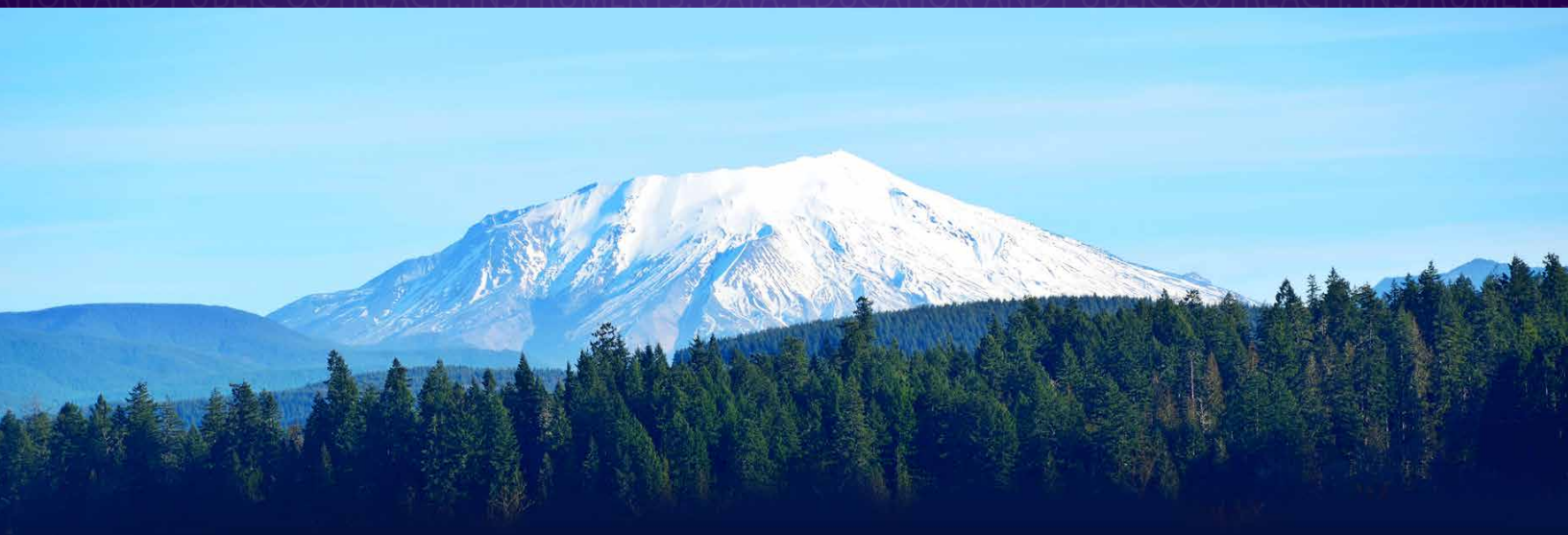
the IRIS CONSORTIUM

2016 IRIS WORKSHOP

June 8–10, 2016, Vancouver, Washington



Emerging Fields and Technologies in Seismology

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2016 IRIS Workshop Report

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June 8-10, 2016, Vancouver, WA
Hilton Vancouver, Washington

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1. Introduction

The 2016 IRIS Workshop was held in Vancouver, WA between June 8 and 10. This meeting location provided something for every scientist: a major subduction zone; the remnants of oceanic crust slipping quietly beneath; impressive geologic history at every road cut; and a volcanic arc towering just outside town. There was also a pre-workshop field trip on June 7 to the Mount St. Helens, led by local experts Seth Moran (United States Geological Survey) and Stephen Malone (University of Washington). The beautiful weather, combined with the stellar guides and the always-impressive Mount St. Helens, resulted in a spectacular trip.

IRIS Workshops in the past have often been cloistered away, sequestered from the local community. The 2016 meeting was held right in the heart of Vancouver, and it was a great place to ponder the big three—earthquakes, tsunamis, and volcanoes—as well as the countless other applications of our science to natural hazards. Much of what we do, much of what was presented over the 2-1/2 days of the workshop, and much of what IRIS enables, has clear and direct relevance to society. IRIS is a consortium of more than 120 universities. And despite the exceptional capabilities of IRIS staff and facilities, the core of IRIS is its member institutions. IRIS exists on the collective strength of our individual university programs. So even though this meeting was about IRIS, it was really about the individual research programs and how the IRIS community can best facilitate those efforts.

This workshop was held at a time of considerable uncertainty. By the time this meeting happens next, in 2018, EarthScope, the most impressive undertaking to date of this community, will be in its twilight. It isn't always clear whether our politicians respect, or even understand, science. Many of our universities have weathered quite challenging times in the past half dozen years. The National Science Foundation (IRIS' primary source of support) is fighting some unprecedented challenges that are rooted ultimately in a poor understanding of how science benefits society. IRIS is, for the first time in decades, essentially competing its very existence.

The IRIS gathering has always been a workshop, and a place to look forward. The scientists came to talk about where we are going, what we need, what we can do, and how we can work together. The Science Planning Committee and the leaders of the plenary sessions and the Special Interest Groups worked hard to represent these as best as possible in the agenda for the workshop. What can we, as a community, achieve together that we cannot alone? What new projects can we facilitate? What new collaborations can we build? What can we deliver to society? It is with that perspective that this year's theme was chosen "Emerging Fields and Technologies in Seismology".

2. Plenary Sessions

2015 marked the 30th anniversary of IRIS. The original motivations that led to the birth of IRIS are instituted as the core programs, and IRIS has been evolving as new ideas and technologies become available. With rapid expansion of seismology into non-traditional areas, the seven plenary sessions explored recent developments and advances, and examined how IRIS can adapt to continue serving the seismological community. The session organizers submitted the following summaries.

2.1 The When, Where, and How of Induced Earthquakes

Organizers: Mike Brudzinski & Elizabeth Cochran
Invited Speakers: Paul Segall, Heather DeShon & Susan Hough
Pop-Up Speakers: Ana C. Aguiar, Sara L. Dougherty, Bertriz Gaite, Yihe Huang & Kayla Kroll

The induced seismicity session was designed to cover a wide range of topics that capitalize on the exciting observations, expanding modeling capabilities, and opportunities for direct societal impact. This session experimented with the presentation format, combining 3 long talks (20 minute + 5 minutes for questions) with 5 short (2 minute) talks. While the format was originally envisioned to broaden the types of studies presented to the IRIS community, this also lead to a broader diversity of voices who had an opportunity to speak to the entire workshop audience.

Paul Segall (Stanford University) gave a long talk considering poroelastic and earthquake nucleation effects in modeling injection induced seismicity. This was designed to go beyond the ideas formed following Rangely, Colorado, where induced seismicity has been thought to result from a decrease in effective normal stress due to an increase in pore-fluid pressure. Theoretical models show that poroelastic coupling may increase or decrease the seismicity rate during injection in a homogeneous medium, depending on the orientation of the faults, and it is expected to dominate over pore-fluid pressure at larger distances. The seismicity rate can also increase following shut-in when the poroelastic clamping effect decreases while pore-fluid pressures are still increasing. Larger events post shut-in may also occur as a result of ruptures

being limited by the time varying volume of perturbed crust, which leads to a loss of larger magnitude events initially that is resolved over time. Paul also cautioned that the inferred diffusivity from observed migration patterns of induced seismicity is likely to be biased by frictional effects and aseismic slip.

Ana Aguiar (Lawrence Livermore National Laboratory) gave a short talk highlighting her work characterizing microseismicity at the Newberry Volcano Geothermal Site using the Google PageRank search algorithm. This method estimates connectivity between all signals recorded on a common station/channel. PageRank can help to efficiently group earthquakes with similar physical characteristics, such as focal mechanisms and stress drop. The ultimate goal is to determine whether changes in the state of stress or in the generation of subsurface fracture networks can be detected.

Sara Dougherty (United States Geological Survey) gave a short talk describing the LArge-n Seismic Survey in Oklahoma (LASSO) project. This dense array of more than 1,800 vertical component nodal seismic sensors was deployed over a 25-km-by-32-km region in north central Oklahoma with active fluid injection for a period of 4 weeks in spring 2016. LASSO will be used to assess the locations, frequency, magnitudes, source properties, and spatiotemporal evolution of micro- and small earthquakes in an effort to improve our understanding of the relationship(s) between injection parameters and induced seismicity.

Heather DeShon (Southern Methodist University) gave a long talk on efforts to understand and mitigate induced earthquakes in North Texas. She highlighted how SMU and collaborators have operated 30+ temporary seismic stations to determine high-resolution earthquake locations and source studies that were then combined with information on subsurface geology and fault structure and 3-D pressure diffusion modeling. The multidisciplinary integration is providing insight into the relationship between fluid migration at depth and microseismicity along pre-existing fault structures in the Fort Worth basin. She recommended that improved monitoring, more timely access to high-resolution well data, and data sharing of subsurface fault information would move the science forward in Texas. Heather then introduced the planned IRIS Wavefields experiment that will target a region of active induced seismicity in North-Central Oklahoma in June/July 2016. She described the integrated deployment of various sensor types and configurations that can be used to address a variety of fundamental questions about faulting and wave propagation. She also highlighted the ample opportunities for training of students and postdocs who will participate in station installation and pick-up.

Beatriz Gaite (Institute of Earth Sciences Jaume Almera, ICTJA-CSIC) gave a short talk describing efforts to improve constraints on hypocenter locations and temporal velocity variations associated with an underground gas storage operation off the eastern coast of Spain. A compact cluster of more than 550 earthquakes was located in the shallow offshore area of the Gulf of Valencia during two months in the fall 2013. The largest event (Mw=4.2) occurred two weeks after gas injection activities had finished and was followed by two Mw=4.1 events the day after. She presented improved locations for a subset of well recorded events using a probabilistic nonlinear earthquake location method that utilized a new 3-D shear-wave velocity model and travel time picks improved via waveform cross-correlation. These efforts demonstrated a correlation between seismicity and the gas injection.

Yihe Huang (Stanford University) gave a short talk on estimates of stress drops of induced earthquakes in the Central United States. Induced earthquakes had shown lower than expected

shaking intensities, leading to the hypothesis that this was due to low stress drops. Stress drops were estimated using the spectral ratio approach, with empirical Green's functions enabling the separation of the source effect from the propagation and site effects. When applied to induced earthquakes in Arkansas, Oklahoma, Texas, and Kansas, the spectral ratio approach indicated induced earthquakes have comparable stress drops to that of tectonic earthquakes. This suggested that the shallow depth is causing the lower shaking intensities at further distances.

Kayla Kroll (Lawrence Livermore National Laboratory) gave a short talk examining the effects of injection schedule on induced earthquakes using the RSQsim rate-and-state based earthquake simulator. The models considered seismicity induced by fluid injection near a single optimally oriented fault with fractally distributed initial shear stresses. The pore fluid pressure changes were caused by either constant injection at low rates or periodic injection at high rates. The simulations indicate periodic, high injection rates lead to increased moment release, but with fewer events when compared to constant, lower rate injection.

Sue Hough (United States Geological Survey) gave a long talk presenting evidence for damaging induced earthquakes during the early 20th century in the Los Angeles Basin. Comparisons of macroseismic observations and early instrumental data with records of oil industry activities indicated evidence for an association between the initial oil boom in the greater Los Angeles area and earthquakes between 1915 and 1932. Both of the damaging 21 June 1920 Inglewood and 8 July 1929 Whittier earthquakes occurred shortly after notable drilling and/or production activities in the immediate vicinity of the event locations. Detailed intensity data for both events are also consistent with the lower intensity signature at further distances, characteristic of induced earthquakes. The likelihood of induced earthquakes was not controlled solely by the total volume of oil produced, but at least in part by the depth and location of production wells.

2.2 Unlocking the Secrets of Subduction Zones

Organizers: Jay Pulliam, Emily Roland & Erin Wirth
Invited Speakers: Kelin Wang, Heidi Houston & Bernd Schurr

The motivation behind this session was to focus on the science questions that motivate research on subduction systems. Subduction zones are the sites of many of Earth's extreme natural events including earthquakes, volcanic eruptions, and tsunami generation, making research into subduction zones of high societal relevance. They are also a natural target for multi-disciplinary, collaborative, and integrative science – both within and outside of geoscience – with links to both biological sciences and climate research.

An additional goal of this session was to foster comments and discussion that would aid the development of in the "Subduction Zone Observatory" concept. To that end, we encouraged the IRIS Community to start thinking seriously about these questions:

1. What do we already know about the subduction system?
2. What are the outstanding questions related to subduction systems that will help motivate our future research?
3. What tools, techniques, and data products do we need to answer these questions?

The poster session covered a wide variety of topics, including links between the deep Earth and surface processes, subduction zone structure, fluid migration, the spectrum of slip behavior,

numerical simulations of megathrust events, and hazard mitigation. In addition, the session's three oral presentations covered a range of topics.

Kelin Wang (Geological Survey of Canada) highlighted recent advances in our understanding of the earthquake cycle due to improved networks and monitoring. However, numerous outstanding issues remain pertaining to great megathrust earthquakes. These include constraining co-seismic slip near the trench, the stress drop during megathrust events, understanding interseismic and post-seismic processes, and the relationship between slow slip events and megathrust earthquakes.

Heidi Houston (University of Washington) presented research showing that tidal stresses can influence tremor during large episodic tremor and slip (ETS) episodes in Cascadia, with tidal sensitivity varying throughout the slow slip cycle, and with distance downdip. Understanding the mechanisms for these effects may help constrain physical conditions on the deep subduction megathrust.

Bernd Schurr (GFZ Potsdam) discussed recent work on the stressing and breaking of a strong asperity during the Mw 8.2 2014 Northern Chile earthquake, with a special focus on analyzing thousands of earthquakes in the years before and after the earthquake. Results revealed that seismicity before and after the earthquake primarily outlined the mainshock asperity, with the asperity itself remaining seismically quiet.

2.3 Renaissance Seismology: Seismology for Non-traditional Targets

Organizers: Kate Allstadt & Victor Tsai
Invited Speakers: Emily Brodsky, Jeffrey Johnson, Timothy Bartholomaus & W. Steven Holbrook

This session highlighted the application of seismology to non-traditional targets such as glaciers, rivers, landslides, volcanic processes, critical zones, and oceans.

