2018 IRIS WORKSHOP REPORT
Foundations, Frontiers, and Future Facilities for Seismology

Report of the Workshop Held
June 12–14, 2018, Albuquerque, NM
Albuquerque Convention Center

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Postdocs, and Early Career Participants
The 2018 IRIS Workshop was held in Albuquerque, NM between June 12 and 14. This meeting location provided an opportunity to highlight the large number of geophysical facilities in this part of the country, including the Albuquerque Seismological Laboratory (USGS), which is a partner of the Global Seismographic Network (GSN), the IRIS/PASSCAL Instrument Center at New Mexico Tech in nearby Socorro, NM, and the Seismic Source Facility at the University of Texas at El Paso. Tours were offered for workshop participants to visit ASL and PASSCAL on Thursday afternoon following the conclusion of the workshop. There was also a pre-workshop field trip on June 11 to nearby Tent Rocks National Monument, led by New Mexico State Geologist Dr. Nelia Dunbar, as well as several pre-workshop courses.

The 2018 IRIS workshop was an opportunity to reflect upon the science that drives the existing IRIS facilities and activities, and what scientific advances and techniques will be required to support and propel future initiatives. Over 2-1/2 days, the workshop covered a vast array of scientific research and the strength of IRIS programs and facilities, as well as the breadth and depth of work conducted by the IRIS community, was clearly showcased.

The 2018 IRIS workshop provided attendees an opportunity to learn more about the development and history of IRIS programs and the exciting directions where the community and IRIS will go in the future. The Science Planning Committee, along with the Plenary Session and Special Interest Group organizers, worked hard to develop a program that highlighted both the past activities and future plans, thus the theme of the workshop, “Foundations, Frontiers, and Future Facilities for Seismology”. Because of the large number of attendees from the regional geophysical facilities, attendees were able to hear a range of academic, government, and industry viewpoints. The mix of historical perspective and forward-looking discussions, along with the networking opportunities, proved particularly valuable for the large number of early career attendees who are still developing their seismic research and career networks.
2. Plenary Sessions

Since its inception in 1984, IRIS has built excellent foundational facilities for seismologists to study the Earth’s interior, earthquakes and other natural hazards. The workshop highlighted exciting scientific advances using current facilities, and explored future frontier facilities, activities and techniques. In part, the future of IRIS includes the expansion of the facilities to support interdisciplinary research activities among the solid Earth, hydrosphere, cryosphere, atmosphere and other surface processes, and to create a more diverse geoscience community.

2.1 SCIENCE BUILT ON A STRONG FOUNDATION

Organizers: Lara Wagner, Brian Stump, Jeffrey Park, John Louie
Invited Speakers: Vedran Lekic, Anne Sheehan, Jeffrey Freymuller, Stefany Sit

IRIS provides facilities critical for the advance of seismology and Earth science. As an introduction and review of IRIS for attendees, new and old, this session highlighted the current science made possible by these facilities, with an eye towards what can be possible with improvements in the foundational facilities. Each talk covered the history and contributions of the four core IRIS programs: GSN, PASSCAL, Data Services/Products and Education/Outreach. Some of the talks looked backward to the original 1984 IRIS Proposal to NSF to remind Workshop participants of the initial goals of the consortium.

In the first talk, entitled "A Seismically Sound Foundation: Reference Models and Datasets," Vedran Lekic (University of Maryland) recounted the history of the Global Seismographic Network (GSN), focusing on the crucial role of the GSN and other permanent seismological networks to understanding the deep structure of Earth. Starting from a series of 1-D models of Earth's seismic velocities and density during the 20th century, the inclusion of radial anisotropy in the 1-D model PREM and the first 3-D models of global Earth structure in the 1980s made clear that a new permanent broadband seismological network was necessary to calibrate earthquake locations and to answer fundamental questions about, e.g., continental versus oceanic lithosphere, the patterns of mantle convection, and the core-mantle boundary layer.

Lekic argued that the GSN is pivotal to generating a 3D Reference Earth model (REM-3D) that ideally represents a consensus view of long-wavelength heterogeneity within Earth's mantle. Unlike pre-IRIS datasets, the 21st-century dataset from the GSN and other global networks is readily accessible to any researcher, so that competing groups can utilize different slices through earthquake data types (P waves, S waves, surface waves and free oscillations) and different data-fitting targets (traveltimes, frequency shifts, and full waveforms), enabling joint modeling of large and diverse datasets. To this end, global seismologists from different US universities and non-US institutions are compiling and reconciling fiducial seismic data-sets of body-wave traveltimes, fundamental-mode and overtone surface-wave dispersion, and free-oscillation multiplet and singlet frequencies. The resulting reference dataset will contain quality-controlled and comprehensive sets of seismic observations and enable the construction of REM-3D.

After proving feasibility with a preliminary 3-D model (https://www.geol.umd.edu/facilities/seismology/3d-reference-earth-model/), the REM-3D project plans to generate a reference model, to background regional seismic studies at all locations and depths, to inform geodynamic modeling, to inspire petrologic hypotheses, and more. Lekic demonstrated that measurements on the global data sets are fairly consistent with each other, typically following a one-to-one proportionality with modest deviations. Nevertheless, coherence comparisons of 3-D mantle models from different groups suggest that mutual agreement is restricted to velocity perturbations with angular degree limited to 9 to 15, depending on depth range. Love-wave phase-velocity measurements appear to have greater coherence between groups, unexpectedly, than do Rayleigh-wave phase-velocity measurements.
Challenges remain, however, that point forward to future GSN improvements. The GSN network has imbalanced geographical coverage because it lacks permanent seafloor stations, so large volumes of Earth’s interior are only weakly interrogated by P and S waves. Lekic noted that poor data coverage in Earth’s oceanic regions led to the popular 1-D PREM model to contain a sharp upper-mantle discontinuity at 220-km depth. This feature, called the Lehmann Discontinuity, is commonly observed in stable continental regions that were sampled heavily in the pre-IRIS dataset, but rarely (if ever) in oceanic mantle.

In the second talk, “Foundations of Portable Seismology: The Program for Array Seismic Studies of the Continental Lithosphere (IRIS-PASSCAL),” Anne Sheehan (University of Colorado Boulder) reviewed the technical advances in portable seismic recording technology, shocking younger workshop participants with photographs of seismic data recorded in remote field locations during the 1970s with smoked-paper helicorders. Field seismology data was typically not shared among researchers and poorly archived even at the institutions that collected the data. A series of NSF and US National Academy reports preached the future of digitally-recorded seismic data and a standardized pool of sensor packages and data-acquisition systems. From these community efforts, the Portable Array Seismic Studies of the Continental Lithosphere (PASSCAL) program joined the GSN as the second data-collecting arm of the IRIS 1984 proposal to NSF.

Sheehan reviewed the pivotal first PASSCAL deployments, noting how IRIS’s first active-source experiment (1986 Ouachita) leveraged on a previous field project by COCORP (Consortium for Continental Reflection Profiling), testing new equipment and practices, setting a 200-km field line with nearly 800 sensors. The 1986 Basin and Range deployment was the first passive-source PASSCAL deployment. A key feature of these deployments was that IRIS archived the data and was made available to other researchers, after a time delay that allowed the field participants to carry out the first round of data processing. The 1991-1992 Tibetan Plateau experiment was the first to deploy broadband sensors in a remote and forbidding field area. Data from the 11 Tibet stations generated dozens of papers, many from researchers who never set foot on the Plateau.

Sheehan recounted the physical migration of the PASSCAL Instrument Center (PIC) from its initial site at Lamont-Doherty Earth Observatory, expanding to a second facility at Stanford University in the early 1990s, and eventually consolidating at the PIC, now managed by New Mexico Tech. PASSCAL developed software to organize and process seismic data and also offered assistance with archival at the DMC.

With the integration of field data into observatory data, seismologists could take advantage of data from PASSCAL deployments in global studies, as well as targeted regional studies. New models for data collection and seismic-structure investigation followed from the innovations of individual PIs and from Mother Nature. In 1989, a number of PASSCAL instruments were deployed to study aftershocks of the Loma Prieta event in Northern California, within days of the main shock. This led to a formal protocol within PASSCAL, called RAMP (Rapid Array Mobilization Program), for responding to unexpected large earthquakes. In addition to standard reflection, refraction and tomographic experiments, seismic receiver functions grew in popularity as an indicator of crustal thickness. Shear-wave splitting was recognized as a novel indicator of anisotropy and mantle deformation. It quickly became common for seismologists and other geoscientists to design and execute large-scale experiments with PASSCAL broadband instruments to study regional tectonic deformation anywhere on the globe. Further waves of deployment innovation are occurring in the PASSCAL program with the advent of cheap, easily-deployed nodal seismometers, which can quickly create seismic arrays with hundreds of sensors across features of geologic interest.

In the third talk, “Open Data, Data Services, and Cross-Disciplinary Collaboration in Geophysics,” Jeffrey Freymueller (University of Alaska Fairbanks), the Director of the EarthScope National Office and the Chair of the UNAVCO Board, reminded workshop participants of how difficult it was, not so long ago, to share geophysical data. His second slide showed a sweaty hand grasping a computer floppy disk, emblazoned optimistically with the words “Reliable & Durable”, and labeled with felt-tip pen as the only copy of geodetic data from a particular field station for a particular time period. By establishing a common data archive at a central mass-storage facility, and common data formats for distribution, the IRIS Data Management System (DMS) enabled seismic researchers to access the entire data trove collected by all their colleagues. This fostered innovative science and the efficient use of taxpayer support for permanent networks and temporary field projects.
From the 1980s, innovation followed quickly with improvements in computer mass storage and in Internet capacity. The IRIS DMS established its current facility in Seattle, Washington, developing useful data-access tools that went beyond simple database requests for user-selected stations, channels and time windows. With DMS software installed on their local computers or accessed over the web, researchers could gather all stations in a region, all earthquakes in desired depth and magnitude ranges. In its first years the DMS often served data on a magnetic tape sent via US Mail. Soon the DMS generated larger heterogeneous datasets that could be served via FTP. The ease of requesting data sets leads many researchers to repeat identical requests, eliminating the need to archive their local data from project to project. Some confusion is possible if the DMS updates the metadata between requests, but most researchers regard this as a minor inconvenience.

In the 21st century, a shift to web services by the DMS has allowed on-the-fly data requests, at least for commonly-requested data intervals around catalogued earthquakes. Sophisticated software packages, such as OBSPY, operate on the assumption that significant numbers of waveforms can be requested from the DMS in real-time, processed and transformed into results from research questions or college-course exercises, with no need to store the data locally. Freymuller ended his talk with an introduction to seismogeodesy, the practice of using the continuous GPS stream as a long-period displacement record, with sample rates now faster than 1 sps. Because a GPS sensor does not saturate in the near field of large earthquakes, it can be used as the final patch in the continuous record of earthquake motion from the smallest to the largest earthquakes. Freymuller showed that this on-scale behavior allows one to verify the traditional Gutenberg-Richter relation between earthquake size and local ground motion amplitude.

In the fourth talk, “Triggering Epicenters in Geoscience: Fostering the Next Generation of Seismologists,” Stefany Sit (University of Illinois Chicago) introduced workshop participants to a number of issues IRIS faces in Education and Public Outreach (EPO). Sit noted that gender parity is now evident in the recent classes of geoscience BA and BS degrees. The representation of African-American, Latino and Native Americans lies near 5% of the total, well below their proportion in the US population. The snapshot of diversity in the IRIS internship program is better, however, with 20-30% participation via special recruitment measures.

As the IRIS internship program celebrates its 20th year, Sit reviewed how the program has grown, impacted students, and influenced the seismology community. Each year the summer program hosts ~15 students that experience a 1-week immersive orientation, 8-10 weeks of research guided by a science mentor, and a final presentation at the AGU Fall Meeting. Sit presented results of a questionnaire to survey the influence that the IRIS internship had on participants’ later academic and career choices. Overall the program serves as a significant recruitment tool for professional seismology. Even respondents who switched to a field outside geosciences reported positive impressions, on average, of the IRIS intern program. Sit concluded by suggesting that education and outreach activities focused on urban geophysical problems could increase the exposure of under-represented populations and, ultimately offer them new career-path options in geoscience.

2.2 ADVANCING EARTH SYSTEM SCIENCE WITH GEOPHYSICAL OBSERVATIONS

Organizers: Vedran Lekic & Greg Waite
Invited Speakers: Yihe Huang, Chris Johnson, Emily Hopper

This session sought to highlight applications of seismology—enabled by IRIS initiatives—together with numerical modeling and geodetic observations, in order to understand Earth systems such as subduction zones, continental rifts, and the interplay between the hydrologic and earthquake cycles.

Yihe Huang (University of Michigan) led the session off with a talk that highlighted the insights enabled by observation-driven simulations of earthquake rupture, focusing on two applications: megathrust earthquakes in the Cascadia subduction zone and the consequences of damage zones in strike slip faults. In Cascadia, ground motion predictions depend crucially on the down-dip extent of slip; Huang’s simulations show that the down-dip extent of slip is controlled by the
strength of the gap region between the down-dip extent of the locked zone and the up-dip edge of the region generating episodic tremor and slip. Understanding the gap zone is therefore a key challenge for the community. Damage zones in strike slip faults yield simulations with more realistic distributions of seismicity, and offer a challenging but fascinating imaging target for future, dense arrays.

Chris Johnson (UC San Diego) showed how geodetic observations are used to map out deformation due to water storage and withdrawal in California with high spatial and temporal resolution. By computing the stress changes expected from this deformation on dip-slip and strike-slip faults, he documented that the occurrence of earthquakes correlates significantly with seasonal stress changes due to the hydrologic cycle. In California, these stress changes are much larger than those due to other time-varying factors, such as tides and atmospheric pressure variations; however, in other areas, stress changes due to these other factors may be significantly larger to trigger seismicity.

Emily Hopper (Columbia University, Lamont-Doherty Observatory) concluded the session with new images of the structure of the Malawi segment of the East African Rift. EarthScope data have enabled the mapping of lithospheric structure across the conterminous United States, revealing broad lithospheric thinning beneath the wide-mode rifting across the Basin and Range and focused thinning beneath the narrow-mode rifting Salton Trough. New data obtained by the SEGMeNT deployment enable lithospheric structure to be imaged beneath Lake Malawi and the surrounding regions. When interpreted alongside active source results, Emily’s images show that the lithospheric mantle beneath the rift is thinned much more than the crust, suggesting that purely mechanical thinning cannot be the dominant process and that thermo-compositional erosion of the mantle lithosphere may play an important role.

2.3 MINING EXISTING SEISMIC DATA WITH NEW TECHNIQUES

Organizers: Brandon Schmandt & Greg Beroza
Invited Speakers: Karianne Bergen, Wenyuan Fan, Robin Matoza

Long archives of continuous seismic data hold the potential to reveal new insights into Earth structure and dynamic Earth processes. The same potential holds for dense seismic networks that are becoming increasingly common through advances in inexpensive sensor technology. The potential of these data sets will only be fully realized, however, if seismologists develop approaches to data processing that take advantage of recent developments in high-performance computing and computational science. Data-intensive computing approaches have had limited impact in seismology to date, but that is starting to change. The focus of this session was to illustrate examples where large data volumes were processed using new approaches, and to provide a forward-looking set of recommendations that the seismological community might consider to accelerate progress in this direction.

Karianne Bergen (Stanford University), a graduate student, provided an overview of machine-learning and other artificial intelligence (AI) approaches, and suggested guidance about which approach was most appropriate given the size of the data set and whether data was labeled or not. She divided problems of interest into three categories: automation, modeling, and discovery, and gave seismological examples of each. She went into depth in a uniformed data-mining approach to earthquake detection using continuous waveform data sets. Her recommendations for accelerating progress in application of data-science methods to seismology included: (1) setting up benchmark problems to be used to compare the strengths and weaknesses of alternative approaches, (2) promoting open-source practice for sharing algorithms, and (3) exposing seismology students to data-science coursework as part of their curricula.

Wenyuan Fan (Woods Hole Oceanographic Institution), a postdoctoral scholar, demonstrated innovative approaches to analyzing array data. He first reviewed recent teleseismic back-projection evidence of dynamic triggering in the near-source regions of large magnitude earthquakes. Next, he used correlation across triplets of stations to determine relative arrival times, and from that, the direction of wave propagation. Direction data were used to optimize the origins of diverse sources including landslides and glacial processes in Greenland. He also explored the use of large-N nodal arrays to study
rupture dynamics of small earthquakes. He showed how using the second-order moments of the moment tensor can lead to a more stable estimate of stress drop. He contrasted this with corner frequency-based measurements of stress drop from the dense, temporary network in Oklahoma and found that corner frequency was smoothly varying with position, but due to the cubic dependence of stress drop on corner frequency would lead to over an order of magnitude variation in corner frequency if determined from a single station. He highlighted the importance of data transfer rates for facilitating advances in seismic data mining.

