysis of the Azimuthal Dependency of the HVSR Spectra in Complex 3D Velocity Structures Using Numerical Modeling

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Using a numerical modeling scheme, we evaluate the azimuthal dependence of the Horizontal-to-Vertical Spectral Ratio (HVSR) in wave fields propagated through a horizontally layered velocity structure and (1D) and (3D) velocity structures. We choose the best combination of the radial, tangential and vertical source components to model the ambient noise's seismic source that better explains the observations on a test site. We adopt this derived source configuration to generate simulated wave fields propagated in a horizontally layered velocity model (1D) and a canonical 3D velocity structure, and then compute their HVSR spectra. Our simulations use four distinct source locations, each providing a different source-receiver azimuth, to evaluate how variations in wave propagation from these configurations influence HVSR spectra. We extend the analysis to two additional velocity models by introducing stochastic perturbations to the deterministic 1D and 3D velocity structures. We find that the source configuration strongly affects the HVSR amplitude across all analyzed velocity structures. Additionally, the results suggest that in sites placed over velocity structures in which the 1D velocity model can be assumed, the spectral shape of HVSR tends to be stable along the azimuths of the whole polar circle. Conversely, sites located over 3D velocity structures may exhibit strong azimuthal-dependent spectral shapes in HVSR spectra if the wave field is governed by unidirectional wave fronts, even in some instances, making the predominant frequency dependent on the source-to-site azimuth. We propose a methodology based on 2D seismic array analysis and wavenumber-domain filtering to identify HVSR spectral-shape fluctuations as a function of azimuth.

We discuss our findings and implications in constraining site terms in ground-motion modeling.

Physical Properties of Fault Zones from the Seismic Source to Earth's Surface

Oral Session • Wednesday 15 April • 8:00 AM Local

Conveners: Alexis Ault, Utah State University (alexis.

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Trigging of Pore Pressure Drop in the Active Milun Fault by the Near-field M7.4 Hualien, Taiwan Earthquake

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Pore pressure directly affects the strength of faults, drives geothermal fluid migration and mineral precipitation, and the controls fault healing rates. Hydrologic observations such as groundwater level near and inside fault-zones are therefore valuable to understand the evolution of faults and seismic hazard. However, these measurements are rare, as they require pressure sensors very close (< 1 km) to the target fault-zone. The 2024 M7.4 Hualien earthquake on the Milun Fault in eastern Taiwan presents a unique opportunity to study these processes due to the density of hydrologic observations near the fault and the documented responses to other regional earthquakes. Here, we

present groundwater level data from seven shallow groundwater wells near the Milun fault, deep borehole data from the Taiwan Milun fault Drilling Project which directly samples the Milun fault-zone, and seismic velocity data from X seismometers in the region. We find ~ 5 m of rapid groundwater level decline during at stations near (< 250 m) the fault, whereas groundwater wells further away show little or no response. Static strain models indicate that the Milun fault experienced dilation strain up to ~10⁻⁵. In contrast, the dynamic strains from the event produced shear strains as large as ~10⁻³. We propose that a combination of two mechanisms produce the water level changes: (1) static strain dilation imparted by the M7.4 earthquake on the Milun fault led to fault-zone fracture opening, and (2) strong ground shaking damaged fault-zone materials. Both mechanisms create permeable pathways for fluid migration and testable predictions of groundwater response. Our observations highlight that earthquake-induced pore pressure changes affect both the long- and short-term evolution of fault strength.

How Depth-dependent Seismic Properties Control Fault Damage Zone Structure: Insights From 3D Damage-breakage Rheology Model

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Understanding the partitioning of deformation between fault slip and bulk damage is crucial for assessing seismic hazards. Constraining depth-dependent fault zone structure remains challenging due to scarce near-fault data. Geological surveys, seismic inversions, and geodetic observations report diverse, even contrasting findings on damage zone geometry and depth extent, reflecting limitations of far-field observations, different definitions of damage, and simplified linear elastic assumptions.

To reconcile the conflicting arguments and provide physical explanations for the observations, we implement a 3D nonlocal continuum damage-breakage model (CDBM) in a MOOSE-FARMS rupture simulator. In our models, damage is generated at all locations where a threshold criterion is reached, so the CDBM governs the entire computational domain. Preexisting faults are represented as sharp interfaces governed by a linear slip-weakening law. The simulation begins with a static solution with depth-dependent seismic properties. This is followed by a dynamic rupture using an explicit central-difference scheme . To explore depth dependent properties, we examine three scenarios in: (1) a hydrostatic pore-pressure profile that produces linearly varying stress with depth, (2) a lithostatic pore-pressure profile imposed at depth which yields constant frictional strength, and (3) a hydrostatic pore-pressure profile with 1D continuous velocity structures. Our simulations reproduce diverse damage zone structures observed in nature: flower-like branching in the shallow subsurface, depth-independent patterns across the seismogenic zone with high velocity reduction near the free surface, and en echelon fractures on the extensional fault side. We correlate the results with field observations, identify key parameters controlling these distinct damage patterns, and provide mechanistic explanations for their formation.

The full simulator developed in this work is publicly accessible via Quakeworx, an NSF-funded science gateway designed to democratize access to advanced earthquake simulations and associated datasets.

Influence of Fault Roughness Coupled With Shear-induced Inelastic Dilatancy on Earthquake Sequences

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We investigate the combined effects of fault roughness, shear-induced inelastic dilatancy, and the associated fluid pore pressure effects on the dynamics of earthquake sequences and aseismic slip. Utilizing the dynamic hybrid finite element-boundary element (FEBE) framework, we simulate sequences of slip events accounting for these factors. Our simulations compare the behavior of rough and planar faults under various fluid diffusivity conditions. In the absence of fluid diffusion, we find that pore pressure effects due to dilatancy make the behavior of rough faults more similar to that of planar ones, reducing the number of precursory events and limiting the effects of stress perturbations on the recurrence interval. On planar faults with dilatancy and fluid diffusion, the recurrence interval alternates between two end-member cases corresponding to absence of dilatancy and dilatancy with no fluid diffusion, showing that drainage can alter the dynamics. For rough faults, fluid diffusion interacts with stress heterogeneity due to fault roughness, leading to temporal clustering of events and influencing the recurrence intervals of larger, fault-

spanning events. Partial ruptures and cascading earthquakes emerge, altering the sequence of events and resulting in a complex dependence of precursory slip on pore pressure diffusion. These cascading behaviors occur when the diffusion timescale required to reduce the frictional resistance of the interface is larger than the seismic timescales but smaller than aseismic timescales. Our findings highlight the critical role of fluid effects in the behavior of rough faults and emphasize the need to incorporate them in models and seismic hazard assessments.

Dilatancy-driven Transitions Between Large Earthquakes and Slow Slip Events in 3D Earthquake Cycle Simulations

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Fluids are increasingly recognized as a first-order control on fault strength and different slip behaviors at subduction zones, yet most earthquake-cycle and dynamic-rupture models prescribe pore pressure or oversimplify its spatial variability. We present a 3-D multiphysics framework that couples the fully dynamic finite-element earthquake cycle solver (EQdyna) with a 3-D porosity & pore pressure evolution model for the surrounding damage zone. The fluid module solves compressible single-phase Darcy flow with permeability evolving alongside porosity. Porosity evolves via a phenomenological law including elastic response to pore pressure changes, time-dependent visco-chemical compaction, and slip-induced dilatancy; the rupture and fluid systems are coupled two-way.

Preliminary simulations show that the damage-zone dilatancy length scale strongly governs seismic event patterns. Narrower damage zones yield smaller, more frequent events with shorter recurrence intervals, more localized porosity changes, and larger coseismic pore pressure transients followed by diffusion and compaction driven recovery; sufficiently strong dilatancy can shift sequences toward slower, SSE-like slip. The model reproduces pre-seismic pressure/porosity anomalies near nucleation, coseismic pore pressure drops over the rupture patch, and post-seismic recovery consistent with diffusion-controlled transients. We will apply the framework to the Chilean megathrust to explore whether fluid-driven porosity/permeability evolution can reproduce key observations: depth-segmented recurrence with weaker deep segments failing more frequently than shallow great earthquake asperities, asperity-bounded foreshock and aftershock belts and transient afterslip, repeaters around the 2014 Iquique rupture, and fluid-rich, low-coupling regions with swarms and rupture barriers near Mejillones. These Chile-focused simulations will incorporate depth-dependent normal stress, heterogeneous damage zone hydro-mechanical properties, and temperature-dependent compaction kinetics.

Rapid Fault Healing From Cementation Controls the Dynamics of Deep Slow Slip and Tremor

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Despite its status as one of the most important discoveries in geophysics, the physical mechanism(s) responsible for slow slip events (SSEs) are not well understood. Here, we synthesize observations of deep SSEs in the Cascadia Subduction Zone and argue that rapid, cohesive fault strengthening may control the dynamics of deep SSEs. Cohesive strength is frequently ignored in constitutive laws used to describe fault rheology in numerical simulations of earthquakes and SSEs alike. To demonstrate its importance, we perform and analyze a suite of petrological experiments that simulate fault healing under representative pressure and temperature conditions. We show that significant cohesive strength recovery caused by dissolution- precipitation processes occurs on timescales of just a few hours. Together, our experimental and observational results support the idea that cohesion is a key component of fault strength under SSE conditions and highlight the need for its inclusion in both future experiments and numerical models of fault slip.

Linear Streaks of Seismicity Around California

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With improvement in the resolution of catalogs, seismicity provides an increasingly important constraint in understanding fault structure and earthquake processes. To first-order, faults are planar structures. However, near-horizontal linear streaks of seismicity have been observed in several different fault zones in California and elsewhere. How common are these seismicity lineations? How do they form? What do they inform us about the earthquake process and the frictional properties on the fault? We systematically search for the linear features in seismicity throughout California in an attempt to address these questions. Our analysis reveals linear features along different sections of the San Andreas fault, the Garlock fault, and the Imperial fault among others. Some of these features appear to be related to the boundary between the locked and the creeping portion of the fault while others are potentially related to swarm activity. We investigate the occurrence of seismicity lineations in terms of other geophysical observations such as repeating earthquakes and creep rate on the fault. Our results show that the occurrence of the linear seismicity features correspond to neither higher repeater density nor higher creep rate but rather the zone of transition between locked and creeping regions.

Correlation Between Anisotropic Crustal Fabric Strength and Fault Creep

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Plate boundaries and with them the stressing of earthquake-generating faults evolve based on a complex interplay of frozen-in lithospheric structure and tectonically evolving crustal and lithospheric damage and fabrics. We explore the connection between fault characteristics developed on geological time scales (such as fault trace geometry and complexity, cumulative displacement, and the development of crustal fabrics) and short time scales (such as the geometry of microseismicity and geodetically detected creeping versus locked fault behavior). Our study focuses on the San Andreas system in California. We use receiver functions to map contrasts in seismic anisotropy in the crust attributable to faults. We find that the mapped strikes of fault fabrics are generally aligned parallel to fault surfaces, with depths extending throughout and below the seismogenic zone. Fault fabric strength as well as depths can vary strongly along the trace of each fault.

We calculate correlations between fault fabric strength, creep rates, cumulative displacement, fault geometry, and geometry of microseismicity. We substantiate moderate correlation of fault trace alignment with creep rate and find a correlation of similar strength between creep rate and cumulative displacement. However, higher correlations are observed between fabric strength and creep rate as well as creep rate and spatial anisotropy of microseismicity. The spatial commonality between fabric development on geological time scales and creep rates and microseismicity geometry on short time scales is lithology. We also investigate the relationship between the depth of inferred fault creep and depth of deformation fabrics. Strong fabrics are seen in the mid crust under portions of the San Jacinto fault previously proposed to creep at depth. A creep-fabric correlation may thus offer a window into in situ creep behavior in the deep crust.

Exploring (A)seismic Slip and Off-fault Deformation Caused by the 2021 Mw5.3 Calipatria Earthquake, Salton Sea, CA

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In the Imperial Valley in southernmost California, a complex network of closely spaced faults accommodates transtensional plate boundary motion in a shallow crustal environment with complex rheology, high heat flow, and volcanic and hydrothermal activity. The influence of these regional characteristics may manifest as swarm-style seismicity with significant pre- and post-mainshock aseismic deformation, as observed by geodetic data [e.g., the 2005 M_W 5.1 Salton Sea (Lohman & McGuire, 2007) and 2020 M_W 4.9 Westmorland events (e.g., Sirorattanakul et al., 2022)], in addition to shallow creep events (e.g., Materna et al., 2024) that increase uncertainty in seismic hazard estimates.

On June 5th, 2021, a M_W 5.3 earthquake occurred ~3 km southeast of the Salton Sea, near the town of Calipatria, in a location that is directly comparable to the 2005 sequence. To better understand the role (a)seismic processes may play in the earthquake cycle in this unique faulting environment, we explore the co- and postseismic motions around the event using two tracks of Sentinel-1 Interferometric Synthetic Aperture Radar (InSAR) and nearby Global Navigation Satellite System (GNSS) data. Both sets of geodetic time series observations reveal a step offset comprising coseismic and earliest postseismic slip and an additional, ~3-month-long decaying postseismic signal near the epicenter. Initial fault slip inversions using a depth-dependent elastic model and a SW-trending steeply-dipping fault, reveal a max slip estimate of ~6-10 cm of normal motion at ~6 km depth for the initial coseismic step displacement, equivalent to a moment ~ M_W 5.4 earthquake, and an initial estimate of longer-term postseismic slip with a max of ~1 cm normal motion at ~4 km depth. High-resolution interferograms reveal the presence of multiple 1-3 km-long surface fractures off the main fault trace after the earthquake, with vertical displacement sense that varies based on azimuth direction from the fault source. Further analysis will investigate their relationship to the mainshock and postseismic processes and draw comparisons with the 2005 sequence.

Estimate of Inelastic Strain and Fault Zone Damage Due to Aftershocks

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Faults are often associated with damage zones expressed in high fracture density, reduced seismic velocities and elastic moduli, and enhanced permeability. Some of the damage can be attributed to off-fault yielding due to a dynamic stress concentration around propagating rupture fronts (“coseismic damage”). Additional damage can be produced by aftershocks that act to relax stress perturbations left behind by the mainshocks. Because aftershocks typically follow power-law distributions, in particular the Gutenberg-Richter law, one can evaluate their contribution to permanent inelastic strain accommodated by fault damage zones. I use aftershock data from several major earthquakes in Southern California, including the M7.3 1992 Landers, M7.1 1999 Hector Mine, M7.2 2010 El Mayor, and M7.1 2021 Ridgecrest earthquakes to quantify the amount of strain accumulated post seismically in the respective fault zones. The observed magnitude-frequency distributions indicate that the size of aftershock ruptures follows a “universal” power-law with a cumulative exponent of -2. A cumulative potency of the entire aftershock sequence can be obtained by integrating the best-fit power-law distribution. Inelastic strain produced by aftershocks is then given by a ratio of cumulative potency to the damage zone volume. The latter is obtained from the spatial distribution of aftershock hypocenters. The inferred patterns of inelastic strain due to aftershocks show a good agreement with geologic observations of distributed deformation around major faults in the Eastern California Shear Zone.

Effects of Non-causative Fault Zones on Ground-motion Path Effects: A Simulation Study

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We consider how the presence of a non-causative fault damage zone (i.e., unaffiliated with the source) affects the propagation of ground motions through physics-based simulations. Damage zones are highly fractured, low velocity structures surrounding fault cores, and their mechanically weak properties have been shown to influence seismic wave propagation and amplify ground motions. Previous fault zone ground-motion studies have focused on the effects of causative fault zone plasticity during earthquake rupture or on the trapping of seismic energy within a fault zone. Field observations also show evidence of attenuation of seismic waves that travel across a separate, non-causative low velocity fault zone, though the specific parameters controlling the attenuation remain unclear. Characteristics of individual fault zones are difficult to constrain and are inconsistent across studies, which makes developing physical relationships challenging.

In this study, we constrain first-order controls on ground motion amplitudes and frequency content using simulations in which an existing non-causative fault zone is included in the assumed velocity structure. Seismic wave propagation is performed using the finite difference code SW4, with the seismic source modeled as a point source. The non-causative fault zone is embedded as a low velocity zone in simple 1D or 3D seismic velocity models. We investigate different non-causative fault zone attributes and their control on ground motions, including fault zone width and velocity contrast at the fault

zone boundary. Additionally, we assess the effects of source–receiver orientations across the fault to explore the relationships between fault zone amplification and attenuation. These results motivate improvements to the USGS San Francisco Bay Area seismic velocity model, which currently does not include low velocity zones at fault boundaries. Additionally, these physical relationships could help inform fault zone characterization studies and may assist in defining the path component in ground-motion attenuation models.

Physical Properties of Fault Zones from the Seismic Source to Earth’s Surface [Poster]

Poster Session • Wednesday 15 April

Conveners: Alexis Ault, Utah State University (alexis.

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POSTER 114

Hydraulic Tomography of Faults Near Cahuilla, Southern California

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A new class of earthquake swarms lasting for years and exhibiting very slow migration patterns has been recently discovered in southern California. Most of these earthquake swarms reveal spatiotemporal patterns consistent with natural fluid injections. The properties of these swarms suggest the presence of a triggering front of seismicity driven by pore-pressure diffusion, consistent with a fault-valve mechanism in which episodic rupture releases transiently overpressured fluids. Understanding this aseismic process can provide insights into the hydraulic properties of faults. We focus on a seven-year-long earthquake swarm (2016–2022) that delineated an approximately 4 km-by-4 km fault near Cahuilla, southern CA. The swarm exhibits very slow diffusive migration consistent with natural fluid injections into a fault. Examining the migration of earthquakes along the fault extent provides insights into the hydraulic properties of the fault and its driving mechanisms. First, we assume that the seismicity evolution is due to a pore-pressure diffusion mechanism with a propagating triggering front. We then reconstruct the hydraulic diffusivity field along the fault using an eikonal-based approach. In this framework, the eikonal equation relates the arrival time of the triggering front to the local propagation speed of pressure diffusion. Spatial gradients in these arrival times define the slowness of the diffusion front, which is inverted to recover diffusivity in a heterogeneous medium. The inverted diffusivity values have a mean of ~10⁻³ m²/s and generally range from 10⁻⁴ to 10⁻¹ m²/s. However, we observe strong systematic variations in diffusivity across the spatial extent of the swarm. Lower diffusivity values are observed near the presumed injection point where the first events occurred. Higher diffusivity values are found up-dip of a near-horizontal permeability barrier located ~2 km above the initial injection depth, previously reported to temporarily slow seismicity migration. Detailed studies of swarms such as this have the potential to provide new insights into their exotic physics and driving mechanisms.

POSTER 115

The Effects of Plasticity on Vertical Off-fault Deformation Percentages for the 1971 San Fernando Earthquake

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Earthquakes involve a partitioning between slip on the fault and off-fault deformation. Significant off-fault deformation was measured for the 1971 M_W 6.6 San Fernando Earthquake, where the steeply dipping Sylmar fault segment, which cuts through both soft and stiff sedimentary layers, has a higher percentage of vertical off-fault deformation than the shallower-dipping Tujunga Fault segment, which cuts through stiffer sedimentary layers (Gaudreau et al., 2023). Our aim is to understand what may have contributed to the differences in off-fault deformation between the two fault segments. Using 2D dynamic finite element models (Barall, 2009), we explore the effects on slip and surface deformation of different fault geometries and material properties, including the implementation of Drucker-Prager plasticity. Specifically, we undertake a parameter study of how plasticity, primarily focusing on bulk friction and cohesion, can affect slip and off-fault deformation. As we decrease the bulk friction and cohesion parameters, our models diverge from our elastic models for the two corresponding fault segments. In particular, these parameters affect the partitioning of slip and off-fault deformation near the surface, where our models with smaller bulk friction and cohesion values have less slip at the surface than those with larger bulk friction and cohesion. For low values of bulk friction, the cohesion takes on increased importance near the surface. We find that models with lower values of bulk friction and cohesion better fit the percentage of off-fault deformation than models with higher values. We calculate the percentage of off-fault deformation at different distances away from the fault and compare these calculations to what was observed. Our models need to be rather finely tuned in both plasticity parameters to produce deformation patterns qualitatively similar to that observed in the 1971 event. The need for such fine-tuning may highlight a limitation of the 2D models or other aspects of our problem formulation.

POSTER 116

Space-time Variations of In-situ Vp/Vs Ratios in the San Jacinto Fault Zone

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The San Jacinto Fault Zone (SJFZ) is highly active seismically, especially in the trifurcation area south of Anza, which is responsible for over 10% of all recorded seismicity in Southern California since 2000. This dense catalog facilitates in situ studies of Vp/Vs ratios throughout the seismogenic zone at different times. We calculate cross correlations of P- and S-waveforms between event pairs selected for proximity: hypocenter separation < 5 km, origin time difference < 1 year, magnitude difference < 1 and Kagan angle < 30°. Less than 1% of event pairs have waveform CC > 0.9 likely due to the complexity of the fault geometry. Event pairs with waveform correlation coefficients (CC) > 0.6 are retained and Vp/Vs ratio is fitted from P- and S-wave lag times following Lin and Shearer (2007). Our observations are consistent overall with the previous results of Lin et al. (2022), showing a median ratio of approximately 1.7 for the SJFZ and a complicated spatiotemporal pattern. We observe temporal variations of Vp/Vs ratio in the trifurcation area, including decreased Vp/Vs ratios after the 2010 El Mayor-Cucapah earthquake and the 2010 M5.4 earthquake, but this is not clearly observed for the 2016 M5.2 earthquake. North of the Anza seismic gap, high Vp/Vs ratios are resolved northeast of the Clark Fault at depths of ~15 km. South of the M5.2 event epicenter, Vp/Vs ratios between the Coyote Creek Fault and the Clark Fault increase toward the northwest. Updated results will be presented in the meeting.

POSTER 117

Integrated Geophysical Investigation of Quaternary Paleo-earthquake Evidence in Soft Soil Deposits Using GPR, ERT, MASW, and HVSR Surveys

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This study presents an integrated geophysical approach combining Ground Penetrating Radar (GPR), Electrical Resistivity Tomography (ERT), Multichannel Analysis of Surface Waves (MASW), and Horizontal-to-Vertical Spectral Ratio (HVSR) to detect Quaternary paleo-earthquake ruptures. The survey was conducted at sites in Incheon, Goyang, Cheongju, and Buan, South

Korea, where Quaternary ruptures were visually identified via trenching and borehole surveys. These sites are characterized as soft soil deposits with shear wave velocities (V_s) below 700 m/s.

Geophysical surveys, performed using site-specific combinations of these methods, consistently identified anomalies corresponding to the known surface rupture zones. Specifically, ERT effectively detected fluid-filled fractures through electrical resistivity (ρ) variations, while MASW identified mechanically damaged zones via reductions in V_s . GPR visualized stratigraphic boundaries and subsurface anomalies through electromagnetic reflection patterns, and HVSr confirmed the location of anomalies via shifts in resonance frequency. The identified anomalies exhibited widths of 20–30 m and extended to depths of 20–25 m, providing subsurface information significantly beyond the conventional depth limit of trenching (3–5 m). These findings demonstrate that non-invasive, multi-method geophysical surveys can successfully trace the continuity of fault ruptures even in soft soil environments. Accordingly, this study suggests a reproducible and cost-effective protocol for fault characterization beneath urban infrastructure where traditional invasive methods are impractical.

POSTER 118

Investigating the Geometric Origin of Slip Asperities

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Understanding how the spatial distribution of earthquake slip is governed by the structural properties of the fault zone remains a fundamental problem in seismology. While slip localization is often attributed to frictional heterogeneities and stress history, these parameters remain largely unobservable at seismogenic depths. Building on the premise that geometric incompatibilities within fault networks can govern fault slip behavior by promoting locking (Lee et al., 2024), this study explores whether these same features serve as spatial indicators for coseismic high-slip asperities. Mechanically, regions of high misalignment are expected to provide increased resistance to shear, potentially necessitating higher local stress accumulation to initiate failure. Under this hypothesis, large-slip asperities would preferentially develop at these geometric complexities, where strain energy is accumulated.

We present a preliminary analysis of 31 large earthquakes ($M_w > 6$), integrating finite fault models with available surface fault trace data. Using a sliding-window approach, we evaluate localized fault network misalignment and compare its distribution to spatial patterns of earthquake slip. Preliminary results suggest that high-slip asperity zones tend to be associated with regions of higher relative misalignment. While these observations are subject to the inherent spatial resolution limits and smoothing of finite fault inversions, the results suggest a potential geometric origin for asperity localization. These findings add to a growing set of observations linking fault geometric factors to earthquake processes.

POSTER 119

Fault Damage Zone Structure at Depth Extracted by FZTWs and Receiver Functions From Teleseismograms

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We identified the fault-zone trapped waves (FZTWs) in teleseismograms from teleseismic earthquakes recorded at a seismic nodal-array consisting of 100 stations deployed atop the Calico Fault (CF) in Mojave Desert, California in 2006. The FZTWs recorded at stations located within the CF compliant zone are characterized by large amplitudes at dominant frequencies 0.5–2 Hz and long durations of ~3.5–4 s and ~6–8 s, respectively, closely following the transmitting P wave and the P-to-S converted S' wave from the Moho discontinuity beneath Mojave Desert. As P' and S' waves enter the bottom of the low-velocity waveguide (LVWG) formed by the CF compliant zone, FZTWs are produced within it due to coherent interference of waves reflected at the boundary between the low-velocity fault damage zone and high-velocity surrounding rocks. We use the receiver functions computed from teleseismograms recorded at stations located within the CF compliant zone to confirm these newly identified FZTWs arising from the P' and S' waves coming from the Moho. This type of FZTWs has not been used before, but they appear to have great promise for diagnosing the depth extension of low-velocity fault damage zone because they arise from teleseismic seismic waves entering the bottom of deep fault zone at the depth where the coverage of seismic waves from explosions and local earthquakes is poor. Based on the previous veloc-

ity model of the CF compliant zone obtained from the FZTWs generated by explosions and local earthquakes combined with teleseismic P-wave travel-times inverse and InSAR observations (Cochran, et al., 2009), our 3D finite-difference simulations of these FZTWs identified in teleseismograms and confirmed by their receiver functions show that the 1–1.5-km wide Calico fault compliant zone with ~40–50% velocity reduction likely extends to ~8-km depth beneath Mojave Desert, consistent with the previous model but ~2-km deeper. Accurately extracting the extension of fault damage zone at seismogenic depth helps for evaluating earthquake physics and seismic energy radiated from the source, and hazards on the ground during earthquakes.

POSTER 120

Monitoring Temporal Variations in Dtp/Dts Ratio Owing to Water-saturation Within the Fault Zone - a Plausible Earthquake Precursor

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In experiments conducted at the rupture zones of the 1992 M7.4 Landers, 1999 M7.2 Hector Mine and 2004 M6 Parkfield earthquakes, seismic waves from repeated explosions and earthquakes recorded at across-fault dense arrays show that a fault co-seismic damaged may regain strength with the logarithmic healing rate in the interseismic period. The “crack dilatancy” mechanisms are likely to operate for co-seismic fault damage and post-seismic healing. We measured the ratio of traveltime changes for P to S waves recorded for the same shot-receiver pairs in repeated experiments to detect variations in apparent water-saturation of cracks within the rupture zone during co-seismic damage and post-seismic heal. According to equations for the elastic moduli of the Poisson solid with penny-shaped cracks, the ratio of Dtp/Dts is 1.22 for dry crack and 0.27 for fully water-saturated crack. In our study area with an anomalous Poisson's ratio of 0.33, the two ratios are 1.64 and 0.17, respectively. At Parkfield, we measured the Dtp/Dts ratios are ~0.52 and ~0.68 (apparent water-saturation degrees ~76% and 64%) within and out of the SAF between two repeated shots before and 3 months after the M6 earthquake, implying that cracks within the SAF opened during the mainshock might being closure and wetter than those out of the zone. At Hector Mine, we measured Dtp/Dts ratio of ~0.72 within the rupture zone between 2000 and 2001, indicating that cracks might being apartially water filled (apparent water-saturation degree ~62%) two years after the M7.2 mainshock. The Dtp/Dts ratios within the Landers rupture zone measured after the M7.4 mainshock were 0.75 between 1994 and 1996, 0.65 between 1996 and 1998, and further decreased to 0.55 until 2001. The apparent water-saturation degree in cracks increased from ~60% through ~68% to ~78% as cracks close gradually in this inter-seismic period. These observations suggest that monitoring the temporal-spatial variations in Dtp/Dts ratio of seismic waves at the active fault may play a plausible precursor for predicting a pending earthquake on it.

POSTER 121

Comparing Fault Zones that Host Induced and Tectonic Earthquakes in Oklahoma and California

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We have developed a new approach to detect and image fault zone structures through the azimuthal variation of earthquake spectra. The spatial distribution of earthquake clusters exhibiting high-frequency amplification provides insight into the characteristics of the fault damage zone. Our previous studies show that high frequency amplification is observed more uniformly along the Ridgecrest fault zone than the Parkfield fault zone. Furthermore, our results demonstrate that fault zone structures previously observed at shallow depths of 3 to 5 km can potentially be imaged at greater depths up to ~10 km using high-frequency energy from earthquake clusters. While this method has primarily been applied to fault zones hosting tectonic earthquakes, characterizing fault zone structures that host induced seismicity is important, as these damage zones often provide pathways for fluid propagation. Hence, we investigated several induced earthquake sequences in Oklahoma, including Fairview, Guthrie, Cushing, Woodward, and Pawnee. Similar to the Ridgecrest and Parkfield analyses, we used stacked P-wave velocity spectra of $M < 3$ earthquake clusters recorded at broadband stations to identify azimuthal variations in high-frequency content. We find that there is also some high-frequency amplification in the Oklahoma sequences, suggesting that fault zone structures hosting induced earthquakes exhibit ground motion amplification behaviors similar to those observed in tectonic fault zones like Ridgecrest and Parkfield.

POSTER 122

Depth-dependent Frictional Stability and Rupture Arrest on the Pütürge Segment of the East Anatolian Fault Zone, Turkey (Türkiye)

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Partially creeping faults contain spatially distinct locked and creeping patches, often interpreted as velocity-weakening (VW) and velocity-strengthening (VS) frictional domains. Ruptures nucleating within VW regions may arrest upon entering VS patches, limiting seismic moment release and influencing ground motions. Identifying the controls on fault zone frictional stability is thus central to understanding rupture termination and seismic hazard. The Pütürge segment (PS) of the East Anatolian Fault Zone, Turkey, exhibits shallow creep ($< \sim 3$ km depth) that approximately coincides with termination of both the 2020 M6.7 Elazığ and 2023 M7.8 Pazarcık ruptures. Here, we investigate how pressure-temperature conditions influence frictional stability and rupture arrest on the PS. Analysis of surface displacements derived from Sentinel-1 SAR pixel tracking indicates the 2023 M7.8 rupture propagated laterally into the PS where slip rapidly diminished. We collected fault gouge from an outcrop exposure of the PS for lab analysis (X-ray diffraction, petrographic and scanning electron microscopy) and rate-stepping triaxial friction experiments at temperatures and effective normal stresses approximating Earth's surface (21°C, 10 MPa), 2–2.5 km depth (100°C, 36 MPa), and 4–5 km depth (200°C, 71 MPa). The gouge, composed primarily of muscovite, quartz, and calcite, exhibits VS behavior at Earth's surface and 2–2.5 km, transitioning to VW behavior at 4–5 km depth. We attribute this frictional transition to thermally activated deformation mechanisms observed in the outcrop and experimental samples. Experimental deformation is dominated by microfracturing and comminution, possibly enhanced by stress corrosion cracking, with more advanced grain size reduction and strain localization in the VW sample. Outcrop samples additionally contain pressure dissolution features. These results show that depth-varying deformation mechanisms and frictional stability can develop even within a uniform lithology, promoting shallow creep and inhibiting upward rupture propagation from depth, with important implications for seismic hazard.

POSTER 123

Influence of Fault Zone Overstrengthening on Future Earthquake Processes

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The evolution of fault zone properties over multiple earthquake cycles influences earthquake rupture nucleation and propagation, ground motion, and seismic hazards. Typically, fault zones are believed to evolve towards tabular damage zones surrounding a low cohesion fault core and are characterized by

increased fracture density and reduced elastic stiffness. However, interseismic mineral alteration and fracture healing can either weaken or strengthen fault zones, influencing future earthquake ruptures. Here, we document post-earthquake fault-zone-strength enhancement through field and laboratory observations of fault core and damage zone rocks from subsidiary faults partially activated during the 2019 Ridgecrest earthquake sequence. Analysis of coseismic slip observed with InSAR shows that only some portions of faults in the Spangler Hills experienced slip during the Ridgecrest earthquake sequence even though Coulomb failure stress change analysis predicts the entire length of the faults would have been stressed towards failure. Field investigations have revealed the presence of pseudotachylite along the faults which is evidence of ancient earthquakes, likely near the brittle-ductile transition. We measured the tensile and uniaxial compressive strength, Young's modulus, Poisson's Ratio, cohesion, and angle of internal friction of fault zone rocks and nearby plutonic rocks using a Split Hopkinson Pressure Bar. We find that post-earthquake healing via propylitic albite alteration within the fault zone increased damage zone tensile and compressive strength and stiffness, and fault core cohesion by ~150% in the location where no slip was observed. The results suggest that fault zone cohesive healing can have long-lasting impacts on slip in distributed fault systems, earthquake dynamics, and seismic hazards.

POSTER 124

Depth Dependence of Seismic Velocity Recovery Following the 2009 L'Aquila and 2016 Amatrice Earthquakes

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Slip on a fault is fueled by strain energy in the surrounding crust. However the availability of this energy source as a function of depth and throughout the seismic cycle remains poorly understood. To explore this gap, we analyzed 24 years of seismic velocity variation $\delta v/v$ data obtained through ambient noise auto-correlation from a seismometer in L'Aquila, Italy. $\delta v/v$ is intrinsically linked to the elastic moduli of the crust, a measure of the medium's response to changes in elastic strain energy. Yet, the physical mechanisms behind seismic velocity variations and their connection to strain energy are unknown. We studied varying lapse time segments in the ambient noise auto-correlation function to constrain the $\delta v/v$ behavior at different crustal depths. During the 2009 M_w 6.1 L'Aquila earthquake and the 2016 M_w 6.2 Amatrice earthquake $\delta v/v$ showed a coseismic decrease at all studied depths. At shallow depths $\delta v/v$ immediately began to recover linearly with logarithmic increments in time, suggesting a thermally activated “healing” process. At deeper crustal depths $\delta v/v$ continued to decrease following the L'Aquila event until the Amatrice event and showed no noticeable recovery in the 15 years following the L'Aquila earthquake. Temperatures and pressures increase with increasing depth, and thermally activated processes are expected to accelerate — the opposite of our observation. The difference in time dependency at shallow and deeper crustal depths for the recovery suggests that the governing mechanisms are different. Additionally, coseismic changes in $\delta v/v$ at shallow depths naturally restore on the order of years while changes at greater depths persist for at least decades, if not permanently.

POSTER 125

Multiparametric Geophysical Monitoring Reveals Fluid-driven Precursors to Seismic and Volcanic Events: Rgunal Network Design and Preliminary Results

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The Geophysical Network of the Universidad Nacional de Colombia (RGUNAL, an acronym from Spanish, and nuanced in English as Robust Geophysical Network of the Universidad Nacional de Colombia) was established to test the hypothesis that transient anomalies in magnetotelluric (MT) apparent resistivity (ρ_a) can precede seismic and volcanic crises linked to episodes of pore-fluid overpressure and migration in the crust. This study presents the design, deployment, and initial findings of RGUNAL, a novel multi-parametric monitoring network that integrates MT devices with gas sensors and real-time telemetry. Three case studies demonstrate the potential of the network. In central Colombia, an anomalous episode in ρ_a was detected ~8 hours before the December 24, 2019, Mw 6.0 Mesetas earthquake at the same depth as its hypocenter. At an Antarctic station, ρ_a anomalies appeared nearly simultaneously with the onset of an intense seismic swarm (~85,000 earthquakes in 2020) near the Orca submarine volcano, indicating that fluid migration triggered the swarm. A 30-km-distant MT station near the Nevado del Ruiz volcano (Colombia) recorded pronounced resistivity and gas anomalies two days before a flurry of volcano-tectonic earthquakes and ash emissions in late September 2023. These preliminary results challenge conventional skepticism by providing clear evidence that electromagnetic and geochemical precursors can accompany—and sometimes precede—seismic and volcanic unrest. The success of the RGUNAL network in capturing such signals paves the way for a new monitoring paradigm, albeit one that demands further validation and integration with traditional observatories.

POSTER 126

Speeds, Modes and Directionality of the 2025 Mw 7.8 Madalay Earthquake Explained by the Fault Core Structure
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The 2025 Mandalay earthquake is an extraordinary event with dynamic rupture features like propagation directionality, supershear speed and pulse-like mode. One unique geological feature of the Sagaing fault is the presence of a 2 km-wide fault core. To verify the effect of fault core on rupture dynamics, a laboratory fault model is constructed and ruptures are triggered on one side of the fault core. The rupture in the positive direction with respect to the fault line is always crack-like growing at the Generalized Rayleigh (GR) wave speed. However, in the negative direction slip pulses are observed. The trailing tip of the pulses propagates at the GR wave speed, while the leading tip of the pulse propagates at either the GR wave speed or at the supershear speed. Higher load and thinner Low Velocity Zone (LVZ) facilitate supershear pulses. The consistence between laboratory and field observations verifies the dictating role of the fault core structure on the rupture dynamics of the 2025 Mandalay earthquake.

POSTER 127

Fault Zone Structure of the Alpine Fault in New Zealand Imaged by Seismic Receiver Functions
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The Alpine Fault in New Zealand is a major continental transform fault that is late in its earthquake cycle, offering a rare opportunity to study strike-slip systems before the next large earthquake. Paleoseismological studies indicate that ruptures of past great earthquakes commonly either terminate within or propagate through boundary zones between major fault sections of the Alpine Fault, where the fault geometry varies. Direct constraints are required for further refinement of the fault geometries at crustal depths. Here, we deployed a dense nodal array of 23 stations with ~100 m spacing for a few months in 2023 cross a 1.5-km-long profile spanning the Alpine Fault trace at Haast, South Island, New Zealand. This array sits atop a critical boundary zone characterized by an abrupt near-surface dip change and by documented terminations of large earthquake ruptures. Teleseismic P receiver functions (RFs) computed from these nodal seismometer data present dramatic, characteristic polarity reversals over backazimuth observed on both radial and transverse compo-

nents, indicative of complex fault-parallel, dipping fault zone structures at crustal depths. In particular, we observe (1) distinct negative-amplitude arrivals at zero delay time clustered in 180 azimuths on radial RFs for individual stations; and (2) an across-fault change of the polarity-reversal patterns in RFs for stations located opposite sides of the fault, with a clear dependence on incoming waves direction. We perform 2-D finite-difference simulations to model these characteristic RFs, which suggests a single dipping fault cannot reproduce our observations. Instead, the new observations require at least two fault planes with finite widths and moderate dipping angles, indicating a structurally complex fault zone at depths. We infer that the fault zone structural complexity at boundary between the central and south segments of the Alpine Fault play a role in governing earthquake rupture arrest or propagation, with direct implications for hazard assessment.

Physics of Earthquakes: Insights from Theory and Observations

Oral Session • Wednesday 15 April • 8:00 AM Local

Conveners: Pavla Hrubcova, Czech Academy of Sciences (pavla@ig.cas.cz); Hitoshi Kawakatsu, University of Tokyo (hitosi@eri.u-tokyo.ac.jp); Patricia Martinez Garzon, GFZ Potsdam (patricia@gfz-potsdam.de); Colin N. Pennington, Lawrence Livermore National Laboratory (pennington6@llnl.gov); German Andres Prieto, National University of Colombia (gaprietogo@unal.edu.co); David Shelly, U.S. Geological Survey (dshelly@usgs.gov); Daniel Trugman, University of Nevada, Reno (dtrugman@unr.edu); Nadine Igonin Ushakov, University of Texas at Dallas (nadine.igonin@utdallas.edu); Vaclav Vavrycuk, Czech Academy of Sciences (vv@ig.cas.cz)

Inference of Absolute Stress From Earthquake-induced Stress Rotations in Subduction Zones
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The stress redistribution from an earthquake can produce localized measurable rotations of the principal stress axes if the absolute level of differential stress in the crust is on the order of the earthquake stress drop. Two simple analytic solutions have been developed to estimate the differential stress from an observed stress rotation. However, each has assumptions that may not be accurate near Earth's free surface. I model synthetic earthquakes in an elastic half-space, and show that the assumptions of the methods are accurate for strike-slip earthquakes, and for deep dip-slip earthquakes. However, they are incorrect for shallow dip-slip earthquakes. I introduce a free surface correction for one of the methods for dip-slip earthquakes. I revise an analysis of stress rotations due to great subduction zone earthquakes, including this correction. The results support the original conclusion of near complete stress drop for many shallow subduction zone earthquakes.

Stress Orientation Around Japan Trench Inferred From Focal Mechanism Solutions of Small Earthquakes
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Understanding the regional stress field is vital for interpreting earthquake generation zones. The orientation of principal stress axes and the stress ratio, inferred from focal mechanism solutions, provide essential information for evaluating active fault dynamics and broader seismological phenomena. Uchide et al. (2022) conducted a comprehensive study focusing on inland Japan, estimating focal mechanisms for numerous small earthquakes. Their work enabled detailed characterization of the local stress field. Advances in machine learning have facilitated automated determination of P-wave first-motion polarities, significantly expanding the scale of viable data analysis.

In the present study, small earthquakes along the Japan Trench are examined using seismic records from the cable-type ocean bottom seismometer network, S-net. This region has experienced several major seismic events,

notably the 2011 Tohoku-Oki earthquake, underscoring its importance in investigations of earthquake generation mechanisms. Focal mechanisms were estimated using the SKHASH method (Skoumal et al., 2024), which yields robust solutions for small-magnitude events. Detection of P-wave first-motion polarity involved fine-tuning the model proposed by Uchide (2020) with a combined dataset of S-net seismic waveforms and manually reviewed polarities.

For stress inversion, this study employs the methodology of Uchide et al. (2022), grounded in the approach of Hardebeck and Michael (2006), enabling reliable estimation of stress fields from focal mechanism data. This framework supports the derivation of high-precision stress orientations and facilitates assessment of spatial heterogeneity in the trench area. The results contribute to a deeper understanding of plate boundary earthquake processes and have implications for long-term earthquake activity forecasting.

Acknowledgments: We used seismic data from S-net maintained by NIED. We also used SKHASH code (Skoumal et al., 2024).

Coseismic Stress Field Perturbations From the 1999 Chi-Chi and 2024 Hualien Earthquakes, Taiwan
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The active collision between the Eurasian and Philippine Sea plates in Taiwan presents a unique opportunity to study crustal stress dynamics. By inverting the earthquake focal mechanisms catalogs from Wu et al. (2008; 2010) and AutoBATS (Jian et al., 2018), we analyze the stress state changes caused by two major events: the 1999 Mw7.7 Chi-Chi earthquake in central-western Taiwan and the 2024 Mw7.4 Hualien earthquake in eastern Taiwan. Shape ratios and principal stress orientations are obtained for 3 to 6 subregions, each tens of kilometers in size, defined around mainshock faults. The mainshocks induced significant temporal changes, causing the regional stress field to rotate and shape ratios to change. These changes are consistent with expectations based on the sense of slip in the mainshocks; for instance, in the subregionsnortheast of the fault, the stress axes rotated by approximately 20 degrees following the 1999 Chi-Chi earthquake.

A comparison of these two earthquakes, which occurred in different tectonic provinces, provides insight into the interactions between central and eastern Taiwan. The Chi-Chi event revealed the response of the western fold-and-thrust belt, while the Hualien event demonstrated rapid stress transfer along the primary eastern plate boundary. Together, these events confirm that the crustal stress field in Taiwan is highly dynamic. The orientation of tectonic forces changes temporally, being significantly perturbed by large earthquakes, which highlights the complex and active mechanics of the collision zone.

Sensitivity of Co-seismic Displacements to Volumetric Components in Intermediate and Deep Earthquake Sources
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Occurrences of intermediate and deep earthquakes under extreme temperatures and pressures remains a long-standing puzzle in geophysics. A common approach to study the mechanisms of these earthquakes is using seismic data to estimate earthquake source properties and comparing them to predictions from hypothesized mechanisms. Since some leading mechanisms, such as dehydration embrittlement and transformational faulting, predict volume changes in the source region, determining whether volumetric components are present in intermediate and deep earthquake sources is important for testing the feasibility of these mechanisms. However, the inferred volumetric components in previous studies—which largely rely on seismic data—are often indistinguishable from their uncertainties, making robust detection difficult.

In this study, we examine if geodetic data can help better constrain the volumetric components of intermediate and deep earthquakes. Specifically, we evaluate the sensitivity of co-seismic displacements to the volumetric components. We start by making systematic predictions of co-seismic displacements produced by pure double-couple and volumetric sources. Wide ranges of earthquake depths (e.g., 100–700 km), magnitudes (e.g., M_W 7–8.5), and focal mechanisms (e.g., fault dipping angles from 0 to 90°) are considered in the modeling. We examine two types of volumetric sources: (1) an isotropic source and (2) a mode I anticrack. After obtaining the modeling results, we estimate the smallest volumetric component (as a percentage of the total seismic moment) that can be potentially resolved using geodetic data, for various combinations of earthquake magnitudes and depths. Our modeling tests demonstrate that co-seismic displacements are sensitive to volumetric com-

ponents, e.g., 5% volumetric component for an M_W 7.2, 100-km earthquake. In addition, our analysis of the 2019 M_W 8.0, 120-km-depth Peru earthquake suggests that, under certain conditions, the presence of a volumetric component may explain the misfit between the observed co-seismic displacements and predictions based on the finite fault slip distribution model.

Stress Variations and Non-shear Earthquakes Prior to the 2021 Iceland Eruption: Implications for Magmatic Fluid Flow Dynamics
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The 2021 Fagradalsfjall eruption on Iceland's Reykjanes Peninsula followed an intense seismic swarm, providing unique insights into fluid dynamics and seismic behaviour at divergent plate boundaries. Analysing moment tensors of 1,306 pre-eruption earthquakes revealed three faulting regimes: strike-slip, normal, and reverse. Each displayed different stress conditions supported by systematic non-double-couple ISO components indicating significant volumetric changes within the earthquake sources. Normal faulting showed negative ISO suggesting crustal subsidence above the dike, while reverse faulting displayed positive ISO indicating opening due to overpressurized fluids trapped by structural barriers. Slightly positive ISO values of strike-slip events pointed to dike movements. Stress inversion disclosed stable orientation of principal stress axes consistent with transtensional setting, yet, highlighted localized stress variations due to dynamic fluid interactions with crustal heterogeneities. The identification of heterogeneous stress within the focal zone combined with volumetric components provides novel perspective on fluid-fault interactions in volcano-tectonic and extensional settings.

Accounting for Site Effects Significantly Reduces Uncertainties in Earthquake Stress Parameters
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We recently developed a method (Ji, Archuleta, and Peyton, 2024) to measure the apparent stress and stress parameters of moderate-size earthquakes using S wave records at close distances (<50 km). We account for site amplification effects using a generic sediment model inferred from Vs30s and the quarter-wavelength approximation (Boore and Joyner, 1995). Using high SNR records of 42 earthquakes (4≤Mw≤5.4), we search for the optimal frequency-dependent crustal attenuation model as well as the site attenuation parameter k_0 (Anderson& Hough, 1984) for each site. We employ a novel strategy combining grid search with statistical analysis, and obtain well-constrained results. We update this method by further refining the site effects relative to one or several reference sites using an iterative algorithm. We evaluate the results using records from independent events within the same Ridgecrest sequence. We find that a) although the perturbation of the inverted k_0 is negligible, significant uncertainties exist in predicted site amplifications. This is expected, considering the uncertainties associated with the precision of Vs30 estimates, the quarter-wavelength approximation, and the empirical relation between Vs30 and the generic model. b) When using the mean site response as the reference, updating the site responses does not significantly affect the mean spectra and stress parameter. But the variations of reconstructed source spectra are significantly reduced, validating the results. The average uncertainty of the stress parameter decreases from 0.15 to 0.06 in log10 units—almost a factor of 10 lower than normally found in seismic studies (Cotton et. al, 2013). However, the solutions still carry the uncertainty associated with reference sites.