Emily Brodsky (University of California, Santa Cruz) gave an overview of forces on the surface of the earth and their seismic waves. She focused on two case studies, one showing how other fields can benefit from seismology and the other on how traditional seismology can benefit from studying non-traditional targets from a seismic perspective. For the former she showed how observations of seismic "noise" from rivers constrain bedload sediment transport rates that geomorphologists have difficulty measuring, and for the latter, she showed how observations of stick-slip events in Antarctic ice streams could be used as a laboratory for understanding tectonic earthquakes.

Jeffrey Johnson (Boise State University) continued on the theme of using seismology along with other tools, such as infrasound and time-lapse cameras, to learn about volcanic processes such as conduit resonance, pyroclastic flows and magma degassing. He demonstrated how combining seismology with other techniques such as infrasound and visual observations was necessary to get the full picture. He discussed the importance of involving multidisciplinary research teams and the ease of including journalists in field excursions to help in public outreach.

Timothy Bartholomaus (University of Idaho) then summarized the numerous ways in which seismological observations reveal key features of important but poorly understood glaciological

processes. These processes are a large source of uncertainty in sea-level measurements yet are difficult to measure directly but can be measured using seismic methods. He focused on how seismic methods have been used to remotely measure subglacial water discharge, to assess iceberg calving style and fluxes, and to understand how glaciers slide.

Steven Holbrook (University of Wyoming) anchored the session with a discussion of two ways in which active-source seismology can similarly be used for a wide range of non-traditional imaging. He showed one example of active-source imaging of the ocean showing an unprecedented level of eddy-scale structure, and showed another example of imaging the shallow subsurface at the watershed scale which suggested interactions between tectonic and topographic stresses.

Multiple speakers also emphasized the importance of outreach activities and the relative ease with which non-traditional targets such as river hydrology, glaciers, and volcanoes can be used in conjunction with seismology to involve students, the media, and engage the public.

2.4 The Legacy of the Transportable Array

Organizers: Robin Matoza & Frank Vernon
Invited Speakers: Robert Busby, Michael Hedlin & Scott Burdick

This session highlighted the many ways in which the Transportable Array (TA) changed long-term research and monitoring capabilities, introduced new technologies, or expanded the footprint of existing facilities. The TA has provided a data set of unprecedented spatial resolution and coverage that has led to dramatic improvements in tomographic imaging of Earth structure, enabled backprojection imaging of distant earthquake ruptures, and illuminated new areas of regional seismicity. The addition of pressure sensors has enabled tracking of atmospheric phenomena including infrasound, gravity waves, and severe weather. Power and communication available at TA sites has been exploited to create micro-research stations of multiple and varied ancillary data-streams.

Bob Busby (IRIS) provided an overview of the TA deployment, highlighting the significant technological advances and logistics required for installation and acquisition on this exceptional scale. These advances include the deployment of cellular modems to achieve low-power, high-bandwidth transmission; post-hole seismometers; borehole installations; helicopter-deployable portable drills; utilization of fiber-optic gyroscopes for sensor orientation; and data management of a continually adapting network. Impacts for society include the increase in long-term science and monitoring capacity of 235 new permanent stations since 2008. Students were engaged in permitting stations, requiring them to interact directly with the public and advocate for science.

Michael Hedlin (University of California, San Diego) highlighted research on infrasound and atmospheric dynamics afforded by the TA pressure sensors. Source localization using a mesh of triangular subnetworks images regions of gravity-wave generation west of the Great Lakes. These TA observations provide ground-based constraints on the mechanisms behind gravity wave generation in the troposphere to complement satellite observations of gravity waves in the stratosphere. Extensive cataloging of infrasound and seismic sources has been performed via automated detection and location methods.

Scott Burdick (University of Maryland) highlighted how the TA has advanced imaging capability of the continent on multiple scales, greatly improving knowledge about the existence and geometry of large-scale features such as slabs and plumes. The use of Bayesian methods helps to assess how various sources of uncertainty (e.g., ambient noise, measurement error, and inadequate model parameterization) map into the inferred seismic structure and its interpretation. Such methods also help to evaluate the gains from the TA deployment by quantifying the reduction in model uncertainty.

2.5 Seismology Across Scales: Enhanced Imaging and Source Characterization

Organizers: Gary Pavlis & Donna Shillington
Invited Speakers: Carl Tape, Karen Fischer, John Hole, Robert Mellors

This session aimed to bring together different types and scales of seismic observations to develop a more complete picture of earth structure and source processes. The increasing availability of data from dense seismic deployments and nested seismic experiments at different scales is creating new opportunities for innovative new seismic analyses and joint analysis and integration. The plenary session featured keynote presentations by Carl Tape (University of Alaska, Fairbanks) and Karen Fischer (Brown University), and contributed presentations by John Hole (Virginia Tech) and Robert Mellors (Lawrence Livermore National Laboratory).

Carl Tape (University of Alaska Fairbanks) delivered an excellent review of controls on wave propagation in the lithosphere, seismic imaging techniques, and seismic source characterization (Figure 2.5.1). He showed a wide range of examples of innovative analysis techniques from his group and others to constrain detailed velocity structure of the sediments, crust and upper mantle, anisotropy, attenuation, and source mechanisms. He particularly focused on the amplification of seismic waves by sedimentary basins, which is both an imaging challenge/opportunity and of significant importance for estimating ground shaking. He also discussed challenges of remote seismic stations (e.g., bear damage), how the ground shaking/wavefield propagation animations can be used for public outreach especially using youtube, and getting a journalist involved in the project.

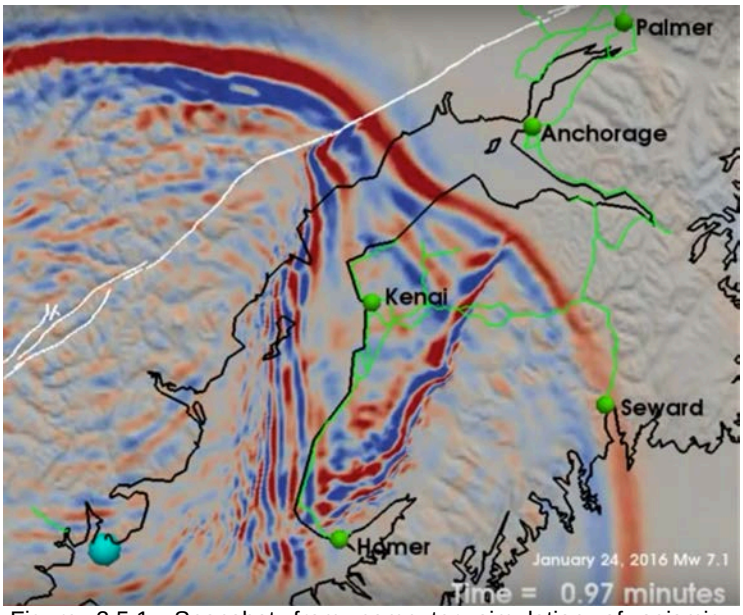


Figure 2.5.1: Snapshot from computer simulation of seismic energy propagation from the Mw7.1 Iniskin intermediate depth earthquake in Alaska showing strong amplification by Cook Inlet basin.
https://www.youtube.com/watch?v=KdiETNfyaUo

Karen Fischer (Brown University) presented a suite of results on the structure of the crust and mantle lithosphere in the southeastern United States from EarthScope TA and Flexible Array experiments, and their implications for the formation and modification of this region by multiple Wilson Cycles and for the continued anomalous topography in the Appalachians. For example, Karen and colleagues image a major shallowly dipping structure in the crust

associated with a suture formed during the most recent (Alleghenian, ~290 Ma) collisional event, which they interpret as evidence for thin-skinned collision and >300 km of shortening. They also observe correlations between crustal thickness, Moho reflectivity, upper mantle velocities, and present day topography in the Appalachians.

John Hole (Virginia Tech) showed results from the IDOR (IDaho-ORegon) experiment in Idaho, which integrates active and passive source imaging as well as geochemical and geological observations to understand deformation and magmatism in this region. They observe substantial, sharp variations in crustal thickness in both their P-wave velocity model from active source data and receiver functions associated with a shear zone and changes in crustal velocity structure associated with the Columbia River Basalts.

Finally, Robert Mellors (Lawrence Livermore National Laboratory) described a new large-N experiment to study wave propagation in support of work at Livermore on discrimination of chemical and low-yield nuclear explosions. A thousand nodes deployed at 25- to 100-m spacing in a rectangular grid recorded an explosive shot. The exceptional constraints on wave propagation from this dataset are being compared with simulations to improve models for seismic wave propagation. These data will be made available to the community in the near future, and could prove a valuable resource for basic research in seismology. This presentation was a type example of the multiple scale issue in understanding the source physics.

This session also included a large and excellent poster session, with 33 posters on diverse studies from around the world.

2.6 Nexus of Technology and Methodology: Pushing the Limits of Resolution

Organizers: Marianne Karplus, Katie Keranen & Fan-Chi Lin
Invited Speakers: Florent Brenguier, David Eaton & Brandon Schmandt

Advances in instrument technology toward smaller, more portable sensors have revolutionized data acquisition, which allows for rapid deployment of thousands of sensors for continuous recording. The three talks in the session highlighted the breadth of new science being done with large N seismic data on both structure and seismic source applications.

The presentation by Florent Brenguier (University Grenoble Alpes – CNRS) highlighted the recent success in using ambient noise cross-correlation to study temporal structural variation. These include applications on structural damaging and healing related to earthquake as well as stress induced structure variation related to volcano eruption cycle. The presentation is concluded with the discussion of the recent large N experiment at Piton de la Fournaise Volcano (La Réunion island). Using data from large N arrays and the double beamforming method to extract body waves from ambient noise demonstrates the future possibility of high resolution 4-D seismic imaging.

David Eaton (University of Calgary) presented recent results of passive seismic monitoring (both surface and downhole) near areas where an increase in seismicity has been observed near hydraulic fracturing and wastewater injection sites. He and his collaborators recently published results demonstrating that in western Canada, basement faults have been activated by hydraulic fracturing. He used template-based methods to detect and locate seismicity, and he showed data from arrays in western Canada incorporating relatively large numbers of

seismometers. He also discussed effects of pore pressure, stress conditions, and pre-existing fractures on the locations of induced seismic events. These results demonstrated how medium or large N arrays could be used for monitoring induced (or other) local seismicity.

The presentation by Brandon Schmandt (University of New Mexico) discussed the recent large N nodal experiment associated with the iMUSH project at Mount St. Helens. Both source analysis and structure imaging are discussed. On the source side, the talk demonstrated the ability to significantly improve the seismicity detection ability with the large N array. On the imaging side, a clear Moho phase (PmP) contrast was observed between east and west of the array suggesting a sharp structure variation in the uppermost mantle. The Education and Public Outreach activities such as student involvement in the large N deployment were also highlighted during the talk.

It is worth mentioning that the concept of large N arrays and the usage of nodal geophone systems have been mentioned in many talks in other plenary sections (e.g., Heather DeShon, Carl Tape, Robert Mellors, etc.). They were also discussed at length during the Active-Source Seismic Workshop that took place on the Tuesday before the IRIS Workshop and during the planning discussions (and SIG) for the upcoming IRIS Wavefields experiment.

2.7 Beyond the Workstation: Seismology in a Post-Desktop World

Organizers: Chuck Ammon & Chen Ji
Invited Speakers: Sarah Minson, Tarje Nissen-Meyer & Rafael Ferreira da Silva

Was there ever a more exciting time to be a seismologist? Seismology is a data rich science reliant on ever advancing and expanding computing capabilities that continue to grow and to become more accessible. Our tools have gone mobile, into our pockets and into the "cloud". The Beyond-the-Workstation Session was organized to explore how technological changes are changing seismological research, education, and outreach. Three speakers shared their experience, ideas, and vision of how seismology is being affected by the mobile computing revolution; the continued advances in computer storage (database), speed, and network reliability; and computer science research and development that can lead to more data-tolerant and scalable scientific workflows.

Sarah Minson (United States Geological Survey) described her experience with smart-phone seismic data acquisition systems in the laboratory and in Chile, where a small prototype deployment of eight seismometers has recorded two moderate-size earthquakes (a larger deployment is underway). The goal is that such consumer-targeted systems can operate as real-time supplements to the necessary higher-quality scientific instrumentation that remains essential for detailed analysis of earthquakes.

Tarje Nissen-Meyer (Oxford University) described efforts (by him and his colleagues) to offer high-quality synthetic (predicted) seismograms to the earthquake research and education community using pre-computed, database-stored calculations for axisymmetric and heterogeneous earth models. Efficient, approximate calculations coupled with robust easy-to-use web-based access provide a general tool for data quality assessment, modeling and interpretation, and for education. Sharing such high-performance computations is not only robust and reliable, it is environmentally friendly (such demanding calculations require energy).

Rafael Ferreira da Silva (University of Southern California), a computer scientist, described some of the efforts of computer scientists to streamline scientific computation with open-source tools to handle many of the storage and inter-process communication issues that are essential in designing scalable error-tolerant software that can handle large and small data sets. Collaboration with computing experts could reduce the barriers for geoscientists to take advantage of the benefits of high performance computing (HPC) in the cloud, such as scalable, on-demand, fast, and inexpensive; as well as allow seismological community to participate in the interdisciplinary development of the national scientific computing tools and facilities.

Three short talks can only highlight some of the issues and opportunities that technological and cultural developments have placed before the seismological community. The session speakers provided an interesting sample.

3. Poster Sessions

The workshop included two poster sessions that are an hour and a half each and featured 122 presentations. These sessions, scheduled with afternoon refreshments, were very well attended with vigorous discussions so much so that getting participants to migrate to subsequent SIG sessions was a challenge.