Robin Matoza (University of California, Santa Barbara), an assistant professor, reviewed recent results from seismic and infrasound studies of magmatic systems that fuel a wide range of eruptive processes. He highlighted the complementary strengths of seismology and infrasound for volcano monitoring and hazard mitigation. Seismology discerns seismicity from mantle depths to the surface, while explosive eruptions, shallow degassing, surface flow, and mass wasting produce infrasound. High rates of volcanic seismicity and distinguishing between source and path effects present challenges. Computations relevant for addressing these challenges, such as continuous back-projection and 3-D wavefield calculations, are increasingly tractable due to steady improvements in computational resources.

The three talks were illustrative, but couldn’t be comprehensive. The parallel poster session helped in this regard as it included a broader range of examples including: machine learning approaches to earthquake detection, sub-array based back-projection for source imaging, and cross-coherence measurements to constrain short scale-length variability in Earth structure. In summary, this session highlighted important new directions for the field of seismology that IRIS, as the world’s foremost curator of seismic data, could play an important role in actuating.

2.4 IDENTIFYING AND MITIGATING HAZARDS IN THE 21ST CENTURY

Organizers: Aaron Wech & Richard Allen
Invited Speakers: Nicholas van der Elst, Diego Melgar, Seth Moran

From volcanic eruptions to earthquakes, seismic and geodetic observations are needed in order to help identify regions of increased risk, better understand the underlying processes and mitigate the effects of both natural, and in some cases, man-made disasters. The goal of this session was to present an overview of several cutting-edge efforts to constrain the physical processes responsible for various natural hazards and develop strategies to reduce the effects of these hazards. The session consisted of three speakers who between them covered processes and issues related to earthquakes, tsunamis and volcanoes.

The first speaker was Nicholas van der Elst (US Geological Survey) who presented a talk titled “What’s new and what’s next in aftershock forecasting”. As he explained, the chaos caused by a major earthquake does not end when the shaking stops. Search and rescue, damage assessment, and lifeline repairs all need to be carried out under the constant threat of damaging aftershocks. In some cases, aftershocks can be even more destructive than the initial event, as was the case in Christchurch, New Zealand. While it may never be possible to predict the exact time, place, and magnitude of an impending earthquake, it is possible to make probabilistic assessments of aftershock hazard based on past behavior and the specifics of an ongoing sequence. Forecasts, and in particular forecast maps, can provide situational awareness, increase public resilience, and help decision makers to prioritize response and recovery operations. The public has increasingly come to expect such information, and information vacuums are likely to be filled by non-authoritative sources. The USGS is therefore developing several lines of aftershock forecasting products with the goal of providing rapid quantitative aftershock information to emergency responders, lifeline operators, and the general public in the wake of moderate and large earthquakes. These products include automatic aftershock forecasts following M5 and larger earthquakes in the United States, as well as fault-specific forecasts following selected earthquakes in California. The USGS is also developing standalone software tools to streamline the process of analyzing and forecasting aftershock sequences within the Epidemic-Type Aftershock Sequence model. This talk presented the science of producing reliable aftershock forecasts, and highlighted recent efforts to implement these methods at the USGS.
The second talk was by Diego Melgar (University of Oregon) and was titled “The weak determinism of large earthquakes: Science insights to speed up warnings.” As was pointed out, large M8+ earthquakes, mostly in subduction zones, pose a substantial challenge for early warning systems. Experience has shown that regional and near-field measurements of just a few seconds of a P-wave are not enough to assess the final magnitude of an event. This leads to initial assessments of the hazards being underestimated and can lead to substantial delays in taking action. A central question is, are large earthquakes deterministic? When, within a minutes-long-rupture process can we distinguish the large from the very large? This is an old and much debated question in earthquake physics, which was discussed in this talk in the context of new findings from global and regional seismic and geodetic observations. Two end member views of this problem exist: in one, rupture is fully deterministic and the early phase (nucleation) of an earthquake has enough information to ascertain the event's final size. At another extreme, there is no determinism whatsoever, and only when a large event has ruptured completely can data constrain its magnitude. Recent results argue strongly for a middle-of-the-road model, one of weak determinism, where at nucleation there is no difference between earthquakes of different final magnitudes, but soon thereafter (in tens of seconds), well before the rupture is finished, the earthquake organizes into a self-similar slip pulse, which is diagnostic of its final magnitude. The observations to support this view of weak determinism were presented and discussed along with their implications for earthquake and tsunami early warning.

The third speaker was Seth Moran (US Geological Survey) with a talk titled “Mitigating volcanic hazards through geophysical monitoring and research.” Volcanoes are complex systems that require a multi-disciplinary scientific approach to fully understand, encompassing the fields of geology, geophysics, geochemistry, hydrology, petrology, physical modeling, and remote sensing, among others. For all these fields, the line between monitoring and research is blurry; research can produce new tools that become operationalized over time (e.g., identifying seismic event families through cross-correlation), and observations made while viewing data from monitoring networks can feed into new research investigations (e.g., cause of changes in the frequency content of seismic events). This feedback loop between research and monitoring is fundamental to mitigating volcanic hazards. Monitoring of Mount Rainier (Washington) provides a good example of this feedback. Through careful geologic research, it is now known that Mount Rainier has produced at least 8 large lahars (or volcanic mudflows) in the last 6,000 years (most recently ~500 years ago) that reached into what are now heavily populated areas of Puget Sound. Most of these lahars have occurred in association with eruptions. A key strategy for lahar hazard mitigation is therefore to establish a robust volcano monitoring system that can detect early warning signs of a potential eruption. Given the degree of societal exposure to volcanic hazards, this monitoring system needs to be capable not only of routine monitoring tasks (e.g., locating earthquakes), but also detecting subtle phenomena in real time that may provide earlier warning or improved situational awareness. From seismology alone, these capabilities include detecting changes in subsurface velocity structure through techniques such as coda-wave interferometry and noise cross-correlation, and detecting changes in event location through methods such as envelope- and template-based cross-correlation. An additional required capability is detecting lahars, including information on flow size and speed—a capability that will require implementation of relatively new-to-volcano-science techniques such as low-latency back-projection-type processing of seismic and infrasound array data. Enabling these and other capabilities requires a substantial expansion of the current monitoring network at Mount Rainier—a network which, when built, will assuredly provide data that will feed back into new research investigations.

2.5 GEOPHYSICAL APPROACHES TO UNDERSTANDING THE HYDROSPHERE AND CRYOSPHERE

Organizers: Sarah Kruse & Paul Winberry
Invited Speakers: Kate Allstadt, Brandon Schmandt, Meredith Nettles

Seismology is increasingly being used as a tool to explore processes near the Earth's surface including fluvial, cryospheric, geomorphic, and critical zone systems. Passive source seismic observations provide the temporal resolution needed to understand short-term dynamics that are not easily captured by other methods while active source seismic studies are now frequently used to provide high-resolution images of structures in the near surface. IRIS is playing a fundamental role in
these scientific advances by allowing investigators to leverage both permanent and portable seismic infrastructure, originally designed for solid Earth exploration, to study these new targets. In this session, three invited speakers highlighted how seismic analysis is advancing our understanding of Earth’s hydrosphere and cryosphere.

Kate Allstadt (US Geological Survey) opened the session with a broad-ranging discussion of how seismic data can shed light on the dynamics of surface mass movements, in particular debris flow and landslides. For simple landslides, the wavefield can be inverted for the surface tractions, which in turn can be related to landslide characteristics. Significant challenges exist for more complex flows, which have no clear phase arrivals and for which flow location can be difficult. Geologic field mapping verifies that complex seismic signals are indeed produced by flows with multiple pulses of internal movement. Precursors to landslides, such as changes in ambient noise and wave velocities, as failure approaches, are also active targets of study. The USGS flume chute at Cascade has been instrumented on a variety of scales to better understand debris flow seismicity and tilting of ground adjacent to flows. A catalog of “exotic events” at IRIS and the growth of the EnviroSeis community are spurring work on these topics.

Brandon Schmandt (University of New Mexico) then described a reach-scale bedload transport experiment almost ideally designed to measure the seismic response of coarse sediment transport. Bedload transport (~2 - >50% of sediment transport) is notoriously difficult to measure experimentally, thus seismic wavefield sensing offers a critical new tool to study bedload physics. IRIS-PASSCAL instruments were deployed around a stretch of the Trinity River, where dam-controlled water releases were maintained at constant discharge while gravel was injected from dump trucks. The goal of the project was to inform river restoration plans to improve salmon habitat. This study found that bedload transport excites frequencies in the 20-100 Hz range, and the river adjust to the supply perturbation in 7-10 hours.

Finally, Meredith Nettles (Lamont-Doherty Earth Observatory, Columbia University) summarized several examples of how geophysics can be critical to understanding Greenland and Antarctic ice sheet dynamics. Mantle viscosities are key to understanding the drivers of isostatic adjustment, and critical for distinguishing the relative contributions of current ice loss from the last glacial maximum. Seismic wave velocities are essential for mapping mantle viscosities. As another example, data coming from the GLISN network aid in understanding variations in the ice-bedrock interface and complicated processes that can cause increases or decreases in wave speeds associated with seasonal variations in ice sheet mass. She subsequently described new results that highlight how active source refraction surveying by Nick Schmerr (University of Maryland) is used to estimate the volume of persistent liquid water within the firn aquifer that forms around the margins of the Greenland Ice Sheet. Finally, she summarized how observations of long-period seismic waves and in-situ geodetic measurements can be used to unravel the mechanics of glacier calving, a dominant process for mass loss from the Greenland Ice Sheet.

2.6 SUPPORTING SCIENCE AND DISCOVERY BENEATH THE OCEANS

Organizers: Anne Sheehan & Nathan Miller
Invited Speakers: William Wilcock, Susan Schwartz, Lee Freitag

This session highlighted current challenges, successes, and new technologies in the application of seafloor seismic and geodetic observations to problems in subduction zone science and earthquake and tsunami early warning systems. Since oceans cover two-thirds of Earth’s surface, making geophysical observations of structure and processes beneath and within the oceans are required to understand Earth systems. The importance of offshore geophysical observations is especially evident at subduction zones, where many earth systems interact and the incoming plate and a majority of the seismogenic region generally lies offshore. Subduction zones are a fundamental component of plate tectonics and drive, for example, global chemical cycles and generation of continental crust, but also produce explosive volcanism and the largest earthquake and tsunami hazards on Earth. Many of the technologies and approaches discussed in this session also benefit earth and ocean science in many other seafloor settings.
William Wilcock (University of Washington) gave a talk on how cabled seafloor observatories on the Cascadia margin can enable earthquake and tsunami early warning and generally advance subduction zone science. Cascadia has recently seen a dramatic increase in geophysical data from campaign-style deployments of seafloor geophysical instrumentation including, most significantly, an extensive array of autonomous ocean-bottom seismographs deployed by the Cascadia Initiative project. Permanent installations of buried or borehole seismometers have a much lower noise floor than do autonomous OBS deployments, enabling recording of small magnitude seismicity, a capability that is especially important for understanding the seismically-quiet Cascadia Subduction Zone. Seafloor geodetic measurements from, for example, seafloor absolute pressure gauges provide direct observations of coseismic upper-plate deformation and are required to resolve ambiguity in plate locking models based on land-only geodetic observations. When delivered in real-time via a cabled array, these geophysical observations can provide timely alerts to precursory and early indications of earthquake rupture, tsunami generation, and estimates of event magnitudes. He estimates that such real-time offshore monitoring could add up to ~15 s to current earthquake and tsunami early warnings for the Washington and Oregon coast. He also presented design parameters and strategies for building out a cabled geophysical observatory that would be suitable for use in earthquake and tsunami early warning. Installing a large-scale system would be expensive, so it is important that new systems leverage existing infrastructure. There are presently two cabled observatories in Cascadia: one operated by Ocean Networks Canada offshore Vancouver Island, British Columbia and one operated by the NSF-funded Ocean Observatories Initiative offshore central Oregon. He proposed adding additional geophysical sensors to these networks. For real-time cabled systems to perform during and after large earthquakes, they must be resilient and redundant, which could be accomplished by adding redundant shore and inter-node links.

Suzan Schwartz (University of California Santa Cruz) gave a talk on shallow slip on subduction megathrusts. At many subduction zones, slip occurs at depths of 20-50 km, which is typically where the slab is beneath land and can be well-characterized by onshore instrumentation. As shown by the 2011 Japan earthquake, a large amount (>50 m) of coseismic slip can, however, occur near the trench on the shallow section of the megathrust. Slow slip events (SSE) also occur on the shallow megathrust, and understanding the full slip behavior of the shallow megathrust requires both geodetic and seismic observations from near the trench. She focused on examples of shallow SSE from the Nicoya Peninsula, Costa Rica and Hikurangi, New Zealand. In Costa Rica, early fluid flow meter installations near the trench showed a flow rate anomaly that correlated with high noise on seismographs. This event was interpreted as a “strain transient”. Later, in 2003, SSEs were observed geodetically on 3 GPS stations. By 2007-2012 many more instruments had recovered many more observations of SSE. Many of these events were down-dip of the seismogenic zone, but some occurred near the trench. In 2015, borehole pressure sensors showed that slow slip propagated from down-dip towards the trench. Along with tremor and low-frequency earthquakes, repeating earthquakes are also good indicators of slow slip events. In the 2014-2015 Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip (HOBITSS) experiment, vertical deformation constraints from 24 seafloor absolute pressure gauges and land GPS stations also showed SSE. Ocean bottom seismograph recordings of repeating earthquakes, which are good indicators of SSE, showed the importance of a subducting seamount in controlling slip patterns and that slow slip migrated from the decollement into faults in the accretionary wedge. She concluded the talk by discussing her success in teaching high school students from the California Summer School for Math and Science about subduction dynamics, slow slip events, and data analysis. The program included instruction in Python programing and hands-on quantitative and programing work on detecting shallow slow slip via observations of repeating earthquakes along the southern Cascadia subduction zone. Five of the students are continuing to collaborate with her.

Lee Freitag (Woods Hole Oceanographic Institution) gave a talk on strategies and motivation for extending cabled and/or buoy-telemetered seafloor observatories via acoustically-linked sensors. Cables and seafloor nodes can accommodate acoustic base stations that can receive data remotely from additional seafloor sensors. A big advantage of acoustically-linked remote sensors is that they can be deployed without an ROV, reducing costs dramatically and enabling more deployments. Limited acoustic bandwidth and limited power on uncabled, remote sensors limits data transmission, but small amounts of episodic data or data selected by an event detector on board the sensor package can be transmitted in near real-time. Remote sensors also require independent timing from on board clocks. He described successful results of episodic and on-demand data transmission between an OBS deployed on the Nootka Fault and acoustically-linked to a surface buoy. He then described results from a 2016 pilot study using an acoustic link for a tsunami warning system in the Mentawai Basin, south of Sumatra, Indonesia. In that study, acoustic data transmission between a seafloor pressure sensor
and a bottom node was achieved at ranges up to 20-30 km at rates of O(100) bps. The acoustic link depends on a negative sound speed gradient near the water surface, which refracts direct paths away from the surface and back toward the seafloor. This sound-speed structure is not present everywhere, but does exist at several locations of interest, including parts of the cabled observatories in Cascadia. He also discussed testing of event detection schemes using data from 2012 Haida Gwaii earthquake-generated tsunami recorded by pressure gauges on Cascadia Initiative OBS. This event detection could eventually be used on board seafloor sensors to select data for near real-time transmission via the acoustic link.

2.7 GEOPHYSICS AT THE FRONTIER

Organizers: Marianne Karplus & Jeroen Tromp
Invited Speakers: Ebru Bozdag, Eric Kiser, Eileen Martin

This session focused on recent and future advances in computing power, using larger numbers of seismic instruments ("large N" or dense arrays), and new technology and methods. As the IRIS community expands into more areas of geophysics and data volumes rapidly increase, this session aimed to look forward to the needs and possibilities of the seismology community in the next 10 years. The three talks highlighted new frontiers in high performance computing, large N arrays used for 3-D active-source imaging, and the use of fiber optic cables for seismic imaging.

Ebru Bozdag (Colorado School of Mines) presented her results from global full-waveform inversion, including her global adjoint tomography model published in 2016. Global adjoint tomography is extremely challenging due to the computational requirements and big data available to be incorporated. She discussed the details and results from progress in that field including suggestions for addressing computational problems and large datasets. The new models jointly invert for the crust and mantle to avoid "crustal corrections", and she is planning to use data from all earthquakes in the global centroid moment tensor (CMT) catalog as well as all permanent and temporary networks available from IRIS. She has made available tools and codes for processing through GitHub repositories and the Computational Infrastructure for Geodynamics.