An Entropic Origin for Gutenberg-Richter Scaling
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The Gutenberg-Richter (G-R) relationship is seen in seismicity throughout the world, suggesting a statistical origin that does not rely on fine-tuned parameters or local fault properties. We develop an entropic explanation of G-R scaling that relies on two robust physical constraints: (1) average slip scales with rupture length, and (2) the cumulative slip from all earthquakes on a fault is consistent with the long-term slip rate (slip conservation). These simple assumptions define an (under-determined) non-negative least-squares inverse problem. Each solution to this inverse problem is a set of earthquake

rates that matches the slip-rate constraint. We use a Markov Chain Monte Carlo (MCMC) algorithm to uniformly sample the solution space. As the fault discretization is refined, deviations from G-R behavior decrease and the strong degeneracy of G-R solutions results in other solutions becoming improbably rare. For faults discretized in both 1D and 2D, this method gives solutions with G-R scaling and b -values close to 1.

Global Repeating Earthquakes Reveal a Scattered Triangular Recurrence Time–moment Scaling Consistent with Crack Models in a Complex Fault Zone

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Repeating earthquakes are recurrent ruptures of the same asperity along creeping faults, and their recurrence time–moment (T_r – M_0) scaling provides key constraints on earthquake physics and fault creep. However, previous studies have reported T_r – $M_0^{1/6}$, which contradicts the classic crack model that predicts T_r – $M_0^{1/3}$. We compile a set of global repeater catalogs and find a highly scattered T_r – M_0 distribution that precludes a meaningful global linear fit. To reveal the true scaling, we first focus on the creeping section of the San Andreas Fault to diagnose the sources of scatter in the T_r – M_0 relation. Leveraging a modern catalog, we select repeaters based on quasi-periodicity and temporal persistence, and correct for differences in background creep rate between sequences. These procedures yield a triangular T_r – M_0 distribution with a robust lower envelope of slope $\sim 1/3$, which we interpret as reflecting total long-term steady fault creep, together with numerous long-recurrence sequences above this lower bound, which likely reflect (1) higher stress drops, and/or (2) local creep-rate variations associated with complex fault structures, and/or (3) earthquake interactions. Furthermore, applying the same selection and correction procedures to global catalogs reveals a similar triangular pattern. Our results suggest that repeater recurrence may still be broadly consistent with the classic crack model, and that the previously reported $1/6$ slope mainly reflects an average trend through scattered data influenced by uncorrected long-recurrence cases. Our study supports the applicability of the crack model for estimating slip and highlights the potential of repeaters as high-resolution creep meters.

The Time Clustering of Earthquakes

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The time history of seismic activity is controlled by the processes that drive earthquake behavior. A classic example is the elastic interactions between seismic events that mediate sequences of aftershocks. Other processes like the migration of fluids in magmatic systems or aseismic slip along subduction plate boundaries can also cause transient seismic sequences. We analyze here earthquake time histories as point processes to constrain the different time scales that govern seismic activity. This approach allows us to examine the potential correlation between earthquakes across a broad spectrum of time scales. Past work has demonstrated how the time scales of correlation are indicative of the time clustering behavior of earthquakes, signaling the underlying driver of seismicity such as a slow slip event (Frank et al., Sci. Adv., 2016) or an upwelling of magmatic fluids (Frank et al., EPSL, 2018). We will present systematic measurements of the time scales of earthquake clustering in a variety of tectonic contexts (crustal aftershock sequences, tectonic swarms, volcanic swarms, deep earthquake behavior, and low-frequency earthquakes) to provide novel constraints on the time scales of different drivers of earthquake behavior.

Gutenberg–Richter or Safer? On the Magnitude–frequency Distributions of Induced Seismicity

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Stress-based models have achieved significant success in estimating induced-seismicity rates and are commonly calibrated using small-magnitude earthquakes near the detection threshold. However, time-dependent seismic hazard assessment requires extrapolating these rates to larger magnitudes, which critically depends on the assumed magnitude–frequency distribution (MFD). The classical Gutenberg–Richter (GR) model assumes an unbounded expo-

nential decay, yet its applicability to injection-induced seismicity remains debated.

Here we compile a global dataset of injection-induced seismic sequences, examining more than 100 cases and selecting 38 high-quality sequences for detailed MFD analysis. Building on the methodology of Li and Avouac (2025, doi:10.1785/0120250130), we apply a robust statistical framework to distinguish between GR and tapered Gutenberg–Richter (TGR) distributions, which predicts a reduced probability of large events. We find that the GR model fails to describe around half of the induced sequences, which are better characterized by TGR behavior.

Numerical simulations of coupled seismic and aseismic slip on rate-and-state faults reproduce the observed diversity of MFDs. Near-field injection produces heterogeneous fault loading that promotes premature earthquake nucleation and yields TGR-like distributions, whereas far-field injection leads to more spatially uniform loading and MFDs resembling tectonic seismicity. Consistent with this interpretation, the observed TGR sequences in nature are associated with smaller, shallower seismicity clouds. Additional structural controls are suggested by their less oblate spatial distributions and larger fractal dimensions.

The prevalence of TGR behavior provides a physical explanation for why maximum magnitudes in many induced sequences are generally remain below magnitude 2–3, and suggests that seismic hazard assessments based on GR distributons are often overestimated.

Impact of Lithospheric Anisotropy on Moment Tensors: Toward Anisotropic Earthquake Seismology

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Kawakatsu (2024, BSSA) recently demonstrated that the systematic source-type dependence of the non–double-couple (NDC) components in GCMT moment tensors for shallow earthquakes most likely reflect transverse isotropy with a vertical symmetry axis in the lithosphere. This NDC in seismic moment tensor manifests seismic anisotropy near the earthquake source—provided we remain within the Burridge–Knopoff-type framework—rather than as a consequence of unmodelled path effects. Direct interpretations of reported MT solutions (e.g., fault geometry and slip direction) that assume an isotropic source-region structure may be systematically biased. Quantifying the magnitude and systematics of this bias requires assessing how in situ anisotropic structures near the seismic source generate NDC components in seismic moment tensors.

Here we examine GCMT solutions in Tibet, where recent surface-wave tomography models (e.g., Priestley et al., 2024) reveal particularly strong azimuthal anisotropy (i.e., $\sim 10\%$ peak-to-peak). We select 32 earthquakes from the quality-controlled MT catalogue of Kawakatsu (2024) and investigate the imprint of azimuthal anisotropy alongside radial anisotropy. Given the assumed radial anisotropy, the NDC in seismic moment tensor indicates in-situ azimuth anisotropy, with the fast direction in N100E and $\sim 10\%$ peak-to-peak amplitude, that are consistent with the tomographic model. These results highlight that both azimuthal and radial anisotropy can significantly influence reported moment tensor solutions. Separating anisotropic-structure effects from source characteristics is therefore essential for reliable seismic source characterization and for advancing anisotropic earthquake seismology.

Characterization of Seismic Sources in the Middle East Using 3D Velocity Models: Current Capabilities and Frontiers

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3D velocity models are important for enhancing the resolution of seismic source parameters at regional distances, reducing contributions from spurious non-double-couple components. We implemented the MEAD-M20 3D velocity model for the Middle East (Örsvuran et al., in revision) to calculate Green's

functions to evaluate its performance for seismic moment tensor inversion. The dataset included 10 seismic events from the 2017–2018 Hojeds sequence (Central Iran) and a M_w 4.9 event in the Central Alborz (Northern Iran) that occurred on June 20, 2025, using both local and regional data.

Our results show that the 3D velocity model reduces the misfit, time shifts, and spurious non-double couple components at periods longer than 30 s, consistent with the model's resolution. Notably, we found that the 3D Green's functions provide reliable solutions at periods as short as 15 s, below the current model's expected resolution, and for events as small as M_w 3.9. Additionally, solutions based on the 3D model are more stable than solutions using a single average 1D model when relying solely on distant stations (>500 km). This likely highlights the importance of accounting for lateral heterogeneities when modeling waveforms at regional distances where 1D model inaccuracies accumulate. Although 3D models are computationally more expensive than 1D approaches, our findings indicate their potential for improving source parameter resolution in complex tectonic regions, particularly when station coverage is sparse.

Inconsistencies in Moment Magnitude Estimates and How to Fix Them

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Moment magnitude (M_w) derived from seismic moment was defined with the intent to be a consistent measure of earthquake size. Here we demonstrate that reported M_w values depend systematically on the rigidity structure assumed in the moment tensor inversion, which varies between regions and users. We perform regional moment tensor inversions for 70 target earthquakes in the Walker Lane and Southern California regions of the western US, comparing magnitude results based on analyses involving a suite of commonly used 1D velocity models. Inversions performed with slower, lower rigidity velocity models produce lower M_w estimates than inversions performed with faster, higher rigidity velocity models: the related epistemic uncertainty averages ± 0.08 for the analyzed earthquakes, with larger uncertainties for shallower events. Using magnitudes based on seismic potency (M_p) instead of M_w can reduce this uncertainty by a factor of 2–3. We introduce a potency-based magnitude M_{pv} involving correcting for both the rigidity at source depth and characteristic rigidity of the velocity model, which produces a robust magnitude scale independent of the velocity model. This formulation can be used to generate uniform and consistent regional and global earthquake catalogs necessary for a wide range of applications in earthquake science and engineering.

Enigmatic Seismic Excitation of the 1957 Andreanof, Aleutian is., Earthquake

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The 1957 Andreanof, Aleutian Is., earthquake (3/9/1957, 51.53°N, 175.63°W, $d=25$ km) is among the most enigmatic great earthquakes instrumentally recorded. The length of the aftershock area is very long (about 1,200 km), and tsunami excitation has been recently confirmed to be very extensive, yet its instrumental seismic magnitude M_s is only about 8.1 to 8.3. Detailed analyses of long-period surface waves in the past gave an $M_w=8.4$, and the seismic-tsunami disparity remains unresolved. The main difficulty in seismic studies is the absence of high-quality seismic data. Here we investigate the cause of this disparity by carefully analyzing some historical seismograms with modern digitization methods. We also take advantage of the 1996 Aleutian Is. earthquake ($M_w=7.87$) that occurred very close to the 1957 event. For the 1996 event, high-quality modern broad-band seismograms are available which can be effectively used as empirical Green's functions for the analysis of the 1957 event. Using the Wiechert (Strasbourg, Uppsala), Milne-Shaw (Wellington), and Benioff (Uppsala, Pasadena) seismograms of the 1957 event, we could determine that the 1957 event had significant secondary excitation of long-period (150 s) waves during about 1,000 s following the first event. The M_w of the combined source is approximately 8.4. Because of the limited bandwidth of the old instruments, we cannot detect long-period energy beyond 150 s. However, the unusually long-lasting excitation over nearly 1,000 s suggests that the event had significant excitation at periods longer than 150 s with a much larger M_w for the total event. Although we cannot address this question quantitatively because of our band-limited data, our numerical experiment using a source with a slow component shows that if the time scale of the slow source is longer than 500 s, our data can be made compatible with an $M_w=8.8$ to 8.9 event, thereby reconciling the results from seismic and tsunami data.

Are Stress Drops Magnitude-independent? Insights From Seismological Stress-drop Estimates for Earthquake Sources Simulated on Rate-and-state Faults

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Stress drop estimates of small earthquakes are based on specific theoretical source models, commonly the Madariaga axi-symmetric circular source in which rupture starts at a point and expands along a planar fault in all directions with the same rupture speed. However, detailed studies of small rupture events indicate a significant degree of complexity. We explore the accuracy of stress drop estimates for several earthquake source models obtained in dynamic simulations on rate-and-state faults, including Madariaga-like symmetric circular sources as well as sources with directivity, elongated shapes, partial ruptures, and complex changes in the slip direction. For a range of focal depths and fault dips, we produce synthetic waveforms on a surface network of 16 stations assuming a known homogeneous bulk and use them to obtain seismologically inferred stress drops with spectral-fitting and second-moment approaches. For the second-moment approach and spectral fitting approach based on S waves, the stress drops are reproduced well on average but with a significant scatter from nearly 0.01 to 100 MPa representative of natural earthquakes, despite the on-fault stress drop variation of only 1.5 to 5 MPa. The spectral fitting approach based on P waves, commonly used for natural sources, consistently underestimates stress drops for non-circular sources. All approaches significantly underestimate stress drops for sources that leave parts of the seismogenic circular patch unruptured. If small earthquakes on natural faults occur along areas with stress concentrations with elongated, largely unidirectional propagation and/or have complex, patchy source shapes, then their stress drops would be significantly underestimated by the current seismological methods, potentially indicating much larger average stress drops for small events. A path forward is to use earthquake sequence simulations to understand the range of physically plausible micro-seismicity sources at different depths and the impact of their dynamics on radiation patterns and stress drop estimates.

Predicting the Depth Scaling of Stress Drop From a Model of Elastic Loading

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Studies of stress drop consistently find that stress drop increases weakly with depth. This is unexpected because frictional models for earthquakes generally suggest that stress drop should scale with overburden pressure, with a nearly linearly dependence on depth at crustal depths. While fixes to the frictional model have been proposed, including relying on near-lithostatic pore pressure, it may be worthwhile to consider alternative mechanisms that are able to capture this behavior. Here we present a model that predicts stress drop that scales linearly with elastic modulus instead of with overburden. This model for elastic loading of geometric asperities was originally motivated by trying to understand why fault network geometries might play a significant role in earthquake seismogenesis and was not intended to address the stress drop paradox. Key ingredients of the elastic loading model include sharp changes in fault geometry and heterogeneity in material properties. Some additional consequences of the model will be discussed. Given the promise this alternative model has in explaining stress drop scaling, we are working on further developing the model.

Constraining Earthquake Stress Drop Methods Using Stochastic Simulations

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As a part of the Statewide California Earthquake Center/U. S. Geological Survey Community Stress Drop Validation Study (<https://www.scec.org/events/2026-community-stress-drop-validation-workshop>), we present a set of synthetic stochastic earthquake Fourier amplitude spectra (FAS) for use

in constraining different methods of estimating earthquake stress drop and other source parameters. The Community Study has brought together over 100 participants worldwide to address questions of variability and uncertainty in estimated spectral earthquake stress drops. In the first stage of the study, over 20 research groups analyzed and submitted stress drop estimates from the 2019 Ridgecrest sequence common dataset; through this work, we demonstrated and quantified the uncertainties and methodological biases in stress drop estimates, and their possible magnitude and depth dependencies. The next step is for the community to investigate and test improved approaches to address some of the remaining unanswered questions. Our first goal in this work is to determine how well different methods can separate source, site, and path effects with known physical quantities as inputs. To do so, we create simplistic synthetic recorded earthquake FAS using the Stochastic Method of SIMulation (SMSIM; Boore, 2003), in which we can precisely prescribe parameters in a way that is consistent with how our community interprets them, such as spectral shape (Brune, Boatwright or double corner), corner frequency, seismic moment, path attenuation (Q), and site amplification and diminution. We generate a simple experimental setup with co-located earthquakes of various magnitudes, recorded on stations at given distances away, varying the spectral complexity and stress drop, path attenuation, and site properties. Using these synthetic spectra, we perform initial tests and then iterate with added complexity to ensure the experimental design is effective for isolating the various components. Within the community, we test several common methods of estimating spectral stress drop including spectral decomposition and empirical Green's function approaches.

Breaking the Cubic Dependence: Stabilizing Earthquake Stress Drop Estimates via Asymptotic Spectral Ratios
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Accurate estimation of earthquake stress drop is fundamental to understanding rupture physics and ground motion scaling. However, traditional spectral fitting methods are often plagued by significant uncertainties, particularly due to the cubed dependence of stress drop with corner frequency and, among others, trade-offs between corner frequency, attenuation, and the limited bandwidth of observation. To address these limitations, we present a novel Dual-Band Asymptotic Spectral Ratio Inversion. Building on the method of Walter et al. (2017), we treat the low-frequency level (LFL, proxy for relative moment) and high-frequency level (HFL, proxy for relative slip ratio) as independent observables. Not only do we decouple magnitude from high-frequency information, but we remove the cubed dependence of corner frequency from the estimation of stress drop.

Our key innovation is an inversion framework that works with spectral ratios and respects the physical bandwidth constraints of the data. We invert for LFL using only smaller magnitude events (where the low-frequency plateau is flat) and for HFL using only larger magnitude events (where the high-frequency fall-off is established). These two independent inversions are then bridged to form relative stress drop ratios using a “Goldilocks” population of intermediate-magnitude events (e.g., M 2.5–3.5) which are valid in both bands. Due to our independence from corner frequency, we can use data from P, S, and CODA phases to corroborate each other and stabilize the inversion. The result is all of the benefits of traditional spectral ratio methods with significantly more data availability and consistency.

We apply this method to a comprehensive dataset of the 2019 Ridgecrest, California sequence. We validate our results by comparing them against traditional corner-frequency fitting methods and the SCEC/USGS Community Stress Drop validation study. Preliminary results indicate that the asymptotic method yields competitive precision (low between-event variability) while maintaining the catalog completeness of large-scale automated approaches.

Focal Mechanisms in the Southeastern South Island of Aotearoa New Zealand Indicate Scale-dependent Partitioning of Transpressional Strain
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The classic Andersonian model of faulting is difficult to apply to plate boundaries with oblique motion, as displacement is accommodated across oblique-slip faults, or it is partitioned into distinct strike-slip and dip-slip faults. Here, we investigate how faults accommodate oblique plate motion by using the focal mechanism solutions of 126 M_{LV} 1.3–4.3 earthquakes in the transpressional southeastern South Island of Aotearoa New Zealand. Focal mechanisms were assigned a *A-D* quality, and of the 91 C or better quality solutions, 57 are strike-slip. In addition, when incorporated into a stress inversion, these focal mechanisms indicate a strike-slip stress state with an WNW-trending maximum principal compressive stress. By contrast, constraints on active crustal-scale faulting from the New Zealand Community Fault Model indicate reverse faulting in this region. A high stress shape ratio can partly account for the coexistence of reverse and strike-slip faults. However, we also propose that the focal mechanisms are typically sampling slip on optimally-oriented small-scale faults in intact crust, while the larger magnitude reverse faulting reflects local stress rotations within pre-existing faults and shear zones in the southeastern South Island. Our study therefore demonstrates how inherited structures influence the scale and orientation of faults onto which transpressional strain is partitioned.

Borehole Seismic Attenuation Measurements and Strong-motion Kappa_0 Estimates Imply More High-frequency Radiation From Earthquakes Than Simple ω^2 Model Predictions
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The classic ω^2 source model predicts that earthquake displacement spectra decay as f^{-2} at high frequencies. Although individual events often have complicated spectra, the ω^2 model has proven a useful approximation to the smooth spectra that result from stacking results from many events, i.e., to the average high-frequency falloff rate. However, resolving whether the average n in the f^{-n} decay is exactly 2.0 is hampered by tradeoffs with the strong near-surface attenuation that occurs beneath recording stations. Here, we review and compare seismic attenuation estimates for the shallow crust from borehole studies with kappa_0 estimates from strong-ground-motion analyses. We find that at several hard-rock sites in tectonically active regions, S-wave t^* estimates for the integrated attenuation from the surface to several kilometers depth are about 0.045 to 0.06 s, significantly greater than hard-rock kappa_0 estimates from ground-motion studies of moderate to large earthquakes. This implies that the average high-frequency falloff rate for these earthquakes is shallower than standard Brune ω^2 model predictions, i.e., $n < 2.0$ for f^{-n} models of displacement spectra. We find additional evidence for these shallower falloff rates by examining spectra from $M > 4.5$ earthquakes recorded in 1992 by the Cajon Pass borehole seismometer at 2.5 km depth. These results have important implications for spectral studies of large earthquakes as well as those of smaller earthquakes that assume the ω^2 model in computing attenuation corrections, which can lead to unrealistically low stress-drop estimates for small earthquakes and strong apparent scaling of stress drop with magnitude.

S/P Amplitude Ratios with Distributed Acoustic Sensing and Application to Earthquake Focal Mechanisms
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Distributed Acoustic Sensing (DAS), which transforms a fiber optic cable into an array of high frequency strainmeters, has the potential to help us characterize earthquakes with a dense sampling of measurements. While earthquake focal mechanisms are frequently determined using *P*-wave polarities and *S/P* amplitude ratios with inertial seismometers, the dense sampling of DAS over potentially large portions of the focal sphere can aid our solutions. Here, we consider ~200 regional earthquakes and thousands of *S/P* measurements on a DAS cable colocated with a network of inertial seismometers near Arcata, California. We demonstrate the *S/P* ratio measurements made on DAS are similar to those made on the inertial seismometers and can be used to constrain focal mechanism solutions. The resulting gradient of *S/P* ratios measured on a DAS array can be used to inform the location of the nodal planes even if the array does not cross a plane, and this could be a useful addition to

P-wave polarity measurements. With the potential for dense spatial sampling from DAS, we may be able to provide meaningful focal mechanisms for more of these small magnitude earthquakes as the availability of DAS recordings increase.

Multi-episode Rupture Kinematics of a Microearthquake in Weak Crust Revealed by Dense DAS Observations
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Small earthquakes ($M < 3$) are commonly assumed to rupture kinematically as a single episode, yet emerging dense observations suggest that even micro-earthquakes may involve multiple, temporally distinct subevents. Here we analyze an M_L 2 earthquake in the Brawley Seismic Zone, recorded by ~7,000 distributed acoustic sensing (DAS) channels along a 27-km dark fiber-optic cable. Using empirical Green's functions, we estimate relative source time functions (RSTFs) along the cable. The RSTFs resolve two distinct source pulses, and the apparent inter-pulse delay varies systematically along the cable, consistent with two spatially separated subevents.

We incorporate DAS- and station-derived RSTFs into a kinematic slip inversion on a fault plane and obtain a two-episode rupture model: a primary nucleation followed ~40 ms later by secondary nucleation on an adjacent, non-overlapping patch separated by a low-slip barrier. In contrast, enforcing a conventional single-episode parameterization with a continuous rupture front fails to resolve this temporal segmentation, instead mapping the time delay onto spurious spatial complexity. Within the associated 3-hour sequence, we combine DAS-based relative locations with slip models. We find that later events preferentially rupture the unbroken patches left by earlier events, producing complementary slip at the sequence scale and indicating systematic stress redistribution. This fragmented rupture behavior resembles the kinematics of larger regional swarms, reflecting mechanical constraints associated with the region's weak crust. High-resolution DAS constraints therefore show that microearthquakes can serve as in situ probes of fault strength, rupture segmentation, and rupture dynamics.

Source Characterizations of Northern California Earthquakes Through Moment Rate Function Properties and Finite-fault Modeling
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A better understanding of the earthquake rupture process is central to studies of earthquake source physics. A point-source approximation has been used widely to identify the underlying faulting mechanics with high accuracy. However this approximation will not allow us to assess rupture directivity and to identify if multiple sub-events are involved. We compile moment rate functions (MRFs) of small to moderate earthquakes ($3 \leq M \leq 6$) for northern California through an empirical Green's function approach with the aim to systematically evaluate rupture complexities and also radiate energy. In particular, our interest is to explore if the moment-scaled radiated energy depends on seismic moment, i.e., if our data set can be explained by whether self-similarity or non-self-similarity scaling. Our results suggest a weak non-self-similarity behavior, which appears to be consistent with results from Kanamori and Rivera (2004, BSSA) that analyzed southern California earthquakes.

We performed finite-fault (FF) modelings for subsets of earthquakes by inverting MRFs including the 2022 Mw 5.1 Alum Rock earthquake. This earthquake exhibits a complex rupture process involving three subevents with a southeast directivity. The peak and median slips are found to be 42 cm and 14 cm respectively, which provides the peak and median stress drop of 28 MPa and 5 MPa. We also developed an FF model for the 2024 Mw 7.0 Mendocino earthquake using strong-motion data (0.02–0.33 Hz). Our FF model yielded a peak slip of ~4 m and a rupture velocity of 2.5 km/s, suggesting that the slip is concentrated in two primary patches: 1) about 10 km west of the hypocenter, with a depth range of 5 to 25 km, where an estimated Mw is 6.84 (62% of the total scalar moment), and 2) 30 km east of the hypocenter, with slip concentrated at a depth of ~20 km. The estimated Mw on this slip patch is 6.69.

Fracture Energy of Earthquakes May Scale Linearly with Slip Across Ten Orders of Magnitude
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Fracture energy governs how faults resist rupture and controls the balance between seismic radiation and fault slip arrest. However, its scaling with earthquake size has remained controversial because estimates from seismic observations show large scatter and inconsistent power-law relations. Here we show that this apparent variability arises primarily from biases introduced by moment–duration relations, rather than from intrinsic changes in fault strength. By re-evaluating observational constraints within a physically consistent rupture framework, we find that fracture energy is nearly proportional to average slip over ten orders of magnitude, spanning laboratory events to large earthquakes. We further demonstrate that the commonly inferred relation in which fracture energy scales with average slip to the power of about 2.5 is an artefact of the statistical spread in moment and duration, whereas the underlying physical relation may be linear. A unified rupture model that satisfies all established source scaling laws emerges naturally from this interpretation. These results suggest that fault weakening during dynamic rupture follows a simple, scale-invariant process, providing a consistent basis for understanding earthquake mechanics across all sizes.

Physics of Earthquakes: Insights from Theory and Observations [Poster]

Poster Session • Wednesday 15 April

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POSTER 65
What's Real and What's Not? Assessing Spectral Stress Drop Observations With Synthetic Earthquakes
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Earthquake static stress drop is a commonly estimated, yet poorly constrained, source parameter.

Independent studies often find conflicting results, even when the exact same earthquakes are examined. In a recent study of earthquakes in the SCARDEC teleseismic source time function database, we compared stress drop estimates from time-domain and frequency-domain methodologies and found significant disagreement depending on the approach, especially for earthquakes with source complexity. Most spectral stress drop methodologies assume a simple source parameterization, which does not accurately capture the complexity of real ruptures for both small and large earthquakes. Here, using synthetic source time functions designed to reflect real variability observed in the SCARDEC catalog, we examine the limitations of this simple parameterization assumption inherent in corner-frequency based methods when applied to complex sources.

We construct a catalog of complex, synthetic source time functions by combining multiple, simple, kinematic source models with known stress drop values. We then estimate spectral stress drop by measuring the corner frequency of the spectral amplitude. By comparing the *estimated spectral* stress drop to the *known* stress drop, we have gained the following insights. Corner frequency-based stress drop estimates provide a reliable estimate of the moment-weighted average stress drop, but not the area-weighted average stress drop. Additionally, we quantify how apparent increases in spectral stress

drop with magnitude can arise purely from bandwidth limitations. Through synthetic studies like this one, we can start to resolve the discrepancies we observe with real data and determine which spectral stress drop observations reflect true earthquake behavior, and how to make more useful, complementary measurements for source characterization.

POSTER 66

Fault Zone Structure and Earthquake Generation Mechanisms at the Xinfengjiang Reservoir, China, From the Earthquake Catalog (2013-2014)

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The Xinfengjiang Reservoir in China has experienced sustained elevated seismicity since the 1962 M6.1 earthquake, yet the corresponding fault zone structure and earthquake generation mechanisms remain poorly understood, particularly regarding the long-term mechanical evolution and the relationship to recent seismicity. Using continuous waveforms from the Xinfengjiang regional broadband network from 2013 to 2014, we compiled a high-precision earthquake catalog along with focal mechanism solutions for 471 events via machine-learning-based phase picking and polarity identification. Based on the seismicity distribution, we define four major seismic zones: Xichang located northwest of the reservoir, the central reservoir, the dam canyon, and the Heyuan urban area. Applying spatial principal component analysis, we identify 30 active faults whose orientations are largely consistent with the focal mechanisms of small earthquakes. We then calculate the excess fluid pressure and find the following results. The seismicity in the central reservoir and dam canyon areas is predominantly controlled by reservoir-induced fluid migration. The faults beneath the central reservoir are shallower with a direct fluid migration channel, making them most prone to triggering. The faults in the dam canyon generally exhibit lower excess fluid pressures, and the seismicity delineates two fluid-infiltration channels with pressure concentration near the low-permeability zones. Xichang became active only after >50 years of impoundment, and the seismicity indicates a typical process of “flow-blocking by low-permeability zones, pressure accumulation, and rupture.” In contrast, seismicity in the Heyuan urban area is mainly governed by the regional NW-SE compressional stress field, which has fostered a mature Riedel shear system with a principal deformation zone striking 265°.

POSTER 67

A Seismically Active Shear Zone in the Uppermost Mantle Beneath the Canadian Rockies

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Continental mantle earthquakes (CMEs) are uncommon but hold important clues for understanding lithospheric rheology. Few of these earthquakes (<10) have been documented in western North America, primarily near the Wyoming Craton in Utah and Wyoming. It is likely that more CMEs exist owing to difficulties in resolving focal depth for small earthquakes, relatively poor station coverage, and other factors. Mapping the distribution of CMEs in western North America is key to better characterizing cratonic evolution in this area. As part of a broader effort, we recently evaluated 25 nominally lower crustal and upper mantle earthquakes in the Milk River region of southwestern Alberta, Canada, a seismically quiescent area located primarily within the cratonic lithosphere of the Medicine Hat Block (Hutchings *et al.*, 2026). We absolutely relocated each of these earthquakes using a framework that stochastically perturbs *P* and *S* arrival times over a suite of local and regional velocity models. We compared the relocated depths to published estimates of Moho depth and found that 17 of the investigated earthquakes locate ~8–16 km below the median Moho. High-precision relative relocations and *P*-wave first-motions define a steeply west-dipping, Moho-crossing normal fault. We hypothesize that these earthquakes are related to regional mantle flow patterns interacting with and eroding the western edge of North American cratonic lithosphere. We are currently experimenting with template matching techniques to detect and locate additional CMEs in the Milk River region.

POSTER 68

Rupture Properties Diversities Across Taiwan Area Revealed by Back-projection Method

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Taiwan, formed through the complex tectonic interaction of two subduction systems, exhibits high seismic activity. These earthquakes offer unique opportunities for studying tectonic-related rupture properties. Since the 1999 Chi-Chi earthquake, dozens of $M \geq 6.0$ events have occurred across various tectonic and geological units. To compare rupture properties across these units, we imaged ruptures by performing the Multiple Signal Classification back-projection method (MUSIC-BP). The rupture properties are compared based on universal estimations to minimize uncertainties arising from different inversion techniques and prior rupture parameter assumptions. Dense seismic arrays deployed in the European-Mediterranean area (ORFEUS) and Australia (ANSN) are used for BP imaging. In this study, $M \geq 6.0$ earthquakes in the Taiwan and Ryukyu areas are processed. The BP results demonstrate high sensitivity in estimating rupture duration, even for events with magnitudes smaller than 6.5. Preliminary results suggest that most earthquakes in the Philippine Sea Plate (PSP) are characterized by shorter durations than Mw-based predictions. Conversely, earthquakes in the Eurasian Plate (EP) have much longer ruptures than predicted. The rupture speeds range from 1 to 2.5 km/s, after excluding events with poor estimates of rupture extents. Better estimations of rupture extent and speed will be obtained after applying the slowness correction for back-projection. The BP imaging rupture database for Taiwan earthquakes enables a detailed investigation into the relationships between rupture properties and seismogenic structures.

POSTER 69

The 10 September 2025 Mw 4.1 Earthquake in Northeastern Utah, USA: An Archetypal Continental Mantle Event

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The 10 September 2025 M_w 4.1 earthquake in northeastern Utah, USA, had a focal depth 68 km beneath sea level, which is ~20–25 km greater than estimates of local crustal thickness, making it a rare example of a continental mantle earthquake (CME). The focal depth is well resolved from arrival time inversion (nearest station ~13 km away) and moment tensor inversion of regional waveforms. Similar to other CMEs in the Intermountain West, there were no obvious aftershocks or foreshocks, and the waveforms were enriched in high frequency energy. Spectral modeling gives a stress drop of ~80 MPa and a radiation efficiency of ~0.08. The high stress drop and low radiation efficiency are consistent with a dissipative source process such as thermal runaway. Also similar to previous Intermountain West CMEs, the event occurred along the boundary of the Archean Wyoming craton where pressure-temperature conditions favor ductile deformation. We hypothesize that edge-driven or regional-scale mantle convection produces increased strain rates near the craton boundary that make either conventional brittle failure or thermal runaway feasible at relatively high pressure-temperature conditions. High conductivity inferred around the edge of the craton may suggest that fluids also contribute to CME occurrence.

POSTER 70

Is Stress-drop Depth Dependent? - Insights From Observations, and the Roles of Normal-stress and Attenuation

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Stress-drop is a fundamental parameter of earthquake physics, reflecting the geometric, rheological, and dynamic properties of the seismic source. Despite its importance, stress-drop estimates derived from traditional source models, most notably Brune’s model, exhibit three to four orders of magnitude of scatter, obscuring physically meaningful trends and limiting their interpretability.

In previous work, we introduced a new formulation (the KLS model; Kurzon et al., 2025) in which the scaling parameter *K*, relating corner fre-

quency, f_C , to source dimension, varies linearly with strain-drop. This formulation dramatically reduces the apparent scatter in stress-drop estimates to approximately one order of magnitude centered near ~10 MPa, consistent with Aki’s (1967) self-similarity, and showing that stress-drop is primarily governed by the ratio between seismic moment, M_0 , and source geometry. Within this reduced scatter, residual variations may reflect second-order effects related to source and rupture properties.

Here we investigate the role of source-depth in modulating stress-drop by analyzing multiple seismic datasets from diverse tectonic environments, complemented by dynamic rupture modeling. Our results show that (1) stress drop increases systematically with earthquake depth; (2) this trend is robustly resolved within the KLS framework even when accounting for measurement uncertainties, whereas Brune-based estimates obscure such variations; and (3) the depth dependence is consistent with increasing normal-stress, decreasing attenuation, or both.

These findings indicate that much of the long-recognized stress-drop scatter is methodological rather than physical, and demonstrate that the KLS model enables stress-drop to serve as a meaningful diagnostic of earthquake source processes and fault-zone properties.

POSTER 71

Large Repeating Gorda Intraplate Earthquakes Occurring Along an Inherited Weak Zone Near the Mendocino Triple Junction

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On 22 December 2022, a destructive earthquake with a magnitude Mw 6.4 ruptured the oceanic lithosphere emplaced beneath Northern California. This event was a repeat of an earthquake that occurred 47 yr earlier, on 7 June 1975, with a magnitude of MD 5.7. Both earthquakes caused significant damage during 10–16 s of strong shaking, primarily in the town of Rio Dell, with Fortuna and Ferndale also affected. Evidence indicates that the hypocenters of these two ruinous earthquakes occurred along the same fault within the downgoing Gorda plate, with the hypocenters located on opposite ends of the slip patch determined for the 2022 event. This pattern of recurring destructive intraplate earthquakes along inherited weak zones throughout the offshore Gorda basin is likely not unique to this sequence.

POSTER 72

A Geometric Explanation for Faulting-style-dependent Non-double-couple Components in Global Moment Tensors

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Global moment tensor catalogs report systematic non-double-couple (NDC) components that have long been interpreted as evidence for complex earthquake sources. However, recent analyses show that most reported NDC contributions – including their polarity – can be predicted directly from the inversion methodology and wavefield sampling, without invoking non-shear rupture processes. Global catalogs show two robust patterns: (1) the polarity of NDC components is not random, but depends systematically on faulting style (thrust events predominantly positive, normal predominantly negative, strike-slip broadly negative), and (2) thrust-faulting earthquakes systematically exhibit smaller NDC amplitudes than normal or strike-slip earthquakes. I show that both effects arise from the interaction between the geometry of radiation patterns and the steep-incidence body and surface waves that dominate global inversions performed with simplified 1-D Earth models. Structural mismodeling along real 3-D paths produces coherent residuals that project differently onto the CLVD basis depending on axis plunge and mechanism orientation, explaining both polarity and magnitude patterns as predictable inversion artifacts. This explanation contrasts with previous interpretations that attributed NDC polarity to anisotropy in the source region, and the smaller NDC of thrust events to intrinsically simpler rupture processes. These results unify two previously separate observations, argue for caution in physically interpreting global NDC values, and motivate the use of 3-D Earth models, especially for regional and early warning applications where waveform fits are more sensitive to lateral heterogeneity.

POSTER 73

West Texas Earthquake Catalog Using a 3D Earth Model

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For over two decades induced seismicity has been an important issue due to the increased number of Oil and Gas well operations. Recently, induced seismicity has also become an important issue related to geothermal and Carbon Capture and Storage projects. The hazard of induced seismicity is a top concern of the public. Due to (a) seismic networks not having a station density similar to the target depth of the human activities and lack of stations at this target depth, and (b) lack of accurate 3D velocity models for basin and basement structures, earthquake catalogs are generally inadequate to provide concrete information for causal assessment of induced seismicity.

Building on the work we presented at SSA 2025 [Importance of accurate earth models and network geometry for earthquake location] we updated our 3D Permian Basin velocity model to cover an extended area of 500 x 500 km² including west and northwest Texas and southeast New Mexico. Using this model, we can relocate seismicity in the Texas part of the Permian Basin and provide a more accurate earthquake catalog. The resulting catalog clearly identifies seismicity within the basin structures (south Delaware basin) and at the top of the underlying basement formation (north Delaware and Midland basin). We tested different 3D grid sizes (from 200m to 500m) for the 3D velocity model and found the grid size has only a small effect on the hypocenter estimation, shifting the source locations up to 250m. Using NonLinLoc, which pre-stores the (large) 3D travel-time grids on disk for each station and phase, the computational time to compute a single event hypocenter location with ~50 seismic phase readings from “cold” start is about 6 secs and 3 sec using the 200m and 500m 3D velocity grids, respectively. These results indicate that current computational resources of TexNet allow location of events using the large, 200m Permian Basin 3D model in daily operations of the TexNet state-wide network.

POSTER 74

Physics-bounded Maximum Magnitude of Production-induced Earthquakes in the Groningen Gas Field

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Estimating the maximum earthquake magnitude is central to mitigating hazards of induced seismicity. In Groningen, earthquake statistics and geological background are intertwined implying a bounded maximum magnitude for the production-induced earthquakes there. We untangle this problem by developing a theoretical model, based on linear elastic fracture mechanics (LEFM), to quantify the maximum size of self-arrested rupture and the condition for rupture runaway. Substituting realistic Groningen parameters into the model suggests a low probability for rupture runaway; conservative forecasts of the maximum magnitude yield a value of 3.78. To verify our model, we derive an upper-bound magnitude-thickness relationship and find it consistent with the observed seismicity. Synthetic magnitude-frequency distributions incorporating model predictions also show good agreement with data. Our model underlines the importance of reservoir thickness, stress drop, background stress and fracture energy; it offers an operable framework to forecast earthquake magnitude by informing the physical model with measurable observations.

POSTER 75

Applications of MTUQ: A Framework for Estimating Moment Tensors, Point Forces, and Their Uncertainties

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Seismic moment tensors and point forces offer a concise way to represent a wide range of phenomena, such as tectonic earthquakes, explosions (natural or anthropogenic), and surface mass movements. Accurately estimating seismic source parameters and their uncertainties is essential for interpreting the underlying physical processes. We present the open-source Moment Tensor and Uncertainty Quantification code (MTUQ), which provides modular tools for point-source inversion using seismic waveforms and first-motion polarities. MTUQ enables workflows that balance computational efficiency with thorough uncertainty quantification, using various Green's function databases (1D and 3D, including strain Green's functions), on platforms ranging from laptops to HPC systems. MTUQ offers complementary approaches to explore and sample the solution space: direct grid searches, Bayesian sampling with explicit use of correlated data-noise covariance matrices, and the Covariance Matrix Adaptation Evolution Strategy (CMA-ES), which allows fast prototyping and testing. Uncertainty quantification is built around the geometric properties of the moment tensor space to enable uniform sampling and distance-based metrics between tensors, supported by a comprehensive visualization library (misfit maps, confidence curves). We demonstrate these capabilities through applications in forensic seismology and catalog building, with a focus on the aftershock sequence following the December 6, 2025, Mw 7.0 Hubbard Glacier earthquake in Alaska. In this context, MTUQ supports a repeatable, automated workflow, with confidence curves used to systematically quantify solution sharpness within the solution space, providing a practical evaluation metric for catalog entries. During the sequence, we identify a shallow (~2 km) Mw 4 doublet with highly similar mechanisms, which we use to demonstrate how separate and joint inversions of this double event affect uncertainty quantification.

POSTER 76
The Spatio-temporal Scales of a Self-sustaining Stress Transfer Mechanism Responsible for Intermediate-Depth Earthquakes Within the Bucaramanga Nest, Colombia
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Deep earthquakes signal localized, seismic ruptures within the mantle that is otherwise viscously flowing at great pressures and temperatures. Any mechanism for deep seismicity must localize stresses to cause seismic deformation, but it's unclear how the stresses are redistributed before and after a rupture. Our previous study identified a migrating front of seismic deformation that plunges 1 km into the slab over three years. We proposed a self-sustaining stress transfer mechanism, where seismic deformation promotes temperature-sensitive viscous deformation and metamorphism. However, the spatial extent of this mechanism and the timescale over which it may trigger subsequent deep earthquakes are not well constrained.

Here we develop a new method to measure the spatio-temporal scale of deep deformation using multi-template families, allowing us to track the evolution of deep seismicity at the scale of several kilometers of the Bucaramanga Nest, Colombia. Using distributions of relative arrival times between events in different families, we estimate inter-family relative locations to observe how closely related the different template families are in time and space. Constraining these spatio-temporal scales is essential to constrain how rupture-induced heat controls the deformation and seismicity rate of deep earthquakes through a self-sustaining stress transfer mechanism.

POSTER 77
Coda-derived Source Parameters of Shallow Earthquakes in Mainland Alaska
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The range of tectonic regimes spanned by mainland Alaska creates challenges for assessing consistent magnitudes, especially when earthquakes are too small or not amenable to moment tensor analysis. This variety also suggests the potential for large variations in the apparent stress of earthquakes. To address these we present a coda envelope calibration for the region. We use

this calibration to derive a new catalog of moment magnitudes and apparent stress measurements. Our calibration is based on a set of 70 reference events with existing moment tensor-derived magnitudes between Mw 3.6 and Mw 5.2. We also use 13 ground-truth apparent stress estimates derived from coda spectral ratios. We use the Coda Calibration Tool (CCT) to correct for the low Q observed at surface stations. This allows us to produce nearly identical source spectra across the region, including spectra from co-located surface and borehole stations. We use this calibration to calculate Mw for 700 crustal earthquakes. We derive a conversion relationship between Mw and ML using an orthogonal regression that accounts for uncertainty in both ML and Mw. This conversion is valid for shallow events in mainland Alaska. We also use the calibration to estimate apparent stress for 200 events. We observe a modest magnitude dependence in apparent stress, in agreement with previous studies. We account for this dependence with a version of apparent stress that has the magnitude effect removed. We also introduce a magnitude- and depth-detrended version to account for a slight depth dependence observed in linear regressions. The final values demonstrate spatial variations in apparent stress across mainland Alaska, with relatively higher values in Southcentral Alaska, the Kaktovik region, and recent earthquakes on the Tintina fault.

POSTER 78
Earthquake Focal Depths and Tectonic Implications of the Shanxi Rift Based on a Depth-phase Scanning Algorithm
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The development of the Shanxi Rift is widely attributed to mantle upwelling, a key factor in generating regional seismicity. Elucidating the deep structure and its spatial relationship with earthquake activity is crucial for understanding tectonic deformation. However, this analysis is often constrained by high uncertainties in focal depth estimates, limiting our ability to resolve the region's detailed tectonic architecture.

In this study, we apply the noval Depth Scanning Algorithm (DSA) method to determine 837 earthquakes ($M_L \geq 2.0$) occurred during the period between 2019 and 2024, recorded by the Shanxi Seismic Network (32 stations). The DSA provides robust focal depth determinations through a workflow involving the generation of depth-phase templates, performing a grid search constrained by depth-phase matching, and subsequent fine-scale refinement to minimize RMS residuals. To enhance computational efficiency for this intensive scanning process, we implemented parallel acceleration to significantly speed up event processing (running time shortens from 18 min per event to 11 min). We further apply forward-modeling tests to validate the reliability of the relocated focal depths derived for the Shanxi earthquake dataset.

Based on 151 well-resolved focal depths (M2.0~M3.9), our results exhibit a clear bimodal pattern of background seismicity, with a dominant shallow peak at 3–7 km (80% of events) and a secondary middle-crust peak at 20–25 km, separated by a quiescent zone at 10–14 km. This bimodal distribution reveals distinct rheological layers and depth-dependent mechanical stratification within the rift system. In addition, we investigate the focal depths of an earthquake sequence of 8 events (M2.0~M4.3) that occurred during the extreme rainfall season in August 2025 in Yunzhou, Shanxi. All events consistently exhibit shallow focal depths (2.4~5.0 km), confined within shallow sedimentary layers. These observations provide independent evidence aligns with a fluid-induced mechanism for this sequence, underscoring the seismic hazards posed by intense rainfall events in an arid-semiarid transitional region.

POSTER 79
The Connected Nucleation Spectrum of an M5.6 Earthquake
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Understanding earthquake nucleation is fundamental for earthquake science. Using dense near-fault seismic observations, we investigate the nucleation of a shallow M_L 5.6 earthquake at a hypocenter depth of 4.68 km, triggered by nearby hydraulic fracturing operations. High-resolution data reveal both a prolonged foreshock sequence and a weak seismic nucleation phase preceding the main rupture.

The foreshock activity lasted approximately 11 months and evolved through three stages. (1) Fault destabilization stage (–11 to –3 months): foreshocks occurred in a stepwise manner and progressively migrated toward the

mainshock hypocenter, indicating gradual fault weakening. (2) Precursory quiescence stage (–3 months to –3 days): seismicity markedly decreased, with reduced event rates and magnitudes and only sparse activity within 0.9 km of the hypocenter. (3) Immediate foreshock stage: seismicity reactivated near the hypocenter, highlighted by an M_L 3.5 foreshock 0.6 km away six minutes before the mainshock, followed by several smaller events. Two very small events (M_L –0.2 and M_L 0.0) occurred 14 s before the mainshock in the immediate hypocenter vicinity, suggesting the possible role of preslip.

A weak seismic nucleation phase lasting ~0.7 s was identified immediately before dynamic rupture. At near-fault stations, the initial impulse of the mainshock is weaker than that of the M_L 3.5 foreshock and exhibits clear directivity, indicating rupture initiation within a confined area. With increasing distance, the mainshock initial impulse becomes stronger than the foreshock and shows enhanced low-frequency energy, implying distinct nucleation processes. Two additional subevents were identified during the nucleation phase, followed by cascading rupture after failure of a strong asperity.

These observations suggest that earthquake nucleation involves long-term fault destabilization, a precursory quiescence period, and re-localization of seismicity near the hypocenter. The mainshock likely initiated within a low-strength zone adjacent to a strong asperity, producing a weak initial rupture before full dynamic failure.

Planetary and Gravitational Wave Seismology
Oral Session • Wednesday 15 April • 8:00 AM Local
Conveners: Karan Jani, Vanderbilt University (karan.jani@Vanderbilt.Edu); Philippe H. Lognonné, Paris Institute of Earth Physics (lognonne@ipgp.fr); Mark P. Panning, Jet Propulsion Laboratory (mark.p.panning@jpl.nasa.gov); Nicholas C. Schmerr, University of Maryland (nschmerr@umd.edu)

Seismic Evidence for Widespread Mantle Heterogeneity on Mars
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A planet's interior can preserve the signatures of early formation, even as it slowly reworks them. Using seismic observations from NASA's InSight mission, we report kilometer-scale heterogeneities distributed throughout Mars' mantle. Their presence is revealed by pronounced, frequency-dependent wavefront distortion and scattering of high-frequency energy from deeply probing marsquakes, indicating pervasive small-scale structure rather than a largely homogeneous mantle. The inferred heterogeneity is ubiquitous and approximately scale-invariant, consistent with a highly disordered interior that retains fine structure over geologic time.