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

The When, Where, and How of Induced Earthquakes: 14 posters
Unlocking the Secrets of Subduction Zones: 21 posters
Renaissance Seismology: Seismology for Non-Traditional Targets: 14 posters
The Legacy of the Transportable Array: 8 posters
Seismology Across Scales: Enhanced Imaging and Source Characterization: 33 posters
Nexus of Technology and Methodology: Pushing the Limits of Resolution: 11 posters
Beyond the Workstation: Seismology in a Post-Desktop World: 4 posters

There were two additional categories specific to the poster sessions, Education and Public Outreach (4 posters) and Facilities, Operations, and Management (13 posters) that were showcased during both of the two poster sessions. The posters covered wider range of research topics than the plenary sessions with more 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 122 posters, 55 were presented by graduate students and 8 were presented by postdocs (note that there may be more if a student/postdoc declared themselves as "General Participant" when they registered for the meeting).

4. Special Interest Group Sessions

Unlike the plenary sessions that were chosen to reflect the workshop theme “Emerging Fields and Technologies in Seismology”, the Special Interest Groups (SIGs) were solicited widely from the community through IRIS announcements. There were 10 SIGs spread over three SIG sessions, and

each one-hour 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 Open Sesame: Piping More Data into the Public Domain

Organizers: Wang-Ping Chen, Xiufen Zheng, Tim Ahern & Rick Benson

The impetus of this SIG stems from a basic tenet of science: Scientific results must be repeatable and independently verifiable. Seismic events, be their source properties or as sources of illumination, are difficult to replicate. As such, open access of seismic data is essential to our science.

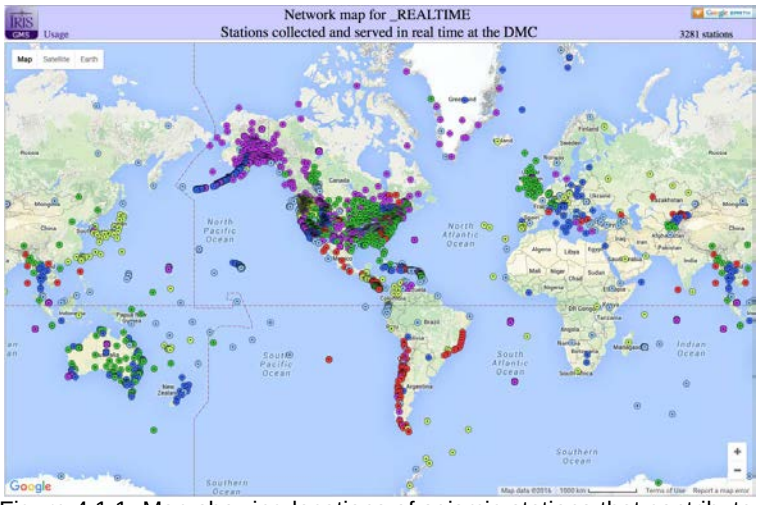


Figure 4.1.1. Map showing locations of seismic stations that contribute open-access data in near real-time to the IRIS Data Management Center (DMC). The geographic distribution of contributing stations is uneven.

From the inception of IRIS, making data openly accessible has been a priority, and much progress has been made in this regard. Nevertheless, many regions around the world remain underrepresented in contributing data to the public domain (Figure 4.1.1). Presentations and discussions in this SIG focused on ways to further advance the open sharing of data.

Rick Benson (IRIS) set the stage by giving an overview of where the IRIS Data Services (DS) stands on this cause. A key point is that IRIS readily and freely shares many software tools for data exchange, provides training in different regions outside of the United States, and even supplies start-up funds as part of the Regional Exchange of Earthquake Data (REED) project, up to ten thousand dollars to developing countries to foster open access of data in under-represented parts of the world.

Considering the rapid development in seismic monitoring capabilities and research activities in China, the accessibility of seismic data from China is of great interest to the community. To this end, Xiufen Zheng, the first delegate from China to attend an IRIS workshop, reviewed the status of data management and sharing services of the China National Seismic Network (CNSN; Figure 4.1.2). While the CNSN *per se* consists of 170

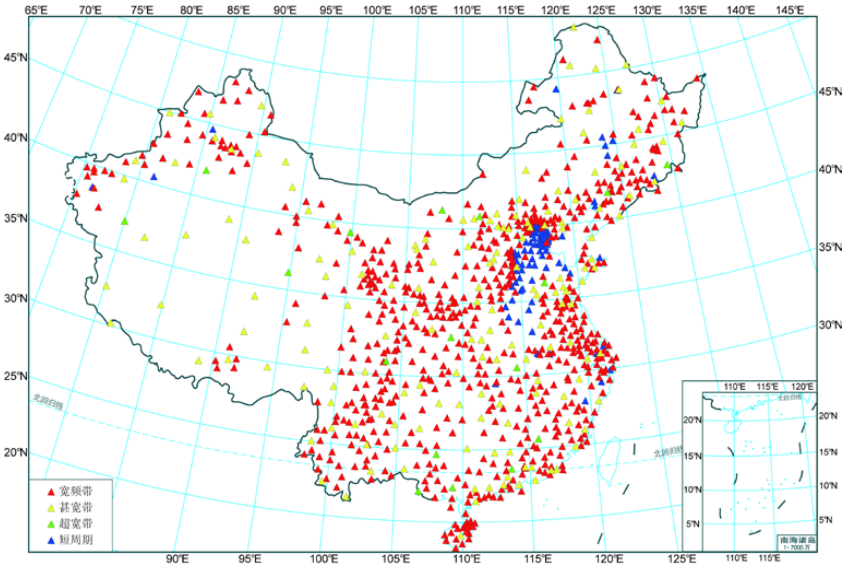


Figure 4.1.2. Map showing locations of over 1,000 permanent seismic stations in China that contribute data to the CNSN Data Management Center under the auspice of the Institute of Geophysics, China Earthquake Administration.

national seismic stations, data from 859 additional regional stations and those from some PASSCAL-style temporary deployments are also under the auspice of the CNSN Data Management Center of the Institute of Geophysics, China Earthquake Administration (CEA).

The CNSN-DMC has benefited already from working closely with the IRIS Data Services. For the Chinese users, the process of requesting data from CNSN-DMC is simple. For international users, however, the best method of accessing Chinese data is through a collaborative research with a Chinese scientist, and the CNSN-DMC can assist in "match-making" between Chinese and overseas collaborators. Furthermore, the CNSN-DMC is gearing up to accommodate a five-fold increase of data influx in the next few years, including those from the new initiatives of earthquake early-warning and strong-motion systems. The CNSN-DMC will also play an important role in fostering the development of the China Geophysical Reference Model, which is just underway.

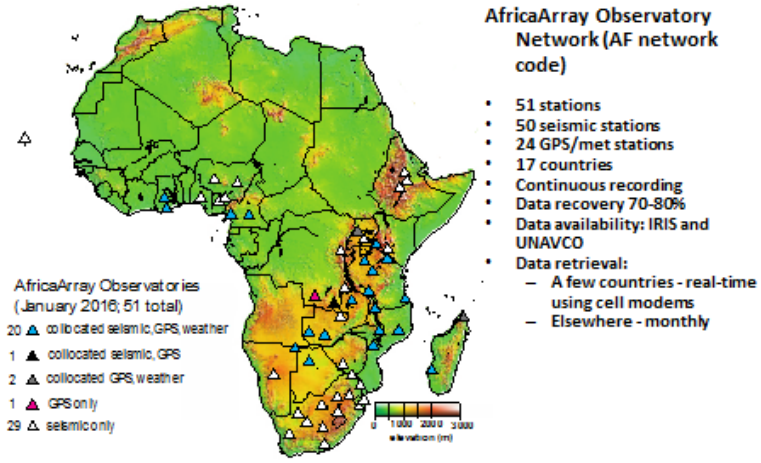


Figure 4.1.3. Map showing location of stations comprising the AfricaArray.

As a potential model for other developing regions, Andy Nyblade (Penn State University) summarized the AfricaArray experience of data sharing in Africa (Figure 4.1.3). This continent-wide effort currently has a network of 50 stations for seismic, GPS, and weather observations. A small group of people, with widespread grass root buy-ins of local institutions, has championed this endeavor for over a decade. A large part of their efforts is capacity building in monitoring, education, and research. Currently, some data are available immediately, in either real time or as soon as being collected from the field (typically every month), and others have a 3-year embargo period.

Paul Richards (Columbia University) spoke on the preservation of historical waveform data with special reference to signals from nuclear explosions. Since most nuclear explosions, particularly those aboveground, occurred long before digital recordings became widely available, there is an urgent need to preserve and digitize this irreplaceable data set. In carrying out such an ambitious task, priorities must be set first, followed by sustained, coordinated efforts.

Finally, we note that a number of under-represented countries in the past have made considerable progress toward the overall goal of open sharing of seismic data. Recent examples include:

- RIMES effort in Thailand that opened up data from Myanmar, Vietnam, and Philippines
- Data from Ecuador freely available after many years of negotiations
- Data contributions from the Korean Meteorological Agency, the Institute of Earth Sciences, Academia Sinica in Taiwan, and University of Tokyo, Japan
- Some data from transportable deployments in China through the Institute of Geophysics, Chinese Academy of Sciences

In conclusion, IRIS Data Services has been the most important factor in facilitating the open access of seismic data on a global scale. The logical path is to continue building upon this success and serve the diverse needs of the community worldwide.

4.2 Best Practices in Observational Seismological Research and Education

Organizers: Meghan Miller & Danielle Sumy

The SIG began with a short presentation from Danielle Sumy (IRIS) and Leland O'Driscoll (University of Oregon). Sumy covered the IRIS tool InClass (www.iris.edu/hq/inclass) that can be used for the purpose of collection and curation of Best Practices material. O'Driscoll covered slides that discussed huddle testing Best Practices, and how the exercise can be used as an opportunity for outreach into the local community, especially in engaging and educating organizations in third world international countries. O'Driscoll also mentioned that it is best to know your staff, their abilities, and who you are working with, how to tackle challenges related to the gain (e.g., high-gain broadband sensors may be clipped by a regional large event), and the growth of earthquake early warning (EEW), and the importance of standardized site design in this process. In these presentations, criteria were also discussed that may help with the dissemination of materials related to instrumentation (e.g., power requirements and proper spacing).

The presentations helped to stimulate discussion among the community, and ideas and comments were proposed. These include:

- repository of photo, video, and animation of installations, in different climates and continents (including the importance of improvisation with materials you may have in a different country, and what worked and what did not)
- list of questions that one should think about when planning site installation, which include how you would get there (by car, aircraft, or ship), whether the location is safe, climate, exposure to the sun and has adequate access to power, what the site will be built out of, what the coupling will be, whether there needs to be drainage or kept water tight, etc.
- ability to tag station installation with metadata, perhaps to include a photo with the gmap included in the metadata aggregator (MDA; ds.iris.edu/mda)
- community wiki and/or forum that can help prompt individual members of the community to put their information and knowledge out there for the entire community to use
- incorporation of site and installation information from PASSCAL experiments into their experiment reports
- placement of before and after site photos in the new SRL Data Mine article thread, among further description of the installation at large

The SIG wrapped up with discussion from Amberlee Darold and others from the Cascades Volcano Observatory (CVO) on their newly developed digitizer, the CS16. The digitizer is easily and rapidly deployable (especially in volcano systems that may not be there the next day), and cost effective. This information helped stimulate further discussion about the future of power systems, communications, and instrumentation in general.

4.3 Data Processing Infrastructure for Seismology

Organizers: Gary Pavlis & Frank Vernon

Current software tools used for data processing in earthquake seismology have much in common with the way instrumentation was prior to the birth of IRIS. In the same way instrumentation was custom developed at a few places in the 1970s, in software today, we have a heterogeneous mix of stuff developed independently by multiple groups. Just as mixing instrumentation in field experiments was a problem in the 1970s, mixing software tools today is a challenge that is limiting progress in the field. Most existing tools are based on archaic concepts that limit performance, interoperability, and maintainability. The objective of this SIG is to identify short-term and long-term goals to address this problem.

The room was nearly at full capacity, which is an indication of the relevance of this topic to the seismological community. The hour was split into three sections:

1. the first 10 minutes: an introduction presented by Gary Pavlis (Indiana University)
2. the next 30 minutes: a discussion led by Frank Vernon (University of California, San Diego) on various issues
3. the last 15 minutes: ideas for initial steps to address the issues we raised

In the introduction, the discussion focused on the problem of research data processing to support passive array data. It was asserted that real-time data acquisition, seismic network operations software (bulletins and catalog preparation by regional networks), and seismic reflection processing had stable existing solutions, and the issue was only interoperability with such software where it exists.

The technical problem was presented with these points:

- Much of our data processing software base is founded on archaic concepts
- Most processing workflows are I/O bound and far from optimal
- All of our software infrastructure is inefficient in human resources

The key assertions are:

- Processing limitations are arguably the biggest throttle on progress in our science today
- We are awash in data we cannot utilize as effectively as we should

The discussion was focused around a series of web pages Pavlis had recently produced for use by the 2016 USArray Data Processing Short Course to be held at the Northwestern University in August (http://www.indiana.edu/~pavlab/IRISWorkshop2016). The discussion wandered around various topics driven by the attendees, and they could be encapsulated into several issues:

1. Different people see the problem from vastly different perspectives due to the nature of their own research data needs and their local infrastructure. Some have access and commonly use high-end High Performance Computing (HPC) machines while others have only poorly maintained desktop systems. There is a continuum of capabilities within the community between these endmembers. This means the problem is both a hardware access problem and a software problem.
2. The ever-increasing complexity of the information technology world complicates our ability to speak the same language. The community is much like a group of nonnative speakers who have mastered the language to varying degrees trying to work together. Sometimes it works and sometimes there are huge disconnects. Multiple people

recognized the solution to this fundamental problem is education, not just of students but scientists at all levels.

3. An important word of hope was an assertion in the discussion that there is a cultural shift toward better code sharing by younger scientists. On a long term, that may be what solves this problem.

The session closed with a discussion of initial steps that can be taken to make progress on these issues:

- A prime community need is to improve interoperability between existing tools. Standardized toolkits, for example, to exchange data between MATLAB and ObsPy would aid research development efforts.
- There was a reasonably strong acceptance to endorse ongoing movements to urge the community to adopt python as a standard for gluing research work flows together. This is already happening in ObsPy, Antelope, and the PASSCAL software suite.
- There is a clear link between discussions held in this SIG and the SIG on High Performance Computing. That working group should be tasked to consider solutions to the broader problems addressed in this SIG. For instance, many of the software maintenance issues that plague smaller research groups could be solved by broad community access to a common major HPC center identified as the standard seismology data processing center.
- There is a need for standard tools to build local database tables from IRIS-DMC web services and synchronize them to the master held by DMC and other data centers.
- Pavlis will ask students in the 2016 and 2017 data processing short courses to discuss this issue and propose solutions. This will help our next generation of scientists pointed in a more common direction.