Eric Kiser (University of Arizona) presented new results from the Imaging Magma under Saint Helens (iMUSH) active-source seismic experiment. The iMUSH active-source experiment included 23 1000-2000 lb borehole shots (coordinated by the IRIS Seismic Source Facility), two deployments of ~2,500 Texan Reftek 125A data loggers with 4.5 Hz geophones, and one deployment of ~900 one-component nodal seismometers with 10 Hz geophones. He presented the latest 3-D Vp velocity models using traveltimes from the iMUSH active-source dataset. He identified a low Vp anomaly believed to represent a magma reservoir beneath Mount St. Helens and calculated the melt fraction in the inferred reservoir. The iMUSH results highlight the potential of very large N arrays to record active sources to image subsurface structure of various geologic settings including active volcanoes. Advances in instrument technology toward smaller, more portable sensors with longer battery lives have allowed for rapid deployment of thousands of sensors for recording of active and passive-sources.

The presentation by Eileen Martin (Stanford University) detailed results from several recent installations of fiber optic cables for seismic analyses including a fiber optic cable installed at the Stanford University campus and a buried fiber optic cable in Alaska. She presented that fiber optic arrival times were consistent with seismic node arrival times for an active-source seismic survey and for earthquake recordings, but the waveforms were strain rates in the cable instead of particle velocities. She further showed that those changes affect signals extracted from ambient noise interferometry using fiber optic data. She presented several codes created by her group at Stanford University that are available on GitHub and encouraged the IRIS community to continue to explore the potential of fiber optic recording for earthquake and seismic imaging projects.

The concepts of high performance computing, large N arrays, and novel instrumentation were mentioned in a number of other talks and posters during the IRIS Workshop including those by Brandon Schmandt, Kate Allstadt, Karianne Bergen, Wenyuan Fan, and more. They were also discussed during several Special Interest Group (SIGs) related to high performance computing, the node owners group, source physics experiments, and others.
3. Poster Sessions

The workshop included two one and a half hour poster sessions that featured ~120 presentations.

The posters were grouped into categories reflecting the plenary sessions (Appendix B).

**Science Built on a Strong Foundation**: 10 posters
**Advancing Earth System Science with Geophysical Observations**: 41 posters
**Mining Existing Seismic Data with New Techniques**: 16 posters
**Identifying and Mitigating Hazards in the 21st Century**: 14 posters
**Geophysical Approaches to Understanding the Hydrosphere and Cryosphere**: 3 posters
**Supporting Science and Discovery Beneath the Oceans**: 14 posters
**Geophysics at the Frontier: New Capabilities and Techniques**: 11 posters

An additional category specific to the poster sessions was Facilities, Operations, and Management (10 posters) that showcased a wide range of technical information available for discussion. In particular, many posters showed work by graduate students, postdocs, and early-career scientists, and offered an opportunity for interaction and collaboration. Of the 117 posters, graduate students presented 37 posters and postdocs presented 11 posters. Undergraduates and others that simply marked themselves as ‘student’ presented an additional 13 posters. Thus, ~52% of all posters were presented by students (undergraduate and graduate) and postdocs.
4. Special Interest Group Sessions

Unlike the plenary sessions that were chosen to reflect the workshop theme “Foundations, Frontiers, and Future Facilities for Seismology”, the Special Interest Groups (SIGs) were solicited widely from the community through IRIS announcements. There were 13 SIGs spread over three SIG sessions, and each SIG session featured three to four SIGs meeting concurrently in different rooms. In order for all participants to get a glimpse of discussion at all SIGs, the SIG organizers presented a short summary of the sessions at the end of the workshop and provided summaries below.

4.1 RESOLUTION OF EXPLOSION INDUCED DAMAGE USING NOISE CORRELATION AT A DENSE 3-COMPONENT ARRAY

Organizers: Eli Baker (AFRL) and Brandon Schmandt (UNM)

This SIG meeting’s focus was to consider a community experiment that would observe a tamped underground explosion with sufficient density and instrumentation to meet two objectives. The first is to use back-projection to identify the location and timing of the generation of different seismic phases. The second is to use tomography (active source and ambient noise), before and after the explosion, to resolve damage on a scale that would allow it to be associated with the location(s) of seismic phase generation. This is an important problem for explosion monitoring, and the results could have relevance to many seismic monitoring applications (e.g. changes due to wastewater injection, hydraulic fracturing, geothermal extraction and injection, CO₂ sequestration, natural groundwater withdrawal/recharge). The meeting opened with four 5-minute presentations to provide background and stimulate discussion. Eli Baker (Air Force Research Laboratory, AFRL) described the proposed experiment, Bob Reinke (Defense Threat Reduction Agency, DRTA) described a 900 lb shot they could detonate at 11.5 m depth in limestone at their test site on Kirtland Air Force Base, Carene Larmat (Los Alamos National Laboratory) discussed lessons learned from the Department of Energy Source Physics Experiments (SPE) that would be applicable to the proposed experiment, and Brandon Schmandt discussed aspects of large N experiments.

The response was strongly enthusiastic, with ~40 people in attendance. A steering committee was formed to carry out planning for an experiment to occur ~October 2019. Members include Paul Schwering (Sandia National Laboratories, SNL), Bob Reinke (DTRA), Kristin Phillips-Alonge (DTRA), Brandon Schmandt (University of New Mexico, UNM), Eli Baker (AFRL), Kent Anderson (IRIS), Katherine Aur (SNL), and Christian Poppeliers (SNL). A broader group of ~20 researchers also wish to stay informed of plans, possibly participate, and provide feedback.

An immediate action item is to write more thorough scientific objectives to reach a level that informs optimal experiment design. To put numbers to the spatial coverage needed (surface and borehole), synthetic calculations are needed and Christian Poppeliers is taking a lead in that direction. Synthetic tests should be informed by geologic constraints and preliminary seismic site characterization. Simulations will need to address instrumentation requirements for the desired back-projection (both near and far field, the latter relying on very dense arrays) and tomographic resolution.

A major challenge will be fielding enough instruments because large numbers of 3-C geophones (e.g., Fairfield nodes or other) and strong motion sensors will be needed. Possible sources being explored included a node facility from SNL, borrowing nodes from the University of Utah, and borrowing nodes and/or Texans from IRIS. Obtaining sufficient strong motion instruments may be the biggest challenge. IRIS has 20 and SNL may have access to 15 or 20 more, and up to 400 might be needed depending on the refined design goals. Eli Baker (AFRL) will write an Air Force Office of Scientific Research proposal for funding borehole strong motion instruments.
Other ideas proposed for longer term planning included characterizing near source structure and noise characteristics, reviewing existing geological characterization, reviewing seismic data from previous explosive experiments at the site, doing an IRIS undergraduate refraction experiment on site, using UNM’s Fall 2018 seismology class to do a refraction experiment at the site, and using a small number of 3 component instruments to assess resolution of noise correlation Empirical Green’s Functions (EGFs) at the site. The 900 lb shot should be preceded by a very small calibration shot to provide EGFs to each station. Finally, there was also strong interest in deploying infrasound sensors (e.g. to fill in gaps in data sets for yield estimation, provide calibration data for code prediction validation).

4.2 RECENT MODERNIZATION OF THE GLOBAL SEISMOGRAPHIC NETWORK (GSN)

Organizers: Katrin Hafner, Pete Davis, Dave Wilson & Jeffrey Park

This SIG updated the community on new instrumentation and infrastructure improvements that have been modernizing the GSN over the last several years. It was well attended by approximately 40 people in addition to the SIG organizers. The session began with an overview presentation by the IRIS GSN program manager, Katrin Hafner, of what the GSN is, its multi-use purposes for fundamental research, earthquake monitoring, tsunami warning and nuclear explosion monitoring, and the long-standing collaboration between IRIS, the United States Geological Survey and the National Science Foundation.

The two GSN network operators then reviewed the development of the new very broadband (VBB) borehole sensors designated to replace the aging KS-54000 borehole sensors currently deployed at GSN stations. The development and purchase of 77 new borehole sensors was funded by the Department of Energy through an interagency transfer to the USGS. Testing results from the Streckeisen STS-6A and the Nanometrics T360 borehole sensors were presented as well as examples of improved station performance at several GSN stations (Figure 1).

Infrastructure improvements allowing for the deployment of the new borehole sensors (e.g. drilling of new boreholes and postholes, improved lighting and ventilation, etc.) facilitated by additional funds in the USGS FY16, FY17 and FY18 budgets were also presented. A total of 20 new borehole sensors have now been deployed (Figure 2).

The presentations concluded with a description of the new infrasound sensors that have been deployed at selected GSN stations, and a discussion of how these measurements can be better utilized in the future. The community was encouraged to retrieve these data from the IRIS DMC and provide feedback on their quality.

Figure 1. Noise Improvement after installation at IU.WVT as compared to STS-1.

Figure 2. Locations of New VBB Borehole Installations of STS-6A (Bright Green Stars)
4.3 FUTURE OF OCEAN BOTTOM SEISMOLOGY CAPABILITIES IN THE US

Organizers: Anne Sheehan and John Collins

The purpose of this SIG was to discuss the upcoming transition of the National Science Foundation (NSF) funded United States Ocean Bottom Seismograph (OBS) facility from the IRIS-managed multi-institution Ocean Bottom Seismograph Instrument Pool (OBSIP) to a single-institution Ocean Bottom Seismometer Instrument Center (OBSIC). The room was nearly full, with just a few seats open in the front and people standing in the back. Approximately 50 people were in attendance including people from NSF, IRIS, OBS facilities, and the IRIS research community.

Anne Sheehan, Chair of the OBSIP Oversight Committee, started the SIG by providing an overview of current instrumentation and capabilities of OBSIP. OBSIP makes ocean bottom seismic equipment available to researchers to conduct studies of marine geology, seismology, and geodynamics. Instruments available through OBSIP include broadband (LP) and short period (SP) ocean bottom seismometers, hydrophones, and absolute and differential seafloor pressure gauges. In the OBSIP model, the instruments have been available through 3 different Institutional Instrument Contributors (IICs)—Lamont-Doherty Earth Observatory (LDEO; 59 LP), Scripps Institution of Oceanography (SIO; 60 SP, 54 LP), and Woods Hole Oceanographic Institution (WHOI; 30 SP, 60 LP).

The annual budget for OBSIP was ~$3.7M/year in base support. The budget for the new OBSIC will be $1.8M/year. WHOI is in negotiations with NSF for the OBSIC. Part of the LDEO and SIO OBS pools belong to those institutions and will not be transferred to OBSIC. The Cascadia ‘Amphibious Array’ equipment purchased with American Recovery and Reinvestment Act (ARRA) funds will be under the control of the new OBSIC. There was discussion about the reduction of number of instruments available through OBSIC. John Collins stressed potential OBS availability from SIO and LDEO via subawards; in other words, more than just the OBSIC fleet will be available. Candace Major from NSF stated that the sub-awardee could be an entity other than SIO or LDEO.

Recapitalization of the fleet was discussed. Candace Major said that there is “No timeline yet”. NSF’s decision to replace OBSIP (three institutions) with OBSIC (one institution) means that NSF’s outlay for “base support” is reduced. Some of that savings in base-support costs might be available for new instrumentation. NSF could re-cap the fleet in 2-3 years if ALL savings were applied to recapitalization, but that will not happen, as they need to apply some savings to increased science support. Candace stated that it is too soon to consider recapitalization, as there is a need to give OBSIC time to get off the ground and establish itself.

The governance for the new OBSIC was briefly discussed. The OBSIP Oversight Committee will remain in effect until January 2019, or until replaced by another OBSIC governance by NSF. Candace Major from NSF indicated that the new governance will be decided on an ~6 month timeframe.

One member of the audience asked how ongoing experiments will be affected; in other words, if LDEO or SIO instruments are deployed in 2018, who will pick them up in 2019? The default is that OBSIC will be responsible, if they are OBSIC instruments. If they are institutional instruments, then the institution involved has a strong desire to do the recovery if they are able to maintain staff. Otherwise, OBSIC will be responsible for recovery.

There were a number of other questions from the audience, mainly directed at NSF, related to proposing OBS experiments. It was extremely helpful to have Candace Major from NSF in attendance.

Nathan Miller (USGS, WHOI) described USGS collaboration with WHOI to build/acquire small OBS for aftershock deployments.

A few slides on OBSIP and PASSCAL use statistics, compiled by Kasey Aderhold (IRIS), were shown and discussed. OBS usage has varied over the years, and both the total data downloaded as well as the number of unique data users increased significantly in the wake of the Cascadia Initiative, which indicates a broadening of the OBS community. PASSCAL usage is much higher, and audience members speculated about whether that is due to the number of instruments available or the cost to deploy. General OBS availability was discussed.

John Collins briefly described OBSIC plans including staffing.
4.4 EDUCATIONAL AND CITIZEN SCIENCE SEISMOLOGY

Organizers: Richard Allen and John Taber

The purpose of this SIG was to explore successful models and challenges of the slightly different approaches of educational and citizen science seismology and to discuss future opportunities for engaging a broad audience. Scientists and education specialists have been supporting and developing educational seismology networks in the US and globally for decades, and citizen seismology has been developing and expanding on a parallel track over the same time period. While there can be somewhat different goals when engaging students versus the public in seismology, this SIG, which included about 40 participants, focused on opportunities for collaboration and highlighted various tools and apps.

For educational seismology, the focus is on student engagement to encourage learning and to show the possibilities of science/geoscience careers. That is one of IRIS’ primary targets, which includes bringing data to the classroom using jAmaseis software (https://www.iris.edu/hq/inclass/software-web-app/jamaseis) and the use of educational seismometers. There are going to be additional opportunities to engage students in the coming year with data from marsquakes, via the NASA InSight mission. There are also expanding opportunities for educating the public with the new Station Monitor app (https://www.iris.edu/app/station_monitor/).

For amateur and citizen science seismology, the focus is more on providing tools for a technical/science hobby, and encouraging engagement in science. To involve the broader public in citizen science, it is important to provide easy access to data and information and to show that the data are being used. Several popular initiatives were highlighted during the SIG, including Raspberry Shake and Boom (https://raspberryshake.org), which offers a plug and play seismometer and infrasound sensor for home or school use, and the opportunity to connect to a global network. LastQuake (https://www.emsc-csem.org/) provides rapid earthquake information plus user involvement, by asking users to enter intensity information via the cell phone app. This builds on one of the earliest geoscience citizen science projects, Did You Feel It (https://earthquake.usgs.gov/data/dyfi/), which is also interested in additional sources of felt information. There was considerable interest in and discussion about MyShake (http://myshake.berkeley.edu), which is collecting ground shaking data using private cell phones (20,000 current users), has a goal of providing earthquake early warning, and will be releasing new features this fall. Finally, a plan was described to engage the public in assisting in the digitizing of scanned helicorder records, using DigitSeis software (http://seismology.harvard.edu/research/DigitSeis.html), which requires a small amount human intervention for each record. Key issues will be to reach interested users and to keep them engaged, perhaps by giving scores so users can compete with friends.

4.5 IMPROVING EDUCATION PRACTICES IN THE UNDERGRADUATE CLASSROOM AND BEYOND

Organizers: Stefany Sit and Derek Schutt

This lightning (~40 minute) SIG was well attended, with 30-40 participants from all career stages. The SIG began with a gallery walk, in which the attendees defined the topics for discussion in each of four categories: Cognitive Learning, Teaching, Broadening Participation, and Outreach.

The gallery walk lead to a lively and positive set of discussions facilitated by the organizers on the topics defined by the audience. Items discussed included:

- Effective techniques for building 3-D learning. One interesting method discussed was using 3-D printed materials to develop spatial reasoning. Several participants were pleased to learn there is an educational repository available.
- Reducing math anxiety. Here, Jackie Caplan-Auerbach discussed her method of having students keep equation journals. Creating a growth mindset and the role of pre-undergraduate education and removing math anxiety was also discussed.
- Building diversity of all types. The important role of geophysics in appealing to potential students who do not find fieldwork attractive was noted.
- Teaching with themes of community and presenting career options.
- Virtual field trips and data analysis field camps.
- Opportunities to create a more inclusive community.

The thirty minutes available for discussion and ideas went by very quickly, and maybe only 10% of the topics raised on the gallery walk were addressed. Given the vibrancy of the discussion, and the many interesting ideas raised, the desire of the community to continue discussions on educational methods is clear. The AGU session on education was mentioned to the group, and the organizers promised to send out an announcement on the informal Facebook group on teaching geophysics and seismology.