The size, persistence, and limited mixing of these structures over billions of years imply a sluggish mantle convection. Joint interpretation of these seismic constraints with thermodynamic/geodynamic forward models of Mars' long-term thermal evolution bounds mantle viscosity to $10^{21.3}$ – $10^{21.9}$ pascal-seconds and weak temperature dependence, with an effective activation energy of 70 to 90 kilojoules per mole, suggesting a mantle deforming by dislocation creep. Together, the results indicate a highly disordered, only partially homogenized martian mantle consistent with stagnant-lid evolution, in sharp contrast to Earth's tectonically recycled interior, and provide a template for how deep compositional structure may persist on other single-plate rocky worlds.

Insights Into Martian Crustal Formation Through Seismic Anisotropy
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The largest seismic event ever detected on Mars, S1222a, occurred on May 4, 2022, likely just north of the hemispherical dichotomy, east of the landing site, and south of Cerberus Fossae. This event was unique in that it generated both Love and Rayleigh waves, including fundamental and higher modes, providing us with a rare opportunity to determine whether large-scale seismic anisotropy is present on Mars. We performed non-linear waveform modeling and used a Niching Genetic Algorithm to find velocity models that can explain the observed fundamental and higher modes in the 6 – 30 s period range. It enabled us to model crustal seismic anisotropy in the crust with greater resolution than in previous studies.

We found seismic velocities be consistent with previous findings and compatible with damaged, altered, or compact basalt and impact melt. Our analysis also revealed anisotropy with a fast horizontal direction of propagation in the top 40 km, consistent with previous work solely based on fundamental-mode Rayleigh wave dispersion curves. Our models display two anisotropic layers, with the deeper layer (25 – 30 km depth) characterized by stronger anisotropy (up to 30 % compared to 10 – 20 % above). The anisotropy models gothrough a minimum at about 20 km below the surface, a depth at which previous studies have detected seismic discontinuities at two other locations. This is also the most likely focal depth for S1222a. While the origin of the anisotropy is uncertain, it is characteristic of a medium with a vertical symmetry axis and could result from both magmatic events and impacts. We thus propose that the anisotropy layering reflects different stages in the formation history of the Martian crust.

New Magnitude Scaling and Seismic Source Characterization for Marsquakes and Impacts
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The InSight mission has revolutionized our understanding of Mars' interior, revealing key seismic discontinuities associated with the crust, mantle, and core. However, most studies to date have focused on structural inferences, while the source properties and magnitude scaling of Marsquakes remain comparatively underexplored. A key example is the largest recorded event, S1222a, whose reported magnitude ($M_w \approx 4.7$), estimated using a recalibrated terrestrial magnitude scale, differs by approximately 0.5 M_w from results obtained through waveform inversion of body and surface waves. This discrepancy corresponds to roughly a fivefold difference in seismic moment, suggesting a systematic bias in current Marsquake magnitude estimates. In addition, focal mechanism determinations have so far been limited, focusing mainly on regional events from the Cerberus Fossae area and S1222a. Here, we present a new, independent Marsquake catalog that includes both magnitude and focal mechanism solutions, extending beyond the existing catalogs produced by the Marsquake Service. The catalog also incorporates impact-related source parameters to account for seismic signals generated by meteorite impacts. Because Marsquakes and meteorite impacts exhibit distinct source physics, depth distributions, and radiation characteristics, we explicitly account for these differences in our source characterization and magnitude estimation. We update the magnitude scaling relations previously used in the Marsquake Catalog by incorporating the latest Martian velocity models and attenuation constraints. Our revised magnitude estimates are validated through comparison with independently derived waveform-based moment tensor solutions for marsquakes and source parameter solutions for impact events. We discuss the implications of these results for regional and global Martian tectonics and on the broader seismic character of Mars, emphasizing the need to recalibrate source scaling relations and to establish a consistent, physically grounded magnitude framework for future planetary seismological studies.

Updating Venus' Predicted Seismicity Using New Global Wrinkle Ridge Map Generated Using Machine Learning
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Venus's young surface implies that it is very likely geologically active, but there are very limited data to constrain rates of activity. Gravity data point to regions that may be actively (dynamically and/or thermally) compensated, and thus potentially active today. Wrinkle ridges (WR) are globally distributed, low strain compressional features [Bilotti & Suppe, 1989]. Sabbeth et al. [2023] estimated seismicity using a scaling relationship between fault length and moment release based on the B&S global shapefile with 65,000 WR. Moment release was bounded using different estimates of seismic layer thickness and assuming activity constrained to 100 m.y., a duration on the order of the average surface age and the cooling time required for a 100 km thick thermal lithosphere to form. Four tiers of fault segmentation were assumed, by analogy to terrestrial seismic activity. They found moment release rates of 5.1×10^{17} N-m/yr, 3.7×10^{17} N-m/yr, and 9.1×10^{16} N-m/yr for fault depths of 50 km, 30 km, and 10 km, respectively.

Initial analysis using machine learning models to map the global wrinkle ridge population reveals a ~38 X increase in the number of global wrinkle ridges using the highest resolution global radar mosaic available, with a resolution several times greater than the mosaic used by B&S (Mendoza, S., et al., AGU 2025 abst. #P23G-2760). The new global distribution has a lower maximum fault length with less linking of fault segments. The machine learning model is closer to the expected power law distribution of faults than the B&S map. Segmentation of longer faults is still likely and will result in a b-value closer to those from terrestrial studies. Although the initial results achieved very good metrics, machine learning mapping is imperfect. Further, not all of the globally distributed WR are correlated with the geoid and/or topographic gradient and thus cannot be inferred to be active on that basis. The vastly larger number of WR mapped using machine learning implies higher predicted seismicity In this presentation we will update seismicity predictions using the latest machine learning results.

From Deep Space to Deep Earth - How the Earth Shapes the Way in Which We Observe the Cosmos

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Over the past 10 years, ground based Gravitational wave detectors represented a leap forward in astronomy and significantly advanced our knowledge of fundamental physics. These instruments are the most precise differential length meters ever built and the sensitivity that they deliver comes at the cost of being extremely susceptible to environmental noise sources linked the the geophysical context in which they are placed. Current detectors, namely LIGO, Virgo and KAGRA, are only mildly affected by the geophysical context, but the future Einstein Telescope (ET) represents a huge step ahead in gravitational wave astronomy, pushing observational sensitivity into regimes where terrestrial effects can no longer be treated as secondary. In this context, geophysics and geology emerge as crucial disciplines which play a central role both in the design of the detector and in the reaching of its science goals. Since ET will be built underground to suppress seismic and Newtonian noise, local geological structures, rock properties, and geodynamic processes will be key factors in determining the noise budget of the detector, the achievable low-frequency sensitivity and to grant the reaching of the design goals of ET.

At the same time, geological constraints shape critical engineering choices, from cavern excavation and infrastructure layout to long-term operational safety. Understanding and modeling these effects is therefore not merely an exercise in site characterization, but a component of the observatory's scientific potential.

This interplay between Earth sciences and fundamental physics redefines the boundary between instrument and environment: the Earth is no longer a passive platform, but an active element of the experiment. By integrating geophysical monitoring, geological modeling, and gravitational-wave data analysis, ET will turn local knowledge of the Earth into a prerequisite for observing the most distant and energetic phenomena in the Universe, illustrating how deep Earth conditions ultimately shape our view of deep space.

Geophysical Site Investigation for a Future Einstein Telescope (ET) in Lusatia, Saxony, Germany

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Gravitational wave detectors are the most precise relative length measurement devices that exist on Earth which makes them very susceptible to environmental noise. Therefore the 3rd generation of gravitational wave detectors like ET will be built underground to minimise the impact of environmental noise, especially seismic and Newtonian noise.

Here we will present the first results from an ongoing site investigation in Lusatia located in the southeast corner of Germany close to Poland and the Czech Republic. Since 2024 numerous geophysical and geological site investigations were carried out. Here we will present results from a large-N passive seismic deployments to investigate in high resolution the subsurface structure, continuous seismic borehole measurements down to 250m depth, and seismic array measurements to characterise the spatial and temporal properties of the seismic noise field in the region. We aim to develop a digital twin of the subsurface also including the incoming seismic noise field to be able to characterise and if possible to predict the seismic wavefield for developing seismic and Newtonian noise mitigation schemes.

Fundamental Noise and Gravitational-wave Sensitivity of the Laser Interferometer Lunar Antenna (LILA)

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The Earth's Moon presents a uniquely advantageous environment for detecting astrophysical gravitational waves (GWs) in the frequency range of millihertz to decihertz. Unlike Terrestrial GW detectors, the quiet seismic environment of the Moon does not impede detection in this band; in fact the ground motions of the Moon will be excited by GWs, making the Moon a resonant amplifier at low frequencies. The Laser Interferometer Lunar Antenna (LILA) mission aims to be limited by thermal Brownian noise in its optics across most target frequencies. By taking advantage of the lunar normal mode resonances, we show that the first phase of the mission, LILA Pioneer, achieves the GW sensitivity required to study astrophysical sources through the millihertz to decihertz range. The advanced phase of the mission, LILA Horizon, would increase GW sensitivity to the cosmological horizon in this band.

Thermoelastic Perturbations in Lunar Regolith: An Analytical Model for Surface Shielding

We present an analytical framework to quantify how surface shielding, such as thermal blankets, rocks, lander components, and deployed instruments, perturbs the lunar subsurface temperature field and how these perturbations may couple into elastic noise relevant for geophysical and gravitational-wave (GW) sensing on the Moon. The Moon represents an attractive platform for mid-band GW detection due to the absence of an atmosphere, minimal anthropogenic activity, and highly stable diurnal forcing, which together enable access to frequency bands between terrestrial and space-based detectors. However, this same environment gives rise to strong radiative thermal contrasts driven by solar illumination, Earthshine, and persistent shadowing. Surface shielding alters the effective boundary condition for heat flux entering the regolith by modifying local albedo and radiative exchange. These elements can act as thermal insulators beneath their footprint while inducing lateral temperature gradients in the surrounding soil. Such gradients may generate long-period ground deformation and tilt noise, potentially biasing sensitive seismic and GW measurements. To address this problem, we develop an analytical solution for subsurface heat diffusion in a semi-infinite lunar regolith, formulated in cylindrical coordinates to explicitly capture the effects of localized shielding. We derive closed-form expressions for the temperature response beneath a single circular shield and extend the formulation to multiple insulating regions. The framework yields scaling relations for the lateral extent and penetration depth of thermal shielding effects, providing predictive tools for instrument siting, thermal mitigation strategies, and future lunar geophysical and GW mission design.

South Pole Seismic Station (SPSS): An Active and Passive Seismic Deployment for Artemis IV Astronauts

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The South Pole Seismic Station (SPSS), recently selected by NASA as a deployed instrument for Artemis IV, would probe the south polar region of the Moon with unprecedented sensitivity, addressing Artemis science goals by constraining the deep and very shallow interior with the most sensitive flight-proven seismometer and an active source survey. The instrument would be deployed by astronauts for ideal seismic coupling, record an active seismic survey performed by the astronauts with a compact seismic source, and continue operating as a long-term seismic station after the astronauts leave.

SPSS has the following four major science objectives: 1. Investigate the physical properties of the deep lunar interior to better understand the geologic processes that affect planetary bodies; 2. Understand the current lunar meteoroid bombardment rate; 3. Monitor real-time environment affecting operations for astronauts and potential for future stable astrophysical and physics observatories; and 4. Determine near-surface and regolith properties to address active surface processes and polar volatiles. SPSS consists of a vertical component Very Broadband seismometer (VBBZ), based on the VBB seismometer for the InSight Mars mission with sensitivity near 10^{-10} m/s² near 1 Hz, provided by CNES, the French space agency and IPGP, as well as 3 vertical component geophones (GEOZ), provided by SLB USA, included in a single long-lived package. Additionally, it includes a Portable Active Seismic Source (PASS), provided by JAXA, Japan's space agency and the University of Tokyo. In combination with the deployment of other instruments, including Farside Seismic Suite (FSS), deployed in Schrödinger Basin by a commercial lander, Lunar Environmental Monitoring Station (LEMS) deployed by Artemis III astronauts, as well as seismometers deployed in the South Pole region by the Change 7 and 8 missions, SPSS has the potential to become a key part of a regional seismic network around the Moon's South Pole.

Lunar DAS: Compact Fiber-optic Sensing to Map the Moon's Interior

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Seismology is a crucial tool for exploring the Moon's interior. While Apollo-era seismometers gave us the first glimpse of the Moon's interior and seismicity, their sparse coverage left key questions unanswered. In particular, lateral heterogeneities in the shallow lunar subsurface remain largely unconstrained. To move beyond the limitations of an Apollo-style sparse seismic network, we need much denser seismic observations. Lunar Distributed Acoustic Sensing (DAS) offers one solution. DAS transforms a single fiber-optic cable into thousands of seismic sensors. By measuring tiny vibrations along the fiber, Lunar DAS can detect and locate moonquakes, image subsurface structures, and monitor activity near landers and habitats—all with the interrogation unit staying on the lander. The fiber itself is passive, rugged, and can be deployed

across the surface without power distribution or data telemetry. Our team has built a TRL-4 prototype and demonstrated its core functions in both the lab and Antarctica. Surface deployment and coupling are being validated through experiments. In this talk, we will report our latest progress toward a TRL-6 lunar DAS system that is lightweight, low-power, and designed for the lunar environment.

Planetary and Gravitational Wave Seismology [Poster]

Poster Session • Wednesday 15 April

Conveners: **Karan Jani**, Vanderbilt University (karan.jani@

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POSTER 132

Seismo-acoustic Characterization of Lunar Rocket Plume Hazards Using Distributed Acoustic Sensing

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Rocket landings and launches on the Moon pose significant and poorly quantified hazards to surface infrastructure, scientific instrumentation, and crew. In the absence of an atmosphere, rocket exhaust can accelerate unconsolidated lunar regolith to extreme velocities (~2 km/s), producing ballistic particles capable of damaging assets over kilometer-scale distances. In addition to mechanical damage, plume exhaust introduces volatiles—particularly water—that may alter regolith properties and compromise measurements of lunar water, a major objective of upcoming Artemis missions.

We investigate the use of optical fiber-based Distributed Acoustic Sensing (DAS) as a novel seismo-acoustic approach to characterize rocket plume-surface interactions. DAS converts a single optical fiber into a dense array of thousands of virtual sensors, enabling high-resolution measurements of ground motion, debris impacts, and subsurface property changes over large spatial scales. Terrestrial analog experiments demonstrate the sensitivity of DAS to plume-like processes. Recordings of a strongly ground-coupled explosion resolve distinct wavefields associated with shock-generated ground motion, prolonged debris fallout lasting more than 10 s, and individual impact events, indicating ejecta heights exceeding 200 m. Complementary laboratory experiments using a lunar regolith simulant show that DAS detects impacts from clusters of small grains (~10 g) at velocities as low as ~1 m/s, with signal amplitudes scaling with impact energy.

These results demonstrate that DAS has the potential to quantify the timing, spatial extent, and intensity of plume-generated hazards while also sensing regolith property changes associated with volatile emplacement. A lunar-deployed DAS system would provide unprecedented situational awareness, improve safety margins for future surface operations, and enable new seismological investigations of anthropogenic activity on planetary bodies.

POSTER 133

Using Inertial Measurement Units as Seismometers for Planetary Missions

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Many upcoming landed NASA missions have Inertial Measurement Units (IMUs) for spacecraft navigation, presenting opportunities for seismic science. We explore using IMUs as strong motion accelerometers to capture active seismic source signals for investigating the lunar subsurface. Most NASA rovers use the Northrup Grumman LN-200S, a triaxial MEMS accelerometer that senses strong ground motion at 1-400 Hz with a minimum noise floor sensitivity of ~0.3 mm/s²/√Hz. IMU data collection is mostly limited to active seismic operations sampling at 100 Hz. Our goals are to 1) quantify IMU sensitivity to seismic signals from a rover and its subsystems; 2) characterize rover transfer function and seismic response; and 3) develop meth-

ods to assess subsurface structure from IMU data. Observed seismic signals are made of four convolved components: instrument response, source time function, rover transfer function, and ground response. Instrument, source, and rover response can be experimentally measured before flight to isolate lunar subsurface seismic velocity variations and properties. For instrument and source characterization, the Regolith and Ice Drill for Exploration of New Terrains (TRIDENT) served as an example seismic energy source. IMUs attached to drill supports of TRIDENT’s engineering model recorded drilling in rotary (16.2 Hz) and percussive (2 Hz) modes in a vacuum chamber. Both modes showed characteristic source functions and frequency responses detectable above the IMU noise floor with signal-to-noise ratios between 30 and 200. Due to the high noise floor, lower frequency content, signal aliasing and limited data, IMU seismic data’s primary value will likely be in relative amplitudes and signal shapes between locations. IMU data from Lava Beds National Monument on solid basalt and tuff fragments suggest even highly aliased signals can distinguish solid basalt from tuff. Rover response varies by design and remains unconstrained. We plan to characterize rover transfer functions using Panning and Kedar (2019) and develop tools for extracting ground response and properties from IMU data.

POSTER 134
Seismological Characterization of the Sardinia (Italy) Candidate Site for the Einstein Telescope
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Einstein Telescope (ET) will be the European third generation gravitational wave detector which construction is foreseen in the next decade. The project is currently in the preparatory phase: one of the crucial issues is to define the most appropriate location to achieve its design sensitivity. The Italian candidate site is located in NW Sardinia, a region characterized by a peculiar geological evolution: it is part of a micro plate which is stable since about 15 Myrs and not affected by present day active deformation due to tectonic processes. This geologic setting, together with a very low degree of anthropization, provides a very quiet environment with very low seismic noise, especially in the frequency band 1-10 Hz where ET is expected to detect low frequency gravitational wave signals.

The Italian candidacy is underpinned by extensive geophysical studies in the area based on various surveys and the installation of a network of geophysical sensors. We report results from deployments of permanent and temporary seismic stations ongoing since 2019. A comprehensive, long-term, broadband assessment of ambient seismic noise has been conducted using both surface sensors and borehole broadband seismometers installed at a 250 m depth. This study confirms that the site’s noise floor approaches Peterson’s New Low Noise Model in the target frequency band 3-9 Hz. We have also deployed several, temporary seismic arrays with varying aperture and geometry, aimed at investigating the amplitude and spatial distribution of noise sources across in different bands and to retrieve the subsurface seismic velocity profiles. Results from the surface wave dispersion curves inversion and from the analysis of HVSr spectra show the presence of a homogenous, high velocity crystalline subsurface that can ensure an ideal and stable environment for hosting and operating ET.

POSTER 135
Detection of a Martian Long Range Thermospheric Acoustic Wave by SEIS/InSight
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We show the first detection on InSight seismometer, SEIS, of a long range, long period thermospheric Acoustic wave generated by the large impact of Sol 1094, which occurred at about 3460 km of epicentral distance. Although associated mostly to a pressure wave, the signal is detected by the 3 axis seismometer through compliance effect amplified by the landig site fabric tilt.

We then model this signal by Normal mode summation. Normal modes are computed by taking into account the solid-atmosphere coupling and , in the atmosphere, viscosity and C O2 relaxation.

Both the normal modes and ray tracing shows that the signal is generated by acoustic waves trapped between the thermosphere and the martian surface, which bounce several times on the ground and are refracted up to about 100 km of altitude. This demonstrates that long period acoustic waves can propagate thousand km away and at altitudes with extremely low densities.

We then invert the source associated to the entry and explosion of the 1094 impactor, which generated on the Ground a 150 m large crater. Although the waveform can be partially retrieve by a near surface explosion, we show that such a source model request likely too large explosion yield. On the other hand, more complex source generated by both the entry supersonic cone and one or several explosions seems more likely and can be made with impactor with mass and entry velocities fitting much better the crater size constraints.

This observation demonstrate that acoustic signals of impacts can on Mars be detected at teleseismic distances and open new direction for future reprocessing of the InSight SEIS data.

POSTER 136
Determining Lunar Interior Structure through LILA, a Lunar Gravitational Wave Observatory Concept
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The Laser Interferometer Lunar Antenna (LILA) is a proposed lunar Gravitational Wave (GW) observatory focused on measuring in the sub-Hz domain inaccessible to Earth-based observations due to continuous seismic noise within that bandwidth. Current proposed iterations of this concept include two strainmeter-based approaches with an initial deployment with two 5-km arms (LILA Pioneer), followed by an extremely sensitive deployment with three 40-km arms (LILA Horizon). While the focus of these observatories would be measurement of GW through the response of the Moon, the very low noise strain measurements required would also provide low frequency measurements of seismic signals from both deep and shallow moonquakes, providing the opportunity of high signal-to-noise measurements of the normal modes of the Moon, which can give unprecedented sensitivity to the deep globally averaged and even 3D lunar structure.

To estimate the strain signals of both deep and shallow moonquakes, we use MINEOS with lunar models. Modes are calculated up to 300 mHz. Normal mode summation displacement seismograms are calculated at a distance of 40 degrees and converted to strain via differencing seismograms at two different distances. All calculations assume an ideal source orientation with propagation along the direction of the strainmeter arm, and so are optimistic estimates, but the large S2N ratio estimated suggests measurement should still be possible even for non-ideal source orientations. S2N ratios are robust enough to also manage amplitude reduction related to scattering and lateral variations.

This demonstrates that a LILA instrument will be able to measure Lunar modes below 10 mHz at high S2N for many moonquakes, allowing measuring splitting of those modes to look at 3D interior structure. It may even be possible to measure the very low frequency (<0.1 mHz) Slichter inner core mode of the Moon.

POSTER 137
Probing Small-scale Lunar Mantle Heterogeneities Using High-frequency P-wave Scattering from Shallow Moonquakes
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Small-scale heterogeneities in the lunar mantle can be detected through high-frequency scattering of seismic waves [1], but their characterization is limited by uncertainties in phase picking. In this study, we present a systematic analysis of P-wave arrival times from shallow moonquakes, using a refined picking strategy based on a detailed characterization of pre-event noise and Signal-to-Noise Ratio (SNR). These improved P-arrival time estimates allow a robust analysis of waveform distortions at high frequencies as a function of epicentral distance. We quantify the amplitude and frequency dependence of P-wave scattering and use these observations to constrain the scale and distribution of small-scale heterogeneities in the deep lunar mantle. Our results will provide new seismic constraints on the thermal state and structural state of the Moon’s interior.

[1] Charalambous et al. (2025), Science, doi : 10.1126/science.adk4292

POSTER 138
Benchmarking Single-station Focal Mechanism Inversion to Characterize Martian Crustal Anisotropy
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On the surface of Mars, only one 3-component sensor was installed as part of the Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) mission. Estimating the location and focal mechanisms of detected Marsquakes has thus been challenging, and yet approximations have been made to obtain these source parameters. Namely, studies of focal mechanism determination have tended to assume a purely double-couple (DC) source to simplify the grid search for the optimal fault parameters. However, this ignores the effects of deformation represented in the Compensated Linear Vector Dipole (CLVD) component. This has led to ambiguity in the obtained mechanisms for events such as S0173a and S0173ab. DC and CLVD-containing mechanisms have been used to characterize seismic anisotropy in terrestrial subducting slabs. Consequently, there is a need to explore the non-DC components of these events to reduce ambiguity and estimate crustal Martian anisotropy. In this study, we tested the ability of single-station Bayesian and grid-search techniques to reproduce the DC and CLVD components of known terrestrial focal mechanisms. Comparing the results of each method, we found that an approach combining grid search and Bayesian techniques works best at reproducing known terrestrial mechanisms. To quantify the uncertainty in using single-station-determined mechanisms in an anisotropy inversion, we inverted a terrestrial focal mechanism catalog to compare with known anisotropy results. With our terrestrial benchmark complete, we can proceed with applying our focal mechanism inversion to Marsquakes and invert for Martian crustal anisotropy.

POSTER 139
A Microseismometer for Venus
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The Mars Insight mission has confirmed that seismology is the most powerful way of investigating the interior of any planet, critical for understanding its structure and evolution. However, Venus, with its high surface temperature and pressure present considerable challenges to developing equivalent instrumentation for a similar surface investigation. While this has motivated the development of airborne approaches to detect seismic activity on Venus using infrasound, ground truth from the deployment of a seismic package on the surface still provides the most direct path to study the interior.

We have adapted the silicon sensor of InSight’s microseismometer design by adopting open-loop sensing and using thermocompressive bonding between the die frame and the glass. We demonstrated that open-loop operation does not compromise the noise floor of the device, with a floor below 5x10⁻⁹ m/s²/rtHz, and are modifying the capacitance topology to allow operation over an enhanced tilt range.

To investigate the viability of this approach, prototype sensors were exposed to a Venus environment in the Glenn Extreme Environments Rig, GEER. Samples used the same wafer fabrication processes as used for InSight. These results suggest the viability of a sensor fabrication flow based on sputtered gold under a protective oxide and thermocompressive bonding. In parallel, we are undertaking the coupled development of electronics to drive the sensor’s capacitance transducer, with all operations based in the analog domain, and the packaging approach to allow integration of the sensor and its proximity electronics in a robust package.

POSTER 140
Seismic Evidence of Active Deep Crustal Deformation Beneath Valles Marineris, Mars
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Valles Marineris, the largest canyon system in the Solar System, has been interpreted through competing formation models, including near-surface collapse, pure tectonic extension, and flexural subsidence related to the Tharsis volcanic load, yet the lack of direct seismic observations has prevented assessment of present-day state of stress in the crust. Here, we report the first seismic evidence of faulting within the Valles Marineris region. We analyze PP and SS body-wave phases from the farthest event from InSight, marsquake S0976a, which occurred near Valles Marineris. A single-station moment-tensor inversion reveals a robust strike-slip mechanism, with a P-axis subparallel to the canyon axis and a T-axis oriented orthogonally, indicating oblique shear on canyon-oblique faults and extension on canyon-parallel faults. Alternative source models for surface mass movements (e.g., landslides) and impact- or explosion-type sources fail to fit the observed waveforms, supporting a tectonic source at depth. The inferred source depth of ~40–42 km places the event in the mid- to lower crust, highlighting deep crustal deformation linked to inherited structural weaknesses from canyon formation. Stress reorganization between collapsed trough segments favors strike-slip faulting, consistent with geodynamic models and matching the mechanism of S0976a. These results provide the first direct seismological confirmation that Valles Marineris remains tectonically active and that its present-day deformation reflects long-lived, crustal-scale stresses retained from its formation.

POSTER 141
High-resolution Characterization of Seismic Scattering in the Lunar Near-surface From Observations and Synthetic Records
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The lunar surface and interior produce intense seismic scattering and weak intrinsic attenuation, as shown by the long coda durations and lack of distinct phases in seismograms. Although these properties have been studied extensively across global and regional scales, far less emphasis has been directed towards scattering across smaller distances. Seismic signals generated by the Apollo 17 Lunar Module (LM) are characterized by durations exceeding 120 seconds, despite source-receiver distances of only 145-245 m. Though these properties have been attributed to wave propagation through the unconsolidated and heterogeneous megaregolith, the exact relationships between scatterer properties, subsurface structure, and recorded waveforms are not yet fully understood. We aim to bridge these gaps through joint analyses of observed and synthetic seismic data. We examine waveforms of newly cataloged LM events recorded by Apollo 17 and estimate rise time and coda duration, quantities directly affected by the scattering and attenuation properties of the medium. We also plan to investigate possible correlations with surface temperature variations, which cycle between 80 K and 400 K over the course of 29.5 Earth days and drive the LM vibrations. We complement our observational analyses by constructing numerical simulations of LM events, modeling scattering using random distributions of velocity perturbations superim-

posed onto a 1D velocity model. We perturb factors such as scatterer size and strength of velocity perturbation to constrain models that can reproduce the rise time and coda decay of the observed waveforms.

POSTER 142

Early Earthquake Detection With Elasto-gravitational Waves

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Earthquakes and the propagation of their generated seismic wavefields redistribute mass within the Earth, producing perturbations in the gravitational potential. These gravitational fluctuations travel at the speed of light, much faster than seismic waves. If detected by gravity gradient sensors, the gravitational signals can provide early warning prior to the arrival of damaging ground motion, enabling protective actions for critical infrastructure and saving lives. Toward that goal, here we introduce the Torsion Pendulum Dual Oscillator (TorPeDO), a gravity gradient sensor that is under development, and explore the feasibility of using it to measure prompt gravitational transients due to earthquakes and propagation of elastic/acoustic wavefields. We will briefly describe the construction of the TorPeDO and its response to earthquakes, with a focus on its sensitivity to earthquakes source parameters which are key for an early warning.

Recent Contributions of Social Science Research to Understanding Earthquakes

Oral Session • Thursday 16 April • 4:30 PM Local

Conveners: James Goltz, University of California, Berkeley (jamesgoltz@gmail.com); Anne Wein, U.S. Geological Survey (awein@usgs.gov)

50 Years of the California Seismic Safety Commission: Where Social Science, Public Policy, Seismology, Geology, and Engineering Collide

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The Alfred E. Alquist Seismic Safety Commission was established in 1975, with its first executive director, Robert Olsen, a respected political and social scientist. It was the inaugural state earthquake commission of its kind, providing the California Legislature and the Governor’s office with insights into seismic safety issues. The Commission facilitated early interdisciplinary research, integrating seismology, geology, structural and civil engineering, and social sciences. Under Olsen’s leadership, social scientists such as Dennis Mileti and Kathleen Tierney began their earthquake research careers as commission staff, contributing to earthquake studies including the 1983 Coalinga earthquake and the Parkfield experiment. Both would go on to become Directors of the Natural Hazards Center in Boulder, Colorado.

The Commission consistently incorporated social and cultural perspectives into its earthquake after-action reports and broader earthquake research, leading California in funding and promoting social science research related to earthquakes. In 2026, it celebrated fifty years of service to Californians. This presentation examines the Commission’s historical role as an interdisciplinary science public policy body, exploring the social and physical sciences as well as engineering, and outlines its future research goals for the next fifty years.

Prototyping User-centered Graphics and Maps for Aftershock Forecasts

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We present new user-centered prototypes for aftershock forecasts graphics and maps. Following large earthquakes, science agencies produce probabilistic aftershock forecasts using statistical models, which are used by different organizations to support decisions on earthquake response and recovery. These forecasts can be communicated through different visual products (including tables, graphics, and maps). The design choices for these products can affect how the forecasts are used and understood by different users. In prior work, we held workshops with users of aftershock forecasts, including emergency managers, civil engineers, critical infrastructure operators, geoscientists, public health officials and public communicators. We identified numerous (and sometimes conflicting) user needs for several forecast product types. User needs varied by profession, use case and over time, among other factors. We proposed a more streamlined three-category typology for product design that can cover much of the variability observed in user needs. We next designed numerous user-centered prototypes for several key forecast products: barplots to show forecast trends by magnitude, lineplots to show forecast trends over time, and heat maps to show the spatial distribution of forecasted shaking. We used a novel method for user-centered design that involves first decomposing a product into its key design elements (e.g., a forecast heat map can be decomposed into its color palette, map overlays, legend characteristics, etc.) and then translating user needs into choices for specific design elements. Using this method, we developed numerous product prototypes that captured key user needs expressed in the user workshops or were aligned with our product design typology. Prototypes were presented to the original workshop participants in a focus group and then refined based on their feedback. We discuss these user-centered and -tested prototypes for aftershock forecasts products and their implications for the visual communication of seismic hazard information.

Used and Useful: Usability Research on Earthquake Event Pages

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The U.S. Geological Survey (USGS) Earthquake Hazards Program produces event pages with products intended to inform decision making as well as situational awareness for a wide variety of users. The earthquake event pages have been active for over a decade, assisting scientists and emergency managers alike with information about earthquakes larger than magnitude 2.5.

By utilizing user experience (UX) research principles combined with social science methods, USGS scientists conducted usability tests on the earthquake event pages to derive key insights for recommendations of improvements. We conducted unstructured facilitated interviews while asking users to interact with our web pages. The users are asked to complete various tasks, what priority products they find most useful, and what improvements could be made to make finding information easier. Tests were conducted in March through July 2025 with a wide range of users including students, hazards researchers, and emergency managers, with over 40 users. Early insights indicate that users could benefit from improved hierarchy in the earthquake event page information to understand what is most important to them (i.e., their priority products), and they require plain language text summaries of both types of hazard events.

The USGS is also conducting usability testing of other products as well, including the newly standardized landslide response event pages, landslide response fact sheets, prototype visualizations of aftershock forecasting, the earthquake sequence prototype, the National Seismic Hazard Model maps, and an interactive volcano hazard assessment.

Real-time Public Reactions to Earthquakes via an Earthquake Early Warning Platform in Japan: Implications for Risk Perception

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We investigate open-ended user responses to earthquake early warning (EEW) from the 2024 Noto Hanto earthquake. Human reactions and perceptions of earthquakes and other hazards have been widely studied using social media data, which is key to informing government agencies and organizations in shaping disaster response and assistance policies. Social media platforms allow users to post freely across locations and time; however, relatively few studies have examined public reactions *at the moment* an EEW notification appears on a smartphone. Earthquakes are unique among natural hazards in that they occur without notice or seasonal expectation, unlike wildfires or hurricanes, and are still unexpected, often jarring events that elicit a range of immediate emotional and behavioral responses. Prior research suggests that the volume of social media posts increases with perceived shaking intensity, yet it remains unclear whether reactions differ when users are prompted to respond through an EEW-specific platform rather than general social media.

In this study, we investigate open-ended (unstructured text) responses submitted by users of a Japan-based EEW mobile application known as Yurekuru-Call. Using Natural Language Processing methods combined with qualitative content analysis, we identify patterns and themes in these short responses. We analyze data collected during the 2024 Noto Hanto Earthquake and Tsunami to examine how reported reactions vary with distance from the epicenter and the type of content expressed within an EEW application. This research provides insight into public attitudes and real-time reactions during a large-scale earthquake in Japan and highlights how EEW platforms may elicit responses that differ from those on general social media platforms such as X (formerly Twitter) and Facebook. We also observe cultural differences in responses by comparing our data with published papers on social media posts from Western countries. These findings have implications for hazard communication, public engagement, and the design of EEW systems that better account for human perception and response.

Assessing Behavioral Response to Earthquake Early Warnings: What We Know and Would Like to Know About Response

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If the core purpose of hazard warnings, including earthquake early warnings (EEW) is to avoid death and injury, it is essential to understand how individuals who receive EEW’s respond when an alert is received. Although the technology is relatively new, having been publically available on the US west coast since 2021, there have been a number of studies that attempt to address behavioral response to EEW (see summary of this literature in Goltz, Nakayachi and Vinnell, 2025). Based on surveys, we have limited evidence that the officially recommended self-protective actions, particularly to drop, cover and hold on, are not among the most likely actions in response to an alert. We also have information on a range of attitudinal factors regarding desirable threshold for warnings, preferred media of alert receipt and other aspects of EEW. What we do not know, but should, are the processes of cognition, interaction and the sequencing of behaviors associated with EEW. Surveys rarely probe these processes in detail and tend to provide only a very superficial understanding of the full range of thoughts, emotions and actions that characterize this briefest of all hazard warnings. One interesting finding in the literature is that higher levels of shaking experienced result in a greater propensity to take protective actions following receipt of alert messages that contain no indication of the levels of shaking likely to be experienced. Do recipients of EEW alerts require the confirmation of initial shaking before initiating self-protective actions? If so, this would invalidate the basic assumption that alert recipients who receive an early warning for earthquakes take action based solely on the information in the warning message *before* shaking is experienced. In this presentation, I will explore how methodologies in addition to surveys can provide a fuller and richer understanding of how individuals respond to EEW.

Recent Contributions of Social Science Research to Understanding Earthquakes [Poster]

Poster Session • Thursday 16 April

Conveners: James Goltz, University of California, Berkeley (jamesgoltz@gmail.com); Anne Wein, U.S. Geological Survey (awein@usgs.gov)

POSTER 172

The Ethics of Infrastructure Resilience to Earthquakes: Philosophy Meets Seismic Policy

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After a major earthquake strikes densely populated areas, survivors will likely face crippling shortages of food, electricity and running water before order is restored. These are basic essentials provided to us by infrastructure services every day. But malfunctioning infrastructure after an earthquake is not inevitable. Indeed justice requires that infrastructure be designed to avoid such disruption. Disaster planners will often try to account for impacts to infrastructure in policymaking, but this raises critical questions of fairness and justice that may be neglected, to the detriment of overall resilience. Infrastructural design can embody a more or less just vision of society: ethics and political philosophy can help us to understand what justice in infrastructure requires, and so explain why infrastructural failures in earthquakes are so morally concerning.

To that end, this paper proposes a set of ethical criteria that policymakers can use to evaluate the resilience of infrastructure to major earthquakes. First, I give an account of infrastructure in this context and outline key relevant features of infrastructure. Then I explain why infrastructure matters ethically in disaster planning, drawing on lessons from historical failures of infrastructure. Next, I turn to existing conceptions of infrastructural resilience from social scientists, and I argue that these conceptions omit certain important issues of justice. My conception of infrastructural resilience appeals to a framework of ethical values, which I explain and discuss in the paper:

1. Distributive Sufficiency;
2. Distributive Equality;
3. Future Risk-Avoidance;
4. Relational Equality;
5. Civic Rights and Entitlements;
6. The Claims of Non-Human Animals;
7. Fair Procedures.

This paper contributes to the social science literature on earthquake resilience by applying a framework of plausible moral principles to the case of infrastructure. Therefore, it shows how ethics and political philosophy can help fill out existing conceptions of infrastructure resilience. I end the paper with a set of original policy proposals which draw on the ethical analysis.

POSTER 173

Operationalizing Equity: Assessing the Usability of Near-real-time Earthquake Information for Supporting Impacted Communities

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Following an earthquake, near-real-time information provides valuable data on potential impacts like economic losses and fatalities to the public and decision-makers in the emergency management, humanitarian, finance, and other sectors. However, earthquake impact information is often designed without formal user input or a focus on impacted communities, resulting in information that is not necessarily suited for a variety of disaster management decisions.

This presentation will describe how we investigated user needs for disaggregated risk metrics. Following initial focus groups with a broad set of users from various sectors, we developed a mockup showing additional metrics of exposure and loss that highlighted impacted communities in a way that supports users’ tasks. We then used an earthquake scenario with a targeted group of users to gain feedback on the mockup through a usability testing workshop. Workshop participants included nine emergency managers from the Federal Emergency Management Agency (FEMA), the California Governor’s Office of Emergency Services (CalOES), the American Red Cross, and Innovative

Emergency Management. Following qualitative analysis, workshop results revealed that disaggregated risk metrics could support emergency managers’ tasks following an earthquake disaster. More broadly, this research highlights how a human-centered design process can create meaningful interactions with stakeholders who can ultimately use products to support impacted communities after future earthquakes.

POSTER 174
Does the Rainbow Palette Negatively Impact the Use of Shakemap?
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Color coding is one of the most powerful – and challenging – illustrative devices for communicating complex data; it is almost ubiquitous across earthquake information communication tools. ShakeMap, which translates seismic models and data into inferred shaking intensities, uses color-coding to provide emergency managers with easy-to-interpret key information to guide their decision-making. However, successful color-coding is strongly dependent on the intended use case, the target audience, and cultural context, and not all color palettes are created equal. Growing social science research indicates the weaknesses in color palettes like the “rainbow” (or “jet”) color palette due to (i) its non-uniform gradient, and (ii) the difficulty in interpreting by individuals with color vision deficiency, who may represent as much as 8% of the U.S. population. We investigate the impact of ShakeMap’s color palette and explore alternative approaches for effective visual illustration in earthquake shaking and impact products. ShakeMap’s jet color palette relies on Western cultural conventions: green signals safety and red signals danger. Additionally, the color scale emphasizes red over blue or green; this perceptual bias highlights areas where shaking is likely to be most impactful. Although the jet color palette is less discernible to individuals with color vision deficiency, ShakeMap benefits from being somewhat predictable, as each map consists of closed, monotonically increasing contours and corresponding labeled contour values. For comparison, we test leading alternative color palettes designed for color vision deficiency. We find that no single color palette effectively communicates data to all color-vision experiences equally, and the jet palette does not significantly underperform alternative palettes. Our insights highlight the challenges of developing earthquake-shaking and impact products that balance the need for effective communication with the limited resources available for production and deployment.

Recent Research on Ground Motion Directionality [Poster]
Poster Session • Friday 17 April
Conveners: Pablo Heresi, University of Chile (pheresi@uchile.cl); Eduardo Miranda, Stanford University (emiranda@stanford.edu)

POSTER 25
Rotation-independent Duration Metrics for Ground Motions: Extending Rotd Concepts Beyond Amplitude
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Rotation-independent amplitude intensity measures, such as $PSA_{ROT D50}$ and $PSA_{ROT D100}$, are widely used in engineering practice and design codes. However, analogous rotation-independent metrics for other aspects of ground-motion characterization, such as duration, are largely absent. Furthermore, existing duration measures are typically defined directly on acceleration, velocity, or displacement time histories, without explicit consideration of structural frequency content or damping. This study develops a new family of rotation-independent duration intensity measures. Two complementary classes of metrics are introduced to characterize how duration varies with rotation angle: (1) percentile-based measures defined in direct analogy to ROTD amplitude metrics, and (2) measures referenced to acceleration-dependent percentile rotation directions, which link duration to the orientation that governs peak structural demand. To enable large-scale computation, the processing framework was optimized for high-performance computing environments, maximizing parallelization and minimizing memory allocation. This allows efficient evaluation

of duration metrics over a wide parameter space, spanning combinations of period, damping ratio, rotation angle, and rotation percentiles. The resulting dataset is derived from the NGA-West3 ground-motion database. Both the software and processed datasets will be released in open-access format. Preliminary results indicate a systematic negative correlation between rotation angles associated with high PSA percentiles and those associated with duration. In other words, the orientation that maximizes spectral acceleration for a given period tends to align more closely with the orientation that minimizes duration. These findings have direct implications for time-history selection, as well as for random-vibration-theory-based conversions from Fourier amplitude spectra to response spectra.

POSTER 26
Impact of Hypocenter Location and Urban Layout on the Regional Seismic Risk of Tall Buildings
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Current regional seismic risk assessments neglect ground motion directionality, that is, the significant variation in horizontal earthquake ground motion intensity with orientation. As a result, these assessments fail to capture differences in seismic hazard and building response arising from changes in either the scenario earthquake hypocenter location or the orientation of the urban grid. This study uses the probabilistic Monte Carlo-based regional seismic risk assessment framework previously developed by the authors, which explicitly incorporates ground motion directionality, to quantify these effects. The investigation considers the 150 tallest buildings in the Financial District of San Francisco, California. The 150 buildings are first subjected to three hypothetical $M_w 7.0$ earthquakes on the Hayward Fault that rupture the same fault area but have different hypocenter locations. The results show that both the seismic hazard and peak building inter-story drift ratios can vary by up to 20% solely due to changes in hypocenter location, suggesting that regional seismic risk assessments for a scenario earthquake should account for ground motion directionality and consider multiple hypocenter locations for a given rupture area. Moreover, inter-story drift ratios at different building heights, not only at the locations of peak drift, can vary by well over 20% with changes in hypocenter location. The 150 buildings are next subjected to the 1989 Loma Prieta earthquake under three different building orientation scenarios. The results demonstrate that peak building responses can vary by as much as 30% depending on the urban grid layout, while responses at individual stories can differ by substantially more than 30%. Together, these findings highlight the combined influence of ground motion directionality and urban layout on seismic hazard and building response, with important implications for city officials, planners, insurers, reinsurers, and other stakeholders involved in regional seismic risk assessments.

POSTER 27
Ground-motion Directionality in Chile From CSN Strong-motion Data
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Chile’s National Seismological Center (CSN) provides open-access strong-motion recordings from networks spanning a wide range of Chilean site conditions. Using this resource, we examine whether earthquake ground motions in Chile exhibit systematic directionality (polarization) and what controls it. We select stations with robust sampling (>100 accelerograms per station). For each record, we rotate the two horizontal components and compute orientation-dependent intensity measures: PGA, PGV, 5%-damped pseudo-spectral acceleration (PSA) for periods 0.05-10 s, and significant duration (D_{5-95}). Directionality is quantified using IMRotD100 (maximum rotated intensity), the ratio IMRotD100/RotD50 (ratio of the maximum rotated intensity to the orientation-independent median, RotD50), and the azimuth of maximum intensity. We then relate these metrics to source, path, and site parameters, including moment magnitude, focal mechanism, source-to-site distance, and dynamic soil properties. Preliminary results indicate that some stations exhibit persistent preferred orientations of maximum intensity across many events and multiple intensity measures, suggesting a systematic contribution from site effects at specific locations, even when accounting for source and path variability. These preliminary outcomes provide empirical constraints for directionality models in subduction environments and help identify when orientation-specific intensity measures could be considered in site-specific hazard and risk assessments in Chile

POSTER 28
Effects of Source Energy Radiation on the Orientation of Maximum Horizontal Ground Motion Intensity
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Horizontal earthquake ground motions at a site vary in amplitude with changes in orientation. The maximum horizontal intensity was typically believed to occur in random orientations for sites beyond the near-field region. A recent study, however, found that for strike-slip earthquakes, maximum intensities tend to occur at orientations close to the epicentral transverse orientation (i.e., the orientation orthogonal to a line connecting the station to the epicenter). Building on this, we analyze the orientation of maximum intensity for both theoretical and recorded strike-slip events. First, we investigate how source depth and the principal stress axes (quantified by their orientation relative to the fault strike) influence the theoretical maximum horizontal displacements on a plane above a shear dislocation in an isotropic, homogenous medium. Drawing on the spatial patterns observed in these theoretical cases as a guide, we qualitatively examine how the orientation of maximum intensity is distributed spatially in recorded strike-slip earthquakes. This analysis uses several types of waveforms, including filtered ground velocities, high-rate Global Navigation Satellite Systems (GNSS) displacements, and oscillator responses to physics-based simulated or recorded strong-motion ground accelerations. Our results show that, for a wide range of azimuthal angles relative to the fault strike, the orientation of maximum intensity typically occurs near the epicentral transverse orientation. However, within cones near the principal stress axes, the orientation of maximum intensity systematically rotates towards the radial orientation. These results indicate that the assumption that maximum intensities for strike-slip earthquakes always align with the epicentral transverse orientation for all source-to-site azimuths may not hold universally. Instead, improved predictions of the orientation of maximum intensity can be made by using the angle from the fault strike as a predictor of whether a given site is close to the principal stress axes. These results have potential applications in future probabilistic seismic hazard analyses.

POSTER 29
Directionality in the Santiago Basin, Chile, During Subduction Earthquakes
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Horizontal ground-motion intensity can vary substantially with orientation—a phenomenon known as directionality—particularly at sites within sedimentary basins. However, site response is commonly modeled as one-dimensional and orientation independent, despite the fact that basin geometry, soil-rock impedance contrasts, and proximity to rock outcrops can produce strong polarization and preferred amplification directions. To quantify these effects, we analyze the directionality of pseudo-acceleration response spectra in the Santiago Basin (Chile) using accelerometric records from the national strong-motion network operated by the Centro Sismológico Nacional. We computed rotated response spectra for each horizontal record and normalized them by the corresponding RotD100 (maximum) and RotD50 (median) values to serve as polarization metrics. We also evaluate the angular differences between the orientation at which RotD100 occurs and key geometric references, namely the basin-edge normal orientation and the event back azimuth. Results show that stations located near rock outcrops exhibit strong and systematic polarization, with preferred orientations aligned with basin-edge geometry and largely independent of event back azimuth, whereas stations underlain by thicker and more heterogeneous sedimentary deposits show weaker and more period-dependent directional patterns. For a substantial fraction of the network, maximum strong-motion orientation is not random but is governed by local site conditions, which motivates the inclusion of directional amplification factors in site-response analyses for urban sedimentary basins.