4.4 Community Wavefield Experiment

Organizers: Justin Sweet & Kent Anderson

IRIS is conducting a Wavefields Demonstration Community Experiment in June/July 2016 in northern Oklahoma. This experiment will make use of cutting-edge 3-component nodal-type sensors. These 5Hz sensors are about the size of a paint can, have onboard GPS timing, and can run independently for up to 30 days. The deployment will take advantage of the concurrent deployment of 1000+ single channel nodes and 45 broadband sensors by Katie Keranen (Cornell University) and these data will become available after moratorium. The IRIS Wavefield Experiment will use instruments provided by IRIS and its community members (~300+ 3-component nodes, 40+ broadbands, and 10 infrasound sensors) in the same area. The experiment design is a collaboration between Keranen; Heather DeShon, Brian Stump, Chris Hayward (Southern Methodist University); Michael Brudzinski (University of Miami); Susan Bilek (New Mexico Tech); Marianne Karplus (University of Texas, El Paso); Fan-Chi Lin (University of Utah); Chuck Langston (University of Memphis); and Xiaowei Chen (University of Oklahoma). The goal of the SIG was to inform the community of the progress of this experiment and to obtain feedback. Approximately 60 people attended.

Kent Anderson (IRIS) began by giving a presentation summarizing the experiment with a quick background on the Wavefields Initiative at IRIS as detailed on the wavefields page (https://www.iris.edu/hq/initiatives/recording-the-full-seismic-wavefield). This experiment was envisioned as forward-looking to test and demonstrate the feasibility of new types of

instrumentation and the new types of science they could enable. The experiment location and design was driven by science concepts submitted by the community. Concepts were reviewed and chosen by a committee of community members.

Anderson described the final experiment design and instrumentation. He gave an interactive tour of the station locations in Google Earth.

- Gradiometric array consisting of 7 nested squares composed of 16 3-component nodes each
- 3 lines of seismic nodes running north-south and east-west near the gradiometric array
- 18 broadband stations deployed in 6 3-station "golay" arrays that surround the gradiometric array with a diameter of about 5 km
- 6 infrasound stations, one at each of the 3-station broadband arrays

The Data from gradiometric array, nodal lines, golay arrays, and infrasound stations will be archived at IRIS DMC and are immediately available to the community. One exciting legacy of this experiment will be the inclusion of 63 3-component nodes in the IRIS PASSCAL instrument pool following the completion of the wavefields experiment. These nodes will be available for the community use in the future.

He also emphasized that the community participation as an integral part of this experiment. The experiment is expecting ~50 people (grad students, post-docs, and faculty) to help with the deployment, and node training and deployment will be provided to kickoff the experiment. The scientists involved in the experiment design will be giving evening science talks following each day's field work. In addition, IRIS plans to hold a USArray-style short course in summer 2017 focused on data handling and analysis for large-N/wavefields data sets.

Heather DeShon (Southern Methodist University) then gave a brief presentation discussing more of the science behind the experiment. There is excitement about the possibility of using active source to obtain high resolution images of the faults that have been responsible for much of the induced seismicity seen recently in Oklahoma. The basement at this location is about 2.2 km in depth, and the faults are suspected to be steeply dipping. Beatrice Magnani (Southern Methodist University) also commented that the experiment will include T-Rex vibroseis trucks, to be active July 14-19th along the nodal lines, that should provide valuable data for near-surface imaging.

4.5 EarthScope Synthesis: Participate!

Organizers: Elisabeth Nadin & Carl Tape

As the end of the formal EarthScope program approaches, it is timely for the geosciences community to work towards synthesis of multiple types of data focused on a single region or topic. For example, data from USArray, Plate Boundary Observatory (PBO), and San Andreas Fault Observatory at Depth (SAFOD) activities could be linked with results from other disciplines. EarthScope science offers many opportunities for synthesis, both within and between disciplines. The EarthScope National Office (ESNO) at the University of Alaska Fairbanks is soliciting proposals from EarthScope scientists to identify and organize workshops on EarthScope synthesis. In early 2016, the ESNO reviewed proposals and selected four workshops to start the community-driven synthesis of EarthScope science. The next solicitation for synthesis workshop proposals will open in September 2016.

This SIG explained the process for submitting (and selecting) synthesis workshops, the expected products for the workshops, and sought feedback from attendees on how to use the workshops to effectively synthesize all EarthScope results (for example, focus on regionalization or on processes?). The ESNO approach to synthesis was discussed, and the four first four synthesis workshops were introduced from the workshop conveners. People seemed supportive of the ESNO efforts toward synthesis. There was a suggestion to initiate a new effort to produce a coffee-table-style book that would convey the excitement and achievements of the EarthScope project, aimed at the general public.

4.6 Work/Life Balance and Time Management: How to Increase Productivity while Staying Sane

Organizers: Christian Poppeliers & Danielle Sumy

The purpose of this SIG was to address and discuss the question: "How do we effectively and healthfully balance professional and personal priorities?" This is a question that many IRIS Early Career Investigators (ECI) often struggle with when starting new careers, especially when faced with family obligations. In an effort to recognize these issues, and (hopefully) provide some advice during this challenging time as an ECI, the SIG organizers asked five panelists, Luciana Astiz (National Science Foundation), Pete Davis (University of California, San Diego), Maureen Long (Yale University), Jay Pulliam (Baylor University), and Wes Thelen (United States Geological Survey), to read a different book on work/life balance and time management strategies. The panelists were asked to implement the suggested work/life balance techniques, and report back to the community about what worked, what didn't, and what would become a mainstay in their daily/weekly routines. The panelists represented a range of career stages and career trajectories.

The panelists were free to choose any book, but many of them found common themes among the various books. The first was that many of these books described four main areas of life (e.g., work, home, community, and the private self), and described that these areas are where we need to spend our energy. The energy level at different times of day was also discussed at length. For example, many of us find that we cannot concentrate for six hours a day on one project and we may need to mix it in with exercise or some other activity during the day. Also, many in the SIG mentioned how we can often be sidetracked by trivial tasks (e.g., sifting through email) early in the day when energy levels are highest and that this time may be best spent working on much more demanding/productive tasks.

We also discussed strategies for minimizing time spent on "low reward" tasks such as house cleaning, service, etc. For instance, many ECIs are told to avoid partake in service-oriented tasks at work and/or to hire a housekeeper or nanny to help out in the home. However, these strategies may not be an option for some ECIs due to professional requirements or financial constraints. While such advice may or may not work for some, there were several general conclusions:

1. it's unlikely that any of us will achieve perfect balance at all times, thus we need to approach work/life/personal balance as a goal achieved over months to years
2. each person's situation is different and each person will make different choices in regards to priorities and commitments

3. we need to be more open to helping each other in the community, become more sensitive to each other's needs, and extend a hand of grace to others and ourselves in times of work/life crises

Finally, one very nice, yet surprising, aspect of the SIG was the range of attendees, who also spanned early to late stage geoscience professionals. This opened the organizers' eyes to the fact that we all struggle to make it through our respective career trajectories take. The IRIS ECI Working Group, as well as the Education and Public Outreach Standing Committee as a whole, will attempt to consider all of these issues as we prepare for the future of the consortium.

4.7 HPC for Seismology (Data and Simulations)

Organizers: Carl Tape & Arthur Rodgers

As the volume of archived seismic data increases, the need to have these data processed in new and more powerful computational systems has become more important. A new working group at IRIS, the High Performance Computing and Seismic Data Working Group (HPCWG), will focus on the use of the seismic data available in the IRIS Data Management Center storage systems within high performance computing environments. The HPCWG will address data-driven seismological research requiring HPC resources, either for data processing or for simulation-based data assimilation. This SIG sought input from seismic data users or seismic modelers who envision opportunities for computational resources. The SIG was attended by about 35 people. The hour started with presentations by the organizers and involved input from participants and discussions.

We opened with remarks on the goals and expected outcomes of the hour discussion. These were:

- Introduce IRIS HPCWG
- Solicit input on HPC use cases/needs/desires from seismology community
- Identify ways in which IRIS could facilitate/advance more widespread use of HPC

Carl Tape (University of Alaska, Fairbanks) described the recently formed IRIS HPC WG, its tasks and membership. This was followed by a broad categorization of the kinds of problems our community is solving with HPC. The SIG has defined four categories of problems with examples:

1. Data Intensive: massive waveform correlation, ambient noise cross-correlation, stacking
2. Forward Calculation: earthquake ground motion, array-based waveform modeling, crustal, upper mantle and D" waveforms
3. Data Inversion: imaging algorithms, adjoint waveform tomography, data plus HPC forward/adjoint simulations
4. Bayesian Methods and Uncertainty Quantification: Monte Carlo, resolution/covariance, model testing, trans-dimensional Bayesian

There was consensus that this list encapsulates the work people are doing.

The organizers gave a brief summary of past activities in this area, including efforts at IRIS Workshops, Computational Infrastructure for Geodynamics (CIG), National Science Foundation, Southern California Earthquake Data Center (SCEC) and National Lab efforts. The successful European efforts in computational seismology were also described (SPICE, QUEST, VERCE, TIDES).

Finally several questions were outlined that are designed to collect information about how people are using (or want to use) HPC in their work:

- Do you use HPC now for your work?
- What kinds of work are you doing or want to do?
- If the kinds of work you are doing is not what you want to do, are you interested in using HPC in the near future?
- What kinds of HPC do you use or want to use? Large shared-memory, Linux cluster, CPU/GPU, Hadoop/Sparc, other?
- Do you need data and HPC in proximity? Is your problem I/O bound?
- What are the barriers to achieving your goals? Learning codes, access to HPC, I/O, workflow, throughput, disk space?
- How can community (IRIS, CIG, others?) help?

Participants did not provide much feedback on these questions, but there was concern that the community at all levels (students, postdocs, and active researchers) needs training to break into these areas of research. Access to cycles remains a problem, from entry level to meso-scale to large-scale parallel systems.

The discussions pointed to general agreement that our community needs to organize, articulate needs, and communicate these to leadership. Organization should involve participation from IRIS, CIG, SCEC, NSF, the National Labs and possibly NASA, USGS and Department of Defense. Our community needs to engage with HPC facilities and funding agencies. The needs to advance our science were identified and these include:

- training workshops on codes and workflows
- graduate courses in scientific computing
- better code development and sharing
- better access to cycles across HPC scales

The SIG organizers will solicit input from the community on the questions discussed in the SIG (possibly with a survey sent by IRIS). There is consensus that our community needs to produce a prioritized plan for advancing use of all forms of HPC for computational seismology. Developing this plan will be the subject on follow-up work.

4.8 Seismology and Social Media: Effectively Communicating Science Online

Organizers: Andy Frassetto & Justin Sweet

There are many ways to leverage social media for personal and societal gain. Broader impact requirements can be developed using blogs, webinars, open source software/data, citizen science projects, and massive open online courses. Scientists can reach directly to the public and answer their questions, or connect to other researchers to discuss recent events or publications. However, efforts online can also devolve into a black hole of wasted time on click bait, trolling, and pseudoscience. This SIG brought together people who are interested in developing the online seismology community in rewarding and productive ways.

Approximately 15 attendees discussed the strengths and limitations of social media as well as the motivations and approaches for using it to communicate on scientific topics. Andy Frassetto (IRIS) highlighted the recently formalized social media strategy used by IRIS. Wendy Bohon (Informal Education Specialist at IRIS, not in attendance) has developed and implemented this

strategy, focusing on creating a strong presence on Facebook, YouTube, Twitter, Pinterest, and LinkedIn, as well as coordinating activities with counterparts at UNAVCO and EarthScope. The general goals are to promote activities and research from across the IRIS consortium and facility, generate repeat visitors, foster dialog with the audience, notify about IRIS products including time sensitive ones, and channel visitors to the IRIS website.

The group reviewed some examples of successful social media communication. A recent "Ask Me Anything" run by Bohon and Danielle Sumy (Project Associate at IRIS) at the news aggregator website Reddit yielded a lively conversation with users and 25 questions were asked and answered. The Pacific Northwest Seismic Network Facebook page, currently with over 8,000 users, served as a good example for how to communicate on a variety of seismology and volcanology topics in a place-based framework. Examples of pseudoscience and strategies for knowing when or when not to engage with more fringe members of the internet were highlighted. The group agreed that there is typically high value in offering accurate information to groups being actively misled.

The discussion also explored ways to make a social media effort work well. Maite Agopian from the EarthScope National Office (ESNO) offered their appreciation of knowing limitations; the ESNO strategy focuses on a few specific social media platforms and makes sure that the content posted is platform specific, such as short posts for Twitter and longer, more graphical posts for Facebook. Attendees agreed that it is best to have dedicated staff time for this, but in tight budgetary environments, this may be a pro-bono activity by social media savvy staff to build momentum and awareness with management. However, perhaps the most important advice given is to have a clear set of end goals beforehand, as well as a system to verify that they are being met.

In general, the group recommended several initiatives that may serve the social media and science communication goals of both the IRIS and broader earth science community. Social media is a useful mechanism to interact with the community and collect content to share with the general public as well as for general usage by IRIS, the ESNO, UNAVCO, etc. Suggested mechanisms included holding one or more formal field photo contests and encouraging Principle Investigators to submit research highlights, in both cases being collected through various social media platforms. In addition, the group strong desired one or more community webinars and SIG meetings of opportunity (at AGU, EGU, ESNM, etc.) to provide detailed insight into the social media strategy and tips for communicating. It is also important to continue to provide social media info (#hashtags) for meetings beforehand, such as what was done for this workshop.