### 4.6 BACKGROUND NOISE: MICROSEISMS, SITE, AND OTHER SOURCES

**Organizers:** Robert Anthony, Keith Koper, Adam Ringler, David Wilson

The room was nearly full of attendees (60–70) throughout the SIG, indicating the high level of interest in this topic within the seismological community. Keith Koper began with an introduction showing some previously published background noise maps of the United States and Antarctica. He then showed some of his recent results of background noise in the secondary microseism band in the United States and suggested that we should extend this analysis over a wide range of frequencies to have a spatially varying reference noise model for the US using TA data. It seemed the consensus among the group was this would be useful and perhaps should extended to infrasound measurements from TA as well.

Keith also proposed a catalog of known strong microseism sources and regions, which although perhaps challenging to implement, would be of great use to studies using ambient noise imaging.

Next, Adam Ringler discussed how Power Spectral Density (PSD) processing techniques could influence estimates of signal power, particularly at long periods. This makes it impossible to directly compare PSD datasets that are processed using different techniques. For the noise maps of the US, Keith Koper and ASL will compare MUSTANG metrics to different PSD processing algorithms and work with the community to decide a “standard” algorithm for PSD generation.

Andy Frassetto and Kasey Aderhold (IRIS) then presented some results from TA Alaska showing that sensors in the array are detecting magnetic field variations from solar activity as well as interesting microseism signals that are modulated by local sea ice concentration.

Omar Marcillo (Los Alamos National Laboratory) then demonstrated a technique to detect tonal noise from wind farms, generators, and additional rotating machinery. This noise has become increasingly prevalent in the central U.S. as wind power has been rapidly expanding in this region in the past decade.

Finally, Chad Trabant and Manoch Bahavar (IRIS DMC) presented a forthcoming data product that automatically calculates H/V spectral ratios. The software enables the user to select a wide range of how the ratios are calculated and should be useful quickly and easily estimating local site conditions (e.g., the presence of a low velocity sediments below the station).

### 4.7 NODE OWNERS GROUP

**Organizers:** Kent Anderson and Justin Sweet

The purpose of this SIG was to bring together node owners, node users, and community members interested in nodes to discuss resource sharing, policies, and best practices. We also used this meeting to discuss recent node pool developments at PASSCAL, and other new and interesting node-related findings that might be of interest to the community. We had approximately 35 people in attendance, about 5 or 6 of whom were confirmed node owners.
Anderson opened the meeting by outlining IRIS’s current node pool (63 general, 200 polar) and plans for future growth. IRIS expects to grow the general node pool to ~400 units by late Fall 2018. The general node pool is targeted to grow by an additional ~1,200 units over the next 3-5 years. Anderson also touched on IRIS’ current node policies related to data and sharing. Lastly, Anderson highlighted a new Resources for Node Owners website (https://www.iris.edu/hq/noderesources), which contains a list of community members who own nodes and are open to collaborating with others who may want to use nodes. The website also has links to node instrumentation specs as well as a growing bibliography of publications that make sure of data acquired with nodes.

Sweet took the podium next and highlighted a forthcoming article on the Oklahoma Wavefield Demonstration Community Experiment published in the Seismological Research Letters (SRL) Data Mine column (https://doi.org/10.1785/0220180079). Next he presented a few recent results from testing he conducted using 3C nodes at PASSCAL. Testing on tilt tolerance showed significant signal degradation when the nodes were installed at tilts of 5° or greater. He also showed results from node burial testing which showed substantial noise improvement on the horizontal channels, even when the node was only half buried. Finally, Justin showed an important finding that once activated, PASSCAL 3C nodes can only move ~300m from their activation point before they lose their GPS lock and timing precision.

Marianne Karplus (UTEP) next spoke about some recent node response testing she conducted in concert with the folks at the USGS Albuquerque Seismic Lab. Their testing showed remarkable consistency in response phase and amplitude across the three test nodes. In comparison to a well-calibrated reference instrument, the node response looked like it could still use some refinement to more precisely represent measured ground motion. These results were published in a recent SRL paper, which can be found at this address https://doi.org/10.1785/0220170236.

Lastly, Anderson opened the floor for questions and general discussion on different types of nodes people use, wish lists for node development, and upcoming experiments that will have a nodal component. The next Node Owners Group meeting is scheduled for the 2018 AGU Fall Meeting.

### 4.8 HIGH PERFORMANCE COMPUTING FOR SEISMOLOGY
**DATA PROCESSING AND SIMULATIONS**

**Organizers:** Carl Tape and Lorraine Hwang

As the volume of archived seismic data increases, the need to have these data processed and modeled in new and more powerful computational systems has become important. The High Performance Computing and Seismic Data Working Group (HPCWG: https://www.iris.edu/hq/about_iris/governance/hpcwg) was established to assess the HPC needs of the seismological community for processing seismic data and for performing simulations.

The first goal of the HPCWG was to identify the computational needs of the seismological community. For this, the HPCWG constructed a 26-question survey of computational needs. We started the SIG with a summary of results from 348 responses to the survey (available at the link above). The take-home points of the survey were:

- Data processing, forward modeling of the seismic wavefield, and inverse modeling are the dominant research categories.
- Most seismologists’ time is spent processing data, learning/compiling/running codes, validating/verifying results, and visualization.
- It seems possible that the large time spent processing data is related to responses showing a range of data formats in use, a lack of HPC resources, and a desire to locate data next to HPC resources.
- Current users of HPC resources expressed a need for more HPC resources and for more training.

The second product of the HPCWG presented was a draft outline of an HPC center for seismology that would be co-located at an existing computational facility, either NSF XSEDE or a national lab. The purpose of the outline was to identify the components of a high-performance computing center for seismological data processing and modeling and to establish components of a proposal to three NSF directorates: Earth Science (GEO/EAR/Geophysics), Cyberinfrastructure (CISE), and Training (EHR).
The targeted services of the proposed HPC center include:
- Training modules, including webinars, online/offline short courses for tools (e.g., obspy)
- Administration support for access to CPU hours for training and research,
- Software engineering support installation and code optimization (reviewed for readiness)
- Adapt to the needs of its user communities such as CIG, IRIS/PASSCAL (including Large-N initiatives), and industries, in order to anticipate the future needs for HPC in solid earth geophysics.

A successful example of a training workshop occurred in September 2017. Members of the HPCWG hosted a CIG-LLNL seismology workshop at the Livermore Valley Open Campus, where participants had access to hundreds of cores on a Livermore cluster. The workshop was extremely successful and exemplifies what could be achieved for training across other sub-disciplines in geophysics, given the availability of HPC resources with pre-installed software. More information can be found here (https://geodynamics.org/cig/events/calendar/swhav/) and from an EOS article summarizing the workshop (https://doi.org/10.1029/2018EO090991).

The SIG then transitioned to a discussion among members in the audience for how to achieve an HPC center for seismology. We discussed what kinds of scientific applications, codes, and people would be in position to use the HPC center to develop and disseminate a particular application (and code). A funded “super user,” who in turn would oversee a small set of trial users, would lead each application. The objective would be for the super users and trial users to work with the HPC hosting facility to improve the application (and code) over the course of a funded project. Several SIG participants expressed interest in playing a role in the proposed HPC center, either within a leadership role, a super user, or a trial user. The HPCWG will use the information gathered at the SIG, and throughout the meeting, to refine the outline for the HPC center for seismology and to discuss the next steps.

### 4.9 COMMUNITY INPUT TO THE WORKING GROUP ON LONG-TERM SEAFOOR SEISMOGRAPHS (WGLTSS)

**Organizers:** Monica Kohler & Jeffrey Park

This SIG was for IRIS community members who were interested in contributing to discussions about the deployment of long-term, high-quality broadband seismic stations on the seafloor to complement existing permanent GSN land stations. Topics of discussion included: a review of the responses to a recent global seismology needs survey, potential scientific targets, site occupation characteristics, and plans for international collaboration. The SIG focused on the recent activities of the IRIS GSN Working Group on Long-Term Seafloor Seismographs (WGLTSS), and solicited feedback on topics that would inform the working group’s recommendations on how to move forward with a pilot experiment.

Findings were presented from responses to a related survey that was recently distributed to the global seismological community. Respondents were asked to provide their preferred responses to a variety of questions including outstanding unanswered scientific questions, seafloor site occupation duration, data retrieval latency, sensor types, data frequency range, types of seismic data, and additional sensor types. Survey results provided a springboard for discussion on topics related to defining a pilot experiment. SIG participants were asked for input on a set of maps showing optimal seismometer locations to record data for a variety of seismic phases, in order to define the global science and associated data targets. The maps included optimal locations for data collection for seismic structure studies using phases from receiver functions, mantle transition zone and upper mantle, lower mantle, Ultra Low Velocity Zones, and the outer and inner core. In particular, maps showing the averages of the above data types (Figure 3) were used as a starting point to begin thinking about a location that would provide the maximum amount of information for a variety of global seismology questions.

Next, the SIG group discussion focused on topics covering pilot deployment options including possible array configurations, and technology that is either current or nearly fully developed. As before, topics were guided by survey results. For example, regarding sensor recording bandwidth, since survey responses did not emphasize extremely broadband, intermediate band appeared to be a good representative with the added benefit that it is low-power. Participants also discussed ideas on array configuration, with the consensus indicating that a mini-array with closely spaced stations is both doable (even
considering the additional shiptime required) and preferable for redundancy. A discussion on the survey respondents’ desire for 4+-year durations centered on the implications for battery life, including either replacement or the development of longer-life batteries, where the current capability is two years. Participants pointed out that sensor burial would result in a big signal-to-noise ratio (SNR) improvement on horizontal long-period data, but that this also increases cost. Thus, at a minimum, shielding should be standard on all stations. Telemetry could include acoustic methods via wave-glider or using a ship of opportunity to retrieve data via acoustics or optics (Figure 4). These would also have implications for battery size and expense.

SIG participants discussed other complementary marine seismology activities, specifically providing feedback suggesting how a pilot experiment could be complementary to Pacific Array seismic arrays and MERMAIDS hydrophone locations, while at the same time distinguish itself in terms of site occupation duration and independent geographic location. The SIG concluded with a discussion on how a pilot experiment should be precisely defined. Consensus views were that: i) it should use new technology (wave gliders, acoustic/optical telemetry means) relative to current temporary OBS deployments, ii) the focus should be on site occupation of 4+ years, iii) the deployment logistics and configuration should be repeatable at other locations, iv) the first site should fulfill the science/data needs but should also be within relatively easy reach of a U.S. port for easier site maintenance, v) data quality

Figure 3. Maps showing a suite of all the types of seismic phases mentioned above, averaged together to show optimal locations for collection of the largest numbers of all of these phases. Top: Africa-centered. Bottom: Pacific-centered. Figure credit: Jessica Irving.

Figure 4. Data offload technology concepts. Above: Complete data offload from a ship of opportunity (optical modem). Right: Continuous acoustic telemetry using wave glider. Figure credit: John Collins and Jon Berger.
should be improved through burial and in-situ battery pack replacement without disturbing the sensor, and vi) the pilot project should provide results distinct and different from what can currently be accomplished with standard shorter-term deployments of OBS, either alone or in array configurations.

SIG participants were encouraged to see the WGLTSS website for more details (https://www.iris.edu/hq/about_iris/governance/wgltss), and to contact Monica Kohler, Jeffrey Park, or Katrin Hafner to provide feedback on WGLTSS activities.

4.10 ORGANIZING FOR THE PRESERVATION OF ANALOG SEISMIC DATA

Organizers: Lorraine Hwang & Paul Richards

Over a century of analog paper and film seismic recordings acquired in the pre-digital era (1880’s–1990’s) are at risk. Decades of analog seismic data are physically deteriorating, and the institutional knowledge regarding these collections and how to use them is slowly fading as a generation of seismologists retires. This data represents a large portion of our seismological observations of the earth important to longitudinal studies of earth processes not only for earthquake hazards but also for phenomena related to climate change.

The session had three (3) main goals:

1. To identify a group of individuals interested in organizing and attending future workshops on preservation of analog seismic data. We had 21 researchers sign into our workshop as well as a handful of others who reached out to the organizers prior to the event but could not attend demonstrating a clear need for organizational activities. From this group, we hope to identify key personnel to organize follow-on activities.

   The following strawman goals were put forth for a future workshop:
   Gather Stakeholders concerned with analog seismic data to assess the current state of worldwide collections, metadata necessary for preservation, and the means to increase its availability. Provide guidelines for preservation of both analog and digital data.

2. To identify current scanning initiatives and data availability. Prior to the session, input from the community was solicited to begin the process of discovery of analog data sets that have been imaged, converted to timeseries and/or at risk. We received contributions from 11 groups including 3 international. A brief review of previous scanning efforts and scanning criteria was given and representatives from contributed projects were given the opportunity to present.

3. To identify key issues in preservation, discovery, reusability and interoperability. Participants were encouraged to contribute during the session to a Google document to add to previously identified issues. These broad issues are listed below
   • What is the inventory of existing data and in what condition is it?
   • What records should be prioritized for RESCUE, the digitization and creation of database with metadata? If everything cannot be saved, what should be saved?
   • What is the necessary metadata?
   • Where should the data be archived?
   • How should costs be supported, users/funders/multiple agencies?
   • What roles do stakeholders play in preservation?
   • What are the science drivers?
   • Are the digitization tools sufficient to conduct the above science?

Discussion on these issues utilized the remaining time and will provide a framework to organize future activities.
4.11 CONNECTING WITH DIFFERENT AUDIENCES: FROM THE PODIUM TO THE PUB
Organizers: Beth Bartel, Maite Agopian, and Wendy Bohon

The purpose of the session was to help scientists practice speaking in general and storytelling in particular for a broad public audience. Between 40-45 IRIS Workshop attendees participated.

The SIG began with skits and a group brainstorm on elements of effective and ineffective presentations, with elaboration on best practices for connecting with an audience. Best practices described addressed both verbal and non-verbal communication. A brief presentation then introduced attendees to the different forums available for public science presentations, including Nerd Nites, The Story Collider, Science on Tap, TED talks, and science salons, all established opportunities for scientists to speak to the public. The presentation then introduced attendees to or refreshed their memory of a basic plot structure, Freytag’s pyramid, and some of the elements of a successful story: people, suspense/tension/mystery, and compelling, vivid, sensory details. The presentation finished with four narrative themes relevant to science stories: the quest or journey, a stranger comes to town, rite of passage/coming of age, and mystery.

After the discussions of technique and opportunities, attendees were given a worksheet with prompts used by Pixar to shape stories. They used these prompts to frame their own stories that they then shared with a partner. At the end of the session, three participants shared their stories with the whole group.

Handouts distributed during the session included a Tips and Tricks sheet with an Additional Resources sheet, the Pixar story prompts, and a Main Idea Map worksheet aimed to help scientists brainstorm engaging points of entry to their science for public presentations or any other science outreach endeavor. The materials developed by the conveners are available for download from the SIG landing page on the IRIS website (https://bit.ly/2og88P).

Note that the conveners invited interested attendees to meet that evening at a pub to continue to share stories. About 20-25 Workshop attendees, most of whom has attended this SIG, met at Dialogue Brewing near the Convention Center, where four SIG attendees shared the stories they had shared with partners at the SIG.

4.12 IRIS PORTABLE POOL MODERNIZATION
Organizers: Kent Anderson & Bob Woodward

The purpose of this SIG was to inform the community of the strategic vision to evolve and modernize the instrumentation of the portable pool as proposed in the SAGE-II proposal. Approximately 40 people attended this SIG.

The meeting opened with an overview of the current state of the portable pool including: inventory, experiment counts since 2000, and several trend plots. The broadband (BB) pool shows a decrease in instrument usage since about mid-2016 and for the first time in nearly a decade, there is no longer a wait for BB instruments. Short period instruments usage is holding fairly steady. Texan usage has decreased since about 2014. Node usage is very high and has been that way since their introduction to the pool in 2016.

Next there was a discussion of the results of an informal survey of the community conducted by the PASSCAL Standing Committee (PASC) last fall to determine their needs for the future of the facility. Approximately 50 community members responded to the following survey questions:
1. What science questions need to be answered?
   a. Imaging, source evaluation, volcanism, cryosphere, RAMP tectonics
2. What methodologies do we need?
   a. Ambient noise tomography, receiver functions, full waveform inversion, joint seismic inversions, Large N
3. What instruments are needed for the future?
   a. BB (10s of Hz to 200s)
   b. IP (100s of Hz to 20-50s)
   c. SP (10Hz to 10s)
   d. HF (>1Hz)
4. How long do portable deployments need to run?
   a. Active source (days to weeks)
   b. Passive source (months to years)
5. What needs are not currently being met?
   a. Telemetry, Nodes (Large N), Longer-duration nodes, longer-period nodes, more posthole IP/BB sensors
6. How do we drive manufacturers to produce what we want?