POSTER 30
Evaluation of Ground-motion Directionality Through Frequency Contributions to Pseudo-spectral Acceleration in Observations and Simulations
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Horizontal ground motions exhibit strong orientation-dependent behavior, yet they are typically reduced to a single orientation-independent scalar intensity measure, such as RotD50, in ground-motion modeling and seismic hazard analyses. This reduction obscures the physical mechanisms that govern directional variability in oscillator response. In this study, we introduce a frequency-contribution framework to evaluate ground-motion directionality through a frequency-based interpretation of pseudo-spectral acceleration (PSA), linking orientation-dependent response to the frequency content that drives peak oscillator demands. Two orthogonal horizontal components of observed earthquake ground motions and corresponding physics-based broadband 3D simulations are analyzed for selected moderate to large magnitude earthquakes in California. Component-specific PSA and RotD50 response spectra are computed across a broad period range. For each oscillator period, we quantify the frequency contributions responsible for peak PSA and evaluate how these contributions differ between horizontal orientations. The framework is applied consistently to recorded ground motions and broadband 3D simulations to assess how well physics-based models capture frequency-dependent directional behavior. Frequency-dependent residual analyses and mixed-effects regression are used to separate event, site, and remaining variability, enabling systematic evaluation component-to-component differences across multiple earthquakes and site conditions. We further examine whether orientation-dependent PSA can be explained by shifts in contributing frequency content rather than differences in overall amplitude alone, and if these effects are period-dependent. By emphasizing frequency contribution as a physical mechanism underlying directionality, this study aims to clarify the relationship between component-specific PSA and commonly used scalar measures such as RotD50, supporting improved interpretation of directional effects in observations, simulation validation, and seismic demand assessment for oriented structures.

POSTER 31
Improved Characterization of Component-to-Component Variability of Horizontal Response Spectral Ordinates
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Engineers are interested in estimating ground motion intensity at specific orientations that are particularly important to engineered structures, such as the longitudinal and transverse directions of buildings, bridges, dams, levees, pipelines, aqueducts, and other types of man-made structures. This means that in addition to the within-event and between-event variabilities of RotD50 spectral ordinates, the total variability of horizontal ground motion intensity must also include the component-to-component (c2c) variability. In older ground motion models (e.g., BJJF97), this was done by adding a c2c variability computed as the arithmetic mean of the squares of the residuals of spectral ordinates computed from recorded horizontal components relative to their geometric mean. This measure of c2c has two disadvantages: (1) it depends on the orientation of the horizontal sensors; and (2) it is based on the geometric mean of the intensities in the as-recorded orientations as the measure of intensity, which is no longer used in modern ground motion models. We evaluate the c2c variability of 5%-damped response spectral ordinates using 4,331 horizontal ground motions recorded in strike-slip earthquakes. Equations for c2c variability that are independent of the orientation of the sensors are proposed to obtain the total variability of the randomly oriented horizontal component. The proposed equations can be used in combination with the following three scalar measures of central tendency of ground motion intensity: (1) geometric mean, (2) RotD50, and (3) MaxRotD50. The proposed equations yield larger variabilities in the medium- to long-period ranges and have smaller event-to-event variability compared to the equation used in previous studies.

POSTER 32
Revisiting Regional Azimuthal Variations in the Seismic Wavefield From Large Earthquakes Incident in the Valley of Mexico, Mexico
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Given the literature indicating azimuthal and source-dependent seismic response in the Valley of Mexico, we aim to identify systematic variations in source and path effects and classify their impact on seismic response. This work presents results from an alternative methodology involving P- and S-wave amplitude spectrum inversion to determine source, path, and site amplification terms. This approach accounts for independent paths and sources, thereby enhancing the robustness of the results compared to classical methods. We classified earthquake genesis regions in Mexico into four zones and clustered spectra by event location. Source parameter analysis is consistent with the scaling relation $M_0 \sim f_c^{-3}$. Furthermore, phenomena such as stress-drop variations position the source as a contributor in the seismic response. Then, the path was shown to be the primary regulator of seismic waves’ spectral content before they reach the Valley of Mexico. We confirm the pronounced azimuth dependence of seismic response, and deeper paths retain more energy in high frequencies than shallower ones, explaining the 19 September 2017 earthquake’s intensity in the 1-5 Hz range. Most paths have S- and P-wave quality factor ratios exceeding 1.0, suggesting partially melted material or magmatic bodies in the Trans-Mexican Volcanic Belt affect attenuation. Finally, site amplification functions amplify at high frequencies at soft-sediment sites and deamplify at hard-rock sites, consistent with observations from H/V ratios estimated at stations within the Valley of Mexico.

Regional Source, Path and Site Effects in Earthquake Ground Motions

Oral Session • Wednesday 15 April • 8:00 AM Local

Conveners: David Barba Galdamez, North Carolina State

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Analysis of Rupture Directivity and Wave Propagation Effects on Simulated Ground Motion for M7 Earthquakes on the Hayward Fault

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As part of the San Andreas Fault system, the seismically active Hayward fault is a major contributor to the significant earthquake hazard in the San Francisco Bay Area (SFBA). Accurate ground motion predictions for large earthquakes on this fault are essential, but challenges arise due to uncertainties in exactly how the fault will rupture in future earthquakes and how wave propagation effects caused by the highly heterogenous subsurface geological structure will influence site-dependent ground motions. This study investigates the combined influence of rupture kinematics and subsurface structure on ground motion, using simulated broadband seismograms for 50 rupture realizations of an M7 Hayward fault earthquake. Ground motions are generated within the physics-based Earthquake Simulation (EQSIM) fault-to-structure exascale computing framework and the Graves-Pitarka kinematic fault rupture generator. In addition to direct comparisons with empirical ground motion model (GMM) estimates, ensemble-averaged ground motion intensities are used to isolate and assess source and wave path effects. We find that the local structure causes complex wave propagation and spatial variability not fully represented by the GMMs. Rupture directivity produces nearly symmetric amplification and deamplification along the fault, while large-slip patches yield localized influences. Among these factors, the wave propagation effects account for the largest deviation from the GMM predictions. Moreover, they contribute differently across frequencies: directivity effects peak at intermediate frequencies (~1.5 sec), but basin amplification and large-slip patch effects are most prominent at lower frequencies. This study contributes to a broader effort towards understanding key factors controlling ground motion variability in the SFBA

and provides detailed constraints for the development of region-specific, non-ergodic GMMs.

On the Scalability of Non-ergodic GMMs From Numerical Simulations: A Case Study Using the SCEC Cybershake Dataset and Southern California Power Network

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In this study, we present a scalable implementation of a non-ergodic ground motion model (NGMM) for the Los Angeles area with applications to the power transmission network. The NGMM is trained and validated using simulated ground motion data from the SCEC CyberShake study 22.12. The NGMM utilizes the ASK14 ergodic ground motion model as its backbone for estimating median intensity measures, complemented by a Gaussian Process (GP) model that accounts for systematic non-ergodic effects. In the simulated dataset, the non-ergodic effects consist of a systematic site effect and a systematic path effect, which are modeled in the GP using Matérn and specialized covariance kernels, respectively, explicitly characterizing the path vector and site location Within-event and between-event kernels are also included in the GP to represent aleatory variability. Implementing the NGMM involves tuning GP hyperparameters and making conditional predictions on large datasets (~1 million datapoints or more). To facilitate hyperparameter tuning, the GPU-accelerated Python package “GPpytorch” is employed. For scalable prediction, sparse conditional point selection methods, including k-nearest neighbor and Kullback-Leibler minimization-based approaches, are explored. Preliminary results indicate that the NGMM provides accurate predictions and uncertainty quantification for the simulated data while reducing overall uncertainty in ground motion modeling. This is demonstrated on the training dataset as well as independently withheld sites and sources, suggesting the model’s ability to represent the underlying effects and generalize to unseen scenarios. The benefits of modeling these regional non-ergodic effects in infrastructure risk analysis are demonstrated through a scenario earthquake risk analysis of a synthetic power transmission network in Southern California.

Comprehensive Ground Motion Analysis in the Mendocino Fracture Zone

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Earthquakes in the Mendocino Triple Junction (MTJ) generate strong peak ground motions in California’s most seismically active region. Yet it is unclear how the observed ground motions compare to those from typical California crustal earthquakes, as well as subduction zone events. We examine 486 earthquakes of M3.0+, with 23 M5.0+ events to improve understanding of regional site and path effects. We compile and process ground-motion waveforms and compute ground-motion metrics using the U.S. Geological Survey open-source software gmprocess (Thompson et al., 2024). Using several NGA-West2 and NGA-Subduction ground-motion models (GMMs), we compare peak ground acceleration and velocity to investigate trends with explanatory variables, and to characterize the spatial distributions of the ground motions. Analysis of the 2024 M7.0 Cape Mendocino earthquake, 2014 M6.8 Indianola earthquake, and many other smaller earthquakes allows for more careful consideration of source, site, and path effects. We conduct robust GMM residual analysis to better evaluate model performance. Potential uncertainties in site-specific contributions arise depending on the magnitude and source conditions, for example, the M7.0 Cape Mendocino earthquake was recorded on 381 stations, compared to only 45 for the M6.8 Indianola earthquake. Such uncertainties are addressed using linear mixed regression analysis to individually evaluate source, site, and path contributions to ground motion residuals. We consider if MTJ earthquakes are more closely modeled with crustal or subduction zone GMMs, and whether this necessitates more physically precise models or alterations to current models for better hazard characterization in the MTJ region.

Application of Non-ergodic Site Response Analysis to Seismic Retrofit Projects in Los Angeles

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Non-ergodic site response analysis represents an advanced approach to characterizing ground motions for seismic design, accounting for site-specific effects beyond ergodic ground motion models (GMMs). While prior studies have primarily applied this method to SSHAC projects in the energy sector or new construction projects targeting the Maximum Considered Earthquake (MCE_R) risk level, very few non-SSHAC projects have employed non-ergodic methods, particularly in Southern California. As such projects are increasingly undertaken following recent changes in the NEHRP Provisions (Stewart et al. 2026), practical and technical issues are sure to arise for which best-practices will need to be defined. This study documents processes and results for case examples from two seismic retrofit projects in Los Angeles, California. These projects consider hazard levels that are lower than the MCE_R level and include the Basic Safety Earthquake-2E (BSE-2E, 5% exceedance in 50 years) and BSE-1E (20% exceedance in 50 years) hazard levels. These projects apply non-ergodic methods in retrofit contexts, where cost-effective hazard mitigation is critical, by incorporating nearby recordings and hazard-consistent inputs to refine site response estimates. They also identify key hurdles to implementation—such as data availability, computational demands, and integration with existing codes—and propose practical strategies for overcoming them.

The evaluations follow ASCE 41-23, the 2026 Los Angeles City Building Code, and ASCE 7-22. The scope includes subsurface investigation with deep surface wave surface wave soundings and ground motion hazard analysis using the following methods: mapped parameters (ASCE 41-23 Section 2.3.2), site-specific hazard analysis using ergodic GMMs (ASCE 41-23 Section 2.3.3, ASCE 7-22 Chapter 21.2), hybrid ground response analysis (GRA) (ASCE 7-22 Chapter 21.1), GRA with hazard curve convolution (Bazzurro and Cornell, 2004), and non-ergodic SRA (Stewart et al., 2017) using nearby strong motion records and GRA. Each of these methods’ results are compared and commentary is provided on use cases for each method.

Spatial and Azimuthal Variability of Seismic Site Response in the Los Angeles Basin Revealed by a Sub-basin Framework

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Large sedimentary basins exhibit strong spatial variability in seismic site response due to complex geometry, internal structural heterogeneity, and multi-dimensional wave-propagation effects that are not captured by conventional one-dimensional site metrics or ergodic ground-motion models. This work develops and evaluates a sub-basin framework for the Los Angeles Basin (LAB) that explicitly links intra-basin structure to ground-motion amplification and residual variability. The basin is partitioned into seven sub-basins using complementary geological and geophysical indicators including topography, crystalline basement depth variability, basin probability, and major fault systems. We integrate NGA-West2 ground motions (including Ridgecrest sequence data) with dense Community Seismic Network (CSN) recordings and compute 5%-damped RotD50 pseudo-spectral acceleration residuals using mixed-effects regression with respect to Boore et al. (2014). Site terms and site-to-site variance are evaluated within each sub-basin to investigate spatial patterns in amplification across spectral periods.

Results demonstrate systematic differences in site response among sub-basins, with deeper and fault-bounded regions exhibiting stronger long-period amplification and higher variance, while structurally smoother sub-basins show lower variability and improved model agreement. We further examine source-to-site azimuthal effects using nested mixed-effects models to quantify azimuth- and aspect-dependent site response. Sub-basins display distinct directional properties, characterized by preferential amplification for specific source-to-site azimuths and basement-surface slope orientations, indicating coupling between basin geometry, basement surface aspect, and incoming wave direction. These findings highlight the importance of sub-basin structure and azimuthal effects in shaping intra-basin variability and support the transition toward non-ergodic, spatially informed ground-motion modelling frameworks for complex urban basins such as in Los Angeles.

Understanding the Regional Variability of Ground Motion Across South America for Subduction Earthquakes

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Ground-motion models (GMMs) are fundamental to seismic hazard and loss assessment; however, most global models rely on the ergodic assumption, treating variability as random and transferable across tectonic regions. Previous studies indicate that site effects vary regionally and can be modelled explicitly, motivating partially non-ergodic approaches. Although several global subduction GMMs include regionalised coefficients or empirical site adjustments, they perform inconsistently in South America (SA_m), overpredicting shaking in the northern Nazca segment and underpredicting it in the southern Andes. Additional limitations include the representation of foreshock and aftershock sequences and elevated short-period between-event variability (the τ “bump”). At longer periods, within-event variability (ϕ) remains large because the widely used V_{s30} proxy correlates poorly with true site response, which is strongly influenced by deeper shear-wave velocity structure, $V_s(Z)$.

To address these issues, this study developed the SISMA database, comprising 38,841 high-quality three-component recordings from multiple networks across SA_m, processed using harmonised, NGA-consistent procedures with comprehensive metadata. A new earthquake-type classification scheme based on Fourier-amplitude-spectrum S-wave horizontal-to-vertical spectral ratios (HVS_R) was implemented, proving more stable than spectral-acceleration-based methods. Regional anelastic attenuation and foreshock and aftershock effects were quantified, reducing between-event residuals. RotD50 was used to develop a regionalised, partially non-ergodic GMM for subduction earthquakes in SA_m. Comparisons with regionalised global models indicate that path-related and depth-scaling effects primarily drive the τ “bump”, and that long-period ϕ variability is substantially reduced. Finally, adopting a single, earthquake-independent attenuation model across the entire continent introduces trade-offs with geometric spreading, affecting predictions at short distances and driving systematic bias between northern and southern regions.

Source Parameters, Attenuation Characteristics and Site Effects Derived From the Non-parametric Generalized Inversion Technique (GIT) for the Mw 8.8 Maule Aftershock Sequence

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Ground-motion records reflect the combined effects of the earthquake source, propagation path, and local site conditions, and separating these contributions remains challenging, particularly for small to moderate events. In this study, we apply a non-parametric generalized inversion technique (GIT) of S-wave spectra to the 2010 Mw 8.8 Maule aftershock sequence in south-central Chile. The dataset includes approximately 7,000 earthquakes with magnitudes between 2.0 and 6.5, recorded over about ten months. To capture spatial variability across the broad rupture area, we perform the inversion in local clusters of around 400 events each. This approach allows the inversion to resolve spatial and depth-dependent variations that would otherwise be averaged out in a single region-wide inversion. From the inverted source spectra, we derive seismic moment, corner frequency, stress drop, and source kappa, and analyze their depth dependence and scaling behavior. Path terms describe a frequency-dependent attenuation factor Q(f), while site terms provide amplification functions that are compared with horizontal-to-vertical (H/V) spectral ratios. Independent cluster inversions are then combined into a unified regional ensemble, and their consistency is evaluated through residual patterns and stability diagnostics across clusters. The results provide new constraints on the scaling of source parameters and the attenuation properties of the Maule region, offering insights into the physical controls on ground-motion variability and a framework for improving regional ground-motion characterization.

Regionalizing NGA-Sub Ground-motion Models for Chile: Source and Path Adjustments

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Accurate seismic hazard assessment in Chile requires ground-motion models (GMMs) that capture repeatable regional source, path, and site effects for subduction-zone earthquakes. While global models from the NGA-Subduction project provide a robust backbone—particularly for large-magnitude scenarios that dominate engineering hazard—observations in Chile suggest systematic departures associated with regional scaling, attenuation, and site response. This study presents an integrated framework to (i) expand the South America portion of the NGA-Sub database using newly processed Chilean recordings and improved metadata, and (ii) evaluate and customize NGA-Sub GMMs for Chilean interface and intraslab events. Model performance is assessed using “new data” not employed in GMM development, focusing on residual trends with magnitude and depth (source) and distance attenuation and anelastic decay (path). We then test whether regional adjustments are needed for magnitude scaling (including potential differences in magnitude-break behavior for data-scarce intraslab events) and for spatially varying attenuation rates between sub-regions (e.g., northern versus southern Chile). To better represent regional effects, we explore sub-regional (non-ergodic) formulations that account for localized path characteristics. This approach helps use NGA-Sub models in Chile while accounting for regional differences, improving both site-specific and national hazard estimates.

Nonergodic Ground-motion Models for Subduction Events in Alaska

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Ground-motion predictions for Alaska subduction earthquakes based on existing ergodic NGA-Sub models show systematic misfits when evaluated against regional observations, indicating limitations of the current models for this tectonic setting. One issue is that available NGA-Sub ground-motion data in Alaska are sparse, with limited event and restricted ray-path coverage, particularly for small-to-moderate magnitudes. In this study, we use an expanded Alaska dataset that includes recordings from interface and slab earthquakes with magnitudes 4.5, substantially increasing both the number of events and the diversity of source–site distribution available for analysis. The new dataset reveals a long-period magnitude-dependent bias in the Abrahamson and Gülerce (2022) Alaska model for small-to-moderate events, which is corrected with an adjustment to the reference ergodic GMM prior to the nonergodic analysis. Nonergodic path effects are separated into 3D anelastic attenuation (dP2PQ) and 3D velocity structure (dP2PV). Overall, the dP2PV provides the dominant improvement in the GMM. The fully nonergodic model has a large reduction in the standard deviation with values between 0.40 - 0.56 natural log units for periods of 0.02 to 10 sec as compared to 1.0 - 1.1 for the ergodic GMM. We also show a comparison of seismic hazard estimates for interface and slab events obtained from the ergodic and nonergodic GMMs for example sites in Anchorage, Juneau, Fairbanks, and the Aleutian Islands at periods of 0.2 and 1 sec.

Short-distance Attenuation Characteristics of Ground Motions for Induced Earthquakes in South Sichuan, China

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The Rongxian shale gas field in the southern Sichuan Basin has experienced increasing induced seismicity, with frequent earthquakes adversely impacting local communities and even causing casualties. This study investigates the short-distance attenuation characteristics of strong ground motions from these induced earthquakes with local magnitudes ranging from 2.0 to 3.9, using 11,161 accelerograms recorded by a dense network of 52 Micro Electromechanical System (MEMS) accelerometers. To ensure data reliability, a deep learning denoising technique and a physics-based dynamic magnitude cutoff strategy were applied. Our analysis reveals that induced earthquakes in Rongxian exhibit significantly faster attenuation than natural tectonic events. Comparative evaluation indicates that the NGA-West2 BSSA14 model systematically underestimates ground motions at distances <10 km while overestimating them at 10–30 km due to a shallower attenuation slope. Comparison with the NAA18 model, which was developed from induced events in

Oklahoma, reveals distinct regional differences: while NAA18 roughly captures the amplitudes of high-frequency parameters, it underestimates the attenuation rate. Furthermore, NAA18 exhibits a magnitude-dependent bias, tending to overpredict high-frequency motions but significantly underpredict long-period Spectral Accelerations (SAs) for small-magnitude events. To address these discrepancies, we developed a region-specific Ground Motion Model (GMM) using non-linear mixed-effects regression. The proposed model accurately reproduces the rapid attenuation and source scaling characteristics of the Rongxian region yielding unbiased residuals. These findings highlight the unique ground motion features of induced seismicity in Sichuan and provide a critical foundation for seismic hazard assessment in the region.

Do 3D Dynamic Rupture Models Capture the Variability in Long-period Velocity Pulses? Insights From the 2023 Mw 7.8 Kahramanmaraş Earthquake

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Capturing ground motion variability, especially in near-fault long-period velocity pulses, is a key challenge for seismic hazard assessment. Empirical methods rely on simplified assumptions and may not fully capture the non-linear interplay of source, path, and site effects. Physics-based dynamic rupture simulations offer a self-consistent alternative, but their ability to reproduce variability in velocity pulse orientation, period, and amplitude remains uncertain (e.g., Yen et al., Earthquake Spectra, 2025).

Here, we systematically investigate the effect of fault geometry and various on-fault heterogeneities on modelled ground motions in 3D dynamic rupture simulations of the Mw 7.8 2023 Kahramanmaraş, Turkey, earthquake. We compare rupture scenarios with large-scale fault waviness, fractal fault roughness, heterogeneous critical slip-weakening distance, heterogeneous dynamic friction, and supershear versus sub-shear rupture speed initiation to a reference model (Gabriel et al., TSR, 2023) and observations, each simulation resolving up to ~ 1 Hz. We systematically analyse rupture dynamics, frequency content, and long-period pulse variability.

While all models capture pulse amplitude variability, models with supershear initiation and Dc heterogeneity exert the strongest influence on pulse period and orientation. Despite added complexity, most synthetic pulses remain predominantly fault-normal, in contrast to the wide range of pulse orientations observed. A simpler dynamic rupture model incorporating more than 800 off-fault fractures able to slip dynamically increases variability in both pulse amplitude and orientation, highlighting the importance of fault zone complexity. Our results highlight the importance of incorporating heterogeneous on-fault frictional properties and off-fault fracture networks to advance realistic, non-ergodic ground motion models toward physics-based seismic hazard assessment.

Ground Motion Directionality of Horizontal Response Spectral Ordinates From the 2023 Kahramanmaras, Türkiye Earthquake Sequence

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The orientation of maximum spectral response is traditionally thought to occur at random orientations for sites beyond the near-field region. However, a recent study found that for strike-slip earthquakes, the orientation of maximum spectral response tends to be close to the epicentral transverse orientation (i.e., the orientation perpendicular to a straight line connecting the station to the epicenter). This study extends those findings by examining directionality in the 2023 M_w 7.8 and 7.5 Türkiye earthquake doublet. We evaluate the orientation of maximum response of 5%-damped linear elastic oscillators, the spatial distribution of the level of polarization, and the response intensities at specific orientations. We find that the maximum spectral response typically occurs near the epicentral transverse orientation, consistent with prior observations for strike-slip earthquakes. However, for the M_w 7.8 event, where the point of maximum slip occurs relatively far from the epicenter, the orientation of maximum response is, on average, closer to the maximum slip transverse orientation (i.e., the orientation perpendicular to

the line connecting the station to the surface projection of the point of maximum slip). This suggests that, for large-magnitude strike-slip earthquakes, the maximum slip transverse orientation may be a more effective predictor of the orientation of maximum response than when using the epicentral transverse orientation. The orientation of maximum spectral response remains close to either the epicentral or maximum slip transverse orientations for Joyner-Boore distances up to 400 km (i.e., furthest distance studied), and high levels of ground motion polarization were observed over large areas. These results highlight the need to develop orientation-dependent ground motion models for strike-slip earthquakes.

Estimating Systematic Source, Site, and Path Effects in Non-ergodic Ground Motion Models: Insights From the Turkish Ground Motion Database

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The development of ground motion models (GMMs) is transitioning from ergodic to non-ergodic approaches, which account for spatially varying and systematic source, site, and path effects. This study utilizes a robust ground motion dataset and different strategies for estimating non-ergodic terms, assessing their interactions in the context of the formulation of non-ergodic GMMs. The study results show that different strategies, specifically the sequence for estimating systematic effects, can significantly impact the trade-off between non-ergodic terms, leading to different mean and correlation length estimates, but without significantly impacting the final non-ergodic standard deviation after removing systematic effects. In this context, a strategy for treating the interaction and trade-off of systematic non-ergodic terms is recommended. Specifically, the proposed approach includes an iterative identification of the distance threshold below which path effects are not expected to contribute significantly to other systematic effects, allowing a more robust estimation of site and source effects. The insights gained in this study highlight that developing GMMs extends beyond a mere exercise of statistical inference or statistical fitting, particularly for non-ergodic ground motion modeling.

Using Earthquake Clustering to Minimize Between-event Ground-motion Residuals for Continental Australia

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This study explores the use of the *k*-means unsupervised machine learning clustering technique to minimize between-event ground-motion residuals in continental Australia. The approach clusters earthquakes in similar geographical locations (longitude and latitude), regulated by similarities in earthquake source attributes (i.e., stress drop). Relative to an ergodic continental-scale Fourier amplitude attenuation model, the study investigates whether the use of *a priori* cluster-based inter-event correction terms—based on the mean stress drop for the cluster—can be used to minimize the standard deviation of inter-event ground-motions residuals, τ . The results of this partially non-ergodic case demonstrate that significant reductions in τ can be achieved through the use of cluster-based corrections, and confirms that an earthquake’s stress drop is a first-order variable in modeling ground motions for Australian earthquakes.

Second, statistical hypothesis testing to assess the independence of the cluster-based samples of earthquake stress drops demonstrates that—in many cases—the difference between the means of the populations is statistically significant. This observation justifies the development of regional ground motions logic trees that can reduce the epistemic uncertainty of seismic hazard models. By contrast, other cases demonstrate that differences in earthquake source characteristics are not significant between clusters. Therefore, clusters with similar source characteristics may be grouped to apply similar ground-motion characterization for national-scale seismic hazard assessments. This information may be used further to develop regionally adjusted backbone ground-motion models that consider regional earthquake source characteristics within continental Australia.

Preliminary Regionally Adjustable Models for Effective Amplitude Spectra Based on the NGA-West3 Dataset

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We develop an earthquake ground motion model (GMM) for effective amplitude spectra (EAS, the smoothed quadratic mean of two horizontal-component Fourier amplitude spectra) as part of the Next Generation Attenuation (NGA) West3 project. The primary inputs are moment magnitude (M), Joyner-Boore distance (R_{JB}) and the time-averaged shear-wave velocity in the upper 30 m, with adjustments to account for regional variations in stress drop, depth, anelastic attenuation and kappa. We consider over 91,000 ground motion records from 1091 $M \geq 3$ earthquakes in the Western Contiguous United States and Alaska, Mexico, Italy, Greece, Turkey, Japan, Taiwan, and New Zealand. Our model utilizes seismological theory to constrain geometrical spreading, anelastic attenuation ($1/Q$), high frequency attenuation (κ), and the spectral shape of the source, and combines them with empirical terms for near-source saturation, linear site amplification, and basin response. The interplay between near-source saturation and geometric spreading when describing amplitude decay in R_{JB} is carefully evaluated in model development. We fit models using a sequential approach that utilizes mixed-effects regression to account for the correlation between observations of the same earthquake and at the same station. Additionally, we fit a random effect on the attenuation slope ($1/Q$) for each earthquake to avoid tradeoffs between variations in attenuation and event terms (e.g., Baltay et al., 2020). We compare the efficacy of alternate earthquake source models, including single and double corner frequency models (Brune, 1976, and Boore et al., 2014, respectively). We observe that Japan has larger than average high-frequency ground motions due to weaker attenuation and stronger high frequency linear site response amplification. By contrast, ground motions in Taiwan are depleted in high frequency energy compared to the global average, with a large value. We plan to develop a GMM for the 5%-damped RotD50 component (Boore, 2010) of pseudo-spectral acceleration (PSA) from a compatible dataset, and investigate its consistency with our EAS model converted to PSA.

Regional Source, Path and Site Effects in Earthquake Ground Motions [Poster]

Poster Session • Wednesday 15 April

Conveners: David Barba Galdamez, North Carolina State University (dfbarbag@ncsu.edu); Evan T. Hirakawa, U.S. Geological Survey (ehirakawa@usgs.gov); Albert Kottke, Pacific Gas & Electric (albert.kottke@pg&e.com); Shiyong Nie, Tufts University (shiyong.nie@tufts.edu); Grace A. Parker, U.S. Geological Survey (gparker@usgs.gov)

POSTER 143
Extraordinarily Large Site Amplification Factors in Noto, Japan, Possibly Due to 3D Resonance
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We have been studying the relationship between the Horizontal-to-Vertical Spectral Ratios of microtremors (mHVSRs) and earthquakes (eHVSRs) and the relationship between eHVSRs and the Horizontal Site Amplification Factors (HSAFs) of earthquakes. We proposed that we can transform mHVSR into pseudo eHVSR based on the empirically-obtained correction factors. We also proposed the Vertical Amplification Correction Function (VACF), which is the average of the Vertical Site Amplification Factor (VSAF*), to transform eHVSR or pseudo eHVSR into HSAF. We proved that this double-correction method can successfully reproduce HSAF from mHVSR at most of the sites.

Immediately after the Noto Peninsula earthquake of Mw7.5 occurred on January 1, 2024, in the northern part of the Noto Peninsula, we visited the heavily damaged cities and towns in the epicentral area to measure microtremors in order to delineate the site amplification factors based on the double-correction method. We deployed our instruments at about 20 sites in Suzu City, Wajima City, and Anamizu Town. Among those observed sites, we found that extraordinarily large HSAFs in the frequency range equal to or less than 1 Hz at three sites, namely, ISK002 in Suzu City, JMA_E10 in Wajima City, and ISK005 in Anamizu Town, however, we cannot reproduce such observed HSAFs by the double-correction method, as long as we use VACF. The extraordinarily large HSAFs and VSAF’s at these sites suggest that they

could be the result of the 3D deep basin resonances above the seismological bedrock.

We then revisited Wajima City and Suzu City on March, 2025 and measured microtremors at 75 sites in Wajima City and 45 sites in Suzu City by using the grid scheme in order to delineate the region with the 3D resonance. Based on the same peak frequency characteristics in MHVRs, we found a square region with the size of 2.5 km in Wajima City with a common resonance frequency of 1 Hz, while we found a rectangular region with the size of 3 km by 6 km or more in Suzu City with a common resonance frequency of 0.25 Hz. Next we would like to perform a numerical simulation to prove the hypothesis.

POSTER 144

Path-dependent Topographic Site Effects Revealed by 3D Ground Motion Simulations and Ambient Noise

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Seismic site response in areas of pronounced topography is strongly influenced by the coupling between source-path effects and local geological and geomorphic conditions, yet these contributions are often treated independently in practice. In this study, we investigate path-dependent topographic site effects at Mortandad Canyon, Los Alamos, using three-dimensional (3D) physics-based ground motion simulations combined with ambient-noise observations and horizontal-to-vertical spectral ratio (HVSr) analyses. We perform a systematic suite of 3D spectral-element simulations based on the Los Alamos National Laboratory Geologic Framework Model, varying seismic source location, dip angle, polarization, and rupture directivity to quantify their influence on peak ground motion amplitudes and spatial variability. The simulations reveal that fault geometry and rupture direction exert first-order control on ground motion, while topographic amplification is strongly modulated by the direction and incidence of the incoming wavefield. To complement the physics-based simulations, we analyze ambient-noise recordings from seismic stations deployed across Mortandad Canyon and compute HVSrs to characterize frequency-dependent site response. HVSrs are used here as an observational tool to identify repeatable resonance features associated with near-surface structure and topography, and are further examined for directional dependence to assess azimuthal variability in site response. Comparison between observed and synthetic HVSrs allows us to distinguish site-specific, surface-wave dominated response from amplification patterns driven by source- and path-dependent wave propagation. These findings highlight both the utility and the limitations of HVSr in complex terrain and underscore the importance of coupled 3D source-path-site analyses for interpreting seismic ground-motion variability in topographically and geologically complex regions.

POSTER 145

Modeling Non-ergodic Path Effects Using Conditional Generative Model for Fourier Amplitude Spectra

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Non-ergodic ground-motion models (GMMs) explicitly capture systematic spatial variations in source, site, and path effects, reducing aleatory variability to 30-40% of ergodic models and enabling more accurate site-specific seismic hazard analysis. Current non-ergodic GMMs rely on Gaussian Process (GP) methods with prescribed spatial correlation functions. While effective, GP-based approaches face computational limitations for large-scale predictions, particularly when generating ground-motion maps over regional-scale domains with dense site spacing and at multiple frequencies.

As an alternative to GP-based approaches, we introduce Conditional Generative Modeling for Fourier Amplitude Spectra (CGM-FAS), a deep-learning approach that addresses these computational limitations while maintaining consistency with established non-ergodic modeling frameworks.

CGM-FAS employs a Conditional Variational Autoencoder architecture to learn spatial patterns and interfrequency correlations directly from data, using geographical coordinates of earthquakes and stations as conditional variables. The hyperparameters from CGM-FAS can be tuned to ensure predicted path effects exhibit variability matching empirical GP-based models.

CGM-FAS offers several advantages: learning spatial patterns without prescribed correlation functions, capturing interfrequency correlations naturally, and enabling rapid large-scale predictions. Once trained, CGM-FAS generates ground-motion maps for a given earthquake scenario at 10,000 sites across 1,000 frequencies within 10 seconds on a traditional laptop, with minimal computational and memory requirements.

POSTER 146

Effect of Subsurface Variability on Surface Ground Motion: Uncertainty Quantification in Equivalent-linear Analysis

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Accurate seismic hazard assessment often relies on simplified site proxies like V_{s30} ; however, this approach masks the inherent uncertainty of subsurface stratigraphy. A single proxy can represent vastly different profiles, creating a hidden risk in design. This study investigates input parameter uncertainty propagation into ground motion metrics, comparing linear (weak) and non-linear (strong) response regimes. Using a representative 6-layer soil profile, Latin Hypercube Sampling (LHS) is employed to generate 300 statistically independent scenarios with variations in shear wave velocity, layer thickness, and unit weight. 1D equivalent-linear (EQL) site response analyses are performed using DEEPSOIL. To isolate nonlinearity while preserving frequency content, profiles are subjected to a real wave motion and a 20x scaled version.

Spearman correlations and Tornado diagrams reveal a shift in governing physics as shaking intensity increases. Under linear conditions, amplification is driven by shallow impedance contrasts, with the shear wave velocity of the underlying layer (V_{s2}) dominating. However, under high-strain non-linear conditions, the parameter hierarchy shifts significantly: layer thickness (H) emerges as a critical driver, governing the path length for damping and energy dissipation. Furthermore, the study identifies a divergence in reliability between output metrics. While the fundamental period (T_0) remains robust and stable against parameter variability, Peak Ground Acceleration (PGA) exhibits high volatility and positive skewness in the nonlinear range. This implies that while nonlinear damping generally suppresses ground motion, outlier profiles can still transmit high energy, necessitating more conservative probabilistic safety factors for amplitude sensitive structures. Consequently, this workflow offers a guidance for refining site-specific logic trees in PSHA studies, assessing uncertainty in site response analyses, enabling resilient design for critical facilities where quantifying the confidence intervals of predictions is as crucial as the predictions themselves.

POSTER 147

Multi-scale Geospatial Site Terms for Fourier Amplitude Spectrum Modeling in NGA-West 3

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We develop a geospatial site model as part of the Kuehn-Kottke-Campbell-Bozorgnia-Nie-Baise (2026; KKCBNB25) Fourier Amplitude Spectrum (FAS) ground-motion model. Rather than relying solely on traditional geotechnical site parameters such as V_{s30} , $Z_{1.0}$, and $Z_{2.5}$, which are not spatially continuous and are commonly estimated using proxies that introduce uncertainty that is difficult to quantify, we implement a multi-layer site modeling framework that integrates multi-scale geospatial and geotechnical data. The framework accounts for site effects operating at different spatial scales. At the large regional scale, geomorphic provinces are used to regionalize site effects across a continuous domain spanning the contiguous U.S., Alaska, Canada, and Mexico. In addition, Bouguer gravity anomaly data are incorporated as a large-scale continuous proxy for regional structural density variations. These large regional scale geospatial terms capture the effects of the deeper velocity profile related to bedrock conditions. At the intermediate scale, surficial geology is used to capture the effects of the surface velocity profile related to sediments and we incorporate a sedimentary basin classification based on the horizontal extent of the sedimentary basin using a Continuous Wavelet Transform analysis of the topography (Nie et al., 2026). At the site scale, measured V_{s30} values are incorporated into the site term through mixed-effects regression when available. This hierarchical approach results a site term with broad spatial coverage while improving accuracy both regionally and locally.

The resulting geospatial site model yields a spatially continuous site term for FAS-based ground-motion modeling in the western United States.

POSTER 148

The Soft Soil Effect of Marine Soil on Ground Motion Parameters

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Most offshore seabed is covered by a thick layer of soft soil that is nearly in the viscous liquid state or semi-plastic state. It magnifies or reduce the seismic site effect, thereby it is an important factor for the determination of seismic design parameters of offshore facilities and the compilation of ground motion zonation map of marine area. This research is based on the dynamic property experimental data of marine soil and the nonlinearity site response simulation to investigate the effect of soft soil on site ground motion parameters. The liquidity index or the shear wave velocity is recommended as the index of marine soft soil. The soil volume with a liquidity index less than 1.0 or the shear wave velocity less than 150m/s is considered as soft soil and it should be paid more attention on its seismic site effect. The investigation shows that the thickness of the soft soil is the key factor to determine its effect on ground motion parameters. The soft soil with a thickness less than 4 meters will magnify the peak ground motion acceleration. With the increase of input ground motion, the amplification becomes more remarkable, and the characteristic period extends to the lower frequency. When the thickness of the soft soil is greater than 4 meters, it deamplifies the site ground motion parameters. The equivalent shear wave velocity of the top 40m soil is recommended as the site classification index of marine site. And the site is classified into 4 classes. It presents the initial study of the characteristic and site effect of thick soft sediment on the seabed, the marine site classification index and site types. The research can provide the assessment of site effects for the seismic ground motion zonation in the marine area and the determination of seismic design parameters for the offshore facilities. This will benefit the structural safety of offshore facilities and speed up the compilation of ground motion zonation map in China.

POSTER 149

Developing a Dataset for Non-ergodic Subduction Ground-motion Models in Alaska

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Ground-motion data from large ($M > 6$) Alaska subduction interface earthquakes are limited and primarily recorded at seismic stations along the Aleutian Islands. When used with NGA-Subduction ground-motion models (GMMs), these data produce large negative residuals, at short-periods, indicating that, on average, the GMMs predict larger amplitudes than are observed. The physical reasons for the lower-ground motions in the Aleutian Islands are not well understood and may not apply to the more-populated parts of Alaska, such as Anchorage. To improve our understanding of the hazards in Alaska, we developed a new dataset of ground motions from earthquakes in the subduction zone of Alaska ($M > 3.5$). By incorporating the smaller-magnitude data, we achieve broader spatial coverage across Alaska, enabling better constraints on the path effects to support regionalized and nonergodic ground-motion modeling. This dataset was assembled using the U.S. Geological Survey's (USGS) *gmprocess* software that provides a consistent workflow, including reproducible configuration and automated quality control. Here we describe the event and station selection, as well as waveform processing, and review procedures. We also provide examples and summary statistics of problems that we identified in the recordings. Emphasis is placed on challenges related to limited data coverage, unique network coverage, and complex Alaska tectonic classification. Using this dataset, we evaluate the performance of existing ergodic subduction GMMs and demonstrate the need for, and effects of, adding a random effect to the path term in the regression. In addition, we examine sources of aleatory variability by attempting to separate the contributions from earthquake source, path, and site effects. This dataset and preliminary analysis provide a foundation for the development of more advanced nonergodic GMMs in Alaska.

POSTER 150

Slip Kinematics, Radiation Pattern, and Rupture Directivity Effects on the Peak Ground Velocity (PGV) of the 2024 Mw4.8 Tewksbury, New Jersey, Earthquake

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The 2024 Mw4.8 Tewksbury, New Jersey, intraplate earthquake produced strong shaking that was widely felt by >170,000 people across the northeast US, from Virginia to northern New Hampshire. The earthquake ruptured a southeast-dipping fault 70 km west-southwest of New York City, with a right-lateral oblique-thrust slip motion, as suggested by focal mechanism, field surveys, and aftershock analyses. Interestingly, the observed Peak Ground Velocity (PGV) and the USGS Did You Feel It (DYFI) reports show stronger ground shaking northeast of the earthquake, which coincided with the more populated area.

We analytically calculate synthetic PGVs accounting for the Tewksbury earthquake's radiation pattern and rupture directivity, and investigate whether its ground motions can be explained by slip obliquity and rupture directivity. The radiation pattern is estimated from the USGS focal mechanism, assuming that S-waves in an elastic whole space generate the strongest motions. We account for rupture directivity effects using the rupture speed and the directivity of the line-source model by Han et al. (2024), in which the rupture propagates obliquely northeastward and down-dip.

We find that the synthetic ground motion matches the spatial pattern observed in the PGV and DYFI reports. Areas ENE and NE of the fault experienced stronger shaking because of two reasons: (i) The S-wave radiation pattern of the right-lateral, thrust slip motion on the southeast-dipping fault has the largest amplitude along the northeast-southwest axis; (ii) The northeast rupture directivity causes the apparent source time function for northeast stations to be of a larger amplitude and narrower. We argue that, to first order, a combination of coseismic slip obliquity and unidirectional rupture directivity produces the highly asymmetric coseismic radiation pattern. Our simple source model can be further improved using a more sophisticated velocity structure or accounting for dynamic effects. Nevertheless, our simple source representation may help inform seismic hazard assessment for intraplate seismicity in the New Jersey-New York region.

POSTER 151

Evaluating Ground Motion Models for the Chilean Subduction Zone

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The selection of ground motion models (GMMs) represents a primary source of epistemic uncertainty in probabilistic seismic hazard analysis (PSHA). For site-specific PSHAs in Chile, where hazard is dominated by South American subduction zone, we have evaluated the applicability and performance of existing subduction zone GMMs for both interface and intraslab earthquakes. We compiled a comprehensive ground-motion dataset (1985-2024) from several sources including the Next Generation Attenuation-Subduction (NGA-Sub) project dataset and several ground motion datasets developed specifically for Chilean subduction zone. The resulting dataset comprises a total of 39,561 ground-motion records from 5,727 earthquakes and 475 seismic stations. This includes 15,126 records from 2,523 interface earthquakes (M 4.0 to 8.8) at rupture distances (R_{rup}) of 13 to 728 km, and 24,435 records from 3,204 intraslab earthquakes (M 4.0 to 7.8) at R_{rup} of 26 to 645 km. We compared these empirical data against the three NGA-Sub models, both the global and South American versions, and two regional GMMs developed using Chilean data, Montalva et al. (2017) and Idini et al. (2017).

Residual analyses indicate that the NGA-Sub GMMs generally align with the data without significant magnitude or distance trends in the residuals, though they tend to underpredict at short periods ($T < \sim 0.5$ sec), particularly for interface events. Among the Chilean models, Montalva et al. (2017) outperformed the NGA-Sub models, exhibiting slightly lower overall residuals and no clear bias. Conversely, the Idini et al. (2017) model shows considerable distance-dependent residual trends, suggesting unmodeled path effects that lead to significant overpredictions beyond 100 km, especially for intraslab events. To provide a more robust ranking, we are performing quantitative evaluations using the log-likelihood (LLH) approach (Scherbaum et al., 2009) and the stochastic area metric (AM) method (Sunny et al., 2021). These results will form the basis for weighting the GMMs in the PSHA logic-tree.

Seismology for All: Expanding STEM Education Through Accessible Tools and Global Collaboration

Oral Session • Wednesday 15 April • 4:30 PM Local
Conveners: Jesse Bonner, Lawrence Livermore National Laboratory (bonner21@llnl.gov); Emily McDonald-Williams, Desert Research Institute (emily.mcdonald-williams@dri.edu); Adam Pascale, Seismology Research Centre (adam.pascale@src.com.au); Beatrice “Bibi” Robinson, Oakland University (brobinson2@oakland.edu); Suzan van der Lee, Northwestern University (suzan@northwestern.edu); Aaron Velasco, University of Texas at El Paso (aavelasco@utep.edu); Cleat P. Zeiler, Desert Research Institute (cleat.zeiler@dri.edu)

Recruitment by Design: Making Seismology and Scientific Computing Accessible and Engaging Through the Seismology Skill Building Workshop
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The Seismology Skill Building Workshop (SSBW) fills a gap in the seismology learning ecosystem, documented at the introductory seismology course level, by providing an accessible and effective pathway for learning scientific computing within a seismology context. There are no pre-requisites or requirements beyond a stable internet, a web browser, and the time and motivation to learn. Since 2020, more than 6,835 participants from 113 countries have registered; over 3,884 have started the course, and 1,068 have completed it. Participation from women (59%) and students from racially and ethnically marginalized groups in the U.S. (~32%) exceeds national geoscience averages, and approximately one-third of participants are non-geoscience majors, demonstrating its effectiveness as an entry point into seismology and computational Earth science. Course completers demonstrate 38% normalized learning gains on pre/post assessments and report 42% gains in interest in scientific computing and seismology, along with 37% gains in perceived preparedness for grad school and employment.

This success has been driven by a sustained focus on learner experience, grounded in instructional design practices that support learning while promoting participation across diverse backgrounds. These transferable design principles, emphasizing early success, scaffolding, and sustained instructional support, are being disseminated through instructor-facing workshops at the 2026 Earth Educators’ Rendezvous. An early roadblock was computing environment setup, which hindered new and under-resourced learners; this was addressed through accessible virtual environments with preconfigured software. After five years, the course continues to evolve from legacy tools (e.g., SAC) toward modern workflows centered on Python/ObsPy in the 2027 workshop. Building on these lessons, the NSF National Geophysical Facility is developing a Computer and Data Science Academy to provide shared infrastructure, including GeoLab, virtual desktops, a learning management system, and micro-credentialing, to expand accessible seismology and computing education beyond the SSBW.

Riding Waves for STEM: Earthquake Location for Dummies
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Earthquake waveform data processing is becoming more automated, so the need for routine seismic data processing is starting to fade, but it is still important for those getting into seismology to understand the process of how to get from wiggly lines on a screen to an earthquake hypocentre and magnitude solution.

Many of the free tools for processing seismic data are technically competent, but often require programming or other computing skills beyond that of new students and inexperienced professionals. While the tasks can be performed using multiple program modules, whether launched by com-

mand line prompts or using graphical user interface elements, we found that an integrated solution was not readily available for a standard earthquake data processing workflow.

The Seismology Research Centre was in the same position, with the two separate programs that we developed to operate our observatory (eqWave and eqFocus) performing the waveform analysis and the hypocentre calculation independently. These were paid applications that required ongoing technical support, putting it out of the reach of most earthquake researchers.

To make this a more broadly-used STEM tool, we started by focusing on improving eqWave, adding basic magnitude and distance calculation based on globally generic values, and, importantly, making it free to use. The program was relaunched as “Waves”, and by removing the cost barrier enabled it to get into the hands of thousands of users, as opposed to the few dozen users of eqWave.

We then undertook a massive redesign to create a graphical user interface to the eqFocus program and integrate it into Waves, bringing professional grade hypocentre calculation using customisable earth models and magnitude formulae to all users. This change brought drag-and-drop waveform analysis and graphically interactive keyboard-free earthquake parameter calculations to amateur and professional users alike.

The SRC continues to develop software tools to demystify the process of earthquake location, helping people understand the workflow to enable them to improve manual and automated software systems into the future.

Toward Developing Local, Impactful Earthquake Science Projects With Community Engagement
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The Community-driven Inclusive Excellence and Leadership Opportunities in the Geosciences (CIELO-G) program, funded by the National Science Foundation, is now in its third year of developing local research projects and promoting community engagement and partnerships in the geosciences. Based at The University of Texas at El Paso (UTEP), CIELO-G is designed to transform geoscience by creating sustainable connections between academia and the diverse communities of the Paso del Norte region. The program supports graduate students and postdoctoral researchers addressing climate science and Earth system challenges, while partnering with local educators, nonprofit organizations, and community members to foster inclusive geoscience learning. CIELO-G is structured around the Collective Impact model, which emphasizes cross-sector collaboration, shared measurement, and continuous communication. Each year, CIELO-G forms interdisciplinary cohorts composed of graduate students, postdoctoral fellows, high school and community college educators, faculty mentors, and local partners. These teams collaboratively design and implement both research and outreach projects that reflect community needs, scientific relevance, and a commitment to geoscience engagement. Projects span a range of activities, including field-based geoscience research, curriculum development, neighborhood-based science events, and climate resilience initiatives. We highlight two seismology related projects: 1) a local seismic network of Raspberry Shake seismometers in local classrooms, homes, and community centers across El Paso to educate the public on earthquake science and collect valuable seismic data to enhance local seismic monitoring; and 2) a Distributed Acoustic Sensing (DAS) and Ambient Noise Tomography (ANT) project to create high-resolution shallow subsurface images in the El Paso, TX region to study the East Franklin’s Mountain fault, as this is a major hazard, and also to understand ground water recharge. Finally, we have leveraged and promoted the Great ShakeOut, with a participation of over 83,000 local residents, mainly school children.