4.9 Advances in Quick Deploy Strategies for Broad- and Intermediate-Period Instruments

Organizers: Lara Wagner, Diana Roman & Kent Anderson

The aim of this SIG was to provide a forum to discuss recent advances in seismometer quick-deploy approaches and to get input from the community on deployment needs and concerns. As the interest in deploying ever larger numbers of instruments for long term and/or broad/intermediate-band seismic deployments grows, so too does a need to be able to deploy the ancillary equipment (digitizers/dataloggers, batteries, GPS units, solar panels, etc.) in an efficient and robust manner to decrease deployment time and increase the likelihood of successful data collection. At the SIG, three different "quick-deploy" systems were presented

along with four "homegrown" seismic digitizer/datalogger systems in various stages of development. Participants in the SIG agreed that there was a need for seismic systems that were lightweight, compact, robust, easy to transport and deploy, and inexpensive. There is also a clear need for further development of low-cost digitizer/dataloggers. Additional needs mentioned by SIG participants included an app to interface with seismic equipment through an iPhone or tablet and to record consistent and easily-shareable metadata, and full-waveform or state-of-health telemetry with two-way communication capabilities for remote maintenance of seismic sensors and digitizers.

4.10 Engaging Undergraduate Students in Research, in Classroom and the Field/Lab

Organizers: Steve Jaume & John Taber

The aim of this SIG was to share potential approaches, tools, and resources to help lower the barrier for faculty to involve undergraduates in research activities early in their careers. Early exposure to research experiences has been shown to be effective in the recruitment of students, improving the retention in degree programs, and contributing to overall increased student success. This is particularly true for students from underrepresented minorities, and therefore may provide an opportunity to increase diversity in the geosciences, particularly if opportunities are provided early enough. However, student ability to engage in research varies considerably from freshman and sophomores who have limited content exposure and research skills, to seniors who are ready to engage in graduate-level independent research. The SIG participants discussed strategies for engaging this range of students and came up with the following lessons learned and recommendations.

Maggie Benoit (The College of New Jersey) discussed issues and her experience mentoring upper level students in research at an undergraduate institution. The recommendations are:

- Set clear expectations and goals: Establish research contract, and have timesheets
- Teach resilience and perseverance
- Require student to communicate about the science, which helps them see the big picture when mired in data
- Have them meet collaborators and feel like part of the team
- Make sure the project is something productive for you

Andy Nyblade (Penn State University) described lessons learned through his involvement in the AfricaArray in enhancing diversity through field and educational experiences.

- Support and mentor undergraduates in preparing for and applying to grad school and for career paths in industry and academia
- Faculty at MSI institutions are key to student success
- Recruiting from geoscience/geology program has lower barrier
- Physics departments are not as receptive to students working in geophysics

Danielle Sumy (IRIS) presented IRIS program on Field Experiences for Undergraduates. The purpose of this program is to encourage students to switch to geophysics and includes educational activity (i.e., not just digging holes). This is an ongoing project based on successful IDOR experience, and the current focus is on engaging younger University of Texas, El Paso students in a field experience. The program will be expanded to IRIS community-wide matching of younger students with field experiments.

Steve Jaume (College of Charleston) examined the issue of providing research-like questions for younger students. As an example, the use of more realistic earthquake location technique than basic S-P time location with 3 stations was discussed. The recommended improvements are:

- Work with real 3-component seismic data
- Find all 4 earthquake source parameters (latitude, longitude, depth, time)
- Quantitatively compare observation to prediction
- Iterate to achieve best solution

Some potential tools for conducting simple classroom research was then discussed such as:

- IRIS Earthquake Browser
- jAmaseis
- SeismicCanvas

In addition, IRIS Data Services data products that are currently available are described:

- Earth Model Collaboration tomographic models
- Centroid Moment Tensors from Lamont Doherty Earth Observatory
- Wilber 3 record sections

The SIG group made following recommendations:

- Create a list of good analysis tools that seismologists could use with upper level undergrads, e.g., SplitLab (with good documentation)
- Develop simple research lessons that use existing IRIS tools and data products
- Design material for geoscience faculty at Two Year Colleges to use in intro courses
- Identify/collect/document other research-light tools for students with no geophysics background
- Update Alan Jones' EQLocate program as a web application

5. Summary

The success of the workshop depended on contributions from a large number of people. IRIS staff, particularly Danielle Sumy, Justin Sweet and Krystin Poitra handled untold number of back end logistics and planning. Krystin Poitra, along with Theresa Saavedra, Leslie Linn, and Perle Dorr handled many of the unseen onsite tasks and registration. The plenary session conveners organized the speakers, and helped bring the planned workshop agenda to life. The plenary session speakers took time to craft talks that not only highlighted the state of the science but posed new questions and inspired new ways of thinking about both Earth processes and the methodologies we use the understand those processes. The SIG organizers proposed and put together exciting sessions covering a broad range of topics related to current issues and challenges of the community. Finally, the success of the poster sessions was critically dependent upon everyone who brought posters to share their research, especially graduate students, postdocs, and early career scientists.

The 2016 IRIS Workshop brought together 235 participants, representing more than 80 institutions and 7 countries. 77 meeting participants were students and postdocs, more than half of whom IRIS was able to support through scholarships. All told, almost a third of the attendees were just at the beginning of their careers. This strong early career showing speaks to the strength of the IRIS community and the efficacy of the resources put into outreach and mentoring the next generation.

The keynote presentation by Steve Malone at Thursday's dinner detailed the evolution of observational seismology and volcano monitoring in the Pacific Northwest. The subject matter was a perfect echo of this year's workshop theme and a reminder that the emerging fields and technologies of today will be the standard practices of tomorrow.

Instrumentation will continue to become smaller and more portable, computing power and our ability to harness it will continue to increase, and technology will become more flexible and diverse. More certainly, the seismological community will continue to use human creativity to apply seismological methods to investigate wide-ranging topics and open entire new fields of our discipline.

Today's emerging fields range from induced seismicity to subduction zone behavior, from surface processes to ice sheet and glacial dynamics, and from the thermohaline structure of oceans to atmospheric gravity waves. Our capabilities continue to stretch: from dreaming about, planning and executing the Transportable Array to pushing the limits of multi-scale imaging and resolution.

When IRIS formed ~30 years ago, a group of extremely forward-thinking individuals understood the power of community and shared facilities to give more people the tools to do important and innovative science. IRIS has changed and grown in ways that they could not have anticipated and will continue to change and grow in the future. This year's attendees left the workshop to return to labs, field projects, and classrooms newly inspired by today's emerging science that is made possible by facilities, collaborations, and education and training supported by IRIS. IRIS can and will change and grow in the future.

Appendix A: Workshop Program

June 08, 2016 Workshop Day 1

Time	Program
8:00 – 8:10	Welcome/Introduction Michael West, University of Alaska Fairbanks
8:10 – 8:40	Invited Talk Eva Zanzerkia, National Science Foundation
8:40 – 10:10	The When, Where, and How of Induced Earthquakes Plenary Session Organizers: Mike Brudzinski (Miami University) & Elizabeth Cochran (United States Geological Survey) Beyond Rangely: Poroelastic and Earthquake Nucleation Effects in Injection Induced Seismicity Paul Segall, Stanford University Popup Talk: Characterizing Microseismicity at the Newberry Volcano Geothermal Site using PageRank Ana C. Aguiar, Lawrence Livermore National Laboratory Popup Talk: LArge-n Seismic Survey in Oklahoma (LASSO): Probing Injection-Induced Seismicity with a Dense Array Sara L. Dougherty, United States Geological Survey The Meandering Path Towards Mitigating Induced Earthquakes in North Texas Heather DeShon, Southern Methodist University Popup Talk: Constraints on Hypocenter Locations and Temporal Velocity Variations Associated with an Underground Gas Storage Offshore Spain Beatriz Gaite, Institute of Earth Science Jaume Almera, ICTJA-CSIC Popup Talk: Stress Drop Estimates of Induced Earthquakes in the Central United States Yihe Huang, Stanford University Popup Talk: Effects of Injection Schedule on Induced Earthquakes Kayla Kroll, Lawrence Livermore National Laboratory Evidence for Damaging Induced Earthquakes during the Early 20th Century in the Los Angeles Basin Susan Hough, United States Geological Survey
10:10 – 10:30	Coffee Break

10:30 – 12:00 Unlocking the Secrets of Subduction Zones

Plenary Session Organizers: Jay Pulliam (Baylor University), Emily Roland (University of Washington) & Erin Wirth (University of Washington)

Unlocking the Secrets of Megathrust Earthquakes
Kelin Wang, Geological Survey of Canada

Evolving Sensitivity of Tremor to Stress During and Between Large ETSs in Cascadia: Implications for Deep Fault Properties
Heidi Houston, University of Washington

Stressing and Breaking a Single Strong Asperity: the Mw8.2 2014 Northern Chile Earthquake
Bernd Schurr, GFZ Potsdam

12:00 – 13:00 Lunch

13:00 – 15:00 Renaissance Seismology: Seismology for Non-Traditional Targets

Plenary Session Organizers: Kate Allstadt (United States Geological Survey) & Victor Tsai (California Institute of Technology)

Forces on Top of the Earth and the Seismic Waves They Produce
Emily Brodsky, University of California, Santa Cruz

Flow and Blow: Integration of Seismic, Infrasound, and Video to Elucidate Surface Phenomena
Jeffrey Johnson, Boise State University

Seismology at the Calving, Sliding and Hydrologic Frontiers of Glaciology
Timothy Bartholomaus, University of Idaho

Of Oceans and Watersheds: Novel Uses of Active-Source Seismology
W. Steven Holbrook, University of Wyoming

15:00 – 16:30 Poster Session I (Appendix B) and Refreshments

The When, Where, and How of Induced Earthquakes

Unlocking the Secrets of Subduction Zones

Renaissance Seismology: Seismology for Non-Traditional Targets

Facilities, Operations, and Management

16:30 – 17:30	Special Interest Group Meetings Session I Open Sesame: Piping More Data into the Public Domain SIG Session Organizers: Wang-Ping Chen (University of Illinois), Xiufen Zheng (China Earthquake Administration), Tim Ahern (IRIS) & Rick Benson (IRIS) Best Practices in Observational Seismological Research and Education SIG Session Organizers: Meghan Miller (University of Southern California) & Danielle Sumy (IRIS) Data Processing Infrastructure for Seismology SIG Session Organizers: Gary Pavlis (Indiana University) & Frank Vernon (University of California, San Diego)

June 09, 2016 Workshop Day 2

Time	Program
8:00 – 8:30	Challenges and Opportunities for IRIS Robert Detrick, IRIS
8:30 – 10:00	The Legacy of the Transportable Array Plenary Session Organizers: Robin Matoza (University of California, Santa Barbara) & Frank Vernon (University of California, San Diego) EarthScope's Transportable Array: A Preposterous Idea, Realized Robert Busby, IRIS Studying Atmospheric Gravity Waves and Infrasonic Sources Using the USArray Transportable Array Michael Hedlin, University of California, San Diego Assessing the Benefit of the USArray with Bayesian Methods Scott Burdick, University of Maryland
10:00 – 10:30	Coffee Break

10:30 – 12:00 Seismology Across Scales: Enhanced Imaging and Source Characterization

Plenary Session Organizers: Gary Pavlis (Indiana University) & Donna Shillington (Lamont-Doherty Earth Observatory)

The 3D Crustal Wavefield for Imaging Earth Structure and Sources
Carl Tape, University of Alaska, Fairbanks

Signatures of Lithospheric Evolution Beneath the Southeastern U.S.
Karen Fischer, Brown University

EarthScope IDOR Controlled-Source and Broadband Seismic Imaging Across the Edge of the Craton and Accreted Terrains in Idaho and Eastern Oregon
John A. Hole, Virginia Tech

The Source Physics Experiment Large Array: A First Look
Robert Mellors, Lawrence Livermore National Laboratory

12:00 – 13:00 Lunch

13:00 – 14:30 Nexus of Technology and Methodology: Pushing the Limits of Resolution

Plenary Session Organizers: Mariane Karplus (University of Texas at El Paso), Katie Keranen (Cornell University) & Fan-Chi Lin (University of Utah)

Large N Experiments and Advancements in 4-D Noise-Based Seismology
Florent Brenguier, Univ. Grenoble Alpes - CNRS

Passive Seismic Methods for Hydraulic Fracture Monitoring: Resolving Fracture Networks, Slow Slip and Earthquake Nucleation Processes
David Eaton, University of Calgary

Investigation of Mount St. Helens Seismicity and Volcanic Arc Structure with a Hybrid Natural and Controlled Source Survey
Brandon Schmandt, University of New Mexico

14:30 – 15:30 Special Interest Group Meetings Session II

Community Wavefields Demonstration Experiment
SIG Session Organizers: Justin Sweet (IRIS) & Kent Anderson (IRIS)

EarthScope Synthesis: Participate!
SIG Session Organizers: Elisabeth Nadin (University of Alaska, Fairbanks) & Carl Tape (University of Alaska, Fairbanks)

Work/Life Balance and Time Management: How to Increase Productivity while Staying Sane
SIG Session Organizers: Christian Popperliers (East Carolina University) & Danielle

	Sumy (IRIS)
15:30 – 17:00	Poster Session II (Appendix B) and Refreshments The Legacy of the Transportable Array Seismology Across Scales: Enhanced Imaging and Source Characterization Nexus of Technology and Methodology: Pushing the Limits of Resolution Beyond the Workstation: Seismology in a Post-Desktop World Education and Public Outreach Facilities, Operations, and Management
17:00 – 18:00	Special Interest Group Meetings Session III HPC for Seismology (Data and Simulations) SIG Session Organizers: Carl Tape (University of Alaska, Fairbanks) & Arthur Rodgers (Lawrence Livermore National Laboratory) Seismology and Social Media: Effectively Communicating Science Online SIG Session Organizers: Andy Frassetto (IRIS) & Justin Sweet (IRIS) Advances in Quick Deploy Strategies for Broad- and Intermediate-Period Instruments SIG Session Organizers: Lara Wagner (Carnegie Institution of Washington), Diana Roman (Carnegie Institution of Washington) & Kent Anderson (IRIS) Engaging Undergraduate Students in Research, in the Classroom and the Field/Lab SIG Session Organizers: Steve Jaume (College of Charleston) & John Taber (IRIS)
18:30 – 20:00	Conference Dinner The Mount St. Helens Eruptions: A Catalyst for Seismic Network Developments in the Pacific Northwest Guest Speaker: Stephen D. Malone, University of Washington