Finally, plans and proposals for modernization of the PASSCAL pool were described. Under the remainder of the SAGE award IRIS aims to:
1. Accept some of the TA equipment into the BB pool
2. Investigate new BB/IP instruments that may ease maintenance burden on the aging BB pool
3. Enhance the node pool (currently: 63 PASSCAL, 200 Polar)
   a. Plan to procure 300+ nodes for PASSCAL before the end of 2018
   b. The goal is to support the strong demand, and ultimately replace the Texans

IRIS plans to implement the following changes to the portable program:
1. Continue support of the BB pool (enhancement from TA)
2. Enhance wavefield imaging capabilities with more nodes, IP, and BB systems
   a. Phase out of Texan pool
3. Develop more capabilities in hazard response/RAMP equipment
4. Improve access to the Seismic Source Facility (UTEP) by moving to a more supplemental proposal basis rather a co-PI model
5. PASSCAL pool inventory targets
   a. Increase nodes to 1200 or more by 2023
   b. Decrease BB from 800 to 650 by 2028 (attrition—not actually going to take working sensors out of the pool)
   c. IP pool growth beginning in earnest by 2023 to 450 by 2028

Some of the future challenges the portable facility faces were also discussed. These challenges include:
1. Sustaining existing equipment in a flat funding scenario (likely)
2. Replacing the ~1,500 aging acquisition systems (DAS) in the current pool
3. Planning for changing science drivers and funding
4. Doing more with less
5. Seeking out other sources of funding (outside SAGE-II)
   a. Mid-sized infrastructure (NSF)
   b. MRI (build on success of GEOICE)
   c. Partnerships with DoE, DoD, NOAA, USGS, and other agencies

The IRIS community is encouraged to provide their input on these plans through their governance representatives on the PASC. IRIS plans future community outreach as they continue to refine design goals for new instrumentation.

The meeting ended with a Q&A which touched on the following topics:
1. Concern about the aging DAS pool and need to recapitalize in the next 5 years
2. Node evolution and plans to purchase several flavors or only one type
3. Call for additional strong motion sensors in the pool
4. Future plans for magnetotellurics (MT) at PASSCAL
4.13 CONTRIBUTE TO EARTHSCOPE’S FINALE
Organizers: Kent Anderson & Bob Woodward

As EarthScope draws to a close in 2019, the EarthScope National Office (ESNO) will be working with researchers over the next year to synthesize and document EarthScope accomplishments, showcasing the wealth of scientific work inspired by the program. We have supported six workshops for community-driven synthesis of EarthScope research. These cross-disciplinary workshops encourage researchers to create a multifaceted view of EarthScope findings for each topic. There will be three new upcoming synthesis workshops: Midcontinent Rift, San Andreas Fault Observatory at Depth, and Wyoming Craton.

The ESNO identified several opportunities for scientists to broaden the impacts of their research. The ESNO encouraged scientists to put their research on the map by contributing their project summaries to the ESNO signature outreach product: an online interactive map of “science nuggets” showcasing EarthScope-funded projects (http://www.earthscope.org/results). There will also be a second Visualizing EarthScope Science Challenge in 2018 (http://www.earthscope.org/public/VESS). With this competition, EarthScope aims to highlight and celebrate the most effective, stunning, and stimulating visuals conveying the work of EarthScope scientists to a broader audience. This challenge is open to the entire EarthScope research community, including faculty, postdocs, and graduate and undergraduate students who use EarthScope data in their research. The submission window is June 25-October 15. Winners will be determined by public vote through social media. EarthScope is also featuring new profiles of a variety of EarthScope scientists on its Humans of EarthScope webpage (http://www.earthscope.org/public/HuofES). In these short interviews, researchers share with future scientists their inspiration and motivation for exploring earth science. In its final year, the ESNO has applied for two EarthScope sessions at the American Association for the Advancement of Science 2019 conference, focused on Synthesis Workshop topics.
5. Summary

The success of the workshop depended on contributions from IRIS staff and consortium members alike. Justin Sweet, Wendy Bohon, Krystin Poitra, and Danielle Sumy, handled the behind-the-scenes logistics and planning. Krystin Poitra, David Fillebrown, Perle Dorr, Rhonda Porter, and Marlo Swanson handled many of the onsite tasks and registration. The workshop science committee, Zhigang Peng, Susan Bilek, and Heather Ford, worked diligently to develop the workshop program and plenary session topics. They coordinated with a plethora of plenary session conveners who organized speakers and helped bring the plenary session topics to life.

The Workshop kicked off with an engaging field trip to Tent Rocks National Monument, presented by Dr. Nelia Dunbar, New Mexico State Geologist, and two mini-workshops on Science Communication for early career scientists and the SZ4D Initiative. Over the following 2.5 days, 22 invited speakers presented during seven plenary sessions, and conveners held 13 special interest group breakout sessions (SIGs) to discuss emerging concepts and themes of seismology. Plenary session speakers took the time to develop their presentations to highlight their science and pose new ideas and insight to the future of their specific disciplines. Their work and thoughtfulness with likely inspire new ways of thinking about the Earth and how we study and understand its myriad processes. SIG organizers proposed exciting sessions that covered a broad range of timely issues that allowed for all interested persons to engage in discussion and professional discourse. Finally, the presentation of ~120 posters during two poster sessions allowed all those in attendance to present their research, and this time was especially apt for graduate students, postdocs, and early career scientists to engage with their peers and colleagues, as well as senior professionals.

The 2018 IRIS Workshop brought together ~270 participants from across the country and around the world, representing over 90 institutions and 6 countries. Approximately 40% of attendees are considered early career investigators, from undergraduate students to post-doctoral fellows. IRIS was able to support about half of these students and postdocs through scholarships. The strong early career attendance speaks to the commitment of the IRIS community to strengthen and encourage the next generation in their science and scientific endeavors.

The keynote presentation by Terry Wallace, Director of the Los Alamos National Laboratory, presented on ‘A Transparent Planet’ at Wednesday’s dinner. His talk provided a fascinating lens to how academic and federal labs can work together to utilize geophysics knowledge to enhance the state of our national security.

Since its inception in 1984, IRIS has built excellent foundational facilities for seismologists to study the Earth’s interior, earthquakes and other natural hazards. Now we are entering a new era where hundreds and thousands of seismic stations (rather than tens of them) are deployed, and tera- to petabytes of data are recorded in a single seismic experiment or generated during a single computer simulation. In addition, automatic procedures and machine-learning techniques are increasingly used to replace human’s efforts to pick seismic events, predict ground motions, and improve earthquake early warning systems. Seismology has become more computationally intensive and data-driven than ever before. Our scientific targets are also expanding, from on-shore to off-shore, from natural to induced earthquakes, from deep Earth structures to shallow and surface processes.

This workshop not only summarized exciting science advances made using current facilities within and beyond IRIS, but also highlighted future frontier facilities, activities and techniques needed to make advancement in earth science. As EarthScope sunsets, and SZ4D and other new initiatives still in their early days, we hope that this workshop has inspired us (especially students and early career scientists) to brainstorm “the next big thing” in our community.

With the recent confirmation of 5-yr funding from NSF, IRIS is at a great position to continue to be the leader in “advancing discovery, research, and education in seismology to understand our planet and to benefit society”. Together with our member institutions and affiliates, we will strive to provide critical facilities for seismological studies of the Earth’s interior and sources, promote exchanges of data and knowledge, train the next-generation seismologists and promote Earth sciences to the general public.
Appendix A. Workshop Program

Click on the presentation titles below to view abstracts.

**JUNE 11, 2018 (DAY 0): FIELD TRIP, REGISTRATION, AND OTHER SHORT COURSES**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>8:00 AM – 12:00 PM</td>
<td>Field Trip: Tent Rocks National Monument</td>
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<tr>
<td>1:00 PM – 5:00 PM</td>
<td>Short Course: Science Communication—Networking Skills for Early Career Scientists</td>
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<tr>
<td>1:00 PM – 6:00 PM</td>
<td>Mini-Workshop on the SZ4D Initiative and Seismology</td>
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<td>3:00 PM – 7:00 PM</td>
<td>Registration</td>
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**JUNE 12, 2018: WORKSHOP DAY 1**

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<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>8:00 AM – 5:00 PM</td>
<td>Registration</td>
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<tr>
<td>8:00 AM – 8:05 AM</td>
<td>WELCOME FROM THE WORKSHOP COMMITTEE</td>
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<tr>
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<td>Presented by Susan Bilek, New Mexico Tech</td>
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<tr>
<td>8:05 AM – 8:20 AM</td>
<td>INTRODUCTORY REMARKS FROM THE NATIONAL SCIENCE FOUNDATION</td>
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<td>Maggie Benoit and Candace Major, National Science Foundation</td>
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<tr>
<td>8:20 AM – 8:30 AM</td>
<td>INTRODUCTORY REMARKS FROM IRIS</td>
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<td>Bob Detrick, President of IRIS</td>
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<tr>
<td>8:30 AM – 10:10 AM</td>
<td>PLENARY SESSION: SCIENCE BUILT ON A STRONG FOUNDATION</td>
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<td></td>
<td><strong>Organizers:</strong> Lara Wagner (Carnegie), Jeffrey Park (Yale), Brian Stump (SMU), John Louie (UNR)</td>
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<td></td>
<td>A SEISMICALLY SOUND FOUNDATION: REFERENCE MODELS AND DATASET</td>
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<td></td>
<td>Ved Lekic, University of Maryland</td>
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<td></td>
<td>FOUNDATIONS OF PORTABLE SEISMOLOGY: THE PROGRAM FOR ARRAY SEISMIC STUDIES OF THE CONTINENTAL LITHOSPHERE (IRIS-PASSCAL)</td>
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<tr>
<td></td>
<td>Anne Sheehan, University of Colorado Boulder</td>
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<td></td>
<td>OPEN DATA, DATA SERVICES, AND CROSS-DISCIPLINARY COLLABORATION IN GEOPHYSICS</td>
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<td>Jeff Freymueller, University of Alaska Fairbanks</td>
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<td>TRIGGERING EPICENTERS IN GEOSCIENCE: FOSTERING THE NEXT GENERATION OF SEISMOLOGISTS</td>
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<td></td>
<td>Stefany Sit, University of Illinois at Chicago</td>
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<tr>
<td>10:10 AM – 10:30 AM</td>
<td>COFFEE BREAK</td>
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<tr>
<td>10:30 AM – 12:00 PM</td>
<td>PLENARY SESSION: ADVANCING EARTH SYSTEM SCIENCE WITH GEOPHYSICAL OBSERVATIONS</td>
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<td></td>
<td><strong>Organizers:</strong> Greg Waite (Michigan Tech) and Ved Lekic (Univ. of Maryland)</td>
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<td></td>
<td>THE INTERACTION OF EARTHQUAKE CHARACTERISTICS AND FAULT MECHANICS AT VARIOUS SCALES FROM OBSERVATION-DRIVEN SIMULATIONS</td>
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<td></td>
<td>Yihe Huang, University of Michigan</td>
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<td>CLIMATE MODULATED WATER STORAGE, THE DEFORMATION, AND CALIFORNIA EARTHQUAKES</td>
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<td>Chris Johnson, University of California - San Diego</td>
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<td>LITHOSPHERIC STRUCTURE OF AN INCIPIENT CONTINENTAL RIFT: CONVERTED WAVE IMAGING OF THE MALAWI RIFT, SOUTHERN EAST AFRICAN RIFT SYSTEM</td>
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<td></td>
<td>Emily Hopper, Lamont-Doherty Earth Observatory, Columbia University</td>
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<td>Time</td>
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<tr>
<td>12:00 PM – 1:00 PM</td>
<td>LUNCH</td>
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<tr>
<td>1:00 PM – 2:30 PM</td>
<td><strong>PLENARY SESSION: MINING EXISTING SEISMIC DATA WITH NEW TECHNIQUES</strong></td>
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<td></td>
<td><strong>Organizers:</strong> Brandon Schmandt (UNM) and Gregory Beroza (Stanford)</td>
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<td></td>
<td><strong>IMPROVING EARTHQUAKE DETECTION WITH DATA MINING AND MACHINE LEARNING</strong></td>
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<td>Karianne Bergen, Stanford University</td>
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<td><strong>EARTHQUAKE RUPTURE PROCESS REVEALED BY DENSE ARRAY ANALYSES</strong></td>
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<td>Wenyuan Fan, Woods Hole Oceanographic Institution</td>
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<td><strong>SYSTEMATIC MINING AND REANALYSIS OF VOLCANO SEISMO-ACOUSTIC WAVEFORM</strong></td>
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<td>DASETS Robin Matoza, University of California Santa Barbara</td>
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<td>2:30 PM – 4:30 PM</td>
<td><strong>POSTER SESSION</strong></td>
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<td>4:30 PM – 6:00 PM</td>
<td><strong>SPECIAL INTEREST GROUP MEETINGS (SIG)</strong></td>
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<td>• Resolution of Explosion Induced Damage Using Noise Correlations at a</td>
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<td>Dense 3-Component Array</td>
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<td>• Recent Modernization of the Global Seismographic Network (GSN)</td>
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<td>• Future of Ocean Bottom Seismology Capabilities in the US</td>
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<td>• Sequential Lightning SIGs (45 min each)</td>
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<td>– Educational and Citizen Science Seismology</td>
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<td>– Improving Education Practices in the Undergraduate Classroom and Beyond</td>
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<td>6:00 PM – 8:00 PM</td>
<td><strong>SHORT COURSE: NEW USER CAPABILITIES AT THE IRIS DMC</strong></td>
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<td>• Research Ready Data Sets: Making requests for data matching quality</td>
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<td>constraints</td>
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<td></td>
<td>• Data Center Federation: Seamless Access to FDSN data centers:</td>
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<td>tapping into global data resources</td>
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<td>• Robust Retrieval of Data from the IRIS DMC</td>
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<td>• Questions and Answer period</td>
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<td>6:00 PM – 6:00 PM</td>
<td>DINNER on your own</td>
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**JUNE 13, 2018: WORKSHOP DAY 2**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>8:00 AM – 8:30 AM</td>
<td><strong>CHALLENGES AND OPPORTUNITIES FOR IRIS</strong></td>
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<tr>
<td></td>
<td>Bob Detrick</td>
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<tr>
<td>8:30 AM – 10:00 AM</td>
<td><strong>PLENARY SESSION: IDENTIFYING AND MITIGATING HAZARDS IN THE 21ST CENTURY</strong></td>
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<td><strong>Organizers:</strong> Aaron Wech (USGS) and Richard Allen (UC Berkeley)</td>
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<td></td>
<td><strong>WHAT'S NEW AND WHAT'S NEXT IN AFTERSHOCK FORECASTING</strong></td>
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<td>Nicholas van der Elst, USGS</td>
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<td></td>
<td><strong>THE WEAK DETERMINISM OF LARGE EARTHQUAKES: SCIENCE INSIGHTS TO SPEED UP</strong></td>
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<td>WARNINGS Diego Melgar, University of Oregon</td>
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<td></td>
<td><strong>MITIGATING VOLCANIC HAZARDS THROUGH GEOPHYSICAL MONITORING AND RESEARCH</strong></td>
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<td></td>
<td>Seth Moran, USGS</td>
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<tr>
<td>10:00 AM – 10:30 AM</td>
<td><strong>COFFEE BREAK</strong></td>
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<tr>
<td>Time</td>
<td>Session</td>
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</table>
| 10:30 AM – 12:00 PM | **PLENARY SESSION: GEOPHYSICAL APPROACHES TO UNDERSTANDING THE HYDROSPHERE AND CRYOSPHERE**  
**Organizers:** Sarah Kruse (Univ. of South FL) and Paul Winberry (Central Wash. Univ.)  
**WHY USE SEISMOLOGY TO STUDY LANDSLIDES AND DEBRIS FLOWS?**  
Kate Allstadt, U.S. Geological Survey  
**SEISMIC CONSTRAINTS ON REACH-SCALE SPATIAL AND TEMPORAL VARIATIONS IN BEDLOAD TRANSPORT**  
Brandon Schmandt, University of New Mexico  
**SEISMOLOGICAL CONSTRAINTS ON GLACIAL PROCESSES**  
Meredith Nettles, Lamont-Doherty Earth Observatory, Columbia Univ. |
| 12:00 PM – 1:00 PM | LUNCH                                                                  |
| 1:00 PM – 2:30 PM  | **PLENARY SESSION: SUPPORTING SCIENCE AND DISCOVERY BENEATH THE OCEANS**  
**Organizers:** Anne Sheehan (Univ. of Colorado) and Nathan Miller (USGS)  
**REAL-TIME OFFSHORE GEOPHYSICAL MONITORING OF THE CASCADIA SUBDUCTION ZONE: APPLICATIONS TO EARTHQUAKE AND TSUNAMI EARLY WARNING AND SCIENTIFIC RESEARCH**  
William Wilcock, University of Washington  
**THE SLIP BEHAVIOR OF THE SHALLOW MEGATHRUST FROM SEAFLOOR OBSERVATIONS**  
Susan Schwartz, UC Santa Cruz  
**EXTENDING THE REACH OF CABLED NETWORKS: PROSPECTS FOR ACOUSTICALLY LINKED UNDERSEA SENSING**  
Lee Freitag, Woods Hole Oceanographic Institution  |
| 2:30 PM – 3:30 PM  | **SPECIAL INTEREST GROUP MEETINGS (SIG)**  
• Background Noise: Microseisms, Site, and Other Sources  
• Node Owner’s Group  
• HPC for Seismology (Data Processing and Simulations)  
• Community Input to the Working Group on Long-Term Seafloor Seismographs (WGLTSS)  |
| 3:30 PM – 5:00 PM  | **POSTER SESSION**                                                      |
| 5:00 PM – 6:00 PM  | **SPECIAL INTEREST GROUP MEETINGS (SIG)**  
• Organizing for the Preservation of Analog Seismic Data  
• Connecting with Different Audiences: From the Podium to the Pub  
• IRIS Portable Pool Modernization  
• Contribute to EarthScope’s Finale  |
| 6:00 PM – 8:00 PM  | **DINNER**  
**Speaker:** Terry Wallace, Director LANL                                  |
### JUNE 14, 2018: WORKSHOP DAY 3