Expanding Earthquake Science Education With Quakeworx Interactive Web-based Tools
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Quakeworx is a web-based science gateway that makes advanced earthquake simulation codes accessible to learners of all levels by removing technological barriers through browser-based applications. The gateway offers interactive tools for visualizing ground motions and seismic wave propagation, creating customizable, fully physics-based shake maps that depict the spatial distribution of shaking intensity, and presenting useful information on earthquake events. These applications make abstract seismological concepts visually and interactively accessible without requiring programming skills or software installations. Since its kickoff workshop in January 2025, over 1,300 users have accessed Quakeworx’s educational materials. The platform has been successfully integrated into graduate-level degree programs and also provides K-12 teachers with the opportunity to incorporate real-world earthquake research into their curricula. By enabling students to create shake maps of past earthquakes, compare predicted and observed ground motions, and interact with earthquake pages, Quakeworx actively engages learners in hands-on exploration of real-world earthquake data. Recent enhancements to Quakeworx include a new application for studying earthquake-tsunami interactions using fully coupled methods, and another application that rapidly generates maps of peak ground velocity for Southern California using reduced-order models. The generated seismic data, including visualizations of earthquake shaking, will be published on the Quakeworx and SCEC websites and can be reproduced by users of the Quakeworx gateway. We also plan to utilize Quakeworx for “interactive supplementary materials” in future papers. By showcasing further examples of educational applications, sharing experiences with early adopters, and gathering community feedback, we will continue to develop Quakeworx as a global resource for broader access to seismological research tools.

Student Perspectives on Increasing STEM Engagement and Lowering Barriers to Seismology
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Seismology is well-positioned for broader participation in STEM due to open data practices, affordability, accessibility of online resources, and research possibilities that are independent of location. Despite seismology being widely accessible, students (K-12 and undergraduate) are largely unaware of these resources, and may not even consider seismology as a potential career path. To increase awareness and accessibility to students and independent learners, I propose a lowering of perceived barriers by expanding seismology programs geographically and by establishing a structured outreach network. Even with the wide availability of online resources that prove useful to students and independent learners, the lack of structured pathways (outside programs such as the Seismology Skill Building Workshop offered by IRIS) contributes to a high barrier to entry. While programs such as SchoolShake benefit K-12 students with a structured introduction to seismology, these resources are largely unavailable in regions with a lower focus on seismology. A proposed solution would include a geographical expansion of community-centric seismology programs with an emphasis on the ability to practice seismology from any location. These programs would include hobby seismometer kits and an emphasis on the multidisciplinary nature of seismology. While the accessibility of seismology serves as its strength, this advantage remains widely unrealized without a geographically expansive, intentional, and structured outreach. Expanding K-12 and community-focused programs with an emphasis on location independence and interdisciplinary connections can transform seismology from a niche field into an entry point for geographically diverse STEM learners.

Seismology for All: Expanding STEM Education Through Accessible Tools and Global Collaboration [Poster]

Poster Session • Wednesday 15 April
Conveners: Jesse Bonner, Lawrence Livermore National Laboratory (bonner21@llnl.gov); Emily McDonald-Williams, Desert Research Institute (emily.mcdonald-williams@dri.

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Lowering Barriers to Seismology Education Through Open-access Computing Tools and Shared Educational Infrastructure
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The NSF National Geophysical Facility operated by EarthScope is working with the geophysics community to develop a Computing and Data Science Academy that brings together a catalog of geophysical technical courses offered through a shared instructional and computing ecosystem. This effort builds on design elements demonstrated to be effective in the Seismology Skill Building Workshop and other workforce training initiatives, including accessible course structures, intentional scaffolding, and instructional design practices that support learners who may not have had prior opportunities to learn scientific computing and data-intensive geophysical workflows.

The Academy emphasizes effective and equitable course design, modular curriculum components, and cloud-based computing environments that reduce barriers to participation for both learners and instructors. Central to this work is EarthScope’s GeoLab, a JupyterHub computing environment that significantly reduces local hardware requirements and eliminates software installation constraints, enabling learners to engage directly with seismological and geodetic datasets. This shared infrastructure not only supports learners across a range of backgrounds and institutional contexts, but also lowers barriers for community members to contribute instructional materials and lead courses using common tools and environments. To further support learner motivation and recognition of skill development, the Academy is integrating micro-credentialing through digital badges that acknowledge participation and demonstrated competency in core computing and data workflows, creating portable evidence of learning that benefits both academic and workforce pathways. This presentation highlights how accessible computing tools and research-informed instructional practices can support global collaboration, broaden participation, and strengthen the seismological community’s role in engaging the next generation of scientists and informed global citizens.

POSTER 153
Seismic Monitoring of Tapir Ground Interactions in Costa Rica: Nodal Arrays as Opportunistic Biologgers for Quantifying Wildlife Visits, and Impulse
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Dense nodal seismic arrays deployed for monitoring volcanic activity, fault-zone seismicity, and rainfall-triggered landslides routinely record signals that are not produced by Earth-internal processes. In tropical environments, a prominent and information-rich source of such “nontraditional” signals is wildlife interacting with the near surface. Here we report opportunistic seismic observations of *Tapirus bairdii* recorded by nodal stations installed along the Braulio Carrillo National Park, Costa Rica. We treat these records as a natural experiment in near-surface force generation and demonstrate how standard seismological tools can be repurposed to quantify animal visitation rates and infer first-order biomechanical attributes of the source. We identify

candidate tapir signals using a combination of time–frequency characteristics, waveform similarity, and array-based coherence, separating them from rain-fall, wind, anthropogenic noise, and small earthquakes. Detected events commonly exhibit impulsive, step-like transients and repeatable microsequences consistent with footfalls and short locomotion bursts. Our results show that nodal arrays in biologically active terrain can function as passive “seismic camera traps,” yielding continuous, weather-robust monitoring of large mammals while simultaneously improving station-level noise characterization for geohazard studies. Beyond tapirs, the framework generalizes to other large fauna and offers a pathway for cross-disciplinary monitoring that links environmental seismology, conservation science, and near-surface wave physics.

POSTER 154

A Community-deployed Raspberry Shake Network for Seismic Monitoring in El Paso, Texas

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El Paso, TX, along with its neighboring city, Ciudad Juárez, in Mexico, forms one of the largest binational communities in the world, with a combined population of over 2 million. On March 26, 2020, the region was shaken by a magnitude-5 earthquake near Mentone, TX (250 km away), the largest event recorded in the last two decades in West Texas. The shaking triggered public concern and, in one case, a local hospital followed evacuation procedures. Since then, West Texas has experienced several magnitude-5 earthquakes, including events in Toyah (2025) and Coalson Draw (2022, 2023), heightening public awareness of seismic risks. Although El Paso experiences relatively low seismic activity, there is potential for a significant earthquake along the Quaternary East Franklin Mountains Fault. Leveraging the Community-driven Inclusive Excellence and Leadership Opportunities in the Geosciences (CIELO-G) program, we have established a local seismic network of Raspberry Shake seismometers in local classrooms, homes, and community centers across El Paso. Currently, nine stations are deployed with plans to expand to fifteen. This community-engaged approach achieves dual goals: educating the public on earthquake science and collecting valuable seismic data to enhance local monitoring. Preliminary results show the network can detect regional earthquakes as small as magnitude 2.5, as well as other seismic signals, including anthropogenic noise, passing trains, and potential quarry blasts. This project serves as a model for how low-cost community science can foster resilience, educational opportunities, and scientific discovery.

POSTER 155

The InSAR Lookbook: A Visual Guide to Understanding Earthquake Deformation Interferograms

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Interferometric Synthetic Aperture Radar (InSAR) is growing in popularity for mapping ground surface deformation from onshore earthquakes. InSAR images (interferograms) are quickly disseminated across the community and various media platforms, yet outside of InSAR specialists there remains a lack of general understanding of how to interpret them. The InSAR *lookbook* is an atlas of static synthetic interferograms that enables rapid identification of earthquake source mechanisms by specialists and non-experts alike, without requiring sophisticated inverse modelling. Its systematic representation of InSAR surface deformation patterns allows it to function as an educational resource for students, the STEM community, and the general public.

The lookbook describes how InSAR fringe patterns are determined by the combination of horizontal and vertical ground motions, and ascending or descending satellite viewing geometries. We synthesize forward model interferograms for a comprehensive suite of faulting styles, including strike-slip, reverse, normal, low-angle thrust, low-angle normal, and oblique-slip faults. This highlights the most common InSAR fringe patterns and demonstrates how strike-slip, dip-slip, and oblique-slip earthquakes produce distinct fringe patterns controlled primarily by their strike angles. We provide practical guidelines for utilizing the lookbook to visually assess earthquake mechanisms and to pick the causative fault plane from two nodal planes. Comparisons between synthetic interferograms and real earthquake observations demonstrate the broad applicability of the lookbook, including complex multi-segment ruptures. Beyond rapid mechanism identification, the synthetic displacement fields offer insights into expected surface deformation patterns and their relationship to strong ground shaking. With the grow-

ing number of InSAR satellites and increasing availability of pre-processed imagery, this resource will be valuable for rapid assessment of coseismic interferograms following large, onshore earthquakes. The InSAR Lookbook was recently published in Seismica.

POSTER 156

Seismology 4 All

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Everyone feels the Earth. Seismology continues to be a unifying science and provides a unique platform to engage in Science, Technology, Engineering, and Mathematics (STEM) outreach. While STEM traditionally seeks to foster relationships in the K-12 arena, we may be missing a bigger opportunity to connect to all learners. With the availability of data and open software, the price for entry into seismology begins with an internet connection and browser enabled device. Additional steps can be taken for under \$500 to install a local seismometer. But where does the budding seismologist go from there? Historically, scientists have been relegated to the halls of academia or research facilities, but today's science can be conducted by anyone with access to technology or data. The tools of science still need to be properly implemented through training, calibration, and validation of results. We are implementing STEM outreach at the community, secondary and postsecondary levels. These programs have provided resources to enable learners at all levels to engage in science and we will demonstrate the tools that have been successful to seismology.

Seismotectonics of Southern and Baja California

Oral Session • Thursday 16 April • 4:30 PM Local

Conveners: John Fletcher, Center for Scientific Research and Higher Education at Ensenada (jfletche@cicese.mx); Devin McPhillips, U.S. Geological Survey (dmcphillips@usgs.gov); Katherine Scharer, U.S. Geological Survey (kscharer@usgs.gov); Drake M. Singleton, U.S. Geological Survey (dsingleton@usgs.gov)

Urban Sedimentary Basins of Southern California: A Plate Boundary View of Seismic Hazard

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Sedimentary basins along the plate boundary in Southern California have been extensively studied, in recent years, due to the elevated seismic risk they pose for nearby communities, and to improve identification of basin-crossing fault networks. These basins cover a ~350 km long corridor affecting critical community lifelines in four major counties extending from the Salton Trough and the expected future rupture site of a major San Andreas fault earthquake, across the San Bernardino basin to the Chino groundwater basin and the San Fernando Valley in the Los Angeles metropolitan area. They display a range of subsurface architectures, include rhombic, wedge-shaped, and triangular basins, and have maximum depths ranging from 2-3 km to ~10 km. Here, previous work showed amplified and prolonged ground shaking from events such as the 1994 Mw 6.7 Northridge earthquake and scenario San Andreas fault events. However, progress in characterizing the pattern of amplification at frequencies relevant for engineered structures with physics-based approaches has been limited by the low-resolution representation of the basins in regional Earth models.

We present an overview of new methods for collecting and analyzing dense seismic array datasets in intensely urbanized areas, and integrating multiple geophysical data types (borehole, gravity and aeromagnetic data) that allow us to develop unprecedented high-resolution 3D images of urban basins including their seismic velocity and attenuation structure. Such models not only facilitate improved ground motion predictions, but also offer detailed images of fault zones, e.g., the Fontana blind fault with seismic sequences

linked to groundwater movement through the Chino basin, and major regional structures such as the Vincent thrust. Combining dense seismic array datasets with machine learning-based earthquake detection methods also allows us to identify new faults hidden beneath the sedimentary cover. We further motivate the next phase of studies in the Imperial and Mexicali Valleys that flank the US-Mexico border.

Shifting Patterns of Faulting in the Big Bend Domain of the Pacific-north America Plate Margin

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The central portion of the Pacific–North American plate margin, here termed the Big Bend domain (BBD), contains kinematically and geometrically diverse fault arrays that accommodate the transfer of shear from the Gulf of California to more distributed deformation belts in the north, including coastal California, the Walker Lane, and the Great Basin. The BBD extends 400 hundred kilometers across the border between Mexico and the United States. This diversity of faulting allows evaluation of factors controlling regional stress and fault slip directions, including (1) relative plate motions, (2) topographic gradients, and (3) regional partitioning of transtensional and transpressional strain.

The BBD is a geodynamically active region in which pronounced decelerations of slip on long-established faults, such as the southern San Andreas fault, are compensated by the Plio–Pleistocene initiation of new faults (e.g., San Jacinto, Elsinore, San Miguel–Vallecitos, and Agua Blanca faults) and by dramatic accelerations of slip on others (e.g., Laguna Salada, Cañada David, and San Pedro Mártir faults). These long-term changes in slip-rates imply significant variations in boundary conditions, applied stress, and lithospheric rheology.

Within the BBD, plate-margin deformation transitions from transtension in the south to transpression in the north. Both regimes require three-dimensional strain, which is accommodated by networks of intersecting faults with diverse orientations and slip senses. Recent multifault earthquakes, such as the 2010 Mw 7.2 El Mayor–Cucapah event, demonstrate that the stability of interlocking fault networks and the limits of differential stress in the seismogenic crust are controlled by cross-cutting, misoriented faults that regulate slip on adjacent, optimally oriented structures. Similarly, events such as the 2019 Mw 7.1 Ridgecrest earthquake highlight significant seismic hazard associated with unmapped faults. These observations underscore the need for coordinated, multidisciplinary studies on both sides of the international border to refine regional fault models.

How Does the Cumulative Interaction of Diverse Faulting Mechanisms Shape the Long-term Tectonic Evolution of the Gulf of California? The Yuha Desert Case of Study

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Existing kinematic models struggle to reconcile the role of lateral and extensional faulting during transtensional deformation associated with the opening of the Gulf of California (GoC). We propose that these fault systems have operated concurrently since the onset of shear (~16–12 Ma), challenging classical two-stage rifting models. We argue that kinematic variability is essential to settle three-dimensional transtensional strain, and that the extensional and lateral components of strain are not linked to changes in regional GoC opening direction. The study area, located in the Yuha Desert near the axis of the Pacific–North American transtensive shear zone, lies within the northern GoC.

Fault geometry, kinematics, and cross-cutting relationships reveal a complex fault network composed of high-angle faults (HAFs) and low-angle faults (LAFs) that generated extensional basins filled with Middle Miocene to late Quaternary sediments. Faults are classified into four groups based on geometry and kinematics: (1) NW-striking dextral HAFs, including the Laguna Salada fault (LSF); (2) NNW-striking normal HAFs; (3) ENE–NE–NNE-striking sinistral-normal HAFs; and (4) east-directed LAFs.

Transtensional shear is strongly partitioned at branching intersections between fault Groups 1 and 2, where extension is settled on NNW-striking faults, while dextral slip localizes along the WNW-striking principal strand of the LSF. Mutual cross-cutting relationships among all fault groups indicate coeval activity since rifting initiation, and Late Quaternary coseismic scarps demonstrate ongoing deformation.

Kinematic T axes from most faults of the Yuha Desert trend WSW–ENE, whereas ENE-striking sinistral faults in the northern area show WNW-trending T axes. This variation reflects local fault rotation or spatial stress heterogeneity; however, cross-cutting relationships preclude temporal changes in the regional stress field. Overall, the Yuha Desert has been dominated by the extensional component of transtensional strain since ~12.3 Ma. Ongoing work includes mechanical interaction analyses, paleostress modeling, and slip tendency analysis.

Complications in Characterizing Seismic Hazards in the Blind Fault System of the Santa Maria Basin, California

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In the onshore Santa Maria Basin (SMB), at the northwestern end of the active Western Transverse Range fold-and-thrust belt, several large blind faults are present that deform Quaternary sediments and are inferred to be capable of producing large earthquakes. Recent mapping and geochronology of late Quaternary fluvial and marine terraces throughout the Santa Maria Basin, and fault modeling of subsurface data, indicate that Late Quaternary uplift and fault slip rates are higher than previously assumed. Regional uplift rates since 120 ka are 0.3-1.6 mm/yr, with higher rates (0.5-4.9 mm/yr) occurring along the crests of major anticlinoria.

This recent work has highlighted some challenges in characterizing the Santa Maria Basin and blind fault systems in general. First, despite the obvious vertical displacements and shortening, kinematic indicators on some exposed fault planes indicate predominantly lateral slip and geodetic strain suggests 1-2 mm/yr of dextral shear. Finding geologic markers to measure this component of lateral slip on the faults is difficult and remains to be done. Second, surface deformation of the fluvial terraces occurs as smaller folds and offsets that do not coincide with axial traces of folds or locations of modeled fault zones in the early Quaternary strata at depth. If coseismic slip at depth does not completely, or mostly, transfer to measurable faults and folds at the surface, displacement rates calculated across the surficial structures are not accurate. Finally, changes in fault dip, surface expression, and uplift rates along strike of the faults makes the connectivity of the primary structures in the area difficult to resolve.

To develop better estimates of slip rate and maximum rupture lengths in the Santa Maria Basin, ongoing work is focusing on measuring the component of lateral slip on the faults, better understanding the connection between deformation observed at the surface and at seismogenic depths, and iterating on fault-related fold models to constrain fault geometry and connectivity

Structure, Seismicity, Earthquake and Tsunami Potential of the San Clemente Fault System

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The offshore San Clemente fault was mapped along the linear escarpment east of San Clemente Island. Precise navigation and acoustic sounding record water depth for accurate mapping of seafloor morphology and create images of subbottom structure. Detailed bathymetry maps reveal seafloor lineaments consistent with active faulting. NW-trending fault sections cut the ridge and basin physiography for more than 600-km, from the Transverse Ranges to the Guadalupe microplate midway down the Baja California Coast. The San Clemente fault cuts southeast across the Northern Borderland and turns south offshore Ensenada to parallel the Baja California coast as the San Isidro fault. Oblique-slip at left bends produce seafloor uplift and right-stepovers create basins consistent with dextral shear. Seismicity records slip along the fault where several segments may combine in large earthquake ruptures. Complex deformation during the 26 December 1951, M5.8 event showed sinistral slip on the NW-trending focal plane, opposite to expected dextral slip. Few aftershocks were recorded. The 4 September 1981, M6 Santa Barbara Island earthquake sustained right-slip along the eastern flank of the Santa Cruz-Catalina Ridge. Abundant aftershocks showed a 20-km deep vertical fault zone. Offshore northern Baja California, the 22 November 2022, M6.2 event in the San Isidro Basin showed right-slip parallel to the modern PAC-NAM relative plate motion vector. Abundant aftershocks include activity on NE-trending conjugate faults beneath the continental shelf. Overall length and fault character suggest M7+ magnitude earthquake capability. Slides along steep sub-

marine slopes and seafloor uplift at fault bends and stepovers may produce destructive local tsunamis.

Seismotectonics of Southern and Baja California [Poster]

Poster Session • Thursday 16 April

Conveners: John Fletcher, Center for Scientific Research and Higher Education at Ensenada (jfletche@cicese.mx); Devin McPhillips, U.S. Geological Survey (dmcphillips@usgs.gov); Katherine Scharer, U.S. Geological Survey (kscharer@usgs.gov); Drake M. Singleton, U.S. Geological Survey (dsingleton@usgs.gov)

POSTER 175

Insights into a Transform Fault Bounded Pull-apart Basin, Cerro Prieto, Northern Baja California, México
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Various geophysical proxies focusing on the southern segment of the Imperial Fault are studied. Observations presented start near the US-Mexico border and run along the Mexicali Valley up to the area where Imperial Fault is presumed to mechanically interact with the Cerro Prieto Fault. Gravity surveying was carried out along the known surface ruptures for the 1940 El Centro and 1979 Imperial Valley earthquakes. Additionally, seismic reflection profiles were reprocessed to associate seismicity lineaments in the region with buried faults. Results suggest various secondary faults following the Riedel model for pull-apart basins in transtensional settings. Our mapping is particularly important as regional earthquake forecast models should address for the whole Californias region.

POSTER 176

A New Approach for Estimating Inbuilt Age Effects on Paleoseismic Event Dates
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Paleoseismic event dates on the San Andreas fault through the Transverse Range in southern California depend almost exclusively on radiocarbon ages from charcoal samples preserved in alluvial deposits. Although calibrated radiocarbon dates for charcoal can be precise, the sample inbuilt age (IA), or time from carbon fixing in the plant to its entrance to the geomorphic system, adds large uncertainties to resulting layer date estimates. The IA distribution includes time for the plant to grow, live, and die or be burned by a fire. Detrital charcoal might come from recent growth or an old tree. Paleoseismic chronologies in southern California have not systematically included the IA effect. An earlier method to estimate the IA distribution (Scharer et al., EPSL, 2024) finds it spans over 400 years and with radiocarbon uncertainties allows the apparent layer age to be younger or older than the mean of the charcoal sample. IA does not include transport time, but comparison with modern fires in the Transverse Range shows that this time is negligible.

We use ideas from order statistics to develop an alternate IA distribution in which stratigraphic layers are strictly younger than the carbon they contain. We assume (with some guardrails) that dates from a single layer represent a random sample from the physical process leading to the IA distribution. We draw dates from the layer's calibrated date distributions, order them, and take differences from the youngest of the set. These differences control the shape and older side of the IA distribution. The youngest date is statistically related to the true layer date by being a sample from the first order statistic PDF of a prior IA model. We show that results depend weakly on the choice of the prior. IA distributions for the Pallett Creek, California site using layers with six or more radiocarbon dates are narrower and better resolved than previous IA models. They also quantify the approximation being made when the youngest (or only) sample from a layer is used as the layer date. We present implications for paleoearthquake dates for the Pallett Creek site.

POSTER 177

Vertical Offset and Recurrence of Large Earthquakes on the Cañada David Detachment, Baja California, Mexico
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Low-angle normal faults are central to extensional tectonics yet remain controversial because their orientation is unfavorable for slip under Andersonian stress conditions, and large earthquakes on active examples are rarely documented. To address this debate, we investigate the Late Quaternary earthquake record of the Cañada David detachment in northern Baja California, Mexico. Using drone-based photogrammetry (~160 km²), high-resolution orthomosaics, and digital surface models (11–15 cm), we mapped fault scarps and alluvial fan sequences along the Cañon Rojo–Chupamirtos fault system, a major strand of the Cañada David detachment. From ninety-nine topographic profiles, we quantified vertical displacements on successive fan surfaces, revealing systematic variations in offset with fan age and fault orientation. Correlations with paleoseismic trench data show that the Cañada David detachment hosted 15–27 large (~M7) earthquakes over the past ~60,000 years, with ~2,000-year recurrence intervals, often co-rupturing with the Laguna Salada fault. Although our results confirm that low-angle normal faults are fully capable of generating major earthquakes, such events may be difficult to identify because they may involve co-rupture with adjacent faults of distinct orientations or nucleation on steeper down-dip segments as predicted by the rolling-hinge model.

POSTER 178

An Updated San Andreas Fault Geometry in Parkfield, California
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The San Andreas Fault is the most well-known fault zone in California. To better address its seismic hazard, models of specific rupture scenarios can be simulated to evaluate the possible extent of rupture propagation, slip, and ground motion. This has become especially relevant for studies with a focus on the relatively short recurrence time of repeating moderate earthquakes in the Parkfield segment. It is pertinent to perform rupture models to assess what the next Parkfield earthquake may look like and prepare for its seismic hazard across central and southern California. As an initial step in such a model, a well-constrained fault geometry is necessary. Currently, the Statewide California Earthquake Center Community Fault Model (SCEC-CFM) has a representation of the Parkfield section that may be too low resolution for use in detailed dynamic earthquake modeling. Variations in both fault strike and dip in this region must be translated as accurately as possible to computer models, since changes in geometry can strongly affect the rupture and slip process. Here, we use USGS's earthquake catalog from 1996 to the present day (2026) to constrain the San Andreas Fault geometry at depth along the Parkfield segment. We use high order polynomials to invert for the geometry of the fault and generate a best fit surface to the data. In light of limited seismic events closest to the free-surface, we will augment our seismicity data with InSAR data. From our results we aim to produce a state-of-the-art, best-

fitting fault geometry for the central San Andreas Fault, where future studies in Parkfield can be conducted including dynamic rupture models and long-term earthquake simulations.

POSTER 179

Testing Uplift Rates of the Palos Verdes Peninsula Using Luminescence Dating on Marine Terraces
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The Palos Verdes Peninsula, located along the southern California coast, is widely known for its preserved suite of 13 marine terrace levels. These marine terraces are geomorphic markers for uplift caused by coseismic slip along the Palos Verdes fault, which is a significant seismic producer in the Los Angeles Basin area, capable of generating >Mw 7 earthquakes. The published uplift rates for the Palos Verdes Peninsula were found based on U-series ages from fossil corals found on the first and second terrace levels, which were dated to ~80ka and ~120ka, respectively. Luminescence dating provides an alternative dating method that can be used to test and refine previous U-series dates. Recent luminescence studies along the coast of California have matched U-series dates in locations where both methods were applied but have also yielded substantially younger terrace ages than previously expected in other locations that lack U-series age control.

To see how luminescence dates compare to previously published U-series dates in the Palos Verdes Peninsula, we used post-infrared infrared stimulated luminescence (pIR-IRSL) on 12 samples taken from the first and second terrace levels at 5 different sites. Fading-corrected ages from the first terrace level coincide with MIS Stage 5a (~80ka). For the second terrace level, some samples yielded ages close to MIS 5e (~120ka), while others appeared much older, which could be due to their anomalously high fading rates and/or incomplete bleaching. Overall, these luminescence ages roughly agree with the previous uranium-series ages, which strengthens the age control of the lowest two terrace levels. Uplift rates calculated with these luminescence ages are approximately 0.64mm/yr and 0.48mm/yr for MIS 5a and MIS 5e, respectively, which are in general agreement with the published rates.

POSTER 180

High Resolution Holocene Slip Rate for the Southern San Andreas Fault in the Salton Trough, California
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There is no geologic slip rate determined for the southernmost San Andreas Fault, a linear segment situated along the modern-day Salton Sea. Further, there are no Holocene slip rates that include the entire fault zone in the Salton Trough. The closest published Pleistocene to present long-term slip rates are in the Indio Hills, located 60 km north of the southern terminus, where the fault is multistranded, resulting in a two-fold uncertainty in slip rates (12-27 mm/yr). New work at Salt Creek on the eastern side of the Salton Sea has resolved a buried channel margin offset about 55 m by the San Andreas Fault. From existing exposures, the displacement uncertainty is probably less than 1 m on the NE side of the fault, whereas on the SW side we must project the contact from an old trench exposure about 7 m away, suggesting the uncertainty is no more than 3 m. The linear trend of the piercing line is nearly identical on both the NE and SW side of the offset, albeit with limited exposures.

To constrain the age of the offset, we dated three samples of detrital charcoal from the fluvial sand unit used as the piercing point, which yielded calibrated ages of 3.52±0.05, 3.47^{+0.08}/_{-0.07}, and 3.45±0.04 ka. The Salt Creek drainage basin includes an archeological site (Dos Palmas Preserve oasis), which was repeatedly occupied during low stands of ancient Lake Cahuilla, potentially introducing an inherited age bias in the charcoal. As a result, the dated charcoal samples provide maximum ages for the host strata, resulting in a minimum slip rate when applied to the offset channel margin. We apply an offset of 55 ± 4 m in <3.45±0.05 ka to resolve a minimum late Holocene slip rate of 15-17.4 mm/yr on the channel, slightly lower than the observed geodetic rate of ~18 mm/yr. Any off-fault deformation is not quantified. Pending Infrared Stimulated Luminescence ages will directly date the piercing point sands, and additional trenches will provide further reduction in displacement uncertainty, resulting in a high-precision late Holocene slip rate for the southern SAF, considered to be very late in its seismic cycle.

POSTER 181

Paleoseismology of the Southern Segment of the Compton Blind Thrust Fault: Defining the Potential for Multi-segment, Large-magnitude Earthquakes Beneath Metropolitan Los Angeles
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The Compton thrust is a 40-km-long blind thrust fault extending beneath the western part of the Los Angeles metropolitan region. An earlier paleoseismological study by Leon et al. (2009) utilized seismic reflection profiles and a transect of continuously cored boreholes to investigate near-surface fault-related folding along the back-limb axial surface of the northern segment of the Compton thrust. These studies revealed that the northern segment of the Compton thrust generated six stratigraphically discrete folding events during the last 14,000 years, with thrust displacements between 1.3 and 4.2 m, consistent with M_w ≥ 7.0 earthquakes based on scaling relationships. As the Compton thrust is segmented between a northern and southern section, comparison between the two is needed to determine if the fault typically ruptures in single- or multi-segment ruptures, or both. In this study, we use a second data set consisting of high-resolution and deep-penetration industry seismic reflection profiles imaging the 30 to 5000 m depth range and a transect of 25- to 42-m-deep, continuously cored boreholes collected across the locus of active folding above the back-limb axial surface of the southern segment to investigate the nature and timing of paleo-ruptures on the Compton thrust. Preliminary analysis of these data reveals an upward-narrowing growth triangle defined by progressive folding of fluvial strata. Radiocarbon and IRSL dating of multiple event horizons defined by these paleo-fold scarps will provide a refined paleo-earthquake chronology as well as an incremental fault slip-rate record. In addition to facilitating comparison of paleo-earthquake ages on the southern and northern segments of the Compton Thrust, this refined paleoseismic record will allow us to explore the behavior of the Compton Thrust relative to other urban faults in the greater metropolitan Los Angeles region. These new Compton Thrust data will be critical for understanding the system-level behavior of the urban fault network as well as developing more accurate seismic hazard assessments in one of the most populous regions in the country.

POSTER 182

New Mapping and Subsurface Data on the Southernmost Extent of the San Jacinto Fault
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Geodetic studies propose ~10 mm/yr of dextral strain is accommodated in the Imperial Basin, California west of the Imperial Fault, yet no fault is mapped here in the USGS Quaternary Fold and Fault Database. We re-examine activity along the trend of the San Jacinto Fault, through mapping on historic air photos and subsurface investigation. We produced a composite, georeferenced orthophoto along the trend of the San Jacinto Fault from the New River to the US-Mexico border using 1937 air photos. The area has very little topography, so we mapped potential fault traces based on vegetation lineaments, contrasts in ground color, and linear troughs in the 1937 photos, and evaluated the persistence of these features using the historical imagery in Google Earth (1984-present). This effort reveals potential additional strands that could extend the San Jacinto Fault (locally called the Wienert Fault) by ~25 km, through the city of El Centro and to within 3 km of the Imperial Fault. Geophysical and other subsurface investigations are needed to confirm potential fault traces at these southerly latitudes.

Our subsurface investigation focused on a sag pond visible in 1937 air photos, just south of the 1987 Superstition Hills earthquake rupture. The sag pond indicates that faulting has been active since the deposition of the youngest Lake Cahuilla sediments, ~300 years ago. We used cone penetration testing (CPT) soundings to characterize the Holocene activity of faulting, revealing a ~15 m wide fault zone. Increasing vertical separation with depth of correlative layers indicates episodic motion across the fault zone and repeated inundation by Lake Cahuilla sediments. A pending IRSL age on a sandy layer from 3.5 m depth will provide age context for this sequence. Overall, this study provides

clear evidence that the San Jacinto Fault is Holocene-active to within 6 km of El Centro and suggests that the fault may extend much farther to the south-east. We examine this revision in the context of published geophysical studies with the aim of contributing to a better characterization of earthquake hazards in the Imperial Basin

Source Properties of Microearthquakes: Insights from Laboratory, Induced and Natural Events

Oral Session • Thursday 16 April • 4:30 PM Local

Conveners: Hilary Chang, Columbia University (hc3627@columbia.edu); Chun-Yu Ke, National Taiwan University (chunyuke@ntu.edu.tw); Yen-Yu Lin, National Central University (yenyulin@ncu.edu.tw); Yajing Liu, McGill University (yajing.liu@mcgill.ca); Semechah Lui, University of Toronto, Mississauga (semechah.lui@utoronto.ca)

Towards Improving Estimates of Small Earthquake Source Properties and Their Interpretation

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Small earthquakes contain a wealth of information about the geometry and stress conditions of the active structures on which they occur. Their relatively large numbers provide high spatial and temporal resolution, and insights into future ground motions in areas without large earthquake recordings. Most estimates of earthquake stress drop, and any resulting magnitude dependence, are made by modeling amplitude spectra and moment rate functions. Recent community work (e.g. Baltay et al., BSSA 2025) has demonstrated the large uncertainties and systematic biases inherent in these methods. These largely result from ambiguities in isolating the earthquake source radiation from the effects of path and site, and also limitations on the frequency resolution of the observations.

I present results of collaborative analyses of relatively well-recorded small, tectonic and induced earthquakes using multiple approaches. I discuss strategies for evaluating the resolution and reliability of results depending on the data quality. With a primary focus on spectral stress drop estimates, I address how using an over-simplified model of the source radiation can lead to large random and systematic uncertainties. I also include observations of rupture directivity showing its potential to provide further insights into earthquake rupture characteristics and fault geometry.

Induced Earthquake With 200-to-800 Hz, Bell-shaped Source Spectra From 6 Kms Deep Injection in Igneous Basement Rock Near Helsinki, Finland

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In June and July 2018, a 6,100 m measured depth borehole drilled into Fennoscandian granitic rocks was stimulated with an 18,000 m³ hydraulic fracture treatment over a 49-day period. We monitored the stimulation with 3 different types of borehole seismic stations, several audio band microphones, and 3 hydrophones in a nearby shallow bay. The seismic stations included a 1950-to-2400 m deep borehole array with 12 levels of triaxial geophones located above the stimulation zone. The microphones were part of a 17-station ground-level motion and noise compliance net surrounding the stimulation well. The hydrophone array was placed on the granite bottom of a ~10 m deep ocean bay overlying the stimulation section of the borehole. The borehole array data were sampled at 2,000 Hz and the microphones at 12,000 Hz. The hydrophones were recorded at 48,000 Hz but resampled down to 2,000 Hz to match the array, both of which were then anti alias filtered at 800 Hz. The array data were then low pass filtered below 200 Hz for use in automated signal detection and processing.

In this presentation we focus on the pre-processed, higher frequency signals of these induced earthquakes observations for an 11-day period in July. The microphone data have spectral energy well above the 200 Hz low pass filtered data. The unfiltered array and resampled hydrophone data reveal that they have roughly bell-shaped, 200-to-800 Hz, source spectra, centered

at ~500 Hz. Further, using unfiltered data for event detection, we identified many more small events – nearly doubling the rate per day, from ~1500 to ~3000. (The different depth levels of the array observations also demonstrate how heterogeneous basement rock properties are.) The induced event P-waveforms are complicated, contain motions from a time series “comb” of multiple bi-directional slips, possibly accounting for the rough bell-shaped source spectra. A simple, but notional, mechanical model that can account for these observations is sequential slips on fractures ending in opposite facing wing fractures.

The Energy Budget of Laboratory Failure Experiments

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Understanding how earthquakes release energy into the surrounding rock is essential for advancing our knowledge of earthquake physics. To overcome the spatial and temporal limitations of conventional seismological methods and geological observations, we investigated laboratory earthquakes in high-pressure rock deformation experiments. Using a combination of novel magnetic thermal analyses, microstructural analyses, and ultrasonic probing we quantified how the released strain energy is partitioned into heat, creation of new surfaces, and generation of seismic waves during laboratory slip events. Our results show that how the energy is distributed depends strongly on the deformation history of the shear zone, including fault geometry and grain size within the principal slip zone. Moreover, we find that stick-slips with larger stress drops exhibit greater damage potential, as a larger fraction of the released energy is radiated as seismic waves, likely due to enhanced fault lubrication during slip.

Ubiquitous Interactions and Subcritical Patches Explain the Irregularity of Repeating Earthquakes

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Repeating earthquakes, or repeaters, are commonly interpreted as repeated ruptures of the same fault patch and are widely used as probes of fault slip behavior, including creep rates, healing, and stress drops. Despite their apparent simplicity, repeaters exhibit strong variability in their recurrence intervals, even when events within a given sequence have nearly identical magnitudes. Previous studies have shown that repeating earthquakes are neither time- nor slip-predictable. We investigate the physical origin of this irregular recurrence by combining statistical analysis of earthquake catalogs with physics-based numerical modeling of coupled seismic and aseismic fault slip.

Using repeating earthquake catalogs in Northern California, we find that most repeaters have at least one neighboring sequence within a few hundred meters and show clear evidence of interaction, as indicated by short intervals between earthquakes occurring in nearby sequences beyond what would be expected by chance. We further identify a substantial population of small repeating sequences that rupture extremely infrequently and are preferentially activated following nearby larger repeaters. These sequences exhibit behavior inconsistent with spontaneous nucleation, suggesting that they occur on subcritical patches and are triggered by stress perturbations from nearby events. Numerical simulations of rate-and-state faults with two velocity-weakening patches quantitatively reproduce both the observed interaction patterns and recurrence variability, and confirm the importance of interactions and subcritical patches. The simulations also show that the source patches of the infrequent repeaters experience slow-slip transients between triggered seismic events, allowing them to keep up with nearby creep.

Our results indicate that repeating earthquakes are rarely isolated systems, provide observational support for a minimum patch size required for spontaneous earthquake nucleation, and highlight the need to account for both seismic and aseismic slip when considering earthquake source physics.

Comparing Earthquake Interaction on Creeping Faults in California with Induced Earthquakes in the Central US

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Small earthquakes along the creeping section of the San Andreas and other creeping faults in Northern California provide an opportunity to explore the nature of earthquake interaction on faults where aseismic slip/creep is predominant and earthquake interaction can occur through earthquake-to-earthquake triggering or fault creep. Creeping faults are known to have repeating earthquakes that rupture essentially the same portions of the fault many times during the instrumental record, presumably because the same failure conditions are set up repeatedly due to creep on the surrounding fault. Because these earthquakes are known to be repeated ruptures of the same fault patches, the sequence of earthquakes that surrounds them might be expected to be similar between cycles, as stress accumulates and is released by a combination of aseismic slip and earthquake activity. We model the stress transfer process between earthquakes over multiple repeat cycles in these creeping sections to understand the differences in behavior between cycles and to compare and contrast the behavior of earthquakes on known creeping faults with the seismicity of faults activated by wastewater disposal in Oklahoma and southern Kansas where the role of aseismic slip is less clear.

Source Properties of Microearthquakes: Insights from Laboratory, Induced and Natural Events [Poster]

Poster Session • Thursday 16 April

Conveners: Hilary Chang, Columbia University (hc3627@columbia.edu); Chun-Yu Ke, National Taiwan University (chunyuke@ntu.edu.tw); Yen-Yu Lin, National Central University (yenyulin@ncu.edu.tw); Yajing Liu, McGill University (yajing.liu@mcgill.ca); Semechah Lui, University of Toronto, Mississauga (semechah.lui@utoronto.ca)

POSTER 183

Investigating Source Properties of Ultra-shallow Nanoearthquakes Using the Midas Borehole Seismic Monitoring System in Taiwan

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Ultra-shallow earthquakes are rare in nature because low normal stress limits the accumulation of shear stress to the critical level required for unstable slip. The shallowest natural earthquakes reported worldwide have occurred at depths of several hundred meters. However, we identified dozens of ultra-shallow nanoearthquakes at depths shallower than 50 m in Hualien, Taiwan, using the seismic monitoring system of the Milun Fault Drilling and All-inclusive Sensing (MiDAS) project. This system integrates conventional seismometers and distributed acoustic sensing (DAS) arrays deployed in boreholes and at the surface. Although these earthquakes are extremely small, they provide a unique opportunity to investigate their source properties and their relationship to the nearby major Milun Fault. Our analyses of source properties indicate that 75 nanoevents occurred at depths of 0–50 m, with hypocentral distances of 60–80 m. The moment magnitudes range from –3 to –1, and the dominant frequency content is approximately 160 Hz. The hypocenters are primarily located beneath a drainage channel near MiDAS Hole B, where the flow direction is parallel to the strike of the Milun Fault. We determined the focal mechanisms by comparing observed waveforms with synthetic waveforms generated from extensive moment tensor combinations. The resulting focal mechanisms exhibit high non-double-couple components, suggesting that these events are not dominated by pure shear fracturing. Together, these results highlight the occurrence of ultra-shallow nanoearthquakes with unconventional source characteristics and underscore the importance of high-resolution near-surface monitoring for understanding seismic processes at such shallow depths.

POSTER 184

Using Borehole Distributed Acoustic Sensing to Investigate Microearthquake Source Parameter Variability in an Enhanced Geothermal System

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Earthquake source parameters are important for understanding source physics and assessing seismic hazard. In an Enhanced Geothermal System (EGS), microearthquakes ($M < 2$) provide information on subsurface stress conditions and responses to human activities. Seismic waves can also reveal geological structures. However, modeling microearthquake spectra is challenging due to difficulties in separating source and path effects, especially at the high frequencies needed to resolve small earthquakes. Borehole Distributed Acoustic Sensing (DAS) provides unprecedentedly dense seismic arrays in the subsurface, offering great potential for characterizing shallow structures and microearthquake source properties, as well as improving measurement accuracy. In this study, we use a DAS fiber-optic cable in a vertical well at the Cape Modern geothermal field in Utah to characterize shallow attenuation (Q) in the upper 2.5 km using microearthquakes occurring during stimulation. Then, we estimate key source properties, including corner frequency, source radius, slip, moment magnitude, and stress drop. We investigate the relevant instrument responses of the cable in each analysis and how they affect measurement uncertainties. We discuss strategies to minimize potential biases in source parameter estimates. The Empirical Green's Function (EGF) method is useful for benchmarking the results. We do not observe obvious deviations from constant spectral stress drop for microearthquakes ($0 < M < 2$). Local low stress drop zones might relate to weaker faults, slower rupture velocity, or higher attenuation. Our work demonstrates the potential of using borehole DAS to help understand microearthquake source parameter variabilities, which is still under debate in the earthquake community.

POSTER 185

Rupture Directivity - Insights From Theoretical Studies Applied to Observations

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Rupture directivity is a seismic source property reflecting the dynamics of the rupture process. When ruptures exhibit a clear sense of direction, they generate asymmetric radiation patterns in seismic amplitudes and corner frequencies, an effect first described analytically by Ben-Menahem (1961) as a moving point-source. Subsequent numerical studies (Kurzon et al., 2019, 2021) demonstrated that incorporating source-volume, damage, and rheological complexity, significantly improves the representation of rupture processes, and that in many cases P-wave radiation patterns are more stable and indicative of rupture directivity than S-waves.

Here, we examine these numeric insights against field observations using a unique dataset of 31 earthquakes (M_w 2.5–4.5) from a seismic swarm in the Sea of Galilee. The events were recorded by ~30 stations with good azimuthal coverage, enabling robust assessment of rupture directivity and rupture properties. Our results show that (1) most events exhibit clear rupture directivity; (2) P-waves display stronger and more consistent directivity than S-waves, in agreement with numerical simulations; (3) S-waves generally show weaker directivity, but agree with P-waves inferred signatures; and (4) rupture propagation is predominantly toward the SE–SSE, compatible with an east-trending oblique fault. In addition, by quantifying the directivity strength from the radiation patterns, we may estimate rupture velocities as $V_r/V_s = 0.65\text{--}0.95$; S to P energy ratio as ~5–15; and S-wave energy loss of ~20–60% during rupture. Our results validate the numerical simulations and demonstrate the ability to infer dynamic rupture properties for small earthquakes.

POSTER 186

Spatiotemporal Evolution of the Dapu Earthquake Sequence in the Frontal Western Foothills, Taiwan: Insights from a Dense Near-source Seismic Array

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Observing the nucleation phase of an earthquake remains a fundamental challenge due to the temporal unpredictability of seismic events. This study focuses on the Dapu earthquake sequence in Taiwan's Western Foothills, which was fortunately recorded by a dense seismic network deployed just one week prior to the mainshock. The high sensitivity of this near-source array

enabled the detection of numerous micro-earthquakes ($M < 1.0$) that were previously obscured in regional catalogs. This unique dataset provides a rare, high-resolution record of the complete seismic cycle, offering a significant opportunity to investigate the transition from subtle pre-seismic activity to post-seismic readjustment. The spatiotemporal evolution of these micro-events allows for a detailed examination of the interaction between the frontal thrust geometry and the rupture process. By analyzing the migration patterns of foreshocks and the spatial distribution of the aftershock sequence, we aim to resolve the fine-scale structural controls and stress-triggering mechanisms within this fold-and-thrust belt. The integration of this high-fidelity catalog facilitates a more robust interpretation of fault nucleation and slip propagation in the region. Our study emphasizes that such dense, near-source monitoring is essential for capturing the “hidden” preparation phase of earthquakes and provides critical constraints for understanding complex fault behaviors in active tectonic zones.

POSTER 187
Lightning-induced Implosive Microseismic Events at Depth Detected by Downhole Distributed Acoustic Sensing in Taiwan
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Cloud-to-ground (CG) lightning can generate seismic waves that travel along the ground surface, but direct evidence for its subsurface energy dissipation has been lacking. Here, we report seismic impulsive waveforms detected by a disturbed acoustic sensing (DAS) system deployed in a borehole in Taiwan, immediately following a CG lightning-strike time, which may be induced by the CG lightning. The strain-rate waveforms exhibit only one distinct seismic phase, with moveouts propagating toward the surface between nodes at depths of 50–86 m, and another set propagating downward between nodes at depths of 86–140 m. The maximum peak amplitude corresponds to a strain rate as low as $\sim 3 \times 10^{-6} \text{ s}^{-1}$. The wave amplitudes show strong attenuation during propagation. Analysis of the source mechanism for the observed seismic impulses by using the finite-difference strain-rate simulation technique indicates that these waves were generated by an implosive event of magnitude $M_w \sim 1.5$ to ~ 1.0 ($M_{xx} = M_{yy} = M_{zz} < 0$, all other components = 0), located 10–20 m from the borehole at a depth of 84 m. Our simulations of the implosive source also explain the unique strain-rate polarizations observed, with downward first motion at nodes closer to the source and upward first motion at nodes farther away. These results provide the first direct evidence that lightning’s subsurface impact can penetrate to depths far greater than previously recognized, highlighting the need to further investigate the underlying physical mechanisms.

POSTER 188
Reconciling Seismological and Numerical Source Parameters of Repeating Earthquakes Near Parkfield
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The repeating earthquake sequences on the creeping section of the San Andreas Fault near Parkfield, California, have long attracted great interest due to intriguing observations, including long recurrence intervals under typical assumptions and unusually high inferred stress drops (25-65 MPa). Lui and Lapusta (2018) proposed numerical fault models that reproduce the fault mechanics and source properties of the San Francisco repeating sequence in Parkfield. In particular, two end-member triggering mechanisms are hypothesized to explain the observations: enhanced dynamic weakening via thermal pressurization (TP) and elevated normal stress (ENS).

In this study, we revisit these repeaters by further examining the consistency between source parameters produced by the proposed numerical models and those inferred from seismic observations. To enable meaningful comparisons, we use detailed slip histories from the numerical simulations to generate synthetic far-field waveforms at pseudo-stations surrounding the

modeled fault to estimate the source-time functions and to compute seismological stress drops using spectral fitting methods. Stress-drop estimates for TP models obtained using the fixed $n=2$ approach are $\sim 20\text{--}50$ MPa, comparable to field observations, whereas the variable- n approach yields overestimated values (> 70 MPa). ENS models generally produce lower stress drops (8-30 MPa) for both n approaches, yet remain consistent with observations. Seismologically inferred stress drops show greater variability than the “true” numerical moment-based values. Regarding source duration, ENS models tend to produce longer and more variable source durations than TP models. Ongoing work compares observed source-time functions (STFs) from Abercrombie (2014) with far-field STFs derived from the simulations, and explores sensitivity to parameters such as shear-wave velocity and normal-stress heterogeneity. These analyses aim to better constrain fault properties that best explain field observations. We also discuss fundamental differences between the two mechanisms and assess which may better explain the empirical data.