June 10, 2016 Workshop Day 3

Time	Program
8:00 – 9:30	Beyond the Workstation: Seismology in a Post-Desktop World Plenary Session Organizers: Charles Ammon (Penn State) & Chen Ji (University of California, Santa Barbara) Smartphone-Based Earthquake Early Warning in Chile Sara Minson, United States Geological Survey Instantaneous Synthetic Seismograms in a Post-{confirue;make;mpirun} World Tarje Nissen-Meyer, Oxford University Automating Scientific Computations: From the User's Desktop to World-Class Supercomputers Rafael Ferreira da Silva, University of Southern California
9:30 – 10:00	Coffee Break
10:00 – 11:00	Special Interest Group Summaries SIG Organizers
11:00 – 12:00	Workshop Summary/Closing Remarks Lindsay Lowe Worthington, University of New Mexico

Appendix B: Poster Presentations

June 8, 2016 Workshop Day 1, 15:00 – 16:30

The When, Where, and How of Induced Earthquakes

Improving Correlation Algorithms to Better Characterize and Interpret Induced Seismicity
Michael Brudzinski (Miami Univ. of Ohio), Robert J. Skoumal (Miami Univ. of Ohio), Brian S. Currie (Miami Univ. of Ohio)

Characterizing Microseismicity at the Newberry Volcano Geothermal Site using PageRank
Ana C. Aguiar (Lawrence Livermore National Laboratory), Stephen C. Myers (Lawrence Livermore National Laboratory)

Constraints on hypocenter locations and temporal velocity variations associated with an underground gas storage offshore Spain.
Beatriz Gaite (ICTJA-CSIC), Arantza Ugalde (ICTJA-CSIC), Antonio Villasenor (ICTJA-CSIC)

Improving Local Magnitude Determinations to Estimate b-value in North Texas
Kevin Kwong (Southern Methodist Univ.), SeongJu Jeong (Southern Methodist Univ.), Brian Stump (Southern Methodist Univ.), Heather DeShon (Southern Methodist Univ.), Jake Walter (Univ. of Texas at Austin)

West Texas seismicity and distinguishing natural from anthropogenic causes
Jake Walter (Univ. of Texas at Austin), Cliff Frohlich (Univ. of Texas at Austin), Julia Gale (Univ. of Texas at Austin), Taylor Borgfeldt (Univ. of Texas at Austin), Susan Bilek (New Mexico Tech), Julie Gerzina (Univ. of Texas at Austin), Peter Dotray (Univ. of Texas at Austin)

The 6 November 2011 M5.6 Prague, Oklahoma Aftershock Sequence Using Subspace Detection
Nicole McMahon (Colorado State Univ.), Harley M. Benz (USGS-NEIC, Golden), Caryl E. Johnson (Introspective Systems LLC.), Richard C. Aster (Colorado State Univ.), Daniel E. McNamara (USGS-NEIC, Golden)

LArge-n Seismic Survey in Oklahoma (LASSO): Probing injection-induced seismicity with a dense array
Sara L. Dougherty (USGS), Elizabeth S. Cochran (USGS), Rebecca M. Harrington (McGill Univ.)

Effects of Injection Schedule on Induced Earthquakes
Kayla A. Kroll (Lawrence Livermore National Laboratory), Keith B. Richards-Dinger (Univ. of California Riverside), Joshua A. White (Lawrence Livermore National Laboratory), James H. Dieterich (Univ. of California Riverside)

Application of Existing Oil and Gas Approaches for Assessment of Induced Seismic Hazard
Robert Walker (Univ. of Southern California), Yesser Haj-Nasser (Univ. of Southern California)

Stress Drop Estimates of Induced Earthquakes in the Central United States
Yihe Huang (Stanford Univ.), Gregory C. Beroza (Stanford Univ.), William L. Ellsworth (Stanford

Univ.)

Stress drop and source scaling of the 2016 Fairview, Oklahoma earthquake sequence
Qimin Wu (Virginia Tech), Martin C. Chapman (Virginia Tech)

Induced-Microearthquakes Classification Using Neural Networks
S. Mostafa Mousavi (Univ. of Memphis), Stephen P. Horton (Univ. of Memphis), Charles A. Langston (Univ. of Memphis)

Seismic Noise Attenuation using Time-Frequency Analyses
S. Mostafa Mousavi (Univ. of Memphis), Charles A. Langston (Univ. of Memphis)

Peak Rates and Largest Magnitude Events in Earthquake Swarms From Different Tectonic Settings
Stephen R. McNutt (Univ. of South Florida), Glenn Thompson (Univ. of South Florida), Jochen Braunmiller (Univ. of South Florida), Stephen Holtkamp (Univ. of Alaska Fairbanks)

Unlocking the Secrets of Subduction Zones

Tremor and LFE activities in the Alaska-Aleutian subduction zone using mini seismic arrays
Bo Li (Univ. of California-Riverside), Abhijit Ghosh (Univ. of California-Riverside)

Extending Alaska's plate boundary: tectonic tremor generated by Yakutat subduction
Aaron G. Wech (USGS, Alaska Volcano Observatory)

Initiation and Propagation Phases of Cascadia Episode Tremor and Slip Events
Ken Creager (Univ. of Washington), Carl Ulberg (Univ. of Washington)

Can clustering identify links between earthquakes and tremor and the processes driving them?
Chastity Aiken (Institute for Geophysics, Univ. of Texas at Austin)

Cascadia Seismogenic Zone Earthquake Detection and Location
Emily Morton (New Mexico Tech), Susan Bilek (New Mexico Tech), Charlotte Rowe (Los Alamos National Laboratory)

The Cascadia M9 Project and 3-D Simulations of Megathrust Earthquakes
Erin A. Wirth (Univ. of Washington), Arthur Frankel (USGS, Seattle), John E. Vidale (Univ. of Washington)

The Seismic Strong Motion Array Project (SSMAP) 2005-2015 and September 5, 2012 (Mw=7.6) Nicoya, Costa Rica Earthquake Investigation
Gerald Simila (Cal State Univ. Northridge), E. Mohammadebrahim (Cal State Univ. Northridge), R. Quintero (Univ. Nacional, Heredia, Costa Rica), K. C. McNally (Univ. of California Santa Cruz)

Towards an onshore/offshore anisotropic body wave tomography model for the Cascadia Subduction Zone
Miles Bodmer (Univ. of Oregon), Douglas R. Toomey (Univ. of Oregon), Max Bezada (Univ. of Minnesota), Brandon Schmandt (Univ. of New Mexico)

Seismic attenuation of body waves measured across an entire oceanic plate
Zachary Eilon (LDEO, Columbia Univ.), Geoffrey A. Abers (Cornell Univ.)

Seismic velocity structure of the Juan de Fuca and Gorda plates revealed by a joint inversion of ambient noise and regional earthquakes
Haiying Gao (Univ. of Massachusetts Amherst)

Surface wave imaging of the Juan de Fuca plate and Cascadia subduction zone
Helen A. Janiszewski (LDEO, Columbia Univ.), James Gaherty (LDEO, Columbia, Univ.)

Constraining subduction zone dynamic beneath the Chilean seismic gap
Jessica Domino (Binghamton Univ.), James Bourke (Binghamton Univ.), Alex Nikulin (Binghamton Univ.)

Rayleigh and Love wave ambient noise tomography of the Central Andes
Colton Lynner (Univ. of Arizona), Susan L. Beck (Univ. of Arizona), George Zandt (Univ. of Arizona), Kevin M. Ward (Univ. of Arizona), Jonathan R. Delph (Univ. of Arizona), Maureen D. Long (Yale Univ.), Lara S. Wagner (Carnegie Institution for Science)

Continent-arc collision in the Banda Arc imaged by ambient noise tomography
Robert Porritt (Univ. of Southern California), Meghan Miller (Univ. of Southern California), Leland O'Driscoll (Univ. of Southern California), Cooper Harris (Univ. of Southern California), Nova Roosmawati (Univ. of Southern California), Luis Teofilo de Costa (Institute of Petroleum and Geology, Timor Leste)

Detecting slab structure beneath the Banda Arc from waveform analysis of deep focus earthquakes
Meghan Miller (Univ. of Southern California), Daoyuan Sun (USTC), Adam Holt (Univ. of Southern California)

Crustal and Uppermost Mantle Shear Velocity Structure across the Mariana Trench
Chen Cai (Washington Univ.), Douglas A. Wiens (Washington Univ.), Daniel Lizarralde (Woods Hole Oceanographic Institution)

Lessons from USArray Informing Concepts for a Subduction Zone Observatory
Bob Woodward (IRIS), Bob Busby (IRIS), Bob Detrick (IRIS), Andy Frassetto (IRIS)

Geodetic records of subduction zone deformation from the Plate Boundary Observatory
Christine Puskas (UNAVCO), David Phillips (UNAVCO), Kathleen Hodgkinson (UNAVCO)

Imaging a magma plumbing system from MASH zone to magma reservoir
Jonathan R. Delph (Univ. of Arizona), Kevin M. Ward (Univ. of Arizona), George Zandt (Univ. of Arizona), Susan L. Beck (Univ. of Arizona)

Deep long-period earthquakes (DLPs) beneath Mount St. Helens
Jiangang Han (Univ. of Washington), John E. Vidale (Univ. of Washington), David Schmidt (Univ. of Washington), Kenneth Creager (Univ. of Washington), Heidi Houston (Univ. of Washington)

Seismic Imaging with the Mount St. Helens Node Array
Steven Hansen (Univ. of New Mexico), Brandon Schmandt (Univ. of New Mexico), Alan Levander (Rice Univ.), Eric Kiser (Rice Univ.)

Renaissance Seismology: Seismology for Non-Traditional Targets

Plate boundary unzipped: Dynamics of a seafloor spreading episode at the East Pacific Rise
Yen Joe Tan (LDEO, Columbia Univ.), Maya Tolstoy (LDEO, Columbia Univ.), Felix Waldhauser (LDEO, Columbia Univ.), William Wilcock (Univ. of Washington)

Phase bias estimation and correction for global coda correlations: Bayesian optimization of a non-diffuse wavefield
Julien Chaput (Colorado State Univ.), Hsin-Hua Huang (Univ. of Utah), Richard Aster (Colorado State Univ.), Fan-Chi Lin (Univ. of Utah)

Environmental Seismology: Using Seismic Noise to Investigate Several Oceanic, Atmospheric, and Surface Processes Across the Planet
Robert Anthony (Colorado State Univ.), Rick Aster (Colorado State Univ.), Daniel McGrath (Colorado State Univ.), Michael Baker (Colorado State Univ.), David Duncan (Colorado State Univ.), Sara Rathburn (Colorado State Univ.), Sandra Ryan (Colorado State Univ.), Douglas Wiens (Washington Univ.), Andrew Nyblade (The Pennsylvania State Univ.), Peter Bromirski (SIO, Univ. of California San Diego), Peter Gerstoft (SIO, Univ. of California San Diego), Ralph Stephen (Woods Hole Oceanographic Institution)

Characteristics of ambient noise near Nenana basin, central Alaska
Kyle Smith (Univ. of Alaska Fairbanks), Carl Tape (Univ. of Alaska Fairbanks), Christopher Bruton (Univ. of Alaska Fairbanks), Michael West (Univ. of Alaska Fairbanks)

Monitoring southwest Greenland's ice sheet melt with ambient seismic noise
Dylan Mikesell (Boise State Univ.), Aurelien Mordret (Massachusetts Institute of Technology), Christopher Harig (Princeton Univ.), Bradley P. Lipovsky (Harvard Univ.), German A. Prieto (Massachusetts Institute of Technology)

Monitoring Active Layer Freeze/Thaw Using Seismic Noise
Stephanie R. James (Univ. of Florida), Hunter A. Knox (Sandia National Laboratories), Robert E. Abbott (Sandia National Laboratories), Elizabeth J. Screaton (Univ. of Florida)

Seismic Array Experiments at the Sanford Underground Research Facility (Homestake Mine) in the Black Hills of South Dakota
Gary Pavlis (Indiana Univ.), James Atterholt (Indiana Univ.), Daniel Bowden (California Institute of Technology), Ross Caton (Indiana Univ.), Lee Liberty (Boise State Univ.), Vuk Mandic (Univ. of Minnesota), Patrick Meyers (Univ. of Minnesota), Tanner Prestegard (Univ. of Minnesota), Victor C. Tsai (California Institute of Technology)

5 years of continuous seismic monitoring of a mountain river in the Pyrenees
Jordi Diaz, Pilar Sánchez-Pastor, ICTJA-CSIC. Josep Gallart, ICTJA-CSIC

Serendipitous seismic recordings of landslides and debris flows over many scales
Kate Allstadt (USGS, Golden)

Towards an analytical model for the seismic signal generated by debris flows
Maxime Farin (California Institute of Technology), Victor C. Tsai (California Institute of Technology), Michael P. Lamb (California Institute of Technology)

Seismic Reconstruction of the 2012 Palisades Rock Fall using the analytical solution to Lamb's Problem
Lucia Gualtieri (LDEO, Columbia Univ.), Goran Ekstrom (LDEO, Columbia Univ.)

Can we use high frequency seismic noise to infer local sea states, breaking wave power, and sediment transport?
Christian Poppeliers (East Carolina Univ.)

Stochastic excitation of seismic waves by a hurricane
Annie Valovcin (Univ. of California Santa Barbara), Toshiro Tanimoto (Univ. of California Santa Barbara)

Inverting for wind velocity and air temperature using volcano infrasound
Hugo Ortiz (Boise State Univ.), Jeffrey Johnson (Boise State Univ.), Mario Ruiz (Instituto Geofisico Escuela Politecnica Nacional)

June 9, 2016 Workshop Day 2, 15:30 – 17:00

The Legacy of the Transportable Array

A sharp gradient in seismic anisotropy across the Appalachian Mountains constrained by observations of Love-to-Rayleigh wave scattering
Maureen D. Long (Yale Univ.), Margaret H. Benoit (The College of New Jersey), Juan C. Aragon (Yale Univ.)