**8:00 AM – 9:30 AM**

**PLENARY SESSION: GEOPHYSICS AT THE FRONTIER: NEW CAPABILITIES AND TECHNIQUES**

*Organizers:* Marianne Karplus (UTEP) and Jeroen Tromp (Princeton)

- **GLOBAL FULL-WAVEFORM INVERSION: TOWARDS EXASCALE IMAGING OF EARTH’S INTERIOR**
  Ebru Bozdag, Colorado School of Mines

- **RECENT RESULTS FROM THE IMUSH ACTIVE-SOURCE SEISMIC EXPERIMENT**
  Eric Kiser, University of Arizona

- **FIBER OPTICS FOR PASSIVE SEISMIC MONITORING: EARTHQUAKE OBSERVATIONS AND AMBIENT SEISMIC NOISE INTERFEROMETRY**
  Eileen Martin, Stanford University

**9:30 AM – 10:00 AM**

**COFFEE BREAK**

**10:00 AM – 11:00 AM**

**SPECIAL INTEREST GROUP SUMMARIES**

**11:00 AM – 12:00 PM**

**WORKSHOP SUMMARY**

**12:00 PM**

**ADJOURN**

**12:30 PM – 5:30 PM**

Facility Tour: Introduction and tour of the IRIS PASSCAL Instrument Center at New Mexico Tech

**1:00 PM – 4:30 PM**

Facility Tour: Tour of the USGS Albuquerque Seismological Laboratory (ASL) and optional tour of the Facility for Acceptance, Calibration and Testing (FACT) at SANDIA
Appendix B. Poster Presentations

Click on the presentation titles below to view abstracts.

SCIENCE BUILT ON A STRONG FOUNDATION

SF1. FACILITATING OPEN SCIENCE FOR DISCOVERY AND SCIENTIFIC PROGRESS SEISMOLOGY
Lorraine Hwang, University of California, Davis; Louise H. Kellogg, University of California, Davis

SF2. STATION QUALITY ASSESSMENT BASED ON TIME-DEPENDENT AMBIENT NOISE FROM MUSTANG: CASE STUDY FOR CREST STATIONS IN ALASKA
Kyle Smith, University of Alaska Fairbanks; Helena Buurman, University of Alaska Fairbanks; Carl Tape, University of Alaska Fairbanks; Natalia Ruppert, University of Alaska Fairbanks; Mike West, University of Alaska Fairbanks

SF3. ESTIMATING UNCERTAINTY IN RAYLEIGH WAVE ELLIPTICITY MEASUREMENTS ACROSS IRIS/USGS NETWORK USING CO-LOCATED SENSORS
Adam Ringler, USGS; David Wilson, U.S. Geological Survey; Walter Zürn, Black Forest Observatory, Karlsruhe Institute of Technology and Stuttgart University; Robert Anthony, U.S. Geological Survey

SF4. DIRECT IMAGING OF FAULTS USING REVERSE-TIME MIGRATION OF MICROSEISMIC DATA
Yu Chen, Los Alamos National Laboratory; Lianjie Huang, Los Alamos National Laboratory

SF5. EVIDENCE FOR TERRANE ACCRETION, LOCALIZED RIFTING AND MAGMATISM FROM THE CRUSTAL VELOCITY STRUCTURE OF THE SOUTHEASTERN UNITED STATES
Rachel E. Marzen, Lamont-Doherty Earth Observatory of Columbia University; Donna J. Shillington, Lamont-Doherty Earth Observatory of Columbia University; Daniel Lizarralde, Woods Hole Oceanographic Institution; Steven Harder, University of Texas at El Paso

SF6. THE SEDIMENT AND CRUSTAL STRUCTURE OF THE EASTERN UNITED STATES
Erin Cunningham, University of Maryland; Ved Lekic, University of Maryland

SF7. SHEAR WAVE SPLITTING IN THE MACKENZIE MOUNTAINS AND NORTHERN CORDILLERA
Derek Witt, Colorado State University (now at Sustainable Water and Innovative Irrigation Management); Derek Schutt, Colorado State University; F Jay Breidt, Colorado State University; Richard Aster, Colorado State University; Jeff Freymueller, University of Alaska Fairbanks; Joel Cubley, Yukon College, Canada

SF8. SHEAR WAVE SPLITTING ACROSS AUSTRALIA
Andrew Birkey, University of California, Riverside; Heather Ford, University of California, Riverside

David Okaya, University of Southern California; Harm van Avendonk, UTIG; Stuart Henrys, GNS Science; Nathan Bangs, UTIG; Katie Jacobs, GNS Science; Dan Barker, GNS Science; Ryuta Arai, JAMSTEC

SF10. IMAGING SEISMIC ZONES AND MAGMA BENEATH MOUNT ST. HELENS WITH THE IMUSH BROADBAND ARRAY
Ken Creager, University of Washington; Carl Ulberg, University of Washington; Geoffrey Aber, Cornell University; Kayla Crosbie, Cornell University; Robert Crosson, University of Washington; Eric Kiser, University of Arizona; Alan Levander, Rice University; Brandon Schmandt, University of New Mexico; Steven Hansen, Macquarie University; Olivier Bachmann, ETH Zurich
ADVANCING EARTH SYSTEM SCIENCE WITH GEOPHYSICAL OBSERVATIONS

A1. MULTI-METHOD INVESTIGATIONS OF EARTH’S OUTER CORE
Jessica Irving, Princeton University; Sanne Cottaar, University of Cambridge; Vedran Lekic, University of Maryland; Wenbo Wu, Princeton University

A2. RADIAL ANISOTROPY BELOW A METAMORPHIC CORE COMPLEX, RUBY MOUNTAINS, NV
Justin Wilgus, University of New Mexico; Chengxin Jiang, University of New Mexico; Brandon Schmandt, University of New Mexico

A3. SEISMICALLY ANISOTROPIC MAGMA RESERVOIRS UNDERLYING SILICIC SUPER-ERUPTIONS OF YELLOWSTONE AND LONG VALLEY CALDERAS
Chengxin Jiang, University of New Mexico; Brandon Schmandt, University of New Mexico; Jamie Farrell, University of Utah; Fan-Chi Lin, University of Utah; Kevin M. Ward, University of Utah

A4. CHARACTERIZATION OF ANISOTROPIC DOMAINS BENEATH NORTHERN APPALACHIANS: EXTRACTING DETAILS FROM MULTI-EVENT OBSERVATIONS
Yiran Li, Rutgers University; Vadim Levin, Rutgers University; Janine Hlavaty, Rutgers University; Stephen Elkington, Rutgers University

A5. A MULTI-LAYERED ANISOTROPIC MODEL BENEATH THE EASTERN NORTH AMERICAN CONTINENT
Xiaoran Chen, Rutgers University; Yiran Li; Vadim Levin, Rutgers University

A6. CRUSTAL THICKNESS VARIATIONS IN EASTERN NORTH AMERICA: IMPLICATIONS FOR THE GEOMETRY OF 3D TECTONIC BOUNDARIES WITHIN THE CRUST
Cong Li, University of Massachusetts, Amherst; Haiying Gao, University of Massachusetts Amherst

A7. INITIAL ALONG-STRIKE REFRACTION TOMOGRAPHY RESULTS FROM THE ENAM COMMUNITY SEISMIC EXPERIMENT ALONG THE EAST COAST MAGNETIC ANOMALY
Collin Brandl, University of New Mexico; Lindsay Lowe Worthington, University of New Mexico; Maria Beatrice Magnani, Southern Methodist University; Brandon Shuck, Institute for Geophysics - University of Texas; Harm van Avendonk, Institute for Geophysics - University of Texas; Donna Shillington, Lamont-Doherty Earth Observatory - Columbia University

A8. ATTENUATION OF TELESEISMIC P WAVES IN POTENTIALLY MELT-BEARING REGIONS
Joseph Byrnes, University of Minnesota; Max Bezada, University of Minnesota; Maureen D. Long, Yale University

A9. APPLICATION OF PS SCATTERING KERNELS TO IMAGING THE MANTLE TRANSITION ZONE WITH RECEIVER FUNCTIONS
Han Zhang, University of New Mexico; Brandon Schmandt, University of New Mexico

A10. CHARACTERIZING LITHOSPHERIC STRUCTURE BENEATH CONNECTICUT USING SP RECEIVER FUNCTIONS
Gillian Goldhagen, University of California, Riverside; Heather A. Ford, University of California Riverside; Maureen D. Long, Yale University

A11. PRELIMINARY RESULTS FROM THE CIELO SEISMIC EXPERIMENT
Heather Ford, University of California, Riverside; Maximiliano Bezada, University of Minnesota; Joseph Byrnes, University of Minnesota

A12. IMAGING THE CRUST-MANTLE BOUNDARY WITH POST-CRITICAL SSPMP IN THE PRESENCE OF LATERAL HETEROGENEITY
Tianze Liu, Stanford University; Simon Klemperer, Stanford University

A13. AN ADAPTIVE BAYESIAN INVERSION FOR UPPER MANTLE STRUCTURE USING SURFACE WAVES AND SCATTERED BODY WAVES
Zachary Eilon, UC Santa Barbara; Karen Fischer, Brown University; Colleen Dalton, Brown University

A14. IMAGING THE SHARPNESS OF THE LITHOSPHERE-ASTHENOSPHERE BOUNDARY (LAB)
Shuyang Sun, VirginiaTech; Ying Zhou, Virginia Polytechnic Institute and State University

A15. FLAT SLABS REVEALED BY SS PRECURSORS
S. Shawn Wei, Michigan State University; Peter M. Shearer, IGPP, Scripps Institution of Oceanography, UCSD

A16. EVALUATING THE ROLE OF WATER IN COSTA RICAN FLAT-SLAB SUBDUCTION
Cameron M Petersen, Northern Arizona University; Ryan Porter, Northern Arizona University
A17. **MANTLE HETEROGENEITY ACROSS THE ANDEAN SUBDUCTION ZONE FROM PRELIMINARY TELESEISMIC S-WAVE TOMOGRAPHY**
Emily Rodriguez, University of Arizona; Daniel Portner, University of Arizona; Susan Beck, University of Arizona; Marcelo Rocha, University of Brasilia; Marcelo Bianchi, University of São Paulo

A18. **VARIABILITY IN SLAB BEHAVIOR WITHIN THE SOUTH AMERICA SUBDUCTION ZONE: NEW OBSERVATIONS FROM CONTINENT-SCALE TELESEISMIC P-WAVE TOMOGRAPHY**
Daniel Portner, University of Arizona; Susan Beck, University of Arizona; George Zandt, University of Arizona; Emily Rodriguez, University of Arizona; Alissa Scire, IRIS PASSCAL Instrument Center; Marcelo Rocha, Universidade de Brasília; Marcelo Assumpção, Universidade de São Paulo

A19. **TOWARD UNDERSTANDING A SEISMIC ANOMALY IN CENTRAL CHILE**
Jessica Domino, Binghamton University; James Bourke, Binghamton University; H. R. Naslund, Binghamton University; Alex Nikulin, Binghamton University

A20. **CONSTRAINING LOWERMOST MANTLE ANISOTROPY: A COMBINATION OF BODY WAVE METHODS**
Neala Creasy, Yale University; Angelo Pisconti, University of Muenster; Maureen Long, Yale University; Christine Thomas, University of Muenster

A21. **EVIDENCE OF AN UNDERSIDE LITHOSPHERIC EROSION BENEATH SOUTHERN CALIFORNIA**
Ailiyasi Ainiwaer (Elyas), Texas Tech University; Harold Gurrola, Texas Tech University

A22. **TOMOGRAPHY OF SOUTHERN CALIFORNIA VIA BAYESIAN JOINT INVERSION OF RAYLEIGH WAVE ELLIPTICITY AND PHASE VELOCITY FROM AMBIENT NOISE CROSS-CORRELATIONS**
Elizabeth Berg, University of Utah; Fan-Chi Lin, University of Utah; Amir Allam, University of Utah; Hongrui Qui, University of Southern California; Yehuda Ben-Zion, University of Southern California; Weisen Shen, Stony Brook University

A23. **RESOLVING STRESS DROP ESTIMATION RELATED TO SPATIALLY VARYING EMPIRICAL GREEN’S FUNCTION AT PARKFIELD**
Jiewen Zhang, University of Oklahoma; Xiaowei Chen, University of Oklahoma; Rachel Abercrombie, Boston University

A24. **DIVERSE VOLUMETRIC FAULTING PATTERNS IN THE SAN JACINTO FAULT ZONE**
Yifang Cheng, University of Southern California; Zachary E. Ross, University of Southern California; Yehuda Ben-Zion, University of Southern California

A25. **DYNAMICS OF ASEISMIC SLIP ON SAN ANDREAS FAULT AND UNDERLYING MECHANISMS**
Mostafa Khoshmanesh, Arizona State University; Manoochehr Shirzaei, Arizona State University

A26. **EARTHQUAKE SWARMS AND SLOW SLIP ON A SLIVER FAULT IN THE MEXICO SUBDUCTION ZONE**
Shannon Fasola, Miami University; Michael R. Brudzinski, Miami University; Stephen G. Holtkamp, University of Alaska-Fairbanks; Charles DeMets, University of Wisconsin-Madison; Enrique Cabral-Cano, Instituto de Geofísica, UNAM, Mexico City; Alejandra Arciniega-Ceballos, Instituto de Geofísica, UNAM, Mexico City

A27. **EVIDENCE FOR SLAB PERMEABILITY-CONTROLLED TREMOR ALONG THE CASCADIA MARGIN**
Jonathan Delph, Rice University; Alan Levander, Rice University; Fenglin Niu, Rice University

A28. **THE EVOLUTION OF THE HYDRATION STATE OF THE JUAN DE FUCA PLATE FROM RIDGE TO TRENCH OFFSHORE WASHINGTON STATE**
Bridgit Boulahanis, Lamont-Doherty Earth Observatory; Juan Pablo Canales, Woods Hole Oceanographic Institution; Suzanne Carbotte, Lamont-Doherty Earth Observatory; Helene Carton, The Institut de Physique du Globe de Paris; Shuoshuo Han, University of Texas Institute for Geophysics; Mladen Nedimovic, Dalhousie University

A29. **ASSESSING THE ROLE OF WATER IN ALASKAN FLAT-SLAB SUBDUCTION**
Sarah Robinson, Northern Arizona University; Ryan C. Porter, Northern Arizona University; Thomas D. Hoisch, Northern Arizona University

A30. **P-WAVE TOMOGRAPHY OF THE MACKENZIE MOUNTAINS REGION**
Aditya Khare, Colorado State University; Derek Schutt, Colorado State University; Richard Aster, Colorado State University; Jeffrey Freymueller, University of Alaska Fairbanks; Joel Cubley, Yukon College

A31. **FULL-WAVE TOMOGRAPHY IN ALASKA/ALEUTIAN FROM OCEAN TO CONTINENT**
Xiaotao Yang, University of Massachusetts Amherst; Haiying Gao, University of Massachusetts Amherst
A32. IDENTIFICATION AND RELOCATION OF EARTHQUAKES IN THE SPARSELY INSTRUMENTED MACKENZIE MOUNTAIN REGION, YUKON AND NORTHWEST TERRITORIES, CANADA
David Heath, Colorado State University; Richard Aster, Colorado State University; Derek L. Schutt, Colorado State University; Jeff Freymueller, University of Alaska, Fairbanks; Joel Cubley, Yukon College, Canada