POSTER 189
The Impact of Wastewater Injection Enhanced In-situ Stress on Hydraulic Fracturing Induced Seismicity Near Kingsher, Oklahoma
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Hydraulic fracturing (HF) in Oklahoma is frequently associated with small earthquakes ($M < 2$), but it can also generate larger, felt events. This process often occurs in areas with long-term subsurface wastewater disposal (WD). Although targeting separate, distinct geological formations, the combined effects of HF and WD may be cumulative with respect to subsurface stresses. This study examines their interaction in influencing seismicity near Kingfisher, Oklahoma, from 2019 to 2024.

We enhanced the Oklahoma Geological Survey catalog by detecting smaller earthquakes using a network-based matched-filter technique and refine new earthquake locations with hypoDD to improve spatiotemporal resolution. Initial analysis shows that seismicity began within approximately a 1 km radius of the primary WD well at focal depths of 6–8 km during the pre-HF period, coinciding with the onset of WD. Following the initiation of concurrent HF and injection at relatively high WD wellhead pressures (> 8 MPa), both the seismicity rate and magnitude increased, delineating a 5 km NE-striking fault. These earthquakes were located beneath four HF wells whose horizontal sections intersect the seismogenic fault. After the injection was paused due to a regulatory inquiry, wellhead pressures dropped below 4 MPa, and the rate of earthquakes associated with HF declined, with only six events of $M > 2.5$ recorded compared to 20 in the previous period. These earthquakes, in both instances, occurred at focal depths of 2.5–12 km, with the shallower events located within the HF zone at 2.8 km depth. We modeled the stress changes on the fault from multiple wells. Preliminary modeling results suggest that an elevation of in-situ stress at the HF formation by 3–6 MPa induced by WD wells resulted in a higher seismicity rate during the HF period compared to HF without concurrent WD injection. We will present updated results on the continuity of seismicity during variable WD injection periods and the relative stress change over the study period. This will help evaluate the potential to trigger seismicity further along the fault in the absence of concurrent HF.

POSTER 190
Small Earthquake Monitoring for Structural Potential Characterization and Source Parameter Analysis in Northern Hualien, Taiwan, by a Borehole Seismometer Array
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Northern Hualien is located at the collision boundary between the Eurasian and Philippine Sea plates and exhibits complex, debated tectonics with high seismicity characterized by earthquake magnitudes ranging from M1 to M8 and focal depths from near the surface to ~ 150 km. To overcome the limita-

tions in seismic monitoring due to sparse Central Weather Administration (CWA) station coverage, this study deployed an additional seismic observation system near Heping Village in 2020. The system includes a 100-m-deep borehole seismometer, a surface strong-motion accelerograph, and a velocity seismometer. The integration of the borehole seismometer with CWA stations forms a seismic array, improving the detection capability for small earthquakes. To analyze instrument characteristics, probabilistic power spectral densities indicate background noise levels ranging from -80 to -120 dB, with the borehole broadband station exhibiting the lowest long-period noise. In addition, the orientation of the borehole sensor is calibrated using long-period waveforms from the 2021 Qinghai, China earthquake, yielding a corrected azimuth of 339° counterclockwise.

To cope with the increasing volume of seismic data and enable efficient event detection, this study uses manual analysis and a deep-learning-based approach. Between October 2022 and December 2023, 10,826 events were manually identified, of which 496 events not listed in the CWA catalog were successfully located, clustering north of the seismic array. Source parameters were estimated using spectral fitting, revealing no significant correlation between stress drop and seismic moment for events of M0–3, suggesting self-similar behavior. To further improve detection efficiency, the deep-learning-based RED-PAN was applied to continuous seismic data from 2024, detecting 72,696 events. The marked increase in seismicity was largely due to the 3 April Hualien earthquake. RED-PAN improved the efficiency of phase picking and event identification. Future work will aim to automate event location by detecting P-wave arrivals at additional stations, enabling automated micro-earthquake location.

POSTER 191
Normal-faulting Earthquakes Under a Compressional Stress Regime, Insights from the Weiyuan Shale Gas Field, China
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It is well known that stress fields are important for earthquake generation and may govern the faulting types. However, here we report abundant small-magnitude normal faulting earthquakes in the Weiyuan shale gas field, China, a region with dominant compressional stress field and thrust-faulting earthquakes. Benefiting from our deployed dense arrays, we are able to construct high-resolution earthquake catalog. Most earthquakes are concentrated in depths slightly below the shale formation and are driven by pore pressure diffusion. We also apply SKHASH to determine focal mechanisms of small earthquakes using P polarities picking from PhasetNet+. The results show a number of normal-faulting events, which are validated by detailed comparison with nearby reverse-faulting events. These normal-faulting events are spatially clustered near hydraulic fracturing platforms, but show no clear spatial separation with the dominant reverse-faulting events, suggesting that they likely arise from highly localized stress heterogeneities. The coexistence of opposite faulting types in such a setting underscores the complexity of stress perturbations associated with shale gas development and highlights the need for heightened attention to seismic hazard assessment in these regions.

Southern California Seismicity: Past, Present and Future

Oral Session • Friday 17 April • 4:30 PM Local

Conveners: Nicolas DeSalvio, University of California, San Diego (ndesalvio@ucsd.edu); Katherine Guns, U.S. Geological Survey (kguns@usgs.gov); Allen Husker, California Institute of Technology (ahusker@caltech.edu); Julian Lozos, California State University, Northridge (julian.lozos@csun.edu); Gabrielle Tepp, California Institute of Technology (gtepp@caltech.edu); Clara Yoon, U.S. Geological Survey (cyoon@usgs.gov)

Do-it-yourself (DIY) Method to Forecast Local Earthquakes: Application to Southern California
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In recent papers, we have outlined nowcasting methods to track the current state of earthquake hazard using only observed seismic catalogs. The basis for one of these methods, the “counting method”, is the Gutenberg-Richter (GR) magnitude-frequency relation. The GR relation states that for every large earthquake of magnitude greater than M_T , there are on average N_{GR} small earthquakes of magnitude M_S . In this talk, we use this basic relation, combined with the Receiver Operating Characteristic (ROC) formalism from machine learning, to compute the probability of a large earthquake. The probability is conditioned on the number of small earthquakes $n(t)$ that have occurred since the last large earthquake, which is called “natural time”. There are two choices to be made. The first is the definition of “local”, which we take to be a circle of some chosen radius R around a point of interest, typically a city location. The second is the magnitude of the future large earthquake M_T , which must be less than or equal to the magnitude of the last large earthquake within the circle. The last large earthquake sets the reference point for the method.

No probability model is assumed, which is a major advantage. Instead, the probability is computed as the Positive Predictive Value (PPV) associated with the ROC curve in a given, defined circular region around a point of interest, typically a city location. We then compute the PPV that a future large earthquake will occur after a future calendar time increment of small earthquakes, and plot it as a function of time since the last large earthquake in the circle. The forecast shows mainshock clustering for example, the tendency of large earthquakes to cluster in time. This tendency is shown by a high initial PPV which then quickly decreases, followed by a slower buildup of probability to the next large event. Here we describe and illustrate the method by applying it to a local region around Los Angeles, California, following the January 17, 1994 magnitude $M_{6.7}$ Northridge earthquake.

The Q-score: A Magnitude-weighted Model Evaluation Score for Earthquake Forecasting

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Earthquake occurrences are often modelled with spatio-temporal point process models, such as the Epidemic-Type-Aftershock-Sequence (ETAS) model. Comparing models and assessing goodness-of-fit of earthquake forecasts can be done using tests developed by the Collaboratory for the Study of Earthquake Predictability (CSEP). However, most current earthquake forecast evaluation metrics, such as the N-test and L-test, do not give additional weight to large-magnitude events. To this end, magnitude weighted goodness-of-fit scores for earthquake forecasting have recently been introduced, such as potency weighted log-likelihood and the Q-score. We define and further investigate the Q-score, which is a quotient emphasizing model fit for the 5% largest earthquakes. Under certain regularity conditions, the expectation of the Q-score should be close to 1, and it satisfies a law of large numbers. The Q-score is evaluated for 27 CSEP next-day gridded forecasts for California earthquake data from 2012, 2014, and 2017. We also compare the log-likelihood scores of the forecasts to assess how well different models, such as ETAS, perform, both for predicting the largest events but also in terms of overall model fit.

A Decade-long Pseudo-prospective Evaluation of UCERF3-ETAS Next-day Seismicity Forecasts

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Rigorous evaluation of earthquakes forecasts is a crucial step in understanding and improving the capabilities of earthquakes forecasting models. The UCERF3-ETAS model is currently one of the most advanced seismicity models and has been used on demand for operational earthquake forecasting of important seismic sequences like the 2019 Ridgecrest one. Here, we have evaluated a very large database of UCERF3-ETAS next-day forecasts for California from 1 August 2008 to 31 August 2018. Each next-day forecast is composed of 100,000 synthetic catalogs generated by the model. The syn-

thetic catalogs comprise events with magnitude $M_w \geq 2.5$, start at 00:00:00 UTC, last 24 hours, and include all events prior to midnight in the history for generating the next day's forecasts. We evaluate the consistency of the model against 17,655 $M_w \geq 2.5$ earthquakes that occurred in California in the period 2007-2018 using the statistical tests for catalogue based forecasts developed by the Collaboratory Study of Earthquake Predictability. We find that the number of events provided by the forecast is generally consistent with the observations, especially during relevant seismic sequences such as the 7.2 M_s El-Mayor Cucapah, while swarm type sequences are more challenging. The magnitude distribution is also consistent overall. We also study the spatial evolution of the magnitude distribution to highlight regions where the model is expecting large earthquakes to happen and find that they are coherent with observed seismicity. Finally, we compare UCERF3-ETAS forecasts against fully prospective next-day forecasts produced by 27 different models operated by CSEP during between 2007 and 2018, and collected in a openly available database which constitutes a natural benchmark for the problem. We find that UCERF3-ETAS improves upon older models by providing positive information gains in most periods. The information gain tends to be zero or negative during swarms when UCERF3-ETAS is compared against models having a non-parametric component signaling possible benefits of including one to better describe this type of seismic sequences.

Non-interacting Seismicity in the San Jacinto Fault Zone: Insights From Earthquake Cycle Simulations

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The San Jacinto Fault Zone (SJFZ) in Southern California exhibits prolific seismicity, characterized by its large amount of microseismicity and productive moderate-sized mainshocks. We built a 15-year (2008-2022) seismic catalog in the SJFZ using deep-learning algorithms. Based on a statistical analysis, we find that there are different seismicity patterns above and below the geodetically determined locking depth. Above the locking depth, the behavior is clustered, and below is largely non-interacting. We further confirm our observations through a declustered catalog obtained from a temporal ETAS modeling that finds the majority above locking depth are triggered, and below are background events. To explore the physical origins of the non-interacting seismicity, we use fully dynamic simulations of earthquake sequences and slow slip on a rate-and-state fault with a stochastic heterogeneous transition zone below the locked seismogenic zone. Our modeling shows that the combined observations of non-interacting seismicity from this study and the lack of repeaters from previous studies provide very strong, non-trivial constraints on the properties of the transition zone. Our findings suggest that adding further complexity to how the heterogeneous transition zone is represented is key to fully reproducing the observed behavior.

Dynamic Rupture Simulations on the Rose Canyon, Spanish Bight, and Descanso Faults, San Diego, Southern California
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The city of San Diego does not have the same reputation for earthquakes as Los Angeles or San Francisco. However, both parts of the San Andreas system and the offshore Borderlands faults contribute to seismic hazard in the region. In particular, the Rose Canyon Fault passes through downtown, then forms a releasing junction with the shorter Spanish Bight Fault under San Diego Bay, which in turn has a 4 km releasing stepover with the offshore Descanso Fault. We use dynamic rupture simulations to investigate potential earthquakes for San Diego, with a particular focus on whether the Rose Canyon, Spanish Bight, and Descanso faults can rupture together in a single event. Our fault geometry comes from a combination of detailed CHIRP data from San Diego Bay and the SCEC Community Fault Model, our surrounding material properties are from the SCEC Community Velocity Model, and we implement a range of on-fault stresses based on local seismicity. We find that the geometry of these faults easily allows them to rupture together – so much so that, even in simulations without the Spanish Bight Fault, rupture is still able to jump the larger releasing stepover between the Rose Canyon and Descanso faults, either in a single event or two closely-spaced events. These simulations suggest that a M7+ earthquake directly under San Diego is physically plausible. Not only does this have significant implications for rupture and ground motion hazard in San Diego, it also may help improve understanding of how plate boundary strain connects from onshore to offshore faults.

Southern California Seismicity: Past, Present and Future

[Poster]

Poster Session • Friday 17 April

Conveners: Nicolas DeSalvio, University of California, San Diego (ndesalvio@ucsd.edu); Katherine Guns, U.S.

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POSTER 151

What's New at the SCEDC & SCSN: Data Products, Services, and Tools for Seismic Data in Southern California

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The Southern California Seismic Network (SCSN) is an integrated seismic network where we acquire data, create seismic products, and archive data. As the archive of the SCSN), the Southern California Earthquake Data Center (SCEDC) provides access to a comprehensive earthquake catalog and seismic data to end users. In addition, the SCEDC also provides catalog review status information that allows users to view the curation status of a given day. Along with the on-prem archive, SCEDC has a cloud-hosted archive which can be accessed free of cost with the additional benefits of increased performance and a more customized computing environment, thus lowering the barriers for scientific investigation. Research groups may use data provided by the SCEDC to create new algorithms or to provide data products that augment the existing catalog viz. double difference catalogs and ML derived catalogs. The archives also include data from seismic instrumentation deployed on a temporary or semi-permanent basis. The SCEDC provides a range of tools to access these data products, both for human users and for programmatic use.

In this presentation, we showcase the latest data products that are available at the SCEDC and how to access them. We also highlight how to discover which data products are available, such as the Data Discovery Map, which is a web-based app which allows the user to geographically query the SCEDC for continuous, triggered waveforms and phase data. We review FDSN and SCEDC web services and PySTP that allow programmatic access to waveform, event, station metadata and availability data in the archive. To smooth the learning curve for SCEDC's cloud-hosted archive, we provide several publicly available templates and examples. We highlight how the machine-learning powered SOA services developed at and adopted by the SCEDC are used for further refining earthquakes detected by the real-time monitoring system and for adding events that were missed in real-time.

POSTER 152

S-wave Attenuation Preceding the 2010 El Mayor-Cucapah, Baja California, Mexico Earthquake (Mw7.2)

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We used strong-motion records from foreshocks recorded by seismic stations located in the epicentral zone of the 2010 El Mayor-Cucapah earthquake (Mw7.2) to estimate S-wave near-source attenuation and the spatial-temporal evolution of the decay parameter κ (κ). We found that κ estimated from foreshocks has significantly higher values than those from mainshock. Since κ is inversely proportional to Q and depends on the state of stress and fluid content, this indicates that Q was higher during the mainshock rupture process, probably due to higher concentration of stress. We calculated the average regional S-wave attenuation $\tilde{\kappa}(r)$ before and during the mainshock and we

found higher attenuation before the main event, suggesting a possible role of crustal fluids in the rupture process. Before and during the main rupture $\tilde{\kappa}(r)$ increased with increasing hypocenter distance, but at short distances ($r < 17$ km) $\tilde{\kappa}(r)$ increased faster before the mainshock. However, during the main rupture $\tilde{\kappa}(r)$ increased faster than during the foreshock sequence for $r > 17$ km, suggesting that the tectonic stress probably decreased beyond that distance. 18 days before the mainshock, the near-source attenuation (κ_s) was low in the ruptured area, $\kappa_s=0.0374$ s, increasing during the next 30 hours to $\kappa_s=0.0490$ s. This higher value of κ_s before the triggering of the mainshock suggests a possible relation between low Q and the presence of fluids. The likely presence of fluids where the foreshocks occurred coincides with a conductor zone interpreted by Cortez-Arrollo et al. (2018) as an aquifer associated with the Cerro Prieto geothermal field. Then, κ_s started to decrease to the value of $\kappa_s=0.0024$ s during the occurrence of the main event. We interpret this decrease in κ_s as due to increasing Q resulting from an increase of tectonic stress before the occurrence of the Mw7.2 earthquake. Additional evidence of fluid presence in the rupture area is a fumarole near the ruptured fault (Fletcher et al., 2014). We conclude that κ is useful for understanding the preparatory phases of the earthquake rupture process.

POSTER 153

Illuminating Hidden Seismicity Patterns Along the San Jacinto Fault Using a Dense, Long-term Array of 300 Seismic Sensors

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Understanding the mechanisms driving earthquake swarms requires the detection of small, often imperceptible earthquakes. These microearthquakes can reveal transient processes such as aseismic slip, fluid migration, or stress redistribution, which may precede larger seismic events. However, many of these precursory processes remain hidden due to the limited detectability of small earthquakes. To uncover the full picture of swarm evolution, fault activity, and foreshock–aftershock behavior, more complete seismic catalogs are essential.

To overcome these detection limitations, we deployed a dense array of 300 nodal sensors for over two years at the Piñon Flat Observatory, along the central San Jacinto Fault in Southern California, one of the most seismically active regions in the state. By applying slant-stacking techniques tuned to the fault geometry and crustal P- and S-wave velocities, we significantly enhance the signal-to-noise ratio and detect ten times more events than the standard SCEDC catalog. These array-based detections are then associated with nearby broadband stations to validate the detections, improve event locations and build an expanded seismicity catalog. This new catalog enables a much improved characterization of foreshock and aftershock sequences and reveals seismicity patterns that were not described before.

POSTER 154

Evaluating Stress Transfer on the Puente Hills Fault Due to Earthquakes on Nearby Source Faults in Southern California

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Stress transfer resulting from fault rupture during earthquakes is commonly reported in and around active plate boundaries. Such processes can have significant consequences in densely populated urban regions, such as Southern California, where they not only adversely affect infrastructure but are also capable of leaving lasting societal impacts. The Los Angeles Basin in Southern California is tectonically active and has generated earthquakes of vary-

ing magnitudes over time. The structural complexity of the basin is further increased by the frequent occurrence of both known and unknown faults of various types, including normal, reverse, and strike-slip faults.

The primary objective of this study is to develop a stress transfer model for the Puente Hills Fault (PHF) resulting from earthquakes triggered by nearby source faults. The Puente Hills Fault is a blind thrust fault that was not identified until 1999, during research conducted following the Northridge earthquake. The fault consists of three segments: the Los Angeles segment, the Santa Fe Springs segment, and the Coyote Hills segment, arranged from north to south.

We use Coulomb 3.3 to evaluate stress transfer effects caused by earthquakes on nearby source faults that may or may not trigger rupture on the Puente Hills Fault. Preliminary results indicate that the Chino Hills Fault (CHF) has no significant influence on the PHF, whereas the Newport–Inglewood Fault (NIF) could potentially trigger rupture on all segments of the PHF. In contrast, the San Jose Fault (SJF) produces variable stress patterns depending on focal depth. Ongoing work focuses on assessing the effects of additional nearby source faults, including the Whittier, San Andreas, and San Gabriel faults, on the Puente Hills Fault.

POSTER 155

Rapid-response Seismic Imaging of the Aftershock Sequence of the 14 April 2025 Mw 5.2 Julian Earthquake

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On 14 April 2025, an Mw 5.2 earthquake occurred ~5 km south of Julian, California, within the Peninsular Ranges between the Elsinore and San Jacinto fault systems. The event triggered a rapid-response seismic deployment aimed at capturing the early aftershock sequence in a structurally complex fault corridor. Beginning on 16 April, within 48 hours of the mainshock, we installed a dense temporary array to understand the fault geometry and aftershock behavior that are relatively poorly resolved by the standard regional catalog made using conventional methods. In total, we deployed 36 nodal seismometers (SmartSolo IGU-16HR 3C 5 Hz) to augment the permanent network, achieving near-complete azimuthal coverage around the mainshock and recording approximately one month of continuous data.

Using these data, we constructed an AI-based earthquake catalog using AI-PAL (Zhou et al., 2025), a streamlined workflow that first builds a rule-based seed catalog and then trains a transformer-based phase detector to scan continuous waveforms, integrating nodal and SCEDC stations. The resulting catalog contains approximately 1,200 earthquakes, representing a sixfold increase relative to the standard SCSN catalog, and reduces the magnitude of completeness by ~0.2. Relocated events and cross-sectional imaging will reveal fine-scale fault geometry and improved delineation of seismicity patterns not resolved in the conventional catalog. Spatiotemporal analyses will further resolve aftershock clustering and migration, providing new constraints on fault structure and potential effect on the Elsinore fault ~7 km northeast of the epicenter. These results will demonstrate that dense temporary deployments combined with AI-based detection substantially improve earthquake catalogs and fault imaging in structurally complex regions, even over short recording intervals.

SSJ-SSOC-SSA Joint Session: From Slow to Fast

Earthquakes: Bridging the Spectrum of Fault Slip

Oral Session • Thursday 16 April • 2:15 PM Local

Conveners: Aitaro Kato, University of Tokyo (akato@eri.u-

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Temperature Controls the Episodic Dynamics of Deep Slow Slip

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The deformation regime that accommodates tectonic motion at plate boundaries changes as pressures and temperatures increase with depth, transitioning from the shallow frictional sliding of seismic ruptures to deep, viscous flow. We use recurring swarms of low-frequency earthquakes in this transition zone to measure the recurrence intervals and durations of accompanying slow slip across four plate boundaries. We observe both of these time scales to systematically decrease with depth. Assuming fault motion is entirely episodic, we find an average slow slip rate of 0.6 +/- 0.3 cm/day across all four plate boundaries that is constant with depth, despite the observed depth-dependent slow slip time scales. Thermal models place these slow slip dynamics within a common, narrow range of temperatures. Our results suggest deep slow slip is the result of the episodic unjamming of the plate boundary by frictional heterogeneities whose relaxation is modulated by the temperature dependence of the surrounding viscous material.

Slow Earthquake Activity and the Role of Seamount Subduction in the Guerrero Seismic Gap, Mexico

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The Guerrero seismic gap off southern Mexico has not produced an $M_w \geq 7.5$ megathrust earthquake for ~115 years; however, geodetic and seismic observations document diverse slip modes along the megathrust interface beneath the gap. Recurrent slow slip events (SSEs), tectonic tremor, and low-frequency earthquakes (LFEs) occur from downdip depths to near the trench. In addition, a tsunami-earthquake-like event on 18 April 2002 (M_w 6.7) ruptured the shallow megathrust with a long source duration, weak high-frequency radiation, and low radiated seismic energy per unit moment (scaled energy); nevertheless, it constitutes a seismic (fast) event relative to SSEs.

Here we integrate residual gravity anomalies and seafloor bathymetry with recent offshore ocean-bottom seismometer (OBS) observations to test whether subducting seamounts govern the spatial partitioning of slow versus fast slip. The 2002 low-scaled-energy rupture and associated near-trench seismicity coincide with rugged incoming-plate relief and positive residual gravity anomalies, consistent with the subduction of a candidate seamount. In contrast, along-strike segments where seamount relief is not apparent and the incoming plate is comparatively smooth exhibit more persistent tremor/LFE activity and episodic SSEs, whereas the farther downdip region landward of the candidate seamount is largely aseismic and is characterized by negative residual gravity anomalies.

We interpret these patterns within a hydromechanical framework in which seamount subduction damages the hanging-wall accretionary wedge, reduces rigidity, and increases porosity and permeability. Enhanced permeability may facilitate drainage and lower pore pressure on the shallow interface, favoring fast yet low-radiated-energy rupture. Conversely, elevated pore pressure along smoother segments lacking seamount subduction may promote slow earthquakes. Together, these results underscore the importance of seamount-controlled structure and fluids in modulating megathrust slip behavior and near-trench tsunami hazard.

Seamount-controlled Tremor Distribution at Hyuga-nada Revealed by High-Resolution Vp and Vs Imaging

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Subducting seamounts are increasingly recognized as a key control on megathrust slip behavior by modulating structural, rheological, and geomechanical properties of the plate boundary. In the Hyuga-nada region off Kyushu, Japan, the subducting Kyushu-Palau Ridge (KPR), a remnant of the Izu-Bonin arc, forms a prominent topographic high and separates the Ryukyu Trench from the Nankai Trough. Tremors and very low frequency earthquakes cluster around the subducting seamount, yet tremors are absent above the flat top of the KPR and instead concentrate along its flank; seismic reflection images also show splay faults at the seamount edge that appear to separate tremor-rich and tremor-poor domains. To better constrain the physical properties controlling this distribution, we integrate active-source and ambient-noise seismic imaging by applying viscoacoustic reflection full waveform inversion (FWI) to KR-0114-8 streamer-cable data (>10 Hz) and analyzing a dense 2020 ocean-bottom seismograph (OBS) survey with one month of continuous recording. Air-gun shots constrain P-wave velocity through traveltimes tomography and waveform inversion, while ambient-noise interferometry provides S-wave velocity from multimode Scholte waves (0.5–1.0 km/s), imaging structure to ~500 m below the seafloor. The combined P- and S-wave velocity models reveal low-velocity zones and anomalous Vp/Vs near splay faults and KPR-related structures; these low-velocity zones are interpreted as regions of elevated pore-fluid pressure and localized fluid migration. Our results suggest that seamount-related fault boundaries and pore-pressure heterogeneity strongly control tremor occurrence in Hyuga-nada.

Coupling Heterogeneity in the Cascadia Slow-slip Zone From GNSS Inversions and Physics-based Modeling

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Slow slip events (SSEs) in the Cascadia subduction zone (CSZ) exhibit pronounced along-strike segmentation in moment magnitude and recurrence intervals. Notably, the central Cascadia segment has longer SSE recurrence intervals but smaller moments. Here, we combine geodetic inversion and physics-based numerical modeling accelerated by scientific machine learning (SciML) to investigate the underlying physics of this variability.

We first derive and invert inter-SSE velocities for CSZ coupling at the SSE depth, exploiting the spatial and temporal alignment of SSEs and tremors. We then use a SciML-based reduced-order model of rate-and-state friction (Magen et al., 2025) for a Bayesian inversion using observable SSE recurrence intervals and moment magnitudes to infer the kinematic coupling and effective normal stress in Cascadia's SSE zone. Our Bayesian inversion suggests near-lithostatic pore pressure (99.3%–99.7% of lithostatic) and coupling values comparable to those geodetically derived. The SSE cycle modeling reveals strong coupling ($60 \pm 23\%$) in the northern SSE zone and weaker coupling ($40 \pm 20\%$) in the central and southern segments. The agreement between the geodetics and the physics-based models validates inter-SSE coupling heterogeneity as a primary control on Cascadia SSE segmentation. While effective normal stress dictates recurrence intervals, coupling variations regulate moment release. Finally, we compare our long-term kinematic coupling model, which averages over transient SSE recurrence, with the inter-SSEs model to assess the amount of slip deficit accumulating in the SSE zone. In northern and southern Cascadia, SSE slip primarily releases the slip deficit accumulated between SSEs. Central Cascadia accumulates a slip deficit (~40% of plate rate) not accounted for by transient events. Whether this slip-deficit will be accommodated by a future large SSE, a change in SSE rate, or during a margin-wide megathrust rupture remains an important question.

Magen, Y., May, D., Gabriel, A.-A., (2025), EarthArxiv, doi: 10.31223/X5QT7V

Spatiotemporal Modulation of Episodic Tremor and Slow Slip Behavior by Tectonic and Environmental Stresses in Cascadia

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Slow earthquakes such as episodic tremor and slow slip events (ETS) are very sensitive to small stress perturbations, yet their links to tectonic and non-tectonic forcings are unavailable. Previous studies suggested that the annual hydrological cycle controls the tremor seasonal behavior in northern Cascadia. However, extended observations reveal a pronounced change in tremor seasonality after 2015, calling this hydrological interpretation into question. In this study, we calculate variations of tectonic and environmental stresses, including hydrological and tidal loading, in northern and central Cascadia and assess their impacts on ETS activity. We find that tectonic stress has exhibited strong interannual variability since 2015, with stress rates exceeding peak hydrological stressing in the northern Cascadia transition zone, which may reduce or mask any potential hydrological influence on ETS seasonality. We also observe a shift in ETS propagation direction from northward to southward since ~2012 in northern Cascadia, coincident with changes in along-strike stress differences. Together, these observations suggest that spatiotemporal variations in tectonic stress on the subduction interface play a key role in controlling ETS nucleation, propagation, and tremor seasonality. Tidal stress modulation is further influenced by tectonic stress near the propagating ETS front, resulting in systematic variations in tremor tidal sensitivity across early, late, and outside ETS stages. These variations may reflect evolving frictional properties over the ETS cycle. In central Cascadia, the pronounced contrast in tidal sensitivity between late-ETS and outside-ETS tremors suggests that a substantial fraction of tremors occurring outside ETS periods may be hosted on forearc faults rather than on the subduction interface. Our results reveal a profound influence on slow earthquake behaviors at different temporal scales from tectonic and environmental forcings and provide new insights into the underlying mechanisms of slow earthquakes.

Supershear Rupture Enabled by Bimaterial Effect and Favorable Energy Ratio Enablein the 2025 Myanmar-Mandalay Earthquake

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Joint seismic and geodetic analyses revealed that the 2025 M_w 7.7 Myanmar earthquake ruptured ~530 km along the Sagaing Fault, with a sustained supershear rupture extending ~450 km on its southern branch. Far-field Mach waves and near-field ground motion confirmed the supershear nature. This exceptionally long supershear rupture caused severe building collapse and soil liquefaction, as observed in satellite imagery, offering insights into the damage potential of such ruptures in urban areas. The sustained supershear propagation was facilitated by fault's linear geometry, prolonged interseismic quiescence, favorable energy ratio, and pronounced bimaterial contrasts across the fault interface. These findings underscore the roles of fault structure, stress accumulation, and material contrasts in governing rupture dynamics, demonstrating that large-scale supershear propagation can occur in complex continental fault systems.

A New Fault Slip Mode Unveiled in the Regional Dynamic Triggering of the 2023 Turkey Kahramanmaraş Earthquake Sequence

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Faults can slip at vastly different rates, generating both high-stress-drop regular earthquakes and low-stress-drop slow slip events (SSEs). Here, we docu-

ment a transitional mode of high-stress-drop but “silent” slip with two $M_w \geq 5$ events that were triggered by the 2023 Turkey Kahramanmaraş earthquake sequence. Specifically, we identify eight fault slip events from radar interferometry, none of which are reported in seismic catalogs. Except for four typical aseismic creep events, two events represent earthquakes whose waveforms were obscured within the coda waves of the mainshocks. Notably, we find two silent events that did not radiate discernible high-frequency seismic energy nor produce local aftershocks but did exhibit high stress drops of 4–6 MPa, similar to regular earthquakes. These two “silent” events likely represent a new fault slip mode positioned between regular earthquakes and SSEs. The identification of these diverse shallow slip events, which are missed in seismic catalogs, calls for reevaluation of faulting mechanisms, the nature of static/dynamic triggering effects, and seismic hazard assessments.

Stress Interactions Among Strong-weak Fault Patches Govern Earthquake Cycle

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Both seismic and aseismic slips have been identified along different fault systems, yet how they interact with each other and affect earthquake nucleation and recurrence remains unclear. Based on tomographic images and spatiotemporal earthquake distributions along the Gofar transform fault before and after the 2008 M_6 earthquake, here we develop a two-dimensional fault model to simulate stress interactions between adjacent strong and weak patches, as well as asperity healing in the fault plane. In our model, strong and weak fault patches are characterized by distinct frictional properties and spatial heterogeneities. We show that stress accumulation and release at different patches drive distinct seismic sequences. Stress transfer within the weak patch, from aseismic zones to small asperities, triggers abundant foreshocks, while transfer from the weak patch onto the adjacent strong patch nucleates mainshocks. The mainshock in turn reloads the weak patch, driving aseismic transients and aftershocks therein. Furthermore, the model highlights the role of asperity healing and frictional heterogeneities in modulating earthquake periodicity and magnitudes. Our results align with observations from the Gofar transform fault, emphasizing the importance of stress transfer among contrasting fault segments in controlling earthquake cycles. These findings suggest combined deterministic-stochastic interactions across scales control different earthquake behaviors.

Characterization of Focal Mechanisms for Small Earthquakes Preceding the Mw 7.5 Noto Peninsula Earthquake

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On January 1, 2024, a M_w 7.5 earthquake struck the northern Noto Peninsula in Japan. Prior to the mainshock, an intense seismic swarm persisted for over three years—driven by fluid propagation and accumulation—and led to two large foreshocks: the M_j 5.4 event in 2022 and the M_j 6.5 event in 2023. High-resolution earthquake catalogs are essential for elucidating earthquake nucleation processes, but they provide only a limited view of the detailed faulting mechanisms, fault structures, and spatiotemporal stress changes involved. In contrast, focal-mechanism solutions for small earthquakes (e.g., $M < 3$)—which are challenging to obtain using traditional methods when station coverage is sparse—provide subtle, qualitative constraints on fault orientations and stress changes. In this study, we aim to deepen our understanding of the Noto Peninsula earthquake's long-term nucleation by characterizing focal mechanisms of small foreshocks to reveal detailed stress evolution and infer associated fault structures.

We employ the recently developed, cross-correlation-based double-ratio inversion method FocMecDR to determine focal mechanisms of small earthquakes preceding the M_w 7.5 Noto Peninsula earthquake. Analogous to the double-difference concept in earthquake location, FocMecDR uses a reference event with a known mechanism (i.e., strike, dip, and rake) and inverts nearby target events by (1) matching relative polarities for pairs of events via waveform cross-correlation and (2) minimizing the misfit between observed and theoretical P/S amplitude double ratios for pairs of events. We focused on the period from January 2020 to March 2024 using the FocMecDR and 135 F-net focal mechanisms as templates, and determined focal mechanisms for more than 1,000 $M > 2$ earthquakes. The detailed variations in focal mechanisms delineate the dipping angles of fine fault structures and the spatiotemporal evolution of stress. Most interestingly, we found reversed normal-fault-

ing earthquakes following large events. In this presentation, we will report these results and discuss the detailed nucleation process before the Mw 7.5 mainshock.

Supercritical Fluid Flow, Phase Transitions, and Seismicity at the Brittle–ductile Transition Imaged by Integrated Active and Passive Seismology
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Supercritical fluids around the volcanic brittle–ductile transition (BDT) are commonly considered to suppress brittle failure because of high temperature and ductile rock behavior. However, how supercritical fluids interact with faults, trigger earthquakes, and possibly influence slow seismic phenomena remains poorly constrained due to the lack of direct subsurface observations. Here, we present integrated active- and passive-source seismic observations from the Kuju volcanic field, Japan, that provide new constraints on the dynamic role of supercritical fluids around and below the BDT.

High-resolution 3D seismic reflection imaging reveals a laterally continuous horizontal reflector at BDT depths, interpreted as a low-permeability seal trapping overpressured supercritical fluids. This seal is locally disrupted along faults, forming permeable windows through which fluids migrate upward. Earthquake hypocenters extend along these faults even under supercritical conditions below the BDT, and concentrate near the disrupted zones above, demonstrating that fault-localized brittle failure can occur and be enhanced when supercritical fluids undergo phase transitions to gas or liquid. Above the permeable window, a plume-shaped zone of extremely low V_p/V_s is imaged by natural earthquake tomography, indicating strong thermal alteration and gas exsolution associated with fluid depressurization. The coexistence of trapped supercritical fluids, localized brittle failure, and gradual fluid leakage implies that similar processes may also modulate slow earthquakes or aseismic slip near the BDT.

By combining active seismic reflection imaging with passive seismic monitoring of earthquakes and seismic velocities, we directly track supercritical fluid storage, migration pathways, and phase transitions in three dimensions. Our results demonstrate that supercritical fluids do not simply inhibit seismicity, but can actively control the occurrence of earthquakes and potentially slow seismic phenomena through fault-focused deformation, seal rupture, and fluid phase changes at the BDT.

SSJ-SSOC-SSA Joint Session: From Slow to Fast Earthquakes: Bridging the Spectrum of Fault Slip [Poster]
Poster Session • Thursday 16 April
Conveners: Aitaro Kato, University of Tokyo (akato@eri.u-tokyo.ac.jp); Jiun-Ting Lin, Lawrence Livermore National Laboratory (lin51@llnl.gov); David Shelly, U.S. Geological Survey (dshelly@usgs.gov); Haijiang Zhang, University of Science and Technology of China (zhang11@ustc.edu.cn)

POSTER 140
Resolving Spatiotemporal Variabilities of Fast and Slow Slip on California Crustal Faults
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High-resolution geodetic observations capture crustal deformation due to fault slip across different time scales and slip modes. Characterizing spatial and temporal variability of fault zones is essential to understanding their dynamics and developing effective physical models. Here, we present the characteristics and relationships of seismic and aseismic fault slip in two distinct settings in California by combining multitemporal InSAR observations with unregularized Bayesian fault slip inference. In the first case of the 2019 Ridgecrest earthquake sequence, we quantify the spatial distributions of coseismic and three-month postseismic fault slip and find highly heterogeneous slip during and after the mainshock, with a clearer separation of two slip modes than previously resolved. The detailed models allow us to explore the fine-scale features of coseismic slip, afterslip, and aftershocks. In the second case of the Superstition Hills fault, we resolve the decades-long sequence of spontaneous and seismically triggered shallow slow-slip events occurring within the sedimentary layer overlying the seismogenic zone. Recent slow-slip events are spatially variable and exhibit lateral segmentations similar to large-

slip asperities in a deeper historical earthquake. In both cases, significant lateral and depth-dependent variations in fast and slow fault slip are inferred. These results imply substantial spatially heterogeneous stress variations during slow or fast earthquakes, which likely emerge from and feed into temporally complex long-term responses. Resolving kinematic constraints and limits holds promise for shedding light on the rheology and heterogeneity of fault zone systems.

POSTER 141
Post-seismic Deformation Associated With the 2020 Mw7.0 Samos (Eastern Aegean Sea) Earthquake
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Large earthquakes not only result in substantial static co-seismic deformation but also include time-dependent post-seismic deformation as stress is redistributed and propagates through the surrounding medium. This study investigates the post-seismic deformation associated with the 30 October 2020 Mw7.0 Samos earthquake (eastern Aegean Sea) using a combination of GNSS and InSAR observations. Although the seismic sequence has been extensively studied from various perspectives, its post-seismic deformation remains underexamined. We analyzed the spatiotemporal evolution of post-seismic deformation and assessed the productivity and total duration of the aftershock sequence to better elucidate the interplay between fault slip and seismicity. To this end, GNSS observations from stations surrounding the affected area were processed using the Precise Point Positioning technique, isolating the post-seismic signal while accounting for the background tectonic motion and noise. InSAR data for the same period were analyzed using the Persistent Scatterers Interferometry technique. To model the post-seismic transient signals, we fitted the displacement time series using a stretched exponential function that captures both the rapid onset of afterslip and the prolonged post-seismic processes contributing to the long-lasting deformation. A joint inversion of both datasets was conducted to explore the properties of post-seismic slip and its relationship with co-seismic slip and aftershock activity. Our analysis reveals evidence of shallow afterslip in regions surrounding the co-seismic slip area, thereby releasing a substantial post-seismic moment budget. At the same time, afterslip was sustained within the main-shock rupture zone, highlighting the slow recovery of fault locking in that region. Overall, the findings provide insights into the spatiotemporal dynamics of post-seismic deformation and contribute to a better understanding of fault behavior following large earthquakes. This work also underscores the importance of combining geodetic and seismological data for resolving post-seismic processes.

POSTER 142
Classifying Missing Seismic Sources Offshore of Southeast Japan
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The offshore region of southeast Japan experiences a broad range of slip phenomena from regular earthquakes to slow earthquakes and submarine landslides. Identifying these slip phenomena can help infer the evolution of fault zone environments, and identifying their interactions with megathrust earthquakes can provide insights into earthquake nucleation processes. Here we systematically detect, locate, model and classify offshore seismic sources in southeast Japan between 2006 and 2016 which emit coherent surface wave packets in the 20–50 s period. We apply our surface wave detector to the ~700 Hi-net high-sensitivity accelerometers and will model the sources using ~76 F-net broadband seismometers. We will further classify the events by their high to low frequency content. Our procedure makes no assumptions about the source type and has previously been used to detect a range of slip phenomena including regular earthquakes, very low frequency earthquakes, and submarine landslides. Further, the method was previously used to identify many events offshore of the Japan trench which occur both landward and

seaward of the trench and have diverse origins. We plan to detect and locate missing events in the Nankai trough, Ryukyu trench and the outer rise region. By modelling and comparatively evaluating these events, we will identify their statistical characteristics in the region.

POSTER 143
Use of Repeating Earthquakes to Discriminate Slow Earthquakes in the Central Pacific Subduction Zone of Costa Rica
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The complexity and dynamics of subduction zones exhibit a mix of fast (seismic) and slow (aseismic) slip, whose physical interaction strongly influences fault system behavior and can promote the nucleation of potentially catastrophic events. Therefore, understanding how seismic and aseismic processes interact is crucial to improve earthquake hazard assessment. Repeating earthquakes (RE), events with highly similar waveforms and magnitudes that rupture the same fault patch at different times, provide a unique opportunity to advance our understanding of this complex relationship. Using the local seismic network and modern template-matching techniques, we studied 20 RE families, with a total of 430 events ranging from 2010 to January 2026, located in the Central Costa Rica Subduction Zone, one of the most seismically active and heterogeneous regions in the country due to the subduction of seamounts and the presence of slow slip events (SSEs) occurring every 22 months or less. We show how the spatiotemporal distribution of RE correlates with the occurrence of large earthquakes ($M > 6.0$) and well-characterized SSE episodes. Additionally, the emergence of localized, uncatalogued SSEs with magnitudes below the detection threshold of GNSS—but observed at the two closest stations—is accompanied by tremors and the continued rupture of an abundant RE family including hundreds of events. The slip rate, calculated from RE assuming constant stress drop, agrees with the previously measured plate convergence rate. Our results suggest that, along with tectonic tremor, RE represents the seismic manifestation of SSEs and could be used as markers to indicate their occurrence, duration, and spatial distribution, especially in areas where GNSS networks are non-existent, lack resolution, or when their magnitude falls below the minimum required for standard identification and localization techniques.

POSTER 144
LFEs and Slow Slip Beneath the Aguas Zarcas Landslide: Evidence for Coupled Gravitational and Strike-slip Deformation in Northern Costa Rica
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On 16 July 2023, a ~10 Mm³ high-velocity landslide in Juan Castro Blanco National Park generated woody debris flows that impacted the town of Aguas Zarcas, northern Costa Rica. To quantify ongoing deformation after this catastrophic failure, we deployed a dense near-field array of 15 3-component nodal seismometers in 2024 and detected >1,500 low-frequency earthquakes (LFEs; $M_w < 1$) organized into repeating families and located using envelope cross-correlation. Building on these detections, expanded template-based searches yield thousands of LFEs that cluster (i) within the landslide basement and (ii) along an intersecting left-lateral strike-slip fault system. LFE recurrence accelerates into tremor-like bursts, implying episodic slow shear at shallow depth rather than isolated brittle failure. Ambient-noise interferometry reveals up to 14% reductions in surface-wave velocity during wet periods, linking hydrologic forcing to transient weakening and strengthening the case for pore-pressure modulation of slip. Photogrammetric analyses further indicate ongoing meter-scale displacements and ~10⁶ m³ of material poised near the crown, underscoring continued hazard. We interpret the observed LFE–tremor sequences as the seismic expression of slow slip events (SSEs) driven by coupled gravitational loading and tectonic shear, demonstrating that this system hosts a spectrum of slip behaviors, from aseismic creep and SSEs to rapid catastrophic collapse. These results motivate real-time LFE/SSE monitoring as a physics-based proxy for evolving instability in hydrothermally altered volcanic terrains.

POSTER 145
How Do Stick-slip Events Initiate on a Rough Fault?
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Laboratory experiments have demonstrated that the slip behavior of a smooth fault is governed by the relationship between the system stiffness k and fault length L relative to the critical stiffness k_c and critical nucleation length L_c . However, as natural faults exhibit roughness at multiple scales, the validity of this stability criterion for rough faults remains to be evaluated. Here, we conducted direct shear experiments on 760-mm-long granite blocks under a normal stress of 10 MPa. The rough interface between the two blocks was created by a natural fracture and is characterized by ~4 mm of topographic variation over a wavelength of ~100 mm. Gouge material was removed to promote instability. When the sample was deformed near the rough fault’s “mated” position, it mostly exhibited stable creep with hundreds of accompanying acoustic emissions ranging from magnitude -7 to -5, but it also produced occasional stick-slip events whereby the entire fault slipped rapidly (~30 mm/s). Our analysis focused on the stick-slip events and their foreshocks. The results show that the slip behavior of our rough fault cannot be explained by the critical nucleation length L_c in the above criterion. On one hand, the entire fault kept creeping without a discernible nucleation process before stick-slip events, and foreshocks were distributed across the fault surface instead of clustering around the epicenters of stick-slip events. This is similar to the behavior of a rigid block with $L < L_c$. On the other hand, stick-slip events produced dynamic rupture fronts that were clearly captured by both slip sensors and high-frequency seismograms. The ruptures were observed to initiate near one end of the sample, propagate toward the opposite end, and then propagate backward, resembling the slip behavior observed on smooth faults with $L > L_c$. Additionally, the initial 100 μ s of a stick-slip event exhibited waveforms that were nearly identical to those of a smaller acoustic emission. Therefore, the behavior of our rough fault aligns more closely with the “cascade up” model described in McLaskey (2019) rather than the “preslip” model.

POSTER 146
Detection of Repeating Microearthquakes in Southeastern Costa Rica
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Despite its small area, Costa Rica’s tectonics are complex and diverse. Zooming into the southeastern region, the subduction of the rough and buoyant Cocos Ridge beneath the Panama microplate has produced a sequence of magnitude 7 and larger megathrust earthquakes roughly every 40 years. The last one, the 1983 M7.4 event beneath the Osa Peninsula, occurred 42 years ago. The likelihood of a similar event occurring in the near future is high, underscoring significant seismic hazard in southern Costa Rica. Recently, slow slip events have been identified off the coast of Osa Peninsula on the shallow plate interface up dip of the 1983 rupture. In some areas, these slow slip events release most of the accumulated slip over their four-to-five-year recurrence time. However, we still lack a detailed view of how fault slip on this interface is partitioned between aseismic creep, slow slip, and stick slip behaviors. Repeating earthquakes, which rupture the same small asperities at different times, provide a sensitive seismic marker of slow and/or aseismic slip on the plate interface, but they have not yet been systematically identified and analyzed in this segment. In this study, we use OVSICORI’s broadband stations around Osa Peninsula to detect and characterize families of repeating earthquakes along the plate interface. We apply strict criteria including robust waveform cross correlation and coherence, double difference relocation, S–P differential times, and source radius overlap to ensure that events in each family repeatedly rupture the same patch. Our preliminary results show several families of repeating events at different depths along the plate interface with different recurrence intervals. By tracking the cumulative seismic moment and inferred slip of these families through time, we aim to map the spatiotemporal distribution of fault slip in the region, estimate local slip and deficits, and place constraints on interplate coupling. These results will provide improved constraints for seismic hazard assessment, including the potential size and likely rupture area of the next large earthquake in southern Costa Rica.

When Strike-slip Is Not Enough: The Full Kinematics of the Central San Andreas Fault

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Fault creep rates along the creeping section of the San Andreas fault (SAF) have been measured and modeled since the 1960s. The modeled average creep rates range from 1 to 3 cm/yr depending on the location along strike. However, such estimates mainly focus on the strike-slip component of the fault slip, overlooking the dip-slip counterpart as well as the fault-normal contraction/dilation motion. Regional stress field orientation inferred from local seismicity indicates that the maximum horizontal stress direction is at an acute angle to the central SAF, suggesting that the fault is experiencing large contractional forces. Additionally, local surface uplift and subsidence across the central SAF are also observed in our results. Therefore, we hypothesize that fault slip/creep along the central SAF is a rather complex mechanism, in other words, the complete 3D fault kinematics should exhibit not only the strike-slip component but also the two other orthogonal vectors acting on the fault.