Crust and lithospheric structure of the Mid-Atlantic Margin from the MAGIC seismic array
Margaret H. Benoit (The College of New Jersey), Maureen Long (Yale Univ.), Scott King (Virginia Tech), Eric Kirby (Oregon State Univ.)

Moho Temperature and Compositional Controls on Lithospheric Bending Strength in the Western United States
Derek L. Schutt (Colorado State Univ.), Anthony R. Lowry (Utah State Univ.), Janine S. Buehler (SIO, Univ. of California San Diego)

Modeling Lithospheric Velocity within the Southwestern US
Ryan Porter (Northern Arizona University), William Holt (SUNY Stonybrook)

A plume-triggered delamination origin for the Columbia River flood basalts
Amberlee Darold (USGS, CVO), Gene Humphreys (Univ. of Orgeon)

Recent craton growth by under-accretion an ocean plateau beneath Wyoming
Gene Humphreys (Univ. of Oregon), Brandon Schmandt (Univ. of New Mexico), Max Bezada (Univ. of Minnesota)

Automatic detection and cataloging of global explosive volcanism using the IMS infrasound network
Robin S. Matoza (Univ. of California Santa Barbara), David N. Green (AWE Blacknest, UK), Alexis Le Pichon (CEA/DAM/DIF, France), David Fee (Univ. of Alaska Fairbanks), Peter Shearer (SIO, Univ. of California San Diego), Pierrick Mialle (CTBTO, Vienna), Lars Ceranna (BGR, Hannover)

A regional study of atmospheric gravity waves using the USArray Transportable Array
Michael A. H. Hedlin (Univ. of California San Diego), Claudia Stephan (Univ. of Reading), Catherine D. de Groot-Hedlin (Univ. of California San Diego)

Seismology Across Scales: Enhanced Imaging and Source Characterization

Surface Wave Phase Velocity Observations from the Malawi Rift: A unique on-shore/off-shore passive source experiment
Natalie Accardo (LDEO, Columbia Univ.), James Gaherty (LDEO, Columbia Univ.), Andrew Nyblade (The Pennsylvania State Univ.), Cindy Ebinger (Univ. of Rochester), Derek Keir (Univ. of Southampton), Gabriel Mbogoni (Geological Survey of Tanzania), Patrick Chindandali (Geological Survey of Malawi), Gabriel Mulibo (The Pennsylvania State Univ.), Richard Ferdinand-Wambura (Univ. of Dar es Salaam), Godson Kamihanda (Geological Survey of Tanzania)

Crust and upper mantle velocity structure beneath and surrounding the northern Lake Malawi/Nyasa Rift Basin from the SEGMeNT project
Andy Nyblade (The Pennsylvania State Univ.), David Borrego (The Pennsylvania State Univ.), Donna Shillington (LDEO, Columbia Univ.), James Gaherty (LDEO, Columbia Univ.), Cynthia Ebinger (Univ. of Rochester), Natalie Accardo (LDEO, Columbia Univ.), Gabriel Mbogoni (Tanzania Geological Survey), Gabriel Mulibo (Univ. of Dar es Salaam), Richard Ferdinand (Univ. of Dar es Salaam), Patrick Chindandali (Malawi Geological Survey), Felix Mphepo (Malawi Geological Survey)

Rayleigh Wave Phase Velocity in the Indian Ocean Upper Mantle
Karen Godfrey (Brown Univ.), Colleen Dalton (Brown Univ.)

Indian Ocean upper mantle structure from surface wave tomography
Zhitu Ma (Brown Univ.), Colleen Dalton (Brown Univ.)

Diffractional Imaging of Mantle Transition Zone Discontinuities Using SdS-SS Traveltimes
Zhen Guo (Virginia Tech), Ying Zhou (Virginia Tech)

Roughness of the Mantle Transition Zone Discontinuities Revealed by High Resolution Wavefield Imaging with the Earthscope Transportable Array
Yinzhi Wang (Indiana Univ.), Gary L. Pavlis (Indiana Univ.)

Preliminary Results of Searching for Upper Mantle Discontinuities
S. Shawn Wei (SIO, Univ. of California San Diego), Peter M. Shearer (SIO, Univ. of California San Diego), Janine S. Buehler (SIO, Univ. of California San Diego)

Receiver Function Analysis of the Arabian Plate and Deep Earthquakes Beneath Harrat Lunayyir
Alexander Blanchette (Stanford Univ.), Simon Klemperer (Stanford Univ.), Walter Mooney (USGS), Hani Zahran (Saudi Geological Survey), Salah El-Hadidy (Saudi Geological Survey)

Reconciliation of Moho depths beneath the Ordos plateau, China, given by Receiver Functions (RF) and Virtual Deep Seismic Sounding (VDSS)
Tianze Liu (Stanford Univ.), Simon Klemperer (Stanford Univ.)

Structural features from seismic tomography on Reykjanes, SW Iceland
Philippe Jousset (GFZ Potsdam), Kristjan Agustsson (Iceland Geosurvey), Arie Verdel (TNO, The Netherlands), Hanna Blanck (Iceland Geosurvey), Steven Franke (AWI, Neumayer Station, Antarctica), Malte Metz (Potsdam Univ.), Trond Ryberg (GFZ Potsdam), Gylfi Pall Hersir (Iceland Geosurvey), Cornelis Weemstra (Univ. Delft, The Netherlands), David Bruhn (GFZ Potsdam)

Adjoint tomography of the North American continent
Hejun Zhu (Univ. of Texas at Dallas), Jeroen Tromp (Princeton Univ.)

Wavefield simulations of earthquakes in southern Alaska for tomographic inversion
Vipul Silwal (Univ. of Alaska Fairbanks), Carl Tape (Univ. of Alaska Fairbanks)

Seismic Structure Beneath the Northern Mississippi Embayment: Inverting Receiver Functions, Surface-Wave Dispersion, and Gravity Observations
Chenping Chai (The Pennsylvania State Univ.), Charles J. Ammon (The Pennsylvania State Univ.), Robert B. Herrmann (Saint Louis Univ.), Akram Mostafanejad (IRIS/PASSCAL), Charles A. Langston (Univ. of Memphis)

Nature of the crust in central Idaho and eastern Oregon from anisotropic/isotropic ambient seismic noise tomography: results from the IDOR project
Paul Bremner (Univ. of Florida), Mark P. Panning (Univ. of Florida), Ray Russo (Univ. of Florida), Victor Mocanu (Univ. of Bucharest), A. Christian Stanciu (Virginia Tech), Megan Torpey (Univ. of Florida), Sutatcha Hongsresawat (Mahidol Univ., Thailand), John C. VanDecar (Carnegie Institution for Science)

EarthScope IDOR controlled-source and broadband seismic imaging across the edge of the craton and accreted terranes in Idaho and eastern Oregon
A. Christian Stanciu (Univ. of Florida), Kathy K. Davenport (Virginia Tech), Raymond M. Russo (Univ. of Florida), John A. Hole (Virginia Tech), Victor I. Mocanu (Univ. of Bucharest), Paul M. Bremner (Univ. of Florida), Sutatcha Hongsresawat (Univ. of Florida), Megan E. Torpey (Univ. of Florida), Steven H. Harder (Univ. of Texas at El Paso), Basil Tikoff (Univ. of Wisconsin-Madison), David A. Foster (Univ. of Florida), John A. VanDecar (Carnegie Institution for Science)

Flow in the asthenospheric channel beneath the Juan de Fuca and Gorda plates: Results from

seismic imaging with Cascadia Initiative Data
Joseph S. Byrnes (Univ. of Oregon), Miles Bodmer (Univ. of Oregon), Douglas R. Toomey (Univ. of Oregon), Emilie E. E. Hooft (Univ. of Oregon), John Nabelek (Oregon State Univ.), Jochen Braunmiller (Univ. of South Florida)

Preliminary analysis of Pn anisotropy beneath the Juan de Fuca Plate
Brandon P. Venderbeek (Univ. of Oregon), Douglas R. Toomey (Univ. of Oregon)

Analysis of high frequency air-gun shots recorded by Cascadia Initiative ocean bottom seismometers
Sampath Rathnayaka (Univ. of Massachusetts, Amherst), Haiying Gao (Univ. of Massachusetts, Amherst)

Phase Velocity Tomography of Mount St. Helens, Washington from iMUSH Array
Kayla Crosbie (Cornell Univ.), Geoff Abers (Cornell Univ.), Kenneth Creager (Univ. of Washington), Seth Moran (USGS, Cascade Volcano Observatory), Roger Denlinger (USGS, Cascade Volcano Observatory), Carl Ulberg (Univ. of Washington)

Local earthquake P-wave tomography at Mount St. Helens with the iMUSH broadband array
Carl Ulberg (Univ. of Washington), Kenneth Creager (Univ. of Washington), Geoffrey Abers (Cornell Univ.), Alan Levander (Rice Univ.), Eric Kiser (Rice Univ.), Brandon Schmandt (Univ. of New Mexico), John Vidale (Univ. of Washington), Heidi Houston (Univ. of Washington)

Local near-instantaneous dynamic triggering of large earthquakes
Wenyuan Fan (SIO, Univ. of California San Diego), Peter M. Shearer (SIO, Univ. of California San Diego)

Imaging 2015 Mw 7.8 Gorkha earthquake in Nepal and its aftershock sequence using global and local seismic arrays
Abhijit Ghosh (Univ. of California Riverside), Bo Li (Univ. of California Riverside), Manuel Mendoza (Univ. of California Riverside), Soma Nath Sapkota (Dept. of Mines and Geology, Nepal), Lok Bijay Adhikari (Dept. of Mines and Geology, Nepal), Marianne S. Karplus (Univ. of Texas at El Paso), John Nabelek (Oregon State Univ.), Aaron Velasco (Univ. of Texas at El Paso), Simon L. Klemperer (Stanford Univ.), Mohan Pant (Univ. of Texas at El Paso), Vaclav Kuna (Oregon State Univ.), Ezer Patlan (Univ. of Texas at El Paso)

Rupture process of the 2015 Mw 8.3 Illapel, Chile earthquake constrained by strong-motion, high-rate GPS and teleseismic data
Xiong Xiong (Chinese Academy of Sciences), Yong Zheng (Chinese Academy of Sciences), Chengli Liu (Chinese Academy of Sciences), Bin Shan (Chinese Academy of Sciences)

Eastern North American Margin (ENAM): Preliminary results of onshore active source seismic data from the Community Seismic Experiment
Thomas W. Luckie (Univ. of New Mexico), Lindsay Lowe Worthington (Univ. of New Mexico), Maria Beatrice Magnani (Southern Methodist Univ.)

Extension and magmatism across the Suwanee Suture and South Georgia Basin from the SUGAR seismic refraction experiment
Donna J. Shillington (LDEO, Columbia Univ.), Rachel Marzen (LDEO, Columbia Univ.), Daniel

Lizarralde (Woods Hole Oceanographic Institution), Steven Harder (Univ. of Texas at El Paso)

Lateral variations within the continental lithosphere: Lessons from waveform modeling
Nicholas Mancinelli (Brown Univ.), Karen Fischer (Brown Univ.)

Lithospheric Discontinuities in Illinois Basin and their Tectonic Implications: Results from the EarthScope OIINK Experiment
Xiaotao Yang (Indiana Univ.), Gary L. Pavlis (Indiana Univ.), Michael W. Hambuger (Indiana Univ.), Hersh Gilbert (Purdue Univ.), Stephen Marshak (Univ. of Illinois at Urbana-Champaign), Timothy H. Larson (Illinois State Geological Survey), Chen Chen (Purdue Univ.)

Looking inside the microseismic cloud using seismic interferometry
Eric Matzel (Lawrence Livermore National Laboratory), Andrea Rhode (Univ. of Texas at Dallas), Christina Morency (Lawrence Livermore National Laboratory), Dennise Templeton (Lawrence Livermore National Laboratory), Moira Pyle (Lawrence Livermore National Laboratory)

Estimation of full moment tensors with uncertainties
Celso Alvizuri (Univ. of Alaska Fairbanks), Vipul Silwal (Univ. of Alaska Fairbanks), Carl Tape (Univ. of Alaska Fairbanks)

The Source Physics Experiment Large Array: A First Look
Robert Mellors (Lawrence Livermore National Laboratory), Catherine Snelson (Los Alamos National Laboratory), Ting Chen (Los Alamos National Laboratory), William Walter (Lawrence Livermore National Laboratory), Satish Pullammanappallil (Optim, Inc), Dustin Naphan (Optim, Inc), Dennis Huff (Greyco, Inc), Arben Pitarka (Lawrence Livermore National Laboratory), Jesse Bonner (National Security Technologies), Frank Spenia (National Security Technologies), Robert White (National Security Technologies), Beth Dzenitis (Lawrence Livermore National Laboratory), Leon Berzins (Lawrence Livermore National Laboratory)

3-D Directivity Analysis of Deep Earthquakes in the Sea of Okhotsk Region
Sunyoung Park (Harvard Univ.), Miaki Ishii (Harvard Univ.)