A33. CRUSTAL ANISOTROPY BENEATH NORTHEASTERN MARGIN OF TIBET PLATEAU INFERRED FROM RECEIVER FUNCTIONS
Zhenxin Xie, Institute of Geophysics, China Earthquake Administration; Vadim Levin, Rutgers University; Qingju Wu, Institute of Geophysics, China Earthquake Administration; Zhanbo Ji, Institute of Geophysics, China Earthquake Administration

A34. CRUST AND UPPER MANTLE STRUCTURE OF THE TIEN SHAN OROGENIC BELT USING FULL-WAVE AMBIENT NOISE TOMOGRAPHY
Ziqiang Li, Institute of Geophysics, Chinese Earthquake Administration; Haiying Gao, University of Massachusetts Amherst

A35. PERIODICAL PULSING OF DEEP SLIP RATE BY RES ON LVF, TAIWAN
Yaochieh Chen, Earth Science Department, National Taiwan Normal University; Kate Huihsuan Chen, National Taiwan Normal University

A36. DENSE SEISMIC ARRAY FOR THE 2018 MW6.4 HUALIEN EARTHQUAKE, TAIWAN: AFTERSHOCK SEQUENCE AND VP TOMOGRAPHY
Wei-Fang Sun, College of Environmental Studies, National Dong Hwa University, Taiwan; Zhuo-Kang Guan, National Central University; Pei-Yu Jhong, National Central University; Hao Kuo-Chen, National Central University; Chien-Ying Wang, National Central University; Wen-Yen Chang, Department of Natural Resources and Environmental Studies

A37. THE MAGMA SYSTEM OF TENGCHONG VOLCANIC AREA FROM LOCAL EARTHQUAKE TOMOGRAPHY
Fei Deng, University of Rhode Island and Institute of Geophysics, China Earthquake Administration; Qingju Wu, Institute of Geophysics, China Earthquake Administration

A38. INFLUENCE OF TOPOGRAPHY AND NON-LINEAR ACOUSTIC PROPAGATION ON INFRASONIC JET NOISE AT SAKURAJIMA VOLCANO, JAPAN
Sean Maher, University of California, Santa Barbara; Robin Matoza, University of California, Santa Barbara; Kent Gee, Brigham Young University; David Fee, University of Alaska, Fairbanks; Yokoo Akihiko, Kyoto University

A39. INVESTIGATING SHORT-PERIOD MICROSEISMS NEAR LAKE MALAWI
Chris Carchedi, Columbia University - LDEO; James Gaherty, Lamont-Doherty Earth Observatory; Donna Shillington, Lamont-Doherty Earth Observatory

A40. PROBING DEFORMATION ON THE FLANKS OF THE MAIN ETHIOPIAN RIFT
Anant Hariharan, Cornell University; Katie Keranen, Cornell University

A41. UPPER MANTLE STRUCTURE OF AFRICA FROM FULL WAVEFORM TOMOGRAPHY AND LONG-PERIOD AMBIENT NOISE
Erica Emry, New Mexico Tech; Yang Shen, University of Rhode Island; Andrew Nyblade, Penn State University; Ashton Flinders, University of Rhode Island; Xueyang Bao, University of Rhode Island

MINING EXISTING SEISMIC DATA WITH NEW TECHNIQUES

M1. CONSISTENT INCONSISTENCIES: A NEW METHOD FOR ASSESSING TIME CORRECTIONS NEEDED FOR ANALOG SEISMOGRAMS
Thomas Lee, Harvard University; Miaki Ishii, Harvard University; Paul Okubo, United States Geological Survey

M2. DEEPDETECT: APPLICATION OF DEEP DENSELY CONNECTED CONVOLUTIONAL NEURAL NETWORK TO DETECT EARTHQUAKE EVENTS
Youzu Lin, Los Alamos National Laboratory; Ting Chen, Los Alamos National Laboratory; Yue Wu, Los Alamos National Laboratory

M3. DETECTION AND LOCALIZATION OF LOW FREQUENCY INDUSTRIAL NOISE
Omar Marcillo, LANL; Jonathan Maccarthy, LANL

M4. ENHANCEMENT OF BODY WAVE SIGNALS IN THE CODA OF SEISMIC NOISE INTERFEROMETRY THROUGH RANDOM FLUCTUATION Suppression
Xin Liu, Stanford University; Gregory Beroza, Stanford University
M5. SINGLE-STATION CLASSIFICATION OF TECTONIC TREMORS
Ting-Chen Yeh, Department of Earth Science, National Taiwan Normal University; Yaochieh Chen, National Taiwan Normal University; Kate Huihsuan Chen, National Taiwan Normal University; Yi-Hung Liu, National Taipei University of Technology

M6. SEISMIC SWARMS BEFORE THE 2008 WENCHUAN MAINSHOCK AND ITS RELATIONSHIP WITH THE ZIPINGPU RESERVOIR
Weilai Pei, Georgia Tech; Dongdong Yao, Georgia Tech; Shiyong Zhou, Peking University; Zhigang Peng, Georgia Tech; Zhifeng Hu, University of California, San Diego

M7. SYSTEMATIC DETECTION AND RELOCATION OF MICROSEISMICITY BEFORE THE 2008 MW 7.9 WENCHUAN EARTHQUAKE
Zhigang Peng, Georgia Tech; Dongdong Yao, Georgia Tech; Xiang Ruan, Sichuan Seismological Administration; Xiaofeng Meng, University of Southern California; Feng Long, Sichuan Seismological Administration; Jingrong Su, Sichuan Seismological Administration

M8. BACK-PROJECTION RESULTS OF THE 4 MAY 2018 HAWAII EARTHQUAKE USING A GENETICALLY OPTIMIZED SUB-ARRAY SELECTION SCHEME
Haiyang Kehoe, University of Arizona; Eric Kiser, University of Arizona

M9. REPEATED ACOUSTIC EMISSION EVENTS BEFORE STICK SLIP IN A LABORATORY EARTHQUAKE EXPERIMENT
Jinxin Hou, Institute of Geophysics, China Earthquake Administration; Fan Xie, Institute of Geophysics, China Earthquake Administration; Yaqiong Ren, Institute of Geophysics, China Earthquake Administration; Zhanbo Ji, Institute of Geophysics, China Earthquake Administration; Baoshan Wang, Institute of Geophysics, China Earthquake Administration; Zhigang Peng, Georgia Institute of Technology

M10. MULTI-YEAR SHALLOW CONDUIT CHANGES OBSERVED WITH LAVA LAKE ERUPTION SEISMOGRAMS AT EREBUS VOLCANO, ANTARCTICA
Rick Aster, Colorado State University; Hunter Knox, Sandia National Laboratories; Julien Chaput, Colorado State University; Philip Kyle, New Mexico Tech

M11. SP RECEIVER FUNCTION PRE-STACK MIGRATION BASED ON SP SCATTERING KERNELS
Junlin Hua, Brown University; Nicholas Mancinelli, Brown University; Karen Fischer, Brown University

M12. STRUCTURAL, SEISMICITY, AND THERMAL MAPPING WITH RECEIVER FUNCTIONS
Vera Schulte-Pelkum, CU Boulder; Gaspar Monsalve, National University of Colombia Medellin; Kevin Mahan, University of Colorado Boulder; Felipe Omero Orlandini, University of Colorado Boulder; Cailey Condit, Rice University; Anne Sheehan, University of Colorado Boulder; Peter Shearer, University of California, San Diego

M13. STRUCTURAL IMAGING OF THE POWDER RIVER BASIN WITH FUNDAMENTAL AND HIGHER MODE SURFACE WAVES
Nishath Rajiv Ranasinghe, University of New Mexico; Chengxin Jiang, University of New Mexico; Lindsay Worthington, University of New Mexico; Brandon Schmandt, University of New Mexico; Anne Sheehan, University of Colorado Boulder

M14. CHARACTERIZING SMALL-SCALE HETEROGENEITY IN EARTH USING COHERENCE FUNCTIONS
Yiteng Tian, University of Connecticut; Vernon Cormier, University of Connecticut; Yingcai Zheng, University of Houston

M15. SEISMIC EVIDENCE FOR WATER TRANSPORT OUT OF THE MANTLE TRANSITION ZONE BENEATH THE EUROPEAN ALPS
Jeffrey Park, Yale University; Zhen Liu, Yale University; Shun-ichiro Karato, Yale University; Bijaya B. Karki, Louisiana State University

M16. QUALITY ANALYSIS OF HIGH-FREQUENCY AIR-GUN SHOT SEISMIC RECORDINGS IN THE JUAN DE FUCA PLATE
Sampath Rathnayaka, University of Massachusetts, Amherst; Haiying Gao, University of Massachusetts, Amherst

IDENTIFYING AND MITIGATING HAZARDS IN THE 21ST CENTURY

H1. CHARACTERISTICS OF PRECURSORY SEISMICITY ASSOCIATED WITH LANDSLIDES
Jackie Caplan-Auerbach, Western Washington University; Anna Foster, Western Washington University

H2. REMOTE EXPLOSIVE VOLCANIC ERUPTION DETECTION, LOCATION, AND CHARACTERIZATION USING THE EARTHSCOPE TRANSPORTABLE ARRAY IN ALASKA
Richard Sanderson, UC Santa Barbara; Robin Matoza, UC Santa Barbara; David Fee, University of Alaska Fairbanks, Alaska Volcano Observatory; Matt Haney, Alaska Volcano Observatory, United States Geological Survey; John Lyons, Alaska Volcano Observatory, United States Geological Survey
H3. INVESTIGATING THE UTILITY OF INFRASOUND ARRAYS FOR LAHAR DETECTION: PILOT EXPERIMENT AT MOUNT ADAMS, WA
Richard Sanderson, UC Santa Barbara; Robin Matoza, UC Santa Barbara; Rachel Haymon, UC Santa Barbara; Jamison Steidl, UC Santa Barbara; Paul Hegarty, UC Santa Barbara

H4. STATION, DATA, AND INSTRUMENT ANALYSIS OF THE CASCADES VOLCANO OBSERVATORY’S SEISMIC NETWORK USING XMAX AND OTHER TOOLS
Amberlee P Darold, USGS; Austin Holland, Sandia National Laboratory (employed at USGS ASL for this work)

H5. SEDIMENTARY BASIN AMPLIFICATION IN THE SEATTLE AND TACOMA BASINS: CONSTRAINTS FROM LOCAL EARTHQUAKES AND 3D SIMULATIONS
Mika Thompson, University of Washington; Erin Wirth, USGS; Arthur Frankel, USGS; John Vidale, USC SCEC

H6. INVESTIGATING BASIN AMPLIFICATION FACTORS FOR SHAKING IN THE RENO, NEVADA REGION FOR LOCAL AND REGIONAL EVENTS
John Louie, Univ. of Nevada, Reno; Michelle Dunn, University of Nevada, Reno; Kenneth D. Smith, University of Nevada, Reno; Eric Eckert, University of Nevada, Reno; Steve Dickenson, New Albion Geotechnical, Inc.

H7. DENSE ARRAY SEISMIC STUDY OF A LEGACY UNDERGROUND NUCLEAR TEST AT THE NEVADA NATIONAL SECURITY SITE
Evans Onyango, University of New Mexico; Lindsay Worthington, University of New Mexico; Robert Abbott, Sandia National Laboratory

H8. HIGH SUSCEPTIBILITY TO REMOTE TRIGGERING OF SEISMICITY IN THE RATON BASIN FROM 2016-2018
Margaret Glasgow, University of New Mexico; Justin Wilgus, University of New Mexico; Brandon Schmandt, University of New Mexico

H9. ON IMPROVING SEISMIC RISK ASSESSMENT FOR A LARGE MAGNITUDE RUPTURE ON THE SAN ANDREAS FAULT IN THE NORTHERN SALTON TROUGH, SOUTHERN CALIFORNIA
Rasheed Ajala, Louisiana State University; Patricia Persaud, Louisiana State University; Joann Stock, California Institute of Technology; Gary Fuis, U.S. Geological Survey; John Hole, Virginia Tech; Mark Goldman, U.S. Geological Survey; Dan Scheirer, U.S. Geological Survey

H10. URBAN HAZARD AND RESOURCE ASSESSMENTS VIA (SEMI)AUTONOMOUS SEISMIC SYSTEMS
Lee Liberty, Boise State University; L. Thomas Otheim, Boise State University; Gabrier Gribler, Boise State University; James St. Clair, Boise State University

H11. DO LOW-COST SEISMOGRAPHS PERFORM WELL ENOUGH FOR YOUR NETWORK? AN OVERVIEW OF LABORATORY TESTS AND FIELD OBSERVATIONS OF THE RASPBERRY SHAKE 4D
Rob Anthony, USGS; Adam T. Ringler, USGS Albuquerque Seismological Laboratory; David C. Wilson, USGS Albuquerque Seismological Laboratory; Emily Wolin, USGS Earthquake Science Center

H12. FINDING THE SOURCE FAULT OF THE APRIL 2017 FARIMAN EARTHQUAKE SEQUENCE
Daniel Graybeal, University of South Florida; Jochen Braunmiller, University of South Florida; Keivan Hosseini, Ferdowsi University of Mashhad

H13. MODELLING EPISODICALLY SLIPPING FAULTS IN SLOWLY DEFORMING REGIONS FOR PSHA
Hugh Glanville, Geoscience Australia; Dan Clark, Geoscience Australia; Jonathan Griffin, Geoscience Australia; Mark Stirling, University of Otago; Gareth Davies, Geoscience Australia

H14. STRESS REGIME IN THE NEPALESE HIMALAYA FROM RECENT EARTHQUAKES
Mohan Pant, University of Texas at El Paso; Marianne Karplus, University of Texas at El Paso; Aaron A. Velasco, University of Texas at El Paso; John Nabelek, Oregon State University; Vaclav Kuna, Oregon State University; Lok Bijaya Adhikari, Departments of Mines and Geology, Kathmandu, Nepal; Abhijit Ghosh, University of California, Riverside; Som Nath Sapkota, Departments of Mines and Geology, Kathmandu, Nepal; Simon Klemperer, Stanford University

GEOPHYSICAL APPROACHES TO UNDERSTANDING THE HYDROSPHERE AND CRYOSPHERE

HC1. MONITORING PHYSICAL PROCESSES IN DEGRADED PERMAFROST USING AMBIENT SEISMIC NOISE AND NOVEL MULTIDISCIPLINARY OBSERVATIONS
HC2. SEISMIC PRECURSORS TO ICEBERG CALVING EVENTS
Kira Olsen, Lamont-Doherty Earth Observatory of Columbia University; Meredith Nettles, Lamont-Doherty Earth Observatory of Columbia University

HC3. THE CALIBRATION OF DIFFERENTIAL PRESSURE GAUGES
John Orcutt UCSD/Scripps, Scripps Institution of Oceanography; Jonathan Berger, Scripps

SUPPORTING SCIENCE AND DISCOVERY BENEATH THE OCEANS

HC4. REALIZATION OF AN OCEAN-BOTTOM GLOBAL SEISMIC OBSERVATORY
John Orcutt UCSD/Scripps, Scripps Institution of Oceanography; Jonathan Berger, Scripps/UCSD; Gabi Laske, Scripps/UCSD; Jeff Babcock, Scripps/UCSD

HC5. DETECTING AND CHARACTERIZING SUBMARINE VOLCANIC ERUPTIONS FROM LAND AND SEA
Gabrielle Tepp, USGS Alaska Volcano Observatory; Matt Haney, USGS/Alaska Volcano Observatory; John Lyons, USGS/Alaska Volcano Observatory; Robert Dziak, PMEL/NOAA; DelWayne Bohnenstiehl, North Carolina State University; Aaron Wech, USGS/Alaska Volcano Observatory; Joseph Haxel, CIMRS/Oregon State University

HC6. ON RETURNING SEISMIC DATA FROM THE OCEANS IN NEAR-REAL TIME: THE PAST, PRESENT, AND FUTURE OF THE MERMAID PROJECT
Joel D. Simon, Princeton University; Frederik J. Simons, Princeton University; Guust Nolet, Geosciences Azur

HC7. IMAGING SMALL-SCALE CONVECTION AND STRUCTURE OF THE MANTLE IN THE SOUTH PACIFIC: A US CONTRIBUTION TO AN INTERNATIONAL PACIFICARRAY
Jim Gaherty, LDEO, Columbia University; Zachary Eilon, University of California Santa Barbara; Don Forsyth, Brown University; Gšran Ekstršm, Columbia University