Here, we use UAVSAR and Sentinel-1 datasets to jointly invert for the 3D surface deformation rates around the central San Andreas fault. For the UAVSAR data, we use a set of polynomial functions to correct for erroneous signals that arise from platform instability. Then, we project the horizontal surface deformation rate components to fault-parallel and fault-perpendicular directions. We model the 3D surface deformation rate with Okada's model, simultaneously solving for the rake angle and the tensile deformation on the fault. Results show that the rake angles vary between 170 and 190 degrees along the fault with the Parkfield segment showing a rather consistent reverse slip sense. In addition to faulting, we also find the tensile deformation can explain the observed surface fault-normal contraction. Possible driving mechanisms of such tensile closing might be due to the regional stress field orientation and/or the internal rotation from shearing.

Observational Evidence of a Very-low-frequency Earthquake (Mw 3.8) Leading to an Earthquake (Mw 4.2): Minto Flats Strike-slip Fault Zone, Central Alaska

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The physical conditions governing earthquake initiation are largely unknown, particularly at time scales immediately preceding rupture. While there is geodetic and seismic evidence of precursory activity in the hours to weeks prior to large earthquakes, the observational evidence immediately preceding the earthquake rupture is limited and controversial. Here we present evidence of a well-recorded event from the Minto Flats fault zone in central Alaska. The event initiated as a high-frequency signal lasting 19 s accompanied by a Mw 3.8 very-low-frequency earthquake (VLFE) on a dipping strike-slip fault. After 24 s of combined high-frequency signal and VLFE, a Mw 4.2 earthquake occurred having the same source mechanism as the VLFE. The precursory activity provides evidence for exceptional conditions for earthquake initiation. These observations highlight the Minto Flats fault zone as a natural laboratory for investigating earthquake initiation processes and provide constraints for numerical and laboratory models of earthquake nucleation.

Constraining Slow Slip in Cascadia Using a Joint Tremor-GNSS Inversion

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In the Cascadia subduction zone, slow slip events (SSEs) are episodes of aseismic fault slip that occur over days to months without producing significant earthquakes. Geodetic data constrain SSE slip through quasi-static inversions at daily to longer timescales, but lack the temporal resolution needed to resolve short-timescale variations in slip. In contrast, tremor, a superposition of low-frequency earthquakes (LFEs), provides insight into slip at much shorter timescales. However, employing LFEs to directly constrain the time history of fault slip is fundamentally challenging. The amount of slip associated with individual LFEs is poorly constrained, LFE locations are uncertain at the scale of the slipping fault, and their source dimensions are orders of magnitude smaller than the areas over which slip is typically inferred. Moreover, it

remains unclear how individual LFEs relate to surrounding aseismic slip. As a result, existing LFE catalogs are incomplete and difficult to interpret physically, with overlapping sources and low-amplitude events complicating the relation between observed seismicity and underlying fault slip.

Here, we develop a framework that leverages the relationship between continuous seismic noise amplitude and underlying LFE rates, allowing tremor amplitudes to function as a proxy for time-varying slip rates. We validate our technique using synthetic tremor generated by systematically varying LFE rates to determine how changes in tremor amplitude reflect changes in underlying slip. This relationship is then applied to real seismic data from individual stations. Finally, we develop a joint inversion in which tremor-derived slip rate estimates serve as dynamic constraints to complement static GNSS displacements, allowing the spatiotemporal evolution of slow slip to be resolved more fully. By integrating tremor-based slip rates over short time windows, this approach aims to recover recorded GNSS displacements while resolving the temporal and spatial evolution of slow slip that geodetic or catalog-based seismic data alone cannot achieve.

How Does Slow Slip Reshape Megathrust Locking?

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Interseismic locking (or coupling) models are inferred from geodetic data—typically from GNSS velocity fields—are commonly treated as long-term, time-averaged representation of megathrust seismogenic potential between major earthquakes. However, a key and little-explored question remains whether such models are stable over time, or whether transient deformation processes—particularly slow slip events (SSEs)—modulate the megathrust locking state in ways that influence earthquake nucleation and timing but remain unresolved by long-term interseismic velocity alone. Here, we build on a probabilistic Metropolis-Hastings framework that estimates the probability of locking versus stable creep on subduction megathrusts directly from GNSS data, without prescribing asperity geometry *a priori*. We present an implementation that explicitly addresses temporal variations in locking rather relying on a single long-term snapshot. We apply this approach to the Cascadia subduction zone, an ideal natural laboratory with two decades of GNSS observations and a well-documented catalog of recurrent SSEs. Using a pseudo-dynamic framework, we pursue three complementary objectives: (1) inferring locking distributions from GNSS velocities computed over successive time intervals; (2) by defining these intervals based on the initiation and termination of documents SSEs; and (3) explicitly testing the effects of accounting for SSE-related transient signals when estimating long-term and inter-SSE coupling. This strategy enables direct comparison of locking and creeping states before, during, and between SSEs, and to evaluate whether transient slow slip episodes overprint the long-term coupling or imprint short-term transient coupling variation along the subduction megathrust.

Arias Intensity as an Indicator of Rupture Kinematics in Tsunami Earthquakes

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Tsunami earthquakes are challenging to evaluate using traditional seismic techniques. They have high seismic moment and magnitudes, generate disproportionately large tsunamis, however they produce low ground shaking on land. This inconsistency indicates a lack of correlation between seismic moment and high-frequency radiated energy. Thus, classic strong-motion data do not represent this properly. We present an evaluation of the applicability of absolute Arias Intensity (AAI) as an energetic measure that can distinguish tsunami-type earthquakes from “normal” subduction-type earthquakes, deep intermediate earthquakes, complex and/or slow-rupturing earthquakes. We studied a set of strong-motion data from multiple Mw 7.6–7.8 ground shaking events by normalizing the time-series data into a common time window that corresponds to each event's origin time; this makes it possible to directly compare the time and amount of shaking across the various sites and events. Tsunami earthquakes are characterized by lower than expected AAI values due to their gradual build-up of radiated energy over much longer durations, while most of the energy released by normal subduction-type earthquakes occurs over a much shorter period of time at considerably higher AAI values. Furthermore, our analysis verified that this difference exists even when con-

sidering equal sizes and hypocentral locations, indicating that AAI is sensitive to the kinematics of rupture and the radiational efficiency of the seismic source. Therefore, we conclude that AAI is able to discriminate between the various types of earthquakes.

Interaction Between Seismic and Aseismic Slip Along the Mendocino Oceanic Transform Fault Offshore Northern California

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Compared to continental strike-slip faults, oceanic transform faults (OTFs) are thought to mainly slip aseismically and host significantly more foreshocks likely triggered by precursory aseismic slip. However, long-term high-resolution observational constraints remain limited. In December 2024, one of the largest ever OTF earthquakes occurred offshore California on the Mendocino OTF. Here we show that compared to similar-magnitude continental strike-slip earthquakes, this moment magnitude (Mw) 7.0 earthquake has an order of magnitude fewer aftershocks which suggests limited inter-event stress triggering. Nevertheless, the aftershock zone expanded with logarithmic time substantially beyond the mainshock's co-seismic rupture zone, hence likely reflects propagating aseismic slip transients. However, foreshock activity within the mainshock's rupture zone is limited and does not indicate any accelerating aseismic slip in the preceding 30 days. The 2016 Mw 6.6 and 1994 Mw 7.0 Mendocino OTF earthquakes share similar aftershock and foreshock characteristics. Our results demonstrate that low-seismic-coupling OTF segments can host aseismic slip transients triggered by earthquakes on neighboring segments while inhibiting these seismic ruptures' propagation, and enhanced foreshock activity is not a general characteristic of OTFs despite prevalent aseismic slip.

Cyclic Sealing and Drainage on an Oceanic Transform Fault

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Oceanic transform faults are commonly regarded as conservative plate boundaries, yet their structural complexity near magmatic systems implies a substantive role for fluids. Here we identify tidally modulated tremor from continuous waveforms recorded by an ocean-bottom seismometer network at the Gofar transform fault on the East Pacific Rise, revealing shallow sealing–drainage cycles. Tremor amplitude correlates with semidiurnal tides during intervals of sparse seismicity and low in situ compressional-to-shear wave velocity ratio (Vp/Vs), but this correlation vanishes following M4.0 earthquake swarms, coincident with elevated Vp/Vs. We propose a valve-like sealing–drainage dynamic to explain these observations: sealing traps volatiles, as expressed by low Vp/Vs, and the resulting low permeability causes external stress perturbations to be converted predominantly into pore-pressure variations, enhancing tidal sensitivity. Rupture opens fractures, producing higher Vp/Vs, increasing permeability, and reducing the amplitude of pore-pressure fluctuations; at the same time, a phase lag develops between the pore-pressure response and the external tidal stressing, which weakens the tide–tremor correlation or causes it to disappear, thereby resetting the system. The cycle repeats through hydrothermal resealing. Our results suggest that transform faults can behave as tidally critical permeable systems in which energy release oscillates between fluid-driven tremor and brittle rupture, paced by magmatic volatile supply and progressive healing.

SSJ-SSOC-SSA Joint Session: Lessons from Recent Major

Earthquake Sequences Around the World

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Tectonic Significance and Observations of Ground Failure From the 6 December 2025 Mw 7.0 Earthquake in Yukon, Canada

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The 6 December 2025 M_w 7.0 earthquake in southwestern Yukon (60.37°N, 139.54°W) was the largest onshore earthquake in Canada in over 75 years. The earthquake highlights the complex tectonics of the St. Elias orogen and the interrelation of the Fairweather–Queen Charlotte fault system at the North American plate boundary with inboard fault systems (Totschunda and Denali faults). We study the mainshock and aftershocks through 6 January 2026, along with widespread ground failure induced by the earthquake sequence. We present double-difference relocations of the sequence, along with associated centroid moment tensor (CMT) solutions and cluster analysis, which collectively indicate a complex rupture on multiple faults along the southernmost section of the hypothesized Totschunda–Fairweather Connector fault zone. The relocated aftershocks cluster along at least two distinct fault planes: a SE-striking plane subparallel to the regional trend of the Connector fault, and a conjugate WSW-striking plane. The CMT solution for the mainshock indicates oblique fault slip and a significant non-double-couple component. Rupture complexity is further supported by CMT solutions for large aftershock events, which indicate strike-slip rupture along the primary SE-striking fault structure (Connector fault) and reverse slip on the secondary conjugate fault. Spatiotemporal evolution of aftershocks shows no pattern, until a resurgence of up to M_w 5.7 aftershocks with reverse kinematics on December 31st that likely occurred on the secondary conjugate fault. Based on satellite imagery and a reconnaissance flight to the epicentral area, we identify over 200 landslides, extensive snow avalanches, and damage to glacial ice associated with the mainshock. Landslides are mostly restricted to the Mt. King George massif within the footprint of the aftershock sequence, whereas avalanches and damaged glacial ice are more widespread. This event has provided an invaluable opportunity to understand the tectonic structures, seismic hazard, and relations between ground shaking and mass wasting in this remote part of the Yukon.

Complex Multi-segment Rupture of the 2025 M 6.0

Afghanistan Earthquake From Sentinel-1 InSAR Data

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On 31 August 2025, a M 6.0 earthquake occurred in northeastern Afghanistan in the southern Pamir-Hindu Kush region. Afghanistan has limited local seismic network data and field access is limited, meaning that InSAR is likely. Despite its modest size, the earthquake had a significant impact resulting in ~2200 fatalities and major economic loss of over \$100 million. It was also a complex event – estimates of the source time function from teleseismic data, as well as the InSAR deformation pattern, indicate that the rupture had multiple subevents. In this study, we use InSAR data from four Sentinel-1 tracks, processed using the ISCE software, to constrain and model the complex multi-segment rupture. To improve the coseismic signal and reduce unwrapping errors, we construct a preliminary model based on hand-digitized data to flatten the interferogram prior to unwrapping then manually correct for any phase jumps. We downsample the data using quadtree decomposition and model the fault geometry (e.g. fault length, fault width, slip) using a rectangular dislocation model (Okada, 1985) and determine the best-fitting parameters through nonlinear optimization (a Powell algorithm with multiple Monte Carlo restarts).

Our preliminary results suggest that the rupture involved near-simultaneous rupture of two faults a primary ENE-striking structure in the north and a secondary WSW-striking two segment structure located ~9 km to the south-east. Both faults exhibited inward-dipping oblique thrust faulting mechanisms with minor left-lateral strike-slip components, suggesting that the earthquake

is accommodating regional tectonic compression. To best fit the observed data, we implement a three-segment fault model, with a bend in the secondary fault, which shows smaller residuals compared to a two-segment fault model. The northern fault is ~6.3 km long with uniform slip of 1.0 m, while the shallower secondary fault segment is ~3 km long with a slight change in strike with a uniform slip of ~1.3 m.

SWOT Satellite Altimetry Observations and Source Model for the Tsunami From the 2025 M 8.8 Kamchatka Earthquake

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On 29 July 2025, an Mw 8.8 earthquake struck off Kamchatka, Russia, generating a Pacific-wide tsunami and marking the largest earthquake since the launch of the surface water and ocean topography (SWOT) satellite in 2022. We analyze tsunami observations from SWOT together with three nearby deep-ocean assessment and reporting of tsunamis (DART) buoys to resolve the source of the event. SWOT provided the first high-resolution spaceborne track of a great subduction-zone tsunami, capturing waveforms that reveal complex propagation, dispersion, and scattering. Inversion of the DART time series using Gaussian unit sources shows that the rupture extended ~400 km along strike, with peak uplift of ~4 m, significantly different from the published finite-fault models available shortly after the event. A blended source that combines the DART-inverted uplift with subsidence from the seismic-geodetic model best matches both datasets and reproduces the SWOT observations. Comparison with reconstructions of the 1952 Mw 9.0 Kamchatka earthquake indicates that the 2025 rupture likely reactivated significant portions of the megathrust that broke in 1952 but occurred farther down-dip and with little to no near-trench slip, consistent with its smaller tsunami impact. These findings highlight the hazard implications of short recurrence intervals of great earthquakes and show how rupture style governs tsunami severity. They also demonstrate the value of satellite altimetry for improving tsunami source characterization, post-event forecasting, and understanding of hydrodynamic processes.

The 2025 and 1952 Kamchatka Earthquakes Viewed From Tsunami Waveforms Recorded Around the Pacific Ocean
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The July 2025 Kamchatka earthquake (Mw 8.8) generated Pacific-wide tsunamis that were recorded on DART bottom pressure gauges and coastal tide gauges. The inversion of 40 DART records around the Pacific Ocean, accounting for the elasticity of the Earth and sea water, shows large (> 9 m) slip in three subfaults at distances of 200 – 400 km SW of the epicenter with depth of 0 – 26 km below the seafloor. The average slip is 3.1 m, providing a total seismic moment of 1.87×10^{22} Nm. This solution is very similar to the USGS finite fault model based on teleseismic data. The inversion of coastal tide gauge records yields a similar result, but slightly larger average slip (3.8 m) and seismic moment (2.28×10^{22} Nm). The large slips occur at similar subfaults, but the amounts are larger (> 10 m).

In this region, a similarly great megathrust earthquake (M ~ 9) occurred in 1952. The 1952 tsunami waveforms recorded at tide gauge stations around the Pacific Ocean were very similar to those of the 2025 earthquake. Johnson and Satake (1999, Pageoph) inverted the tide gauge records and estimated the large slip at deep plate interface, without accounting for the elasticity of the Earth and sea water. We conducted the inversion of the 1952 tide gauge records for the slip distribution and clock correction at each station, considering the elasticity and station corrections obtained from the 2025 DART and tide gauge inversions. The result shows that the 1952 slip distribution was similar to that of 2025, except for the depth of the largest slip and the northern slip where foreshock and aftershocks occurred in 2025. This difference, or complementary slip, can explain the shorter interval than expected from backslip rate (~ 8 m/century) estimated from GPS analysis (Burgman et al., 2005, JGR).

Rapid Characterization of the 2025 M8.8 Kamchatka, Russia Earthquake

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The July 29, 2025, M_w 8.8 Kamchatka, Russia, earthquake was the sixth largest instrumentally recorded earthquake. This event was seismically well-observed at regional and teleseismic distances, but publicly available near-source data were sparse at the time of the event, presenting unique challenges for rapid source and impact characterization. The U.S. Geological Survey (USGS) National Earthquake Information Center (NEIC) provides global real-time monitoring for earthquakes, including rapid response information products that estimate source characteristics, shaking, and the resulting damage and impacts. We describe the USGS rapid response earthquake information products following the Kamchatka event and discuss their implications for future hazards in the region. We describe potential improvements to our response workflows motivated by this event, including constraints on source geometries and the automated selection of fault geometries for finite-fault inversions. The rapid response products together support the interpretation of a unilateral southwestward rupture with significant slip on the southwestern end of the rupture extent. The M_w 8.8–9.0 event in 1952, which ruptured a comparable extent of the Kuril-Kamchatka subduction interface, has many similarities to the 2025 rupture. This illustrates that incomplete release of slip deficits may remain following great earthquakes and highlights the usefulness of comparative studies between historic and modern events.

Rupture Propagation and Arrest in Global Strike-slip Earthquakes Constrained by CCTV Video, and Near-fault Seismic Observations

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Our understanding of earthquake rupture dynamics is limited by a scarcity of near-field observations. Important source attributes, such as local slip rise time and the dynamics of rupture arrest are poorly resolved by remote seismic recordings. In this study, we use direct video observation of seismic slip and near-fault ground motion recordings of global large strike-slip earthquakes to gain new insight into rupture propagation and arrest. We analyze CCTV footage captured during the 2025 Mw 7.7 Myanmar strike-slip earthquake, using pixel cross-correlation of successive video frames. This analysis reveals pulse-like slip propagation with rise time of 1.3 s, amplitude of 2.5 m and peak slip velocity of 3.2 m/s. The slip velocity function obtained by direct on-fault observation aligns with a pulse of near-fault ground velocity recorded during the same earthquake. The agreement suggests that near-fault (<3 km) ground velocity captures the first-order features of on-fault slip velocity during this surface breaking earthquake. Based on this new insight, we expand our analysis to include seismic observations from global large continental earthquakes (Mw 7-8) to generate a catalog of slip-parallel ground velocity pulses in the near-field of the slipping fault. Informed by dynamic rupture models, these records suggest slip rise time on the fault is short (1 – 9 s) and is arrested by stopping phases originating from low velocity layers near the surface, and from fault segment boundaries. Records from elongated strike-slip ruptures show the influence of rupture segmentation. Slip and rise time near the segment boundaries are truncated by the arrival of stopping phases, and are larger near the center of the fault segments, consistent with a crack model of rupture. We suggest that for large strike-slip earthquakes, ruptures propagate in a segmented manner, and are repeatedly punctuated by abrupt arrest at fault segment boundaries.

Along-fault Slip-rate Heterogeneity as a Control on Rupture Segmentation: Insights From Recent Major Strike-slip Earthquakes in Turkey and Myanmar

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Recent large earthquakes have challenged long-standing assumptions about rupture segmentation on major faults. The 2023 Mw 7.8 Kahramanmaraş earthquake on the East Anatolian Fault and the 2025 Mw 7.7 Sagaing fault earthquake in Myanmar both exhibited complex rupture behaviors and unexpected large magnitudes that may not be fully explained by fault geometry alone. Here we present a comparative, physics-based investigation of these two events to explore how along-fault variations in long-term slip rate influence rupture extent, segmentation, and maximum earthquake size.

Using seismic cycle simulations constrained by geodetic, geological, and seismological observations, we show that modest along-strike slip-rate variations (~10–20%) exert a strong control on rupture segmentation in both geometrically simple and structurally complex strike-slip systems. On the Sagaing fault, slip-rate heterogeneity related to the extrusion of the Yunnan and Shan-Thai plateaus reproduces the observed rupture extent and slip distribution of the 2025 mainshock and the nonstationary rupture termination points of historical earthquakes, despite the fault's apparent structural simplicity. On the East Anatolian Fault, along-strike slip-rate variations arising from slip partitioning across a complex fault network explain the recurrence of single-segment earthquakes and the rare occurrence of multi-segment ruptures such as the 2023 event.

Together, these case studies highlight a common physical mechanism linking long-term tectonic loading to short-term rupture dynamics across diverse tectonic settings. Our results suggest that rupture segmentation and earthquake magnitude can be emergent properties of spatially variable slip accumulation, in addition to other factors including structural and rheological heterogeneities. These recent major earthquakes offer new lessons from and underscores the importance of incorporating slip-rate heterogeneity into seismic hazard assessments.

Complex Initial Rupture of the Narli Fault Triggered the 2023 Mw 7.8 Kahramanmaraş Earthquake

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We investigate the initial stages of the 2023 M_w 7.8 Kahramanmaraş Türkiye earthquake to understand how the rupture of the Narli Fault began, evolved and triggered of the main rupture along the East Anatolian Fault. Using a combination of seismic and geodetic data we analyzed the Narli Fault rupture to characterize its evolution and the resulting stress change on the East Anatolian Fault. Rupture initiated at its southern end at 11 km depth and propagated northward 40 km to its intersection with the EAF. The rupture began as a cascade, initially on a normal fault plane before quickly transitioning to a steeper left-lateral strike slip rupture. Fault slip increased from south to north, and remained predominantly below 5 km depth except along a 12 km segment of the central Narli Fault where surface displacements measured 3 m. The average rupture velocity was subshear, with the rupture passing two near field strong motion instruments 22 km from the epicenter 10 s after origin. Rupture initiated on the East Anatolian Fault 17 s after origin time at the intersection of the Narli and East Anatolian Faults where stress changes due to the Narli Fault rupture were concentrated. The initiation of the M_w 7.8 Kahramanmaraş earthquake is another clear example of a complex beginning to a great strike slip earthquake.

Complex Fault Structures in Southeastern Türkiye Revealed by High-resolution Aftershock Location and Focal Mechanism Catalog of the 2023 Kahramanmaraş, Türkiye, Earthquake Sequence

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In February 2023, the Kahramanmaraş earthquake doublet struck southeastern Türkiye, consisting of a Mw 7.8 event along the Sakçagöz–Narlı Fault and a Mw 7.5 event near Ekinözü. These mainshocks triggered widespread aftershocks across the main fault ruptures, and surrounding regions within the complex Maraş triple junction. To better characterize the evolving aftershock sequence, we deployed approximately 200 SmartSolo nodal seismometers recording at 500 Hz across the rupture zone over a four-month period beginning in May 2023. To fully exploit the high-frequency nodal recordings, we developed a deep learning–based detection framework capable of processing high-sampling-rate waveforms. Specifically, we first applied the EQTransformer model to events listed in the Türkiye Disaster and Emergency Management Authority (AFAD) catalog. High-probability picks were selected as labels to construct a curated training dataset. Using this dataset, we trained a phase-picking model for 500 Hz nodal data. In parallel, we also trained a separate model using local data to process 100 Hz broadband recordings from permanent stations. The trained models were applied to approximately 100 days of continuous seismic data from more than 300 stations, yielding over 80,000 detected events after phase association between May 2 and August 23, 2023. Compared with the original AFAD catalog, the resulting event catalog contains nearly six times more earthquakes. Earthquake relocation was then performed using the XCORLOC and HypoDD programs with waveform cross-correlation to construct a high-resolution aftershock catalog, and focal mechanisms were determined using the refoc and HASH methods. Based on this high-resolution catalog, we constructed a detailed fault structure map that reveals complex fault geometries, including splay faults branching from the East Anatolian Fault, adjacent secondary fault structures, and horsetail faulting near the Savrun Fault. The improved structural resolution provided by this study offers new insights into fault complexity and significantly enhances our understanding of seismic hazards in southeastern Türkiye.

Tibetan Plateau Kinematics Revealed in a Single Event: The Mw 7.1 January 7, 2025 Tingri Earthquake

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The 7 January 2025 Mw 7.1 Tingri earthquake ruptured the southern Xainza–Dinggye rift in the Tibetan Plateau, ~200 km north of the Himalayan frontal thrust system. This rift is part of a network of discrete normal and strike-slip faults that accommodate gravitational collapse and lateral extrusion of the Plateau, despite ongoing India–Eurasia convergence. Sub-pixel image correlation and coseismically shifted DEM differencing of very-high-resolution (~0.5 m) satellite optical imagery reveals the full three-dimensional (3D) coseismic displacement field of the earthquake. Rupture occurred on two west-dipping faults: the Lagoi Fault in the north, cutting through mountainous terrain at relatively high elevation (~5500 m) within granitic-gneissic rocks, and the Dingmuco Fault in the south, bounding a lower elevation (~4200 m) basin within Tethyan metasedimentary rocks. Northern deformation consists of coherent, block-like oblique hanging wall subsidence with left-lateral slip (>2 m). Southern deformation is more distributed, with comparable magnitudes of subsidence and northwestward translation accommodated along a series of hanging wall faults. Footwall rebound is not observed. Between these domains, a ~5–10 km-wide east–west transition zone absorbs diffuse north–south contraction (~1 m) and right-lateral motion (~1.5 m), above a concave-up along-strike curved fault imaged by aftershocks that may direct slip toward its deepest center. Collectively, these observations suggest primary roles of gravity in the collapse of high elevations, weak lower crustal flow, and both lithologic and fault curvature influence on the distribution of discrete and diffuse hangingwall deformation and the direction of fault slip. The earthquake reflects geotectically- and geomorphically- documented interior Plateau-scale kinematics, but over the spatial and temporal scale of a single event.

SSJ-SSOC-SSA Joint Session: Lessons from Recent Major Earthquake Sequences Around the World [Poster]

Poster Session • Friday 17 April

Conveners: Dara E. Goldberg, U.S. Geological Survey (degoldberg@usgs.gov); Ryo Okuwaki, University of Tsukuba (rokuwaki@geol.tsukuba.ac.jp); Zhigang Peng, Georgia Institute of Technology (zpeng@gatech.edu); Dun Wang, China University of Geosciences (wangdun@cug.edu.cn)

POSTER 8
Preliminary Results on Foreshock Behaviors and Mainshock Rupture Processes of the 2025 Mw 8.8 Kamchatka Earthquake Sequence

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The July 29 2025 Mw 8.8 Kamchatka earthquake ruptured the plate interface off the east coast of the Kamchatka Peninsula along the Kuril-Kamchatka subduction zone and generated tsunamis recorded across the Pacific Ocean, followed by volcanic eruptions in Kamchatka. The mainshock was preceded by an energetic foreshock sequence that began with a Mw 7.4 event on July 20, located near the mainshock hypocenter. However, the physical mechanisms driving this foreshock sequence and its link to the mainshock are not completely clear. In this study, we present a detailed seismological and geodetic analysis of the sequence by investigating the rupture characteristics of the Mw 8.8 mainshock, the spatiotemporal evolution of the foreshock and early aftershock sequence, and the processes driving their interaction by integrating teleseismic back projection, single-station template matching detection, statistical analyses, and geodetic observations from GNSS and InSAR. Teleseismic back projection reveals that the mainshock ruptured predominantly toward the southwest with a total source duration of ~220 s. The Mw 7.4 foreshock triggered afterslip along the plate interface, which likely drove an expanding aftershock of its own and eventually triggered the mainshock nucleation. This event also shows anomalously high aftershock productivity relative to other M7+ events before and after the mainshock, consistent with an elevated likelihood of triggering a larger earthquake. We also identify possible segmentation of the megathrust rupture zone along the Kuril-Kamchatka subduction zone that is separated by higher topography in the upper plate. These results provide new insight into the physical mechanisms of foreshocks and segmentation of mainshock ruptures along major subduction zones, with direct implications for short-term forecasting and seismic hazard assessment of megathrust earthquakes in this and other regions.

POSTER 9
Controls of Along-strike Dip Variations on Multi-Section Ruptures: 3D Dynamic Earthquake-cycle Simulations of the Sagaing Fault

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The 2025 Mw 7.7 Mandalay earthquake ruptured nearly 500 km of the Sagaing fault and propagated across multiple historically inferred fault sections. Observations of coseismic horizontal displacement show systematic along-strike asymmetry that reverses from north to south, suggesting a non-vertical fault geometry with changing dip: an east-dipping northern segment, a near-vertical central section, and a west-dipping southern segment, forming a helix-shaped fault surface. Motivated by observations from this earthquake, we investigate the influence of helix-shaped 3D fault geometry on rupture behavior and ground motion across multiple earthquake cycles using a fully

dynamic earthquake-cycle simulator, EQdyna. We start with smaller, generic models for computational efficiency and a more systematic exploration of the effects of helix-shaped fault geometry, then move to the Sagaing fault models. Using rate-and-state friction, we simulate both the quasistatic and dynamic processes of earthquake cycles. We examine how helix-shape geometry may produce ruptures with different extents and their frequencies over many earthquake cycles. We aim to understand how helix-shaped fault geometry may produce ruptures comparable to the 2025 Mandalay earthquake, facilitate rupture continuity across historically inferred fault sections, and influence the occurrence of large, system-spanning ruptures relative to more localized events.

Preliminary results suggest that along-strike dip variation produces more complex rupture behavior than vertical-fault models. As the dip angle changes along strike, it drives time-evolving normal stress heterogeneity and localized stress accumulation, creating “earthquake-gate” regions that modulate rupture propagation. These zones can act as barriers that slow or arrest rupture propagation when normal stress is elevated, but under favorable stress states, they promote large slip and rupture growth, effectively behaving as slip asperities. These results indicate that dip-change plays a key role in regulating rupture continuity and extent on the Sagaing fault.

POSTER 10
Geosystemics Applied to the Seismic Preparatory Phase: Lessons from two Recent Major Earthquakes

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Recent large earthquakes provide an opportunity to test a geosystemic approach to the seismic preparatory phase, integrating lithospheric, atmospheric and ionospheric observations within the Dobrovolsky region. Using the Mw 7.1 Wushi (22 January 2024) and Mw 7.7 Myanmar (28 March 2025) earthquakes as case studies, we analyze medium term lithospheric signals (multi year) together with short term atmospheric and ionospheric anomalies (days to months before the mainshocks). In the Wushi case, about 60 anomalies are identified, with lithospheric changes persisting for about a year and atmospheric/ionospheric perturbations confined to the last three months, including outgoing longwave radiation anomalies spanning from four days before to four days after the mainshock. The Myanmar event is studied through eleven classes of potential precursors, whose temporal evolution displays a characteristic sigmoid pattern typical of a critical system approaching failure, and whose spatio temporal clustering supports the lithosphere-atmosphere-ionosphere coupling framework. Focusing on Swarm satellite data for the Myanmar earthquake, we detect Y component magnetic anomalies on 22 of 85 half orbits up to eight days before the event; empirical magnitude estimates based on anomaly duration yield $M \approx 7.2$, close to the observed M 7.7, while anomaly “energy” values cluster in a narrow range, suggesting a potential characteristic signature of seismic related disturbances. Taken together, these results highlight that (i) multi scale, multi parameter anomalies accelerate with an exponential or sigmoid trend toward the mainshock, (ii) combined ground and satellite based observations can help localize the impending event, and (iii) satellite magnetic and atmospheric anomalies may offer useful ingredients for short term forecasting schemes, although validation on broader datasets is required to assess robustness and operational applicability.

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POSTER 11
Were the Last Two Major Megathrust Earthquakes in Kamchatka Partial Ruptures? Insights From Modeling of InSAR Data From the 2025 M8.8 Event

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The July 29, 2025 M8.8 Kamchatka earthquake was one of the ten largest earthquakes in instrumental history. It occurred along a portion of the southern shore of the Kamchatka peninsula where pre-event GNSS velocities had indicated a high likelihood of frictional locking of the Kamchatka megathrust. The estimated source location overlaps in space with the source region of the 1952 M9.0 great Kamchatka earthquake, however there were significant differences between the two events – notably in the sizes of the tsunamis, with the 1952 tsunami having significantly greater runup across the Pacific basin.

We use InSAR data from multiple tracks of the Sentinel-1 mission to investigate the details of the coseismic slip of the 2025 earthquake. Using the ISCE2 software to process the data, we employ ionospheric corrections and GACOS troposphere corrections to reduce noise, and obtain good correlation across the peninsula despite the forested terrain. We resolve up to ~1.2 m of line-of-sight displacement, peaking along the SE shore. In addition, we identify fringes on the northeastern Kuril Islands that constrain the likely westward terminus of rupture. Superimposed on this earthquake deformation field are multiple volcanic deformation signals across the peninsula and islands, apparently stimulated by the earthquake. We model coseismic slip using a triangulated mesh of the megathrust, using our models of interseismic locking as a constraint on rupture area; we find that we are able to reproduce the observed displacements with up to 12 m of slip, divided into two asperities, and modest (< 4 m) trenchward slip, consistent with the modest tsunami for the event. We note that 1) tsunami inversions of the 1952 event require greater shallow slip than our model shows, suggesting that the 2025 event was not a repeat of 1952; and 2) the amount of peak slip is over double the slip deficit that likely accrued since 1952, given the 80 mm/yr convergence accommodated by the megathrust, implying that the 1952 event may also have been a partial rupture.

POSTER 12
Rupture Modeling of Major Tsunamigenic Earthquakes With Both Earthquake and Tsunami Observations

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The U.S. Geological Survey National Earthquake Information Center (NEIC) includes both seismic and geodetic observations in rapid earthquake source models. In general, NEIC’s finite fault models are derived from teleseismic observations, and may include local strong-motion, Global Navigation Satellite System (GNSS) and/or satellite imagery observations, when available. Although these local observations provide improved coverage and resolution, the largest magnitude earthquakes occur at subduction zone interfaces, precluding full azimuthal coverage from terrestrial observations alone. The limitations of terrestrial observations for constraining rupture are especially evident in cases in which the preferred earthquake slip model is incompatible with the resultant tsunami (e.g., 2020 M7.6 Sand Point, Alaska). The accuracy of slip models has important consequences for operational ground shaking and loss estimates, as well as for studies of the kinematic properties of large earthquakes. In aiming to improve the quality of large, offshore earthquake rupture models, we demonstrate new tools within the NEIC’s Wavelet Inversion for Slip (WISP) finite fault modeling software that interact with the tsunami modeling software, GeoClaw, to facilitate joint inversion of onshore earthquake observations with offshore tsunami observations. Our preliminary work demonstrates that earthquake source characterization is improved when offshore tsunami observations are considered, specifically Deep-ocean Assessment and Reporting of Tsunamis (DART) data. The tsunami amplitudes observed at available DART stations provide important constraints on the up-dip extent of slip and the amplitude of vertical deformation that may be poorly resolved by terrestrial observations alone. We illustrate the results of joint inversions of on- and off-shore instrumentation for impactful tsunamigenic earthquakes, including the recent 2025 M8.8 Kamchatka earthquake. We demonstrate the improved fits to tsunami observations afforded by including DART data alongside terrestrial observations when characterizing these significant tsunamigenic events.

POSTER 13
Low-frequency Observations of the M8.8 Kamchatka Russia Earthquake Across the Global Seismographic Network

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The July 29, 2025, Mw 8.8 Kamchatka Peninsula, Russia earthquake provides us with an excellent opportunity to analyze low-frequency normal mode records from the Global Seismographic Network (GSN). We compare this event with the March 11, 2011, Mw9.1 Tohoku, Japan, earthquake and show that improvements in the GSN make this arguably the highest-fidelity earthquake ever recorded by the GSN as evidenced by significantly improved signal-to-noise ratios (SNR) for several normal modes at frequencies near and below 1 mHz. We also show that improvements in calibration methods provide a uniform estimate of normal mode OS0 across the network. Finally, we show that we can further improve the SNR of normal mode observations by applying a pressure correction algorithm to remove the effects of long-period atmospheric pressure variations at stations with co-located barometers. As an example, we apply this method to the split normal mode multiplet OS2 and find a mean improvement of 2.3 dB. Our work demonstrates that pressure corrections can be easily applied when working with low-frequency seismic data to improve the SNR in a non-trivial way

POSTER 14
Spatiotemporal and Statistical Analysis of Foreshock Activity Preceding the 2025 July 29 Mw 8.8 Kamchatka Peninsula Earthquake

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The July 29, 2025, Mw 8.8 Kamchatka Peninsula earthquake was preceded by a 10-day foreshock sequence, including a Mw 7.4 and three Mw 6.6 events that began on July 20. I conducted a comprehensive spatiotemporal and statistical characterization of this sequence to quantify its properties in the context of regional seismicity patterns. Using IRIS FDSN catalogs spanning 1970-2025 with a radius of 350km centered around the epicenter of the Mw 8.8 event, I analyzed seismicity rate, Gutenberg-Richter parameters, and centroid migration for the foreshock sequence. The same analysis was conducted with 17 additional high-activity sequences in the region. The analysis was normalized to $M_c = 4.0$ for consistency, with bootstrap uncertainty estimation using 1000-5000 iterations. The foreshock sequence exhibited a b-value of 0.78 ± 0.07 , consistent with 55-year background levels of 0.77 ± 0.30 . The sequence exhibited an a-value of 7.30 ± 0.27 , $+1.84\sigma$ above the background mean of 5.04 ± 1.23 . The seismicity rate of the sequence was significantly higher ($+54\sigma$, $p < 0.001$) than the background mean (15577 M4.0+ events/year, background 139.2 ± 285.9 M4.0+ events/year), ranking as the most productive sequence in the analysis timeframe. Centroid migration analysis using 12-hour sliding windows reveals complex, non-linear progression during the foreshock sequence. Ongoing analyses include the evolution of spatial clustering, directional consistency metrics, and comparison with previous high-activity sequences. These results provide quantitative insights into the behavior of the foreshock sequence that began on July 20, 2025, and on high-activity sequences in the Kuril-Kamchatka trench, offering insights for future analysis.

POSTER 15
Constraining Near-trench Slip Using SWOT-observed Tsunami Wave Trains

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Tsunamis generated by large subduction earthquakes pose severe coastal hazards, yet rupture properties near the trench are often weakly constrained by land-based geodesy and sparse offshore pressure records. Following the 29 July 2025 Mw 8.8 Kamchatka earthquake, the Surface Water and Ocean Topography (SWOT) mission sampled the tsunami wavefield near the source

region and captured a clear train of short-wavelength, dispersive waves trailing the leading tsunami. We combine SWOT observations with InSAR and deep-ocean measurements to evaluate how dispersive wave physics and propagation conditions influence source characterization. Using dispersive tsunami simulations and sensitivity tests to earthquake slip, we examine which aspects of the shallow rupture and bathymetry control the observed trailing-wave structure and directionality, and we quantify what additional constraints are gained relative to conventional non-dispersive modeling.

SWOT has now sampled dispersive tsunami signals for multiple recent events, including the 19 May 2023 Loyalty Islands tsunami and the 2 May 2025 Drake Passage Mw 7.4 earthquake, motivating a broader assessment of how often trailing dispersive waves occur and when they are observable.

We highlight three implications: (1) dispersive modeling can be adopted to reproduce the full near-source tsunami wavefield, beyond the long leading waves used in standard approaches; (2) wide-swath altimetry provides complementary spatial information on tsunami structure; and (3) integrating satellite altimetry with geodetic and in-ocean observations offers a pathway to more robust tsunami source characterization.

POSTER 16

Joint Geodetic Coseismic Slip Inversion for the 2025 Mw 8.8 Kamchatka Earthquake Using a 3D Spherical Earth Model

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The 2025 Mw 8.8 Kamchatka megathrust earthquake generated deformation from the near field to global scales, providing a rare opportunity to constrain a coseismic source model using both local and very far-field geodetic observations. We estimate the coseismic slip distribution through a joint inversion of GNSS offsets from stations within ~4000 km of the epicenter and multi-track Sentinel-1 InSAR LOS data. To better model far-field static deformation while accounting for Earth curvature and three-dimensional elastic heterogeneity, we compute Green's functions using a 3D finite-element model on a spherical Earth that spans the full lateral extent of the planet and extends to the core-mantle boundary, since truncated regional domains do not accurately represent the millimeter-scale far-field deformation. The megathrust geometry is constructed from Slab2, and the near-trench portion of the interface is explicitly represented to improve constraints on vertical deformation relevant to tsunami generation.

Our preferred model indicates that coseismic slip is primarily concentrated at 20–40 km depth, with a peak slip of ~8 m, and little slip on the near-trench portion of the interface. This slip pattern produces limited near-trench uplift (< 3 m), consistent with the relatively modest tsunami following the event. The northern termination of slip is near the creeping segment and aligns with the 1952 rupture limit, indicating structural control on rupture extent. The model reproduces the observed far-field decay, with horizontal displacements less than 2 mm beyond ~2000 km from the epicenter. Sensitivity tests show that lateral and vertical variations in shear modulus strongly affect both the amplitude and decay of static displacements from regional to far-field distances, whereas the influence of Poisson's ratio is comparatively minor. Compared with the 3D structure model, uniform-structure models predict larger far-field deformation—by up to a factor of two at distances of thousands of kilometers, indicating that increasing rigidity with depth in the real Earth reduces long-wavelength deformation.

POSTER 17

Bilateral Supershear Rupture of the 2025 Mw 7.7 Myanmar Earthquake Imaged by Global P-wave and Regional Surface-wave Back-projections

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We present high-resolution rupture imaging of the 2025 M_w 7.7 Myanmar earthquake using global teleseismic P waves and regional-distance Rayleigh waves. Most radiated energy was released near the epicenter within the first 20 seconds, followed by bilateral rupture propagation along the central Sagaing Fault, extending ~350 km southward and ~100 km northward, with sustained supershear speeds (~4.6–5.0 km/s) in both directions. Global P -wave back-projection captures the overall rupture extent and energy evolution, while

fault-limited regional Rayleigh-wave back-projection using data from the dense Southern Yunnan array in China resolves finer segmentation and timing. The event's low apparent stress and its occurrence along a long, straight, strain-accumulated fault segment are consistent with a mature fault system and supershear rupture behavior. This study demonstrates the complementary strengths of global teleseismic and regional-distance arrays and underscores the value of integrated seismic imaging for rapid response and hazard assessment in active tectonic regions.

POSTER 18

Linkage Model and Seismic Hazard of Fold Accommodation Fault: Insights From the Pengzhou Fault in the Longmen Shan Piedmont Zone, Western China

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The Pengzhou Fault is a key structure resulting from the eastward propagation of the Longmen Shan into the Sichuan Basin. Its activity was evidenced during the 2008 M_w 7.9 Wenchuan earthquake by the development of nearby surface folds and ground fissures. This study integrates field surveys, borehole data, and high-resolution 3D seismic data to analyze the structure of the central Longmen Shan Pengzhou blind structural belt. We employ fold-related fault theory, quantitative displacement analysis, and InSAR data to resolve the fault's three-dimensional geometry, growth history, and seismic hazard. Seismic interpretation reveals that the Pengzhou Fault is a high-angle, fold-accommodating fault localized within the forelimb kink band of a detachment fold above the Lower Triassic Jialingjiang Formation. Displacement analysis indicates a linkage growth model, whereby fault segments identified by displacement peaks have coalesced through fold amplification and lateral connection to form the current fault. Slip tendency analysis demonstrates that the fault does not present a uniform hazard. Instead, linkage zones characterized by steeper dips and abrupt changes in strike exhibit elevated slip tendency and earthquake potential, marking them as priority targets for earthquake monitoring and hazard assessment. The study offers important constraints on foreland propagation mechanisms of the Longmen Shan and provide a framework for assessing seismic hazard associated with growing fold-accommodating faults in similar tectonic settings.

Subaqueous Evidence for Earthquakes, Coseismic

Landslides, Tsunamis and other Cascading Hazards

Oral Session • Wednesday 15 April • 4:30 PM Local

Conveners: Daniel S. Brothers, U.S. Geological Survey

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Submarine Faulting and Landslide Deposits in the Outer California Borderland, Southern California

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The Outer California Borderland (OCB) is a tectonically complex region offshore southern California, which accommodates motion between the Pacific and North American plates. Despite geomorphological and seismic evidence of active faulting and slope failure processes, the OCB remains one of the least understood portions of the plate boundary. We present high-resolution sub-bottom and multibeam bathymetry data from three OCB basins - San Nicolas, Cortes, and Veleo, which are all aligned adjacent to the long and continuous Ferrello fault zone. This comprehensive dataset images recent deformation along multiple fault segments, and both proximal and distal submarine mass transport deposits (MTDs) across all three basins. The geophysical data are tied to Ocean Drilling Program boreholes in the San Nicolas Basin (Site 1013) and Cortes Basin (Site 1012) for age constraints and sediment physical properties. The data show consistent acoustic stratigraphy across the three basins from the Late Pleistocene to Holocene, which enables mapping and correlation of MTDs across multiple depocenters. In several locations, MTDs are observed to fill accommodation at faults, suggesting earthquake triggered

slope failure. Furthermore, fine-grained MTDs are observed in the high-resolution subbottom data that were not resolved using older technologies and are not distinguishable with visual core observation alone. These types of MTDs are likely underrepresented in slope stability and geohazard assessments in many regions. Overall, observations from the three OCB basins provide critical context for the reconstruction of regional paleoseismicity, submarine sedimentary processes, and marine geohazards.

Lack of Empirical Links Between Shaking and Turbidity Current Generation in Barkley Canyon, Cascadia Subduction Zone

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Seismic hazard estimates for the Cascadia Subduction Zone (CSZ) rely on shaking proxies such as offshore turbidites that can be used derive to magnitude and recurrence intervals. These assume that shaking from CSZ earthquakes remobilizes seafloor sediment, but empirical observations of seismically-generated turbidity currents are lacking in the CSZ. Few quantitative estimates exist linking shaking intensity to turbidity current generation, challenging our ability to fully constrain past shaking and earthquake characteristics. The Ocean Networks Canada (ONC) cabled seafloor array in Barkley Canyon provides concurrent seismic, turbidity, and other oceanographic data in a seismically active portion of the margin. Multiple large regional (>M6) and moderate local (<M6) earthquakes occurred during the ONC operating period 2016–2023, allowing us to search for direct observations of shaking and concurrent canyon system processes.

Using the Barkley Canyon Axis (BACAX) oceanographic nearbed turbidity sensor data, we created a catalog of turbidity events at BACAX using a short-term average/long-term average (STA/LTA) algorithm to identify elevated signal levels with a subsequent exponential decay. To determine the likely cause, we examined associated oceanographic data (i.e., oxygen, temperature), and acoustic doppler current profiler (ADCP) velocities. We also computed shaking intensity from regional seismicity and theoretical strain measurements generated by large regional and teleseismic events. We evaluated correlations between the turbidity events and associated metadata. We found nearly all 50 events at BACAX are internal tide generated, and unrelated to shaking, except one down-canyon event that is not preceded by significant shaking or strain. We conclude that there were no statistically significant links between ground motions and turbidity events at this site. This method may be used at other canyon systems, where sediment transport processes may differ from the sediment-starved Barkley Canyon.

Distinguishing Earthquakes From Flood Deposits in a Submarine Canyon Head: Implications for the Marine Paleoseismic Record

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Submarine canyons are often the focus of marine paleoseismic investigations, yet interpretations of these event deposits require improved constraints on event triggering and sediment routing. While earthquakes often trigger sediment gravity flows, canyons can also be affected by oceanographic disturbances (e.g., storms, waves, tides). Astoria Canyon, located on the northern Cascadia margin, has a detailed record of both major flood periods and megathrust earthquakes, providing a natural laboratory to investigate differences between these two types of deposits. To assess this, we collected a series of ~4 m long sediment cores along the floor of the upper canyon. Cores from ~800 m water depth preserve varved stratigraphy due to a lack of bioturbation in sediments at depths of the oxygen minimum zone, allowing for detailed geochronology and event characterization. Geochemical and stratigraphic analyses reveal two distinct modes of gravity-flow deposition: terrestrial-rich turbidites associated with river floods, and heterogeneous, marine-sourced debris flows triggered by the 1700 CE Cascadia earthquake. We demonstrate that a diagnostic compositional model can reliably differentiate these origins: flood turbidites are identified via terrestrial geochemical composition and lower flow structures, while earthquake deposits contain marine material remobilized in high-density flows. These results revise several assumptions of

highstand canyon sediment routing; nonseismic sediment gravity flow triggers remain active, coseismic flow deposits accumulate on the upper slope, and correlating deposit density structures is unreliable over short distances. Together, these findings demonstrate that canyon channels impose a complex filter on downslope transport, and that margin-scale assessments of highstand dormancy, canyon head flushing, and long-distance runout remain oversimplified. Insights from this study emphasize transport in localized, short-runout flow events, and future seismoturbidite analyses may benefit from compositional comparisons against upslope sources both near and far from the site of deposition.