Constraints on radial anisotropy in the central Pacific upper mantle from the NoMelt OBS array
Joshua Russell (LDEO, Columbia Univ.), James B. Gaherty (LDEO, Columbia Univ.), Peiying (Patty) Lin (Taiwan Ocean Research Institute), Ge Jin (ConocoPhillips)

Seismic Investigation of the Kunlun Fault: Analysis of the INDEPTH 2-D Active-source Seismic Dataset
William Seelig (Univ. of Texas at El Paso), Marianne Karplus (Univ. of Texas at El Paso)

Nexus of Technology and Methodology: Pushing the Limits of Resolution

Full-waveform imaging of the magmatic-hydrothermal reaction zone beneath a mid-ocean ridge
Gillean M. Arnoux (Univ. of Oregon), Douglas R. Toomey (Univ. of Oregon), Emilie E. E. Hooft (Univ. of Oregon), William S. D. Wilcock (Univ. of Washington), Joanna Morgan (Imperial College London), Michael Warner (Imperial College London), and Brandon P. VanderBeek (Univ. of

Oregon)

Seismic Imaging of Newberry Volcano
Benjamin Heath (Univ. of Oregon), Emilie Hooft (Univ. of Oregon), Douglas Toomey (Univ. of Oregon)

Subsurface Imaging in Yellowstone Using Ambient Noise
Sin-Mei Wu (Univ. of Utah), Fan-Chi Lin (Univ. of Utah), and Jamie Farrell (Univ. of Utah)

Upper crustal LP earthquakes during quiescent period at Mount St. Helens in Summer 2014
Margaret Glasgow (Univ. of New Mexico), Steve Hansen (Univ. of New Mexico), Brandon Schmandt (Univ. of New Mexico)

Systematic detection of seismic events at Mount St. Helens with an ultra-dense array
Xiaofeng Meng (Univ. of Washington), Renate Hartog (PNSN), Brandon Schmandt (Univ. of New Mexico), Alicia Hotovec-Ellis (Univ. of Washington), Steven Hansen (Univ. of New Mexico), John Vidale (Univ. of Washington), Jake Vanderplas (Univ. of Washington)

Rayleigh wave tomography of Mount St. Helens, Washington from ambient seismic noise
Yadong Wang (Univ. of Utah), Fan-Chi Lin (Univ. of Utah), Jamie Farrell (Univ. of Utah), and Brandon Schmandt (Univ. of New Mexico)

Isolating retrograde and prograde Rayleigh wave modes using a polarity mute
Gabriel Gribler (Boise State Univ.), Lee M. Liberty (Boise State Univ.), and T. Dylan Mikesell (Boise State Univ.)

Detecting invisible events using local similarity conversion for dense arrays
Zefeng Li (Georgia Tech) and Zhigang Peng (Georgia Tech)

Monitoring ground motion with ultra-long and ultra-dense networks
Philippe Jousset (GFZ Potsdam), Thomas Reinsch (GFZ Potsdam), Jan Henninges (GFZ Potsdam), Hanna Blanck (ISOR, Iceland Geosurvey), and Trond Ryberg (GFZ Potsdam)

Next Generation Portable Broadband Systems
Tim Parker (Nanometrics Inc.) and Andrew Moores (Nanometrics Inc.)

Data Latency and Compression
Joseph M. Steim (Quanterra Inc.) and Edelvays N. Spassov (Kinemetrics Inc.)

Beyond the Workstation: Seismology in a Post-Desktop World

A Seismic Outreach: Shifting the Sentiment of Science in Oklahoma
Jennifer K. Morris (Oklahoma Geological Survey) and Jefferson C. Chang (Oklahoma Geological Survey)

Crowd-Sourcing Seismic Data for Research and Education Opportunities with the Quake-Catcher

Network
Danielle F. Sumy (IRIS Consortium), Robert M. de Groot (USGS, Pasadena), Elizabeth S. Cochran (USGS, Pasadena)

GISMO: A MATLAB toolbox for seismic research, monitoring & education
Glenn Thompson (Univ. of South Florida), Celso Reyes (unaffiliated)

What to do, with waveforms from decades of analog recording in the US?
Paul G. Richards (Lamont-Doherty Earth Obs. of Columbia Univ.)

Education and Public Outreach

GeoGirls: A Geology and Geophysics Field Camp for Middle School Girls at Mount St. HelensGeoGirls: A Geology and Geophysics Field Camp for Middle School Girls at Mount St. Helens
Catherine Samson (Western Washington Univ. and Mt. St. Helens Inst.), Kate Allstadt (USGS), Abi Groskopf (USGS), Sonja Melander (USGS), Elizabeth Westby (USGS), and Carolyn Driedger (USGS)

Overview of EarthScope Transportable Array Outreach Activities in Alaska and Western Canada
Lea Gardine (Univ. of Alaska Fairbanks), Perle M. Dorr (IRIS Consortium), Carl Tape (Univ. of Alaska Fairbanks), Tammy Bravo (IRIS Consortium), Joel Cubley (Yukon College), Mary Samolczyk (Yukon College), Michael E. West (Univ. of Alaska Fairbanks), and Robert W. Busby (IRIS Consortium)

Earthquake Locations and Seismic Velocities Using a Minimum of Assumptions
Steven C. Jaume (College of Charleston), Dante Curcio (College of Charleston)

Educational access to real-time seismic data
Tammy Bravo (IRIS), Kevin Frechette (ISTI)

June 8, 15:00 – 16:30 & June 9, 2016, 15:30 – 17:00, Workshop Days 1 & 2

Facilities, Operations, and Management

PH5 for integrating and archiving different data types
Steve Azevedo (IRIS/PASSCAL), Derick Hess (IRIS/PASSCAL), Bruce Beaudoin (IRIS/PASSCAL)

Simplifying SEED metadata creation; Nexus Application
Lloyd Carothers (IRIS/PASSCAL), Bruce Beaudoin (IRIS/PASSCAL), Steve Azevedo (IRIS/PASSCAL)

ShakeAlert Testing and Certification Platform: Point Source and Ground Motion Based Evaluations

Elizabeth S. Cochran (USGS, Pasadena), Monica D. Kohler (California Institute of Technology), Douglas D. Given (USGS, Pasadena), Jen Andrews (California Institute of Technology), Men-Andrin Meier (California Institute of Technology), Egill Hauksson (California Institute of Technology), Sarah Minson (USGS, Menlo Park), Mohammad Ahmad (USGS, Pasadena), Jonathan DeLeon (USGS, Pasadena), Stephen Guiwits (USGS, Pasadena)

Array Network Facility Operations for the Central and Eastern United States Network
Trilby Cox (USArray ANF, SIO-UCSD), Frank Vernon (Univ. of California San Diego), Jennifer Eakins (Univ. of California San Diego), Geoff Davis (Univ. of California San Diego), Jon Meyer (Univ. of California San Diego), Juan Reyes (Univ. of California San Diego), Jon Tytell (Univ. of California San Diego), Robert Busby (IRIS)

Leveraging EarthScope USArray with the Central and Eastern United States Seismic Network
Robert W. Busby (IRIS), Danielle F. Sumy (IRIS), Robert L. Woodward (IRIS), Michael Brudzinski (Miami Univ. of Ohio)

Use of MUSTANG in IDA DCC Operations
Peter Davis (Univ. of California San Diego), Mary Templeton (IRIS), Robert Casey (IRIS), Tim Ahern (IRIS)

New DMC Data Products
Alexander Hutko (IRIS DMC), Manoch Bahavar (IRIS DMC), Chad Trabant (IRIS DMC), Robert Weekly (IRIS DMC), Mick Van Fossen (IRIS DMC)

The IRIS Federator: Accessing Seismological Data Across Data Centers
Mick Van Fossen (IRIS DMC), Chad Trabant (IRIS DMC), Tim Ahern (IRIS DMC), and Robert Weekly (IRIS DMC)

OBSIP: An Evolving Facility for the Future of Geoscience
Brent Evers (IRIS OBSIP), Kasey Aderhold (IRIS OBSIP)

EarthScope Magnetotellurics: Program Status and Science Examples
Andy Frassetto (IRIS), Adam Schultz (Oregon State Univ.), Bob Woodward (IRIS)

The Global Seismographic Network (GSN): Proposed Equipment Upgrades for Maintaining High Quality Network Performance
Katrin Hafner (IRIS), Pete Davis (IDA, Univ. of California San Diego), Dave Wilson (ASL, USGS), Bob Woodward (IRIS), Danielle Sumy (IRIS)

The Seismic Source Facility: Turnkey Seismic (Explosion) Sources for Active-Source Profiling
Steven Harder (Univ. of Texas at El Paso), David Okaya (Univ. of Southern California)

Seismic Observations of Surface-Hole Installation Techniques
Justin Sweet (IRIS), Noel Barstow (IRIS/PASSCAL), Bruce Beaudoin (IRIS/PASSCAL), Cathy Pfeifer (IRIS/PASSCAL), Kent Anderson (IRIS)

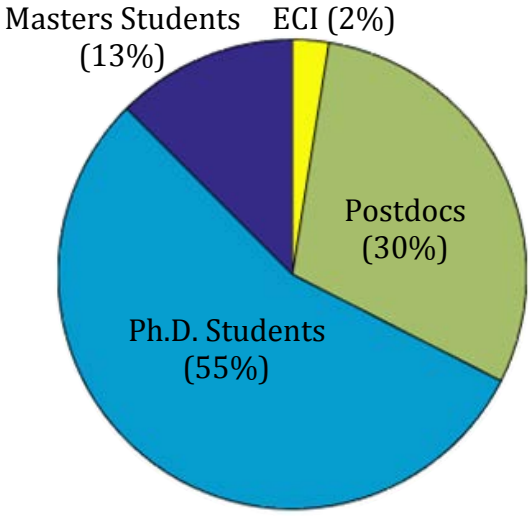
Appendix C: Post Workshop Survey of Graduate Students/Postdocs/Early Career Participants

We conducted a post-workshop assessment survey that targeted 77 graduate students, postdoctoral researchers, and early career investigators (ECI) who attended the Workshop. The survey garnered responses from 40 participants for a ~52% response rate.

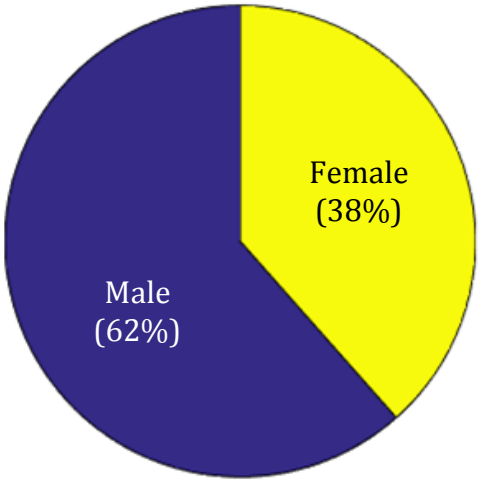
Information about Respondents

The distribution of respondents for their career level, gender, nationality, and ethnicity are summarized below. None of the respondents identified themselves with any sort of disability and one respondent (4%) identified his/her ethnicity as Hispanic/Latinx. 65% of respondents attended the IRIS Workshop through IRIS support while 28% attended through a PI/Advisor grant, and 50% of the respondents attended an IRIS/EarthScope related workshop for the first time.

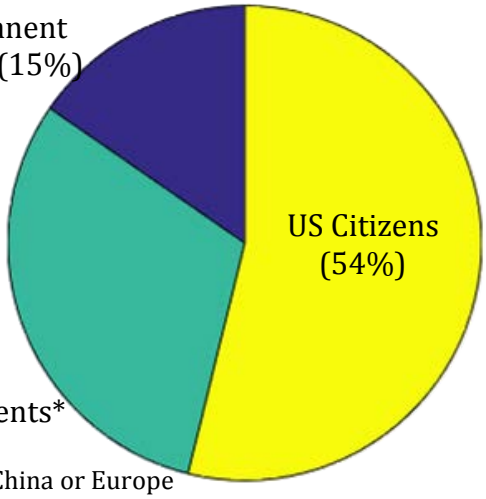
Career Level



Gender

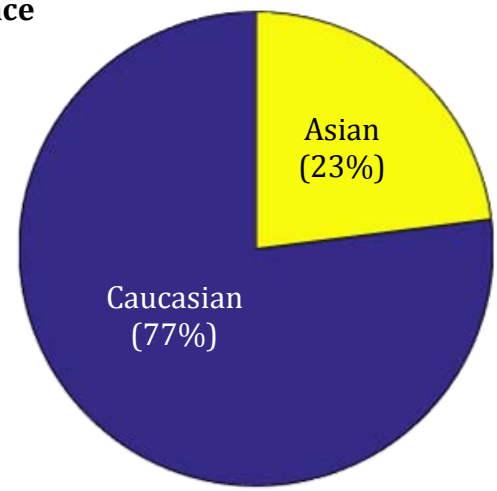


Nationality



* predominantly from China or Europe

Race



No one identified themselves as Black, American Indian, Alaska Native, Native Hawaiian, or other Pacific Islander

Workshop Survey Results

More than 70% of respondents attended the IRIS Workshop to receive feedback on their research, to network with others, and to learn more about research related or unrelated to their work. In particular, the networking opportunity was the top ranked purpose to attend the workshop (93%). 94% agreed or strongly agreed that the workshop was a valuable use of their time.

Many respondents were most excited by the choice of leading researchers who spoke during the plenary sessions and the session topics, especially the Renaissance Seismology session. Positive comments were also made regarding the ability to network at breaks, during the field trip to Mount St. Helens, and during the poster session. 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.

Special Talks, Plenary Sessions & Poster Sessions	VV/SV (%)
NSF Program Overview by Eva Zanzerkia	71
IRIS Overview by Bob Detrick	68
Dinner Lecture by Steve Malone	88
Induced Earthquakes	100
Subduction Zones	91
Renaissance Seismology	100
Legacy of the TA	94
Seismology Across Scales	88
Nexus of Technology	91
Beyond the Workstation	62
Poster Session I	79
Poster Session II	79

Pre-Meeting Activities, SIGs & Summaries	VV/SV (%)	N
Active Source Workshop	80	5
Data Services Short Course	80	5
Mount St. Helens Field Trip	100	16
Open Sesame	80	15
Best Practices	65	20
Data Processing	90	21
Wavefields Demonstration	80	15
EarthScope Synthesis	77	13
Work/Life Balance	70	20
HPC for Seismology	83	24
Seismology & Social Media	45	11
Quick Deploy Strategies	93	14
Engaging Undergrads	56	9
SIG Summaries	72	25
Workshop Summary	67	24

The column N gives the # of respondents who attended the session and the VV/SV column gives % of attendants who ranked the session as VV or SV.

Respondents were asked about several workshop outcomes, and how they think the workshop could help them over the next year. Data processing skills, advice on research, and networking were top comments on how the workshop directly impacted their research.

Workshop Outcome	VV/SV (%)
Network with Peers	79
Gained New Research Perspectives	79
Plan to Communicate with Peers about Workshop	76
Established Professional Connections	72
Forged New Collaboration	40

In the Next Year	L/EL* (%)
Collaborate with Someone Outside Your Department	72
Collaborate with Someone You Met at the Workshop	55
Seek Out New Connections on Campus	55

* L/EL indicates responses of "Likely" or "Extremely Likely".