HC8. SEISMIC ANISOTROPY OF OCEANIC LITHOSPHERE FROM OBS NOISE CORRELATIONS
Joshua Russell, Columbia University - LDEO; James B. Gaherty, Lamont-Doherty Earth Observatory of Columbia University; Peiying (Patty) Lin, Taiwan Ocean Research Institute, National Applied Research Laboratories; Daniel Lizarralde, Woods Hole Oceanographic Institution; John A. Collins, Woods Hole Oceanographic Institution; Greg Hirth, Geological Sciences Department; Rob L. Evans, Woods Hole Oceanographic Institution

HC9. SKEWED MANTLE MELT DELIVERY INDUCES SEGMENT-SCALE VARIATIONS IN MID-OCEAN RIDGE MAGMATIC AND HYDROTHERMAL PROCESSES
Gillean Arnoux, University of Oregon; Douglas Toomey, University of Oregon; Emilie Hooft, University of Oregon; William Wilcock, University of Washington

HC10. QUALITY ANALYSIS OF EMPIRICAL GREEN’S FUNCTIONS FOR OCEAN BOTTOM SEISMOMETERS IN CASCADIA
Xiaotao (Tao) Yang, University of Massachusetts Amherst; Haijing Gao, University of Massachusetts Amherst; Sampath Rathnayaka, University of Massachusetts Amherst; Cong Li, University of Massachusetts Amherst

HC11. FIGURING OUT THE FOREARC: SHORELINE-CROSSING SEISMIC IMAGING IN CASCADIA
Helen Janiszewski, DTM, Carnegie Institution for Science; Geoffrey Abers, Cornell University; James Gaherty, LDEO, Columbia University; Anne Becel, LDEO, Columbia University

HC12. LINKS BETWEEN SEDIMENT CONSOLIDATION AND CASCADIA MEGATHRUST SLIP BEHAVIOR
Shuoshuo Han, University of Texas Institute for Geophysics; Nathan Bangs, The University of Texas at Austin; Suzanne Carbotte, Lamont Doherty Earth Observatory, Columbia University; Demian Saffer, The Pennsylvania State University; James Gibson, Lamont Doherty Earth Observatory, Columbia University

HC13. BUOYANT ASTHENOSPHERE BENEATH CASCADIA INFLUENCES MEGATHRUST SEGMENTATION
Miles Bodmer, University of Oregon; Douglas R. Toomey, University of Oregon; Emilie E. E. Hooft, University of Oregon; Brandon Schmandt, University of New Mexico

HC14. ONSHORE-OFFSHORE VELOCITY MODELS NORTH OF THE MENDOCINO TRIPLE JUNCTION IN NORTHERN CALIFORNIA
Alan Jacquez, University of Texas at El Paso; Marianne Karplus, The University of Texas at El Paso; Aaron Velasco, The University of Texas at El Paso; Rodrigo A. Romero, The University of Texas at El Paso
GEOPHYSICS AT THE FRONTIER: NEW CAPABILITIES AND TECHNIQUES

GF1. TEMPORAL VARIATION OF S-WAVE SPLITTING MEASUREMENTS BEFORE AND AFTER THE M6 2014 NAPA EARTHQUAKE
Hongru Hu, University of Houston; Aibing, Li, University of Houston

GF2. TOWARDS QUASI-AUTOMATED ESTIMATES OF DIRECTIVITY AND RELATED SOURCE PROPERTIES OF SMALL TO MODERATE EARTHQUAKES WITH SECOND SEISMIC MOMENTS
Haoran Meng, University of Southern California; Yehuda Ben-Zion, University of Southern California; Jeff McGuire, Woods Hole Oceanographic Institution

GF3. AN EXPERIMENTAL INVESTIGATION OF DISTRIBUTE ACOUSTIC SENSING VERSUS GEOPHONES IN NEAR-SURFACE APPLICATION
Yue Hu, Princeton University; Frederik J. Simons, Princeton University

GF4. SEISMIC INTERFEROMETRY AT A LARGE, DENSE ARRAY: IMAGING THE SOURCE PHYSICS EXPERIMENT
Eric Matzel, Lawrence Livermore National Laboratory; Robert Mellors, Lawrence Livermore National Laboratory; Steven Magana-Zook, Lawrence Livermore National Laboratory

GF5. FEASIBILITY STUDY OF VERTICAL SEISMIC PROFILING METHODS TO IMAGE THE SOCORRO MAGMA BODY WITH A LARGE-N NODAL ARRAY AND LOCAL SEISMICITY
Diego Quiros, Baylor University; Nishath Ranasinghe, University of New Mexico; Jay Pulliam, Baylor University; Lindsay Lowe Worthington, University of New Mexico; Susan Bilek, New Mexico Tech; Brandon Schmandt, University of New Mexico; Richard Aster, Colorado State University

GF6. CONFIRMATION OF THE ACCURACY OF THREE-COMPONENT TEXAN DATA BY COMPARISON TO COLOCATED THREE-COMPONENT RT-130 DATA
Thom Luckie, University of Southern California; David Okaya, University of Southern California

GF7. IMAGING THE CASCADIA SUBDUCTION ZONE USING A DENSE NODAL GEOPHONE ARRAY
Kevin M. Ward, The University of Utah; Yadong Wang, University of Utah; Fan-Chi Lin, University of Utah; Brandon Schmandt, University of New Mexico

GF8. THE ALASKA AMPHIBIOUS COMMUNITY SEISMIC EXPERIMENT (AACSE)
Geoff Abers, Cornell University; Aubreya Adams, Colgate; Peter Haeussler, USGS-Anchorange; Emily Roland, University of Washington; Patrick Shore, Washington University in St. Louis; Susan Schwartz, UC Santa Cruz; Anne Sheehan, University of Colorado; Donna Shillington, Lamont-Doherty Earth Observatory of Columbia University; Spahr Webb, Lamont-Doherty Earth Observatory of Columbia University; Doug Wiens, Washington University in St. Louis; Lindsay Worthington, University of New Mexico

GF9. HIGH RESOLUTION IMAGING OF LITHOSPHERIC STRUCTURES BY FULL WAVEFORM INVERSION OF BROAD-BAND TELESEISMIC RECORDS
Yi Wang, Sun Yet-Sen University; Sébastien Chevron, Géosciences Environnement Toulouse; Rui Gao, Sun Yet-Sen University

GF10. RSTT DEVELOPMENT IN AUSTRALIA
Hugh Glanville, Geoscience Australia; Marthijn de Kool, Geoscience Australia; David Jepsen, Geoscience Australia; Spiro Spiliopoulos, Geoscience Australia; Hugh Glanville, Geoscience Australia

GF11. USING BOLIDES FOR PLANETARY SEISMOLOGY: STUDY OF ATMOSPHERIC SOURCES AND STRONG CRUST SCATTERING
Carene Larmat, Los Alamos National Laboratory; Foivos Karakostas, Institut de Physique du Globe de Paris; Jonathan K. MacCarthy, Los Alamos National Laboratory; W. Scott Phillips, Los Alamos National Laboratory

FACILITIES, OPERATIONS, AND MANAGEMENT

FOM1. AUSTRALIAN EARTHQUAKES 2016
Hugh Glanville, Geoscience Australia; Andrea Thom, Geoscience Australia

FOM2. EARTHSOSCOPE TRANSPORTABLE ARRAY OUTREACH ACTIVITIES IN ALASKA AND WESTERN CANADA
Lea Gardine, University of Alaska Fairbanks-Geophysical Institute; Tammy Bravo, IRIS Consortium; Maité Agopian, University of Alaska Fairbanks-Geophysical Institute; Perle Dorr, IRIS Consortium; John Taber, IRIS Consortium; Michael West, University of Alaska Fairbanks-Geophysical Institute; Carl Tape, University of Alaska Fairbanks-Geophysical Institute; Robert Busby, IRIS Consortium
FOM3. EARTHSCOPE TRANSPORTABLE ARRAY IN ALASKA: OVERVIEW AND FUTURE PLANS
Robert Busby, IRIS; Robert Woodward, IRIS; Kasey Aderhold, IRIS; Max Enders, IRIS

FOM4. EARTHSCOPE MAGNETOTELLURIC ACTIVITIES: STATUS, PRODUCTS, AND FUTURE
Andy Frassetto, IRIS; Adam Schultz, Oregon State University; Bob Woodward, IRIS

FOM5. THE GLOBAL SEISMOGRAPHIC NETWORK (GSN): DEPLOYMENT OF NEXT GENERATION VERY BROADBAND (VBB) BOREHOLE SENSORS AND IMPROVING OVERALL NETWORK NOISE PERFORMANCE
Katrin Hafner, IRIS; Peter Davis, UCSD/IDA; David Wilson, USGS; Danielle Sumy, IRIS

FOM6. REVISION OF METADATA SENSITIVITIES AT IRIS/IDA STATIONS
Weiwei Xu, Institute of Geophysics, China Earthquake Administration; Peter Davis, University of California, San Diego; Dan Auerbach, University of California, San Diego; Erik Klimczak, University of California, San Diego

FOM7. SENSOR SUITE: THE ALBUQUERQUE SEISMOLOGICAL LABORATORY INSTRUMENTATION TESTING SUITE

FOM8. ZLAND 3C 5HZ NODE TEST RESULTS
Justin Sweet, IRIS; Kent Anderson, IRIS

FOM9. OCEAN BOTTOM SEISMOMETER DATA QUALITY USING MUSTANG
Kasey Aderhold, IRIS; Bob Woodward, IRIS; Gillian Sharer, IRIS; Laura Keyson, IRIS; Andy Frassetto, IRIS

FOM10. INSIGHTS FROM OPERATIONS OF THE U.S. OCEAN BOTTOM SEISMOGRAPH INSTRUMENT POOL
Robert Woodward, IRIS; Kasey Aderhold, IRIS; Andy Frassetto, IRIS

FOM11. NEW TOOLS FOR EDUCATIONAL AND PUBLIC ACCESS TO SEISMIC DATA
Mladen Dordevic, IRIS; Russ Welti, IRIS; John Taber, IRIS; M. Hubenthal, IRIS
Appendix C. Post Workshop Survey of Graduate Students, Postdocs, and Early Career Participants

We conducted a post-workshop survey to assess the efficacy of the 2018 IRIS Workshop. We garnered a response from 96 of the 272 workshop attendees, for a 35% response rate.

INFORMATION ABOUT RESPONDENTS

Below we summarize information about the gender, career level, and ethnicity of respondents. Only 62 respondents (23% of total attendees, and 65% of total respondents) provided demographic information, and provided gender parity (e.g., a 50/50 split of male to female). Of those, no one identified with any sort of disability. Only one respondent (2%) identified his/her ethnicity as Hispanic/Latinx. 45% of respondents attended the IRIS Workshop through IRIS support, while 16% and 19% attended through a PI/Advisor grant or through their own personal grant, respectively. 5% attended the meeting at their own personal expense. Because of the unique makeup of the attendees this year, given the location to many national labs, there was also 16% of respondents who were federally or industry supported. 45% of the respondents attended an IRIS/EarthScope related workshop for the first time.
**WORKSHOP SURVEY RESULTS**

In the survey, responders were able to choose multiple reasons as to why they wanted to attend the IRIS Workshop. The top purpose of attending was to network with others, as 93% of respondents chose this answer. 77% of respondents (62 out of 81) believed they had adequate time for networking opportunities. In addition, ~72% wanted to learn about fields either related or unrelated to their current research, respectively. ~47% also wanted to receive feedback about their own research. 90% agreed or strongly agreed that the workshop was a valuable use of their time.

Many respondents were most excited by the number of early career investigators at the meeting, and watching them present their research during the plenary and poster sessions. Many remarked it was an excellent networking opportunity, and provided a chance to see where the seismology community is headed in the future. The need for more poster time was also expressed in response to how to make the workshop more useful. The majority of the respondents rated many of the individual workshop components as “very valuable” (VV) or “somewhat valuable” (SV). The tables below highlight the breakdown for each activity.

<table>
<thead>
<tr>
<th>Special Talks, Plenary Sessions, &amp; Poster Sessions</th>
<th>VV/SV (%)</th>
<th>Pre-Meeting Activities, SIGs &amp; Summaries</th>
<th>VV/SV (%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSF Remarks from M. Benoit and C. Major</td>
<td>64</td>
<td>Science Communication Workshop</td>
<td>93</td>
<td>15</td>
</tr>
<tr>
<td>Introductory Remarks by Bob Detrick</td>
<td>65</td>
<td>SZ4D Workshop</td>
<td>88</td>
<td>25</td>
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<tr>
<td>IRIS Challenges and Opportunities by Bob Detrick</td>
<td>68</td>
<td>IRIS DMC Short Course</td>
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<td>20</td>
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<tr>
<td>Dinner Lecture by Terry Wallace</td>
<td>56</td>
<td>Tent Rocks Field Trip</td>
<td>95</td>
<td>20</td>
</tr>
<tr>
<td>Science Built on a Strong Foundation</td>
<td>82</td>
<td>Resolution of Explosion Induced Damage Using Noise Correlations at a Dense 3C Array</td>
<td>77</td>
<td>30</td>
</tr>
<tr>
<td>Adv. Earth System Science with Geophysical Observations</td>
<td>86</td>
<td>Recent Modernization of the Global Seismographic Network</td>
<td>74</td>
<td>31</td>
</tr>
<tr>
<td>Mining Existing Seismic Data with New Techniques</td>
<td>86</td>
<td>Future of Ocean Bottom Seismology Capabilities in the US</td>
<td>88</td>
<td>33</td>
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<tr>
<td>Identifying &amp; Mitigating Hazards in the 21st Century</td>
<td>79</td>
<td>Sequential Lightning SIG: Educational &amp; Citizen Science Seismology Network</td>
<td>93</td>
<td>28</td>
</tr>
<tr>
<td>Geophysical Approaches to Understanding the Hydrosphere &amp; Cryosphere</td>
<td>79</td>
<td>Sequential Lightning SIG: Improving Education Practices in the Undergraduate Classroom &amp; Beyond</td>
<td>93</td>
<td>29</td>
</tr>
<tr>
<td>Supporting Science &amp; Discovery Beneath the Oceans</td>
<td>79</td>
<td>Background Noise: Microseisms, Site, &amp; Other Sources</td>
<td>97</td>
<td>34</td>
</tr>
<tr>
<td>Geophysics at the Frontier: New Capabilities and Techniques</td>
<td>77</td>
<td>Node Owner’s Group</td>
<td>87</td>
<td>23</td>
</tr>
<tr>
<td>Poster Session I</td>
<td>84</td>
<td>HPC for Seismology (Data Processing &amp; Simulations)</td>
<td>83</td>
<td>23</td>
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<tr>
<td>Poster Session II</td>
<td>80</td>
<td>Community Input to the Working Group on the Long-Term Seafloor Seismographs (WGLTSS)</td>
<td>95</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organizing for the Preservation of Analog Seismic Data</td>
<td>90</td>
<td>21</td>
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<tr>
<td></td>
<td></td>
<td>Connecting with Different Audiences: From the Podium to the Pub</td>
<td>92</td>
<td>26</td>
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<tr>
<td></td>
<td></td>
<td>IRIS Portable Pool Modernization</td>
<td>85</td>
<td>26</td>
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<td></td>
<td></td>
<td>Contribute to EarthScope’s Finale</td>
<td>80</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SIG Summaries</td>
<td>85</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Workshop Summary</td>
<td>70</td>
<td>46</td>
</tr>
</tbody>
</table>

The column N gives the # of respondents who attended the session and the VV/SV column gives % of attendants who ranked the session as very valuable (VV) or somewhat valuable (SV).
Respondents were asked about several workshop outcomes, and how they think the workshop could help them over the next year.

<table>
<thead>
<tr>
<th>Workshop Outcome</th>
<th>VV/SV* (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network with Peers</td>
<td>88</td>
</tr>
<tr>
<td>Plan to Communicate with Peers about the Workshop</td>
<td>81</td>
</tr>
<tr>
<td>Established Professional Connections</td>
<td>76</td>
</tr>
<tr>
<td>Gained New Research Perspectives</td>
<td>68</td>
</tr>
<tr>
<td>Forged New Collaboration</td>
<td>46</td>
</tr>
</tbody>
</table>

* VV/SV indicates responses of “Very Valuable” or “Somewhat Valuable”.

<table>
<thead>
<tr>
<th>In the Next Year</th>
<th>L/EL* (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaborate with Someone You Met at the Workshop</td>
<td>62</td>
</tr>
<tr>
<td>Collaborate with Someone Outside Your Department</td>
<td>60</td>
</tr>
<tr>
<td>Seek Out New Connections on Campus</td>
<td>38</td>
</tr>
</tbody>
</table>

* L/EL indicates responses of “Likely” or “Extremely Likely”.

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