Lacustrine Record of Paleoseismicity in the Patagonian Andes South of the Chile Triple Junction: Evidence of Seismic Activity From a Silent Subduction Zone

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The Austral subduction zone, south of the Chile Triple Junction, is an anomalously quiescent subduction zone where the Antarctic plate slides beneath the South American plate. This subduction zone is responsible for fueling the system of active volcanoes that cap the Patagonian Andes and has experienced moderate crustal seismicity in the last century, suggesting that—like other long-quiescent, highly destructive subduction zones—it may be capable of producing large magnitude, tsunamigenic earthquakes.

We investigate the paleoseismological record of this region by analyzing the lacustrine deposits of Lago Argentino, one of the largest Patagonian proglacial lakes located east of the Andean Cordillera. We analyze 10 gravity and piston cores extracted from the lake sediment and integrate them with CHIRP seismic profiles to identify megaturbidites and turbidites in two sub-basins within the lake. The cores show a sedimentary record characterized by annually laminated sediment (varves), occasionally interrupted by volcanic ashes (tephra) and event deposits. some of which we interpret as turbidites and mass transport deposits (MTD). We use a semi-automated varve-counting method to date the identified deposits and correlate them across the sub-basins.

The results of our analysis show at least three mass-transport deposits in the last 1,500 years. The seismic reflection data indicate the presence of a deeper, older event. These megaturbidites and turbidites can be correlated across subbasins separated by bathymetric barriers, indicating that they originated from independent subaqueous landslides, supporting the interpretation of these events as being simultaneously triggered by ground shaking. Our interpretation suggests a recurrence interval of ~500 years. Considering the seismotectonic settings of the region, which shows the occurrence of recent events with $M_w > 5$ along nearby north-south trending thrusts within the Patagonia precordillera, we link these deposits to crustal seismicity, likely driven by glacial isostatic adjustment driving fault reactivation, rather than activity along the subduction megathrust.

Post-glacial Seismoturbidite Deposits in Ozette Lake, Washington, Reveal Clustering and Bi-modal Recurrence of Strong Shaking During the Last 14,000 Years

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Ozette Lake is a ~100 m deep coastal lake situated above the locked portion of the northern Cascadia megathrust and is known to contain a sedimentary record of prehistoric earthquake shaking based on previous research. The deepwater depocenters contain evidence for earthquake-triggered turbidite deposits spanning the post-glacial sedimentary record, but only the last 12 events have been previously sampled and dated. To extend the record, a full post-glacial sediment record was collected using a suite of percussion-driven piston-cores in Ozette Lake in 2021. At each core site we penetrated through the stratigraphic boundary separating coarse-grained outwash sediments below from fine-grained, organic-rich, post-glacial sediments above. The post-glacial section in the proximal subbasin contains thirty-three primary, sand-bearing turbidite deposits inferred to be earthquake triggered (based on physical characteristics). Detailed radiocarbon dating (172 dates total), tephrochronology (Mazama ash), and Bayesian age modeling were used to con-

struct a long-term age-depth model of earthquake shaking history. The results yield a mean recurrence interval of 420±180 years for the last ~14.2 kyr B.P. However, the distribution of recurrence intervals is markedly bimodal and fluctuates throughout the Holocene amongst shorter intervals of ~325 years and longer intervals of ~625 years. Comparison of individual primary event ages with other well-dated paleoseismic sites in northern Cascadia suggests most of these primary turbidite events were generated by megathrust earthquakes, including full- and partial-margin ruptures. Lastly, four secondary, fine-grained event deposits are subtly expressed in portions of the proximal basin; these have also been dated and may be associated with earthquakes along the North Olympic Fault Zone. In summary, the density of reliable dates and relatively low uncertainties in the Ozette Lake record can serve as a benchmark for reevaluating other paleoseismic archives in northern Cascadia.

Subaqueous Evidence for Earthquakes, Coseismic Landslides, Tsunamis and other Cascading Hazards [Poster]

Poster Session • Wednesday 15 April

Conveners: Daniel S. Brothers, U.S. Geological Survey (dbrothers@usgs.gov); Jenna C. Hill, U.S. Geological Survey (jhill@usgs.gov); Jillian Maloney, San Diego State University (jmaloney@sdsu.edu); Drake M. Singleton, U.S. Geological Survey (dsingleton@usgs.gov); Robert Witter, U.S. Geological Survey (rwitter@usgs.gov)

POSTER 157

Submarine Deformation by the Intra-arc Strike-slip System in Southern Chile: Faulting, Sedimentation, and Seismicity Processes on the Liquiñe-Ofqui Fault Zone

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The Chile subduction margin is strongly shaped by tectonic and climatic processes. The oblique convergence generates strain partitioning, evidenced by large megathrust earthquakes and upper-plate strike-slip fault systems. As a consequence, southern Chile has hosted two of the largest earthquakes recorded in history: the Mw 8.8 Maule 2010 and the Mw 9.5 Valdivia 1960 events. Here, transient deformation is mainly expressed in the Liquiñe-Ofqui Fault Zone (LOFZ).

The LOFZ is a dextral intra-arc strike-slip fault system extending between ~37–48°S. South of ~42°S, it is located in a fjord-archipelago setting, where additional complexity arises from interactions between tectonic, glacial, climatic, and oceanographic processes. In this region, the LOFZ has exhibited seismic swarms related to fluid circulation and larger-magnitude events, such as the M 7.1 event in 1927 and the Mw 6.2 event of April 2007. The latter triggered a landslide and tsunami at latitude 45.5°S, resulting in casualties.

In this work, we study a submarine trace of the LOFZ using multichannel seismic reflection data, collected at 42°S in the Gulf of Ancud, to map the fault system and characterize deformational and depositional processes. We complement our analysis with focal mechanism calculations and relocated seismicity. Our results reveal the submarine continuation of the LOFZ, evidenced by a pull-apart basin and associated transtensional faults. Stratigraphic relationships suggest diachronous fault activity and syn-kinematic sedimentation. Together with ongoing seismicity and a 2008 swarm, this indicates active strike-slip deformation on the continental shelf, with fluids playing a role. The presence of submarine landslides highlights the potential for cascading geohazards. We also observe moraine deposits and changes in sedimentation style within the pull-apart basin, showing interaction between faulting and glacial-marine processes. These findings highlight the critical role of fault systems in fjord-archipelago settings in controlling sedimentation, geomorphology, and tsunami hazards.

POSTER 158

Lacustrine Paleoseismic Proxies from Lake Whatcom, Washington, USA: Decoding Megathrust and Crustal Shaking Using 14 m Sediment Cores

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Lacustrine paleoseismic investigations in seismically active regions, including Alaska, Chile, the Alps, and the Cascades, provide valuable long-term records of megathrust and crustal earthquakes, critical for assessing seismic hazard. Here we present chirp subbottom data, shallow sediment cores (1–2 m), and two 14-m composite piston cores collected from Lake Whatcom, WA, located in the northern Cascadia subduction zone. Lake Whatcom provides a comparison with coastal lacustrine paleoseismic sites (e.g., Ozette, Crescent) as it lies ~300 km inland from the subduction interface and near multiple zones of active crustal deformation capable of generating ground motions exceeding 5.5 MMI. Lake Whatcom also presents an opportunity to examine down-core petrophysical differences between shaking-induced and hydroclimatically induced event deposits.

Lake Whatcom sediments contain mass-transport deposits (MTDs) and regionally correlated volcanic tephra (i.e., Mazama) within a stratigraphically conformable lacustrine archive. These sediments record watershed evolution from a glacially dominated regime to present-day conditions. Preliminary observations suggest that some MTDs are earthquake-triggered, forming laterally extensive event deposits with sharp basal contacts. These deposits have coarse sediments at the base that fine upward and are typically capped by fine-grained clay. In contrast, flood-induced deposits are typically fine at their base, coarsen towards peak flood discharge. As discharge decreases, sediments fine upward accordingly. To constrain depositional chronology, we sampled composite core UW01 and obtained 54 radiocarbon ages to construct a Bayesian P-sequence age model that provides a framework for evaluating MTD timing and postglacial (~14ky) changes in sedimentation. These new observations from Lake Whatcom help distinguish megathrust from crustal earthquake shaking. Comparing Lake Whatcom's age model with well-dated records from sites such as Lake Ozette allows us to identify proxies for regional megathrust events and distinguish them from earthquake proxies of nearby Cascadia crustal faults.

POSTER 159

Characterizing Earthquake-triggered Sedimentation in an Intraplate Setting: Delta Collapse and Turbidite Deposition From the 2020 Mw 6.5 Stanley Earthquake (Idaho, USA)

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The 2020 moment magnitude (M_W) 6.5 Stanley earthquake generated Modified Mercalli Intensity VI–VII shaking at Stanley Lake, a proglacial basin ~20 km southeast of the epicenter in the Sawtooth Range of central Idaho. Strong shaking triggered the collapse of a ~0.015 km² delta into Stanley Lake, creating an opportunity to study how lacustrine systems in intraplate tectonic settings respond to and preserve evidence of strong ground motion. In 2025, we conducted a single-beam bathymetric survey and extracted 20 short (0.6–2.0-m-long) percussion-driven gravity cores along three longitudinal transects spanning the delta failure zone, lake depocenter, and moraine-bound eastern margin. Our objectives were to (1) characterize the extent, thickness, texture, and composition of the 2020 earthquake deposit; (2) compare seismically triggered, background, and deltaic sedimentation; and (3) explore evidence of strong ground motion at Stanley Lake from prehistoric earthquakes on nearby faults such as the Sawtooth fault. Our sonar survey reveals rough bathymetry extending from the delta failure zone into a 0.5-km-long, 0.4-km-wide, and ~26-m-deep depocenter. Sediment cores include a near-surface turbidite that is intercalated with laminated background sediments and varies from ~0.5 m to a few millimeters thick in the center of the basin, as well as older coarse beds and tephra deposits. Ongoing analyses using core imaging, particle-size analysis, X-ray fluorescence, and radiocarbon and luminescence

dating will characterize the physical and geochemical signatures of the earthquake deposit and the history of basin sediments. Our results will advance our understanding of how earthquake-triggered sediment failures and resulting turbidity flows vary spatially within intraplate lake basins and whether sedimentologic and geochemical proxies can help distinguish seismic from non-seismic deposits in paleoseismic reconstructions.

POSTER 160

Detailed Marine Paleoseismic Records From Earthquake Triggered Submarine Landslides in Outer Prince William Sound, Alaska

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The USGS is engaged in a multi-year effort to investigate the earthquake, landslide and tsunami hazards along the Alaska-Aleutian Subduction Zone. As part of this work, high-resolution chirp subbottom and sparker seismic reflection profiles were collected across Prince William Sound (PWS) in 2024 and 2025. PWS, which lies atop the Alaska-Aleutian megathrust boundary, has extremely high sedimentation rates that offer detailed marine paleoseismic records of both megathrust and smaller regional earthquakes.

Sediment in the central sound is primarily sourced from glacial retreat and the Copper River delta, whose sediment plume is swept northward along the coast and funneled into southern PWS at Middle Ground Shoal (MGS) in Orca Bay. MGS is an ~100m thick prodelta with extensive mass wasting visible in both the seafloor bathymetry and subbottom data. Slope failures are also pervasive along the steep walls of the central PWS channel. The headwalls and debris fans of these failures are evident in the bathymetry data and imaged as multiple, stacked mass transport deposits (MTDs) in the subbottom data. These chaotic, blocky MTDs grade into highly reflective deposits interpreted as sand-rich graded beds in the basin centers. With an epicenter in northeastern PWS, the 1964 M9 Great Alaska earthquake appears to have triggered widespread slope failures with stratigraphically synchronous deposits across the central basin and Orca Bay. The 1964 deposit is a 4-8m thick MTD that thins basinward into a series of stacked graded beds. Beneath this, we observed at least 10 basin-wide, MTD-graded bed events within the late Holocene (<~4.5kyr), consistent with previous megathrust recurrence estimates. The largest and most widespread deposit appears to be the penultimate event, which has a ponded MTD >30m thick in the deeper parts of the basin. Many of the ponded deposits are also overlain by a series of stacked graded beds indicative of failures from multiple slips of the basin. Numerous additional, thinner graded beds between these megathrust event deposits may record more frequent, smaller intraslab or crustal earthquakes.

POSTER 161

Offshore Site Effects in Alaska: Geologic Factors and Pervasive Small-strain Nonlinearity

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The importance of site amplification and the geologic factors controlling it are well understood for onshore sedimentary basins, while offshore site amplification has not been addressed adequately, despite its significance for slope stability during great earthquakes including compounding hazards from earthquake-triggered submarine landslides, and for the quantitative interpretation of the turbidite record as a paleoseismic proxy. In this study, we investigate linear and nonlinear site amplification using waveforms of regional and teleseismic earthquakes recorded by 75 ocean bottom seismometers from the Alaska Amphibious Community Seismic Experiment (AACSE), spanning Kodiak Island and the Alaska Peninsula, across water depths of up to ~5 km. We derive a linear amplification factor using a generalized inversion framework, and compare the site terms with ground motion model predictions. We also compare site terms with geomorphic parameters, such as slope angle and water depth, which illuminate geologic controls on offshore ground motion variability. Additionally, we search for evidence of nonlinearity by evaluating the amplitude dependence of site period, derived from horizontal-to-vertical spectral ratios. Preliminary results show that some stations exhibit nonlinear

dynamic softening at relatively low peak ground acceleration, even approaching the level of seismic ambient noise.

POSTER 162

Using Lake Records to Investigate Earthquakes in Stable Continental Interiors: Case Study of the 1638 M6.5 New Hampshire, USA, Earthquake

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In 1638 CE, an estimated M6.5 earthquake generated significant ground shaking in south-central New Hampshire, in the stable continental region of the northeast United States. Given the challenges of preserving fault surface rupture in low-strain, humid continental vegetated regions and limited historical accounts, the source and extent of shaking of this event remains poorly understood. Lacustrine paleoseismology is a tool to study the record of earthquakes in both high- and low-strain tectonic areas. To better constrain the character of the 1638 earthquake, we compiled and analyzed archived and published cores and core data from 12 lakes in the proposed epicentral region. As a starting point, we focused on lakes within the estimated, yet highly uncertain, ground-shaking Modified Mercalli Intensities (MMI) of V½ to VIII. Some previous cores from this area exhibit grain-size and composition changes that could be interpreted as promising evidence for shaking-related sediment disturbance or transport, consistent with other historical earthquakes studied in eastern US lakes. However, many of these cores were collected and studied in the context of climate and environmental studies, and an overarching consensus on the correlation and/or trigger of the deposits is largely unexplored. We seek to resolve the timing and character of possible disturbance deposits within these cores to determine if they may be attributed to the 1638 or earlier earthquakes. Our contribution aims to: 1) improve shaking intensity estimations by defining an area that experienced significant ground-shaking, and 2) identify older earthquakes using the 1638 earthquake signature in lakes as a historic analogue. This rich dataset of prior work may guide locations to extract additional cores to better characterize regional ground shaking from the 1638 and possibly older earthquakes.

POSTER 163

Evidence of Widespread and Historical Earthquake-triggered Deformation, Slope Failure, and Associated Deposits Within Lake Washington and Lake Sammamish

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The greater Seattle, Washington region is exposed to complex seismic hazards from Cascadia megathrust, deep intraslab, and shallow crustal earthquake sources. To better constrain the timing, distribution, and effects of strong ground motion from these sources, the U.S. Geological Survey is conducting a multiyear paleoseismic investigation of Lake Washington and Lake Sammamish. These lakes lie within zones of strong to very strong predicted ground motion during a Cascadia megathrust event and are intersected or bounded by several active crustal faults, including the Seattle fault zone. Continuous postglacial sedimentary records that are sensitive to ground-motion-induced deformation are well preserved in both lacustrine basins.

Two multi-week field campaigns in 2021 and 2024 acquired chirp subbottom profiles and sediment cores from both lakes, along with high-resolution bathymetry in Lake Sammamish. Bathymetric data document multiple slope failures along basin margins, while chirp profiles image shallow faulting and deformation, basin-wide unconformities, and buried mass-transport deposits (MTDs). In Lake Washington, radiocarbon ages from sediment cores link the timing of MTDs—including prominent turbidite deposits—to the 923–924 CE Seattle fault rupture. Lake Sammamish preserves a correlative basin-wide unconformity, deformation, and turbidites, although evidence for extensive slope failure is limited.

In Lake Washington, thin sand deposits along basin margins are spatially correlated with chirp sub-bottom amplitude anomalies. 137Cesium activity profiles from the upper 50 cm of sediment show a pronounced peak attributed to maximum fallout in 1963. We interpret a shallow MTD correlated to low

137Cs values, and just above the 137Cs peak, as the lacustrine response to the 1965 M6.7 Puget Sound intraslab earthquake (local MMI ~6.5). This age estimate is compared to independent trace-metal chronology. Planned USGS coring in 2026 will further refine regional earthquake chronologies and assess spatial variability in shaking recorded in these lake basins.

POSTER 164
Potential Effects of the 1983 M6.9 Borah Peak Earthquake on Nearby Lakes
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Lacustrine sedimentary archives can improve estimates of prehistoric earthquake timing and intensity, but doing so requires modern analogues to understand how lakes respond to intense shaking, especially across diverse basin types and environments. The 1983 M6.9 Borah Peak earthquake in central Idaho remains one of the largest intraplate earthquakes in the United States. Here, we revisit sediment cores previously collected from multiple Holocene lakes in this region. The lakes exist (either fully or partially) within the slope-failure prone Eocene Challis Volcanic Group and many of the lakes are landslide dammed. While the original cores were designed to investigate longer-term Holocene sedimentation and watershed response to climate and lake formation, we hope to gain insight to paleoseismic activity using the Borah Peak earthquake as a historic analogue. As the original work entertained the possibility for landslide-dammed lakes to have a seismic origin, the numeric chronologies from these lakes demonstrated that they formed asynchronously, deeming failure by regional strong shaking unlikely. Furthermore, mass movements of similar type and scale were not documented due to intense shaking from the Borah Peak earthquake. Our goal is to assess whether these lakes archive a response to seismic shaking within their sedimentary records by analyzing surface drives for a subset of the lakes within the modeled Modified Mercalli Intensity (MMI) range of VI to VII½ for the Borah Peak earthquake. Additionally, we hope to use the previously characterized lake chemistry and sedimentation to assess additional variables that may influence the sensitivity of lacustrine systems to earthquake shaking when relating the earthquake records from each lake. These data will contribute to the growing catalogue of historic analogues of seismically disturbed lakes in the Intermountain West and comparable intraplate settings.

POSTER 165
Fingerprinting of Mass Transport Deposits Using High-resolution XRF Core Scanning
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Earthquake-triggered mass transport deposits (MTDs) are used in subaqueous paleoseismology to investigate earthquake cycles in seismically active regions. Distinguishing earthquake-triggered MTDs from MTDs triggered by fires or floods is a critical step that allows subaqueous sediments to function as natural seismographs, constraining earthquake recurrence and regional seismic hazard. Confidently attributing an MTD's triggering mechanism in lake and fjord sediments can be challenging. To address this, we apply geochemical analysis alongside petrophysical measurements of sediment cores to examine depositional processes in these aqueous environments. We employ X-ray fluorescence (XRF) core scanning as a non-destructive approach to rapidly measure a suite of elements at high spatial resolution. The XRF downcore data reveal clear compositional variations within MTDs that distinguish them from the background sediments. These variations reflect shifts in provenance, mineralogy, sorting, grain size, and/or event-induced changes related to redox conditions.

This study integrates high-resolution XRF core scanning with petrophysical properties to investigate the provenance of MTDs in fjord sediments from Prince William Sound, Alaska, located along the Alaska-Aleutian subduction zone, and lake sediments from Lake Whatcom, Washington, situated in the Cascadia subduction zone. Both study sites contain MTDs triggered by earthquakes, marked by sharp basal contacts. In Prince William Sound, this transition is captured by increases in quartz and alumina-silicate (Si) and decreases

in the small-grained silt fraction (i.e., K). In addition, a synchronous decrease in redox-sensitive elements (e.g., Mn) suggests that subaqueous MTDs are likely to result in bottom-water anoxia. In contrast, land-derived MTDs (e.g., landslides, debris flows, floods) are likely to introduce fresh organic matter and shift the bottom water to more oxic conditions. This study explores the geochemical signature of MTDs at two different sites to reconstruct the processes and impacts of earthquake-triggered mass-wasting events.

POSTER 166
Evidence of Seismic, Climatic, and Volcanic Events in the Sedimentary Record at Chelatna Lake, Alaska Over the Past 11,000 Yrs.
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Chelatna Lake is located on the southern slope of the Alaskan Range and experiences strong ground motion from megathrust, intraslab, and crustal sources along the Alaska-Aleutian plate boundary. The lake is 11.8 km long, 1.3 km wide, 133 m deep, and occupies a glaciated valley with approximately 5% of the catchment under ice. To develop the paleoseismic record from Chelatna Lake we collected a comprehensive dataset of high-resolution Chirp, multi-beam bathymetry, and sediment cores—the longest core reaches 17.5-meters beneath the lake floor.

Chirp and bathymetry data reveal evidence of widespread slope failures, including a buried landslide complex over 4 meters thick that extends across the entire lake basin. Several older mass transport deposits, also interpreted as slope failures, are imaged in the Chirp data. The sediment consists of varved stratigraphy interrupted by thicker anomalous beds—interpreted as either seismically or flood generated turbidites—as well as tephra. Two groups of interpreted earthquake-related deposits are revealed within the sediment record, 1) thin, light brown turbidites and 2) darker, sandy megaturbidites. Cs-137 activity in the lake sediment suggests that at least three thin turbidites record historical earthquakes, including the 2018 Mw7.1 Anchorage and the 1964 Mw 9.2 Great Alaska earthquakes. Core-to-seismic correlations reveal that the large subaqueous failures imaged in the Chirp data are represented in the cores as thick megaturbidites. We further sub-sample the sediment record to develop an age model informed by radiocarbon and tephrochronology data and to extract downcore physical properties (e.g., grain size, XRF, and geotechnical data). Initial observations indicate over 50 earthquake-related deposits are preserved over the past ~11,000 years in Chelatna Lake. The long sedimentary record in Chelatna Lake, variation in earthquake-related deposits, and abundant local and regional seismic sources presents an opportunity to investigate the relationship between seismically triggered deposit characteristics and quantitative estimates of strong ground motions.

POSTER 167
Shaking Evidence Near the Epicenter of the 1964 Great Alaska Earthquake at Allison Lake, Alaska USA
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Proximal to the epicenter of the 1964 Mw9.2 Great Alaska Earthquake, Allison Lake contains a high-resolution, sedimentary archive of deposits that record >4000 years of post earthquake shaking. Located in Alaska's Chugach Mountains above Port Valdez and Prince William Sound (PWS), the 58-m-deep lake is fed by a glaciated, high-precipitation watershed. The Allison Glacier covers 20% of the watershed and supplies the lake's primary inlet stream and voluminous fine-grained sediment across a broad fan delta.

Sediment cores collected in the lake between 2006–2010 revealed annual laminations of silt and clay (varves) with thicknesses that correlate with regional precipitation records. Varve counting and the 1963 peak in ¹³⁷Cs activity suggest that a 5-cm-thick graded turbidite records 1964 earthquake shaking. In 2023–2024, we returned to the lake to investigate evidence of older earthquakes and acquired lake-wide, multibeam bathymetry, sub-bottom

chirp profiles, additional short (<2m) percussion-driven gravity cores, and a 13-m long composite piston core collected with a Uwitech platform. Chirp data resolve multiple large-volume, mass-transport deposits beneath the lake floor that correlate with 8-10 thick (5–40 cm) megaturbidites in the composite core. CT-scanning, XRF intensity, grain-size and multi-sensor core logger data characterize lake sediment properties. Three sub-facies distinguish the thick, gray megaturbidites from thinner (<5 cm) gray and brown turbidites: 1) basal normally-graded sand overlain by 2) light-grey silt and clay that is capped by 3) millimeter-scale silt-clay lamina. Varve counts, tephrochronology, radionuclide and radiocarbon dating inform an age-depth model that spans the past 4400 calendar years before 1950. This interdisciplinary analysis aims to differentiate seismically triggered deposits from flood-related sedimentary features in Allison Lake. Ongoing work focuses on comparing the lacustrine paleoseismic record of Allison Lake with submarine landslide evidence from nearby Port Valdez and to reexamine the regional paleoseismic history of the eastern Alaska-Aleutian subduction zone.

Time-Dependent Seismic Hazard Assessment: Models, Data and Applications

Oral Session • Wednesday 15 April • 4:30 PM Local
Conveners: Aybige Akinci, National Institute of Geophysics and Volcanology (aybige.akinci@ingv.it); Fabian Bonilla, Gustave Eiffel University (luis-fabian.bonilla-hidalgo@univ-eiffel.fr); Pablo Heresi, University of Chile (pheresi@uchile.cl); Felipe Leyton, University of Chile (leyton@csn.uchile.cl); Gonzalo A. Montalva, University of Concepción (gmontalva@udec.cl); Katleen Wils, Ghent University (katleen.wils@ugent.be)

A Three-dimensional Diffusion Model for Spatiotemporal Aftershock Forecasting Applied to Taiwan Seismicity
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This study proposes a novel spatiotemporal aftershock forecasting framework based on a three-dimensional heat-diffusion ordinary differential equation (Heat-Diffusion ODE), addressing key limitations of traditional two-dimensional earthquake models in representing three-dimensional spatial structure and physically consistent diffusion processes. The proposed model integrates octree-based nonuniform spatial partitioning for three-dimensional feature engineering and constructs a physically consistent spatial diffusion operator using a graph Laplacian formulation combined with the finite-volume method (FVM). Temporal aftershock decay following a mainshock is modeled through incorporation of the Omori-Utsu law. The model is applied to an earthquake catalog from Taiwan spanning 2001–2025 and is systematically benchmarked against the classical two-dimensional Epidemic-Type Aftershock Sequence (ETAS) model. Results demonstrate that, across a wide range of magnitude thresholds and forecasting time windows, the proposed three-dimensional model consistently outperforms ETAS in terms of the area under the ROC curve (AUC), F1-score, and Matthews correlation coefficient (MCC), indicating more robust risk-ranking performance in three-dimensional space. Parameter stability is further assessed through bootstrap resampling, confirming the robustness of the estimated model parameters. These results indicate that coupling three-dimensional spatial feature engineering with physics-informed diffusion dynamics substantially enhances both the predictive performance and physical interpretability of spatiotemporal aftershock forecasting, providing a viable alternative to conventional spatiotemporal statistical models.

The Modulation of Microseismicity by the Solid Earth Tides Characterizes Fault Zone Physics and May Help With Physics-based, Time-dependent Seismic Hazard Assessment
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Recent advances in earthquake detection techniques have enabled the detection of a large amount of new, small earthquakes, thereby providing insight into small-scale deformation processes in the crust. In particular, this progress helps observe weak phenomena like the modulation of the rate of seismicity

by the small stress perturbations induced by the solid Earth tides along terrestrial faults (~1kPa). Our recent work has shown that the tidal modulation of microseismicity along the Ridgecrest fault zone, in California, varied in strength and in style (stress-controlled vs stress-rate-controlled seismicity) over time. Our analysis revealed that the modulation of on-fault seismicity significantly increased in strength in the few years preceding the 2019 M7.1 mainshock and that, most importantly, the modulation of on-fault and neighboring seismicity transitioned from a stress-controlled regime to a stress-rate-controlled regime. Here we present similar observations along other fault zones that experienced large earthquakes (Parkfield, Kumamoto). We focus on the implications these observations have on fault zone physics to understand whether certain processes may establish fault zone conditions that are favorable for failure in large earthquakes. This work aims to improve on our ability to assess seismic hazard throughout time using new observational constraints on the physical state of a fault.

Time-dependent Ground-motion Scenarios for Large Megathrust Earthquakes and Mature Seismic Gaps Along the Chilean Margin
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Time-dependent seismic hazard assessments require ground-motion models that explicitly account for rupture timing and spatial variability of intensity measures due to evolving fault conditions. Here, we present a simulation framework that combines empirical models for the Effective Amplitude Spectrum (EAS) and the Group Delay Time (GDT) with physics-informed rupture scenarios to generate broadband ground-motion time histories for large subduction earthquakes. The empirical EAS and GDT models are derived from a curated strong-motion dataset from the Chilean subduction zone. For megathrust earthquakes, the total seismic moment is decomposed into subevents with prescribed rupture and travel times. We first apply the framework to the 2010 Mw 8.8 Maule, 2014 Mw 8.1 Iquique, and 2015 Mw 8.3 Illapel earthquakes, using coseismic slip models and also interseismic coupling distributions, to examine whether coupling can serve as a proxy for earthquake ruptures. Results show systematic differences: slip-based simulations slightly overestimate observed amplitudes, whereas coupling-based scenarios yield lower, more conservative ground motions while preserving realistic temporal characteristics, particularly record duration. Residual analyses indicate improved performance relative to commonly used predictive models, especially in terms of temporal coherence and spatial variability. Finally, we apply the methodology to mature seismic gaps identified from coupling models, including the Atacama and Central Chile segments, last ruptured in 1922 (Mw~8.5) and 1730 (Mw~9.0), respectively. Simulations at virtual stations reveal high ground-motion levels in densely populated cities such as Valparaíso and Santiago, underscoring the importance of time-dependent scenario-based hazard assessments for exposure, vulnerability, and risk associated with 1730-type events. Overall, integrating geodetic coupling into time-dependent ground-motion forecasts demonstrates how rupture timing and fault loading influence seismic hazard estimates, with direct relevance to engineering applications and seismic risk in subduction environments.

Assessing Temporal Variations of H/V Spectral Ratio From Long-term Seismic Noise Records
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Site response plays a key role on the spatial distribution of damage produced by earthquakes, becoming a relevant topic on seismic hazard estimation. This leads to several methodologies devoted to properly perform site characterization, but only a few of them have addressed time variations of site response. In this study, we used the horizontal-to-vertical spectral ratio (HVSr) to characterize the site response, combined with cluster analysis to define changes in the site's behavior. We studied data from more than 100 stations of the Chilean Seismic Network, some of them with more than 12 years of continuous record-

ings. We performed HVSR calculations on a complete day (24 hours) for 1 day in each month of each year. Then, we clustered all the resulting HVSR's curves into 3 possible responses: flat curve, low amplitude peak and large peak. These changes seem to occur daily, with changes in the percentage of each case. This behavior is shown to be present in less than 10% of the total of the network. We are currently working on understanding the underlying mechanism that produces this phenomenon.

Non-Poisson Probabilistic Seismic Hazard Analysis
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In Probabilistic Seismic Hazard Analysis (PSHA), the Poisson assumption remains the dominant framework: earthquakes are assumed to be temporally and spatially independent. However, earthquake are not independent, most notably in the form of aftershock sequences. Traditionally, PSHA address this by declustering catalogs to remove dependent events. While this satisfies the Poisson assumption, it ignores that dependent events can cause damage to structures. Simply removing the dependent events leads to systematic underestimation of the hazard. Recently, simplified approaches have been developed to include dependent events. For example, the United States Geological Survey incorporates dependent events into the activity rate and magnitude-frequency distributions but relies on the spatial distribution of independent events to model the locations of future earthquakes. The hazard is computed using the Poisson assumption. We propose a methodology for non-Poisson PSHA that accounts for the dependence of aftershocks on the occurrence of the mainshock. We modify the probability of exceedance of the ground motion from a single event used in PSHA to the probability of exceedance from any event in the sequence (foreshock, mainshock, or aftershock). The rate of the sequence is the mainshock rate, treating the foreshock-mainshock-aftershock sequence as a single occurrence. The sequences are assumed to be independent of each other. This approach efficiently includes potentially damaging ground motions from dependent events while avoiding inappropriate application of the Poisson assumption. We demonstrate this methodology for two examples: the 2023 Turkey-Syria sequence and the 2019 Ridgecrest sequence. By modeling the sequences, there is little effect on the hazard at short return periods, but there can be a significant increase in the hazard at long return periods. This is opposite to the results if the Poisson assumption is applied to the undeclustered rates, underscoring the importance of modeling the earthquake sequence as Poisson rather than modeling the undeclustered events as Poisson.

Time-Dependent Seismic Hazard Assessment: Models, Data and Applications [Poster]
Poster Session • Wednesday 15 April
Conveners: Aybige Akinci, National Institute of Geophysics and Volcanology (aybige.akinci@ingv.it); Fabian Bonilla, Gustave Eiffel University (luis-fabian.bonilla-hidalgo@univ-eiffel.fr); Pablo Heresi, University of Chile (pheresi@uchile.cl); Felipe Leyton, University of Chile (leyton@csn.uchile.cl); Gonzalo A. Montalva, University of Concepción (gmontalva@udec.cl); Katleen Wils, Ghent University (katleen.wils@ugent.be)

POSTER 55
Smoothing Kernel-based Versus Uncertainty-driven Seismicity Models: Performance Comparison in the Gulf of Corinth (Greece)
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Grid-based seismicity models constitute a powerful tool for forecasting spatially varying earthquake occurrence rates. These models are purely data-driven and rely on the assumption that future earthquakes follow the spatial

pattern of past seismicity. Among them, smoothed seismicity models have been widely used for more than a decade in earthquake forecasting and seismic hazard assessment. However, their application typically requires declustering of earthquake catalogs, which reduces the effective sample size and may potentially bias the spatial representation of seismicity. In this study, we investigate and compare two fundamentally different approaches. The analysis is carried out for the Gulf of Corinth, one of the most densely instrumented and seismically active areas in Greece. The first approach applies a recently proposed smoothed seismicity method that does not require distinguishing background and triggered seismicity. The model is implemented using a complete earthquake catalog covering the period from 1980 to 2025, after the estimation of the correlation distance of the epicentral distribution of the earthquakes. Following, we employ an alternative uncertainty-based model, based on Voronoi diagrams of epicentral locations, in which seismicity rates are defined within spatial cells adapted to the local density of epicenters. We exploit the capability of this model to better capture seismicity rates in areas with sharp spatial heterogeneity (abrupt transitions between high and low seismic activity), a limitation commonly associated with smoothed seismicity modeling techniques. The two models are subsequently compared using appropriate performance metrics, with the goal of determining the model that best represents the observed seismicity patterns, thereby enhancing the reliability and robustness of earthquake forecasts.

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POSTER 56
Toward the Incorporation of Anelastic Path Attenuation in Non-ergodic Ground-Motion Models (GMMs): A 3D Perspective for the Chilean Subduction Zone
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The availability of robust strong-motion databases for the Chilean subduction zone (e.g., Bastías et al., 2025) has enabled the development of ground-motion models that explicitly incorporate systematic source, path, and site effects, thereby relaxing the ergodic assumption. In most non-ergodic implementations, the path term is parameterized using the Dawood and Rodríguez-Marek (2013) cell-type approach, in which the seismogenic region is discretized into a 2D surface grid and each path is represented by the proportion of source-to-site distance crossing each cell.

In this study, we use the anelastic path term from a non-ergodic ground-motion model for the Chilean subduction zone (Montalva et al., in preparation) to explore how assumptions about (a) three-dimensional structure, (b) path-cell size, and (c) earthquake magnitude and source complexity affect the inferred anelastic attenuation. We perform several runs in which the same residual field is reinterpreted under different path parameterizations: 2D surface cells versus conceptual 3D volumetric cells that follow slab geometry, multiple grid resolutions, and single-patch versus multi-asperity representations for large megathrust earthquakes. The analysis and cell effects are fitted using a Bayesian approach.

Results indicate that, for megathrust earthquakes, a multi-asperity source produces more coherent cell activation patterns and sharper along-strike gradients that are consistent with known segmentation and attenuation contrasts between northern and southern Chile. These findings suggest that a 3D-aware activation of path cells is required to obtain physically meaningful anelastic terms, with implications for probabilistic seismic hazard analysis. The methodology is directly transferable to other subduction zones with sufficient strong-motion coverage.

POSTER 57
New Seismic Hazard Research Capabilities in OpenSHA v26.1
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OpenSHA continues to evolve as an open-source, Java-based platform for reproducible seismic-hazard analysis, now delivering a suite of science-

focused enhancements in the latest major release, v26.1. This update reintroduces the Intensity Measure Event Set Calculator with a graphical user interface to complement the command-line tool. This application allows users to compute ground motions from a variety of earthquake rupture forecasts (ERFs) and intensity measure relationships (IMRs). The tool allows users to compute mean and sigma values for multiple intensity-measure types (IMTs) across arbitrary sets of sites and for multiple IMRs. Bulk import/export of site lists and optional retrieval of site-specific parameters from web services streamline multi-site hazard and risk workflows. The user interface in the Hazard Curve and Spectrum applications has also been refined to be more intuitive, and the ERF-data service now supports data retrieval from multiple backends, thereby improving data availability during network outages. This release also includes a number of minor bug fixes and improvements, including encrypted connections to servlets, protecting data exchange for GMT-based map generation and site-data queries.

The upcoming OpenSHA release, expected March 2026, will incorporate the USGS 2025 National Seismic Hazard Model for Puerto Rico and the U.S. Virgin Islands (NSHM25-PRVI). This is the first regional update since 2003 and the first PRVI model in OpenSHA. This development, currently available for testing in the nightly developer builds before formal release, includes the updated branch-averaged ERF and IMRs for crustal and subduction sources. Collectively these advances expand OpenSHA's geographic scope, accelerate bulk intensity-measure calculations, and increase the stability of routine hazard analyses for seismologists.

POSTER 58
Seismic Hazard Assessment for the Levant Fault System Using the MCQsim Earthquake Simulator
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This study focuses on the Levant Fault system, a 1200-km strike-slip fault connecting the Red Sea to the East Anatolian fault. We aim to understand how using earthquake simulators may improve PSHA there. We use the physics-based simulator MCQsim (Zielke & Mai 2023) to produce long rupture catalogs that replace traditional fault-based source models. We use slip rates and fault geometry as in El Kadri et al. (2025), represent the system with 49 sections extending down to 17km depth, and mesh them into small triangular elements. Each element is assigned a slip rate, static and dynamic friction, and strength properties. Between earthquakes, the faults are loaded with backslip. We generate a 200,000-year rupture catalog with magnitudes up to Mw7.6, consistent with reported historical seismicity. At the scale of the fault system, the long-term magnitude-frequency distribution follows a Youngs and Coppersmith characteristic shape. Rates in the moderate magnitude range M<6 are larger than observed in the instrumental period, even when accounting for variability in time. Rates in the upper magnitude range are within the uncertainty of observed historical rates. On the long-term, 9% of the moment rate budget is not accommodated by earthquakes, compatible with a system that is thought to be entirely locked. In fact, analyzing the total slip rate per element shows that this unspent budget occurs on short fault sections due to artificial tapering of slip at the edges for modeling. Participation rate maps show that moderate events are distributed homogeneously along the fault system, while M7+ events are unven along the main strand, likely due to geometrical reasons. We show that the fit with scaling relationships strongly depends on how earthquake dimensions are estimated from slip distributions. We combine the ruptures with a ground-motion model, and propagate the uncertainties identified up to the hazard levels. Further work is required to understand how results depend on uncertainties on input parameters, as well as why ruptures currently do not jump over major discontinuities, limiting the maximum possible earthquakes.

POSTER 59
Time-dependent Seismic Hazard Assessment of the San Ramón Fault in Santiago, Chile
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Seismic hazard assessment is fundamental for earthquake-resistant design, as it provides estimates of the ground-motion intensities that may affect a given site. In probabilistic seismic hazard analysis (PSHA), multiple seismic sources and their occurrence probabilities are combined. A key assumption in conventional PSHA is that earthquake recurrence is time independent and follows a Poisson process. However, this assumption may not adequately represent the tectonic behavior of individual faults, potentially leading to systematic under- or overestimation of the true hazard. For this reason, time-dependent, non-Poissonian recurrence models—such as the Brownian Passage Time (BPT) model—have been proposed to explicitly account for fault inactivity and renewal effects. Previous studies have shown that hazard levels increase when the elapsed time since the last rupture approaches the mean recurrence interval. In central Chile, the San Ramón Fault is an active reverse fault located along the western foothills of the Andes, whose surface trace crosses densely populated areas of Santiago. Paleoseismic evidence indicates two major surface-rupturing earthquakes, with an elapsed time since the last event comparable to its mean recurrence interval. In this study, we implement a BPT-based PSHA for the San Ramón Fault and quantify the effect of fault inactivity by comparing it with a conventional Poissonian model. Seismic hazard maps for Santiago, expressed in terms of horizontal peak ground acceleration (PGA) with a 1% probability of exceedance in 100 years, reach values of up to 0.88 g near the fault when the BPT model is used, compared with about 0.36 g under the Poisson assumption. Uniform hazard spectra at representative sites across Santiago show that BPT-based intensities can be up to three times larger than those obtained with a Poisson model, demonstrating that the choice of recurrence model has a significant impact on seismic hazard estimates for the San Ramón Fault.

POSTER 60
Utilizing the RSQSim Long-term Earthquake Simulator to Generate a Synthetic Earthquake Catalog for the Eastern California Bay Area
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Along the western coast of the United States, the greater San Francisco Bay Area is a high seismic risk area with a high population density and a high probability of experiencing an earthquake which could cause significant ground shaking in the next 30 years (Field et al., 2013; Peterson et al., 2023). It is important to note that large, ground shaking earthquakes are not isolated phenomena, but are snapshots in a much larger seismic cycle which includes tectonic loading, earthquake swarms, aseismic creep, foreshocks and aftershocks. Understanding the relationship between these aspects of time-dependent fault system behaviour can yield valuable insights into what kind of seismicity could be expected temporally and geographically.

We utilize physics-based long term earthquake simulations (Tullis et al., 2012) for the eastern region of the greater San Francisco Bay area. Specifically, we use the quasi-static long term earthquake simulator RSQSim (Richards-Dinger & Dieterich, 2012) to generate a synthetic earthquake catalog. We construct a discretized fault system geometry by projecting the surface traces of major faults in the east bay down to 15 km depth and discretizing into 500 m elements. We implement a hybrid loading scheme (Shaw et al., 2018; Shaw, 2019) to tectonically load the fault system based on historic slip rates on each fault segment. We run models with differing frictional properties for 25,000 years of seismicity and evaluate the characteristics of the catalog such as evaluating the Gutenberg-Richter coefficients, average recurrence intervals, foreshock and aftershock sequences. Initial results highlight that firstly, it is rare to see multifault ruptures in the RSQSim catalog with slip mostly being constrained to one major fault segment during an event. Secondly, we see a large variation in recurrence intervals of Mw > 6.5. Thirdly, the incorporation of creeping sections significantly changes the generated catalogs compared to a purely velocity-weakening model. The next step is to generate synthetic ground motions from the RSQSim events to form a time-dependent ground motion map for the region.

On the Temporal Stationarity of Systematic Effects in Non-ergodic Ground-motion Models: Evidence From Chilean Megathrust Sequences

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State-of-the-art fully non-ergodic ground-motion models (GMMs) focus on explicitly modeling repeatable systematic effects associated with site, source, and path. Under the ergodic assumption, these effects are instead absorbed into the aleatory variability, which can lead to an overestimation of seismic hazard, particularly at long return periods (Hu et al., 2024; Lavrentiadis et al., 2023).

Systematic effects reflect physical mechanisms that are not represented by an ergodic backbone model but may be repeatable across events (e.g., regional differences in stress drop or coupling) or sites (e.g., basin-related amplification or regional attenuation structure). In practice, these terms are commonly treated as spatiotemporally stationary, representing repeatable, time-invariant average effects; however, this assumption may not hold in the presence of time-dependent processes and therefore must be evaluated carefully. For instance, residual-based analyses have documented spatiotemporal variations in ground motion for subduction interface earthquakes (e.g., Piña-Valdez et al., 2018), including a temporal evolution of frequency content within an earthquake sequence.

In this study, using the strong-motion database of Bastías et al. (2025), we analyze two Chilean subduction earthquake sequences (Iquique 2014 and Illapel 2015) to estimate systematic effects before and after the megathrust mainshock. We define time windows to minimize contamination from foreshocks and aftershocks. We then develop fully non-ergodic GMMs using sequence-based subsets and estimate event-specific systematic terms to evaluate the stationarity assumption for the maximum horizontal component (RotD100), the median horizontal component (RotD50), and the vertical component. The results indicate modest differences in the inferred systematic effects when the influence of the mainshock is reduced through the adopted time-windowing strategy, and they further reveal spectral-period and directional dependence in these effects.

Physics-based Seismic Hazard Assessment Using RSQSim Synthetic Catalogs: Validation Against USGS NshM 2023 for Los Angeles

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We present a physics-based probabilistic seismic hazard analysis framework integrating RSQSim earthquake simulators with Monte Carlo temporal sampling for Southern California. Using a 715,000-year RSQSim synthetic earthquake catalog, we applied sequential and random temporal windowing to assess hazard variability and convergence. Ground motions were computed using NGA-West2 ensemble models (ASK14, BSSA14, CB14, CY14) with equal weighting (0.25 each), incorporating California-specific basin depth correlations for VS30 = 760 m/s. Over 800 sites across the greater Los Angeles region were analyzed across multiple 50,000-year windows, producing hazard curves for 2%, 5%, and 10% in 50-year probability levels. Independent windows show strong temporal stability, with an average window-to-window coefficient of variation of approximately 4%.

Comparisons between physics-based and USGS hazard estimates reveal level- and location-dependent differences. For the 10% in 50-year level, RSQSim and USGS estimates are similar (mean 0.37g), with comparable numbers of sites showing higher or lower values. At the 2% in 50-year level, RSQSim yields a mean of 0.54g versus 0.71g from USGS, with 85% of sites exhibiting lower physics-based estimates. Spatial patterns show RSQSim values averaging 66% of USGS near the San Andreas Fault and 84% within the Los Angeles Basin, with some near-fault sites as low as 25%. These differences reflect methodological contrasts: USGS approaches rely on independent fault sources and averaged recurrence rates, whereas RSQSim models fully interacting fault networks with earthquake clustering, stress transfer, and multi-fault ruptures. Results suggest that incorporating fault interactions can significantly alter hazard estimates near major faults, particularly for rare, long-recurrence events.

Unrecoverable Crust Destructions Incurred by Low-permeability Heterogeneity—Based on Time-dependent Continuous Leakage Detecting Models

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Aquifers with low permeabilities in both the horizontal and vertical directions often exhibit nonhomogeneous pore pressures, leading to significant pore-pressure gradient. As we find, these gradients can even induce permanent changes in the crust medium when encounter shaking of tele-seismic waves. In this study, we calculated the permeability and related poro-elastic parameters and revealed some of the underlying physical mechanisms. Low permeability ($<10^{-15}$ m², an empirical low permeability threshold value in laboratory experiments) combined with heterogeneity tends to cause unrecoverable changes in the crust, which may trigger geohazards such as landslides, mudslides, and even earthquakes. Therefore, in order to reduce the potential induced hazards, perhaps, enhancing the permeability to be $>5 \times 10^{-15}$ m² in either the horizontal or vertical directions could be an effective approach. This research is based on the leakage detecting models of the water level responses to the loading of the Earth Tides and the Barometric pressure.

Innovations in Time-dependent Methodologies for Earthquake Loss Modeling

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In traditional probabilistic seismic hazard analyses (PSHA), earthquake recurrence is treated as a time-independent process. Under this approach, it does not matter when the last earthquake occurred, the probability of the next and other nearby earthquakes remains unchanged. However, this framework ignores the observed, and well-documented, time-dependent nature of earthquake recurrence. Here, we will examine how traditional, time-independent earthquake recurrence assumptions provide an incomplete picture of potential insurance industry losses. Using Cotality's recently released US earthquake model (based on the USGS's NSHM 2023 update), we will demonstrate how modeling three key time-dependent earthquake processes—renewal (elastic rebound), clustering, and aftershocks—provides a more accurate assessment of a portfolio's exposure. For example, incorporating renewal (elastic rebound) time-dependent approaches into recurrence models allows insurers to understand which faults pose the greatest near-term risk to their portfolio. Additionally, modeling the spatial/temporal clustering of large earthquakes, such as in the 1811-1812 New Madrid sequence, provides a more accurate assessment of tail risk. Lastly, accounting for the cumulative damage of a mainshock and its subsequent aftershocks gives insurers a better picture of the likely total claims from all shaking. By incorporating these time-dependent methodologies, Cotality's new US earthquake model is helping insurers ensure their financial stability.

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