2019 SAGE/GAGE Workshop Report

Earth in 4D: Bridging the Timescales in Dynamic Earth Processes
October 9-11, 2019, Portland, Oregon
Hilton Portland Downtown

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**DISCLAIMER:** Please note that the Plenary Session and Special Interest Group organizers wrote their own summaries. Their work was only briefly edited for content. Their comments and opinions do not necessarily reflect IRIS or UNAVCO and/or the SAGE and GAGE facilities.
Executive Summary

The Workshop kicked off with three short courses on InSAR, Rapid Response to Geohazards, and New Tools and More Data. IRIS and UNAVCO also hosted two short early-career events on networking and communication the evening before the start of the workshop, and the first morning over breakfast. Over the 2.5 days of the formal workshop agenda, 20 invited speakers presented during five plenary sessions, and conveners held 18 technical topic sessions or special interest group breakout sessions (SIGs) to discuss emerging concepts and themes of seismology and geodesy. Plenary session speakers took the time to develop their presentations to highlight their science and pose new ideas and insight to the future of their specific disciplines. Their work and thoughtfulness will likely inspire new ways of thinking about the Earth and how we study and understand its myriad processes. SIG organizers proposed exciting sessions that covered a broad range of timely issues that allowed for all interested persons to engage in discussion and professional discourse. Finally, the presentation of ~104 posters allowed all those in attendance to present their research, and this time was especially apt for graduate students, postdocs, and early career scientists to engage with their peers and colleagues, as well as senior professionals.

The 2019 SAGE/GAGE Workshop brought together 303 participants (Table 1) from across the country and around the world, representing over 90 institutions and 6 countries. Approximately 25% of attendees are considered early career investigators, from an undergraduate student to postdoctoral fellows/researchers. The workshop was able to support about two-thirds of these students and postdocs through NSF-funded scholarships. The strong early career attendance speaks to the commitment of the IRIS and UNAVCO communities to strengthen and encourage the next generation in their science and scientific endeavors.

<table>
<thead>
<tr>
<th>Participant Career Stage</th>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>303</strong></td>
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Michael Poland, Scientist-in-Charge at the U.S. Geological Survey Yellowstone Volcano Observatory, provided the keynote presentation at Thursday's dinner. His talk, ‘Science F(r)iction: Challenges and opportunities for science communication in a world that's gone bonkers’, provided a fascinating look into the efforts, challenges, and pitfalls into science communication among various media outlets, including the news and social media.
The National Science Foundation announced that the next award for seismic and geodetic facilities will need to be operated and managed under a single, unified facility. Several formal conversations took place within the conference agenda itself to address questions and concerns from the community to NSF. Specific mention was made to reflect on the changes and meaning of a single operator to the IRIS and UNAVCO staff, and to gather input from early-career scientists, member institutions, and affiliates.

1. Introduction

The 2019 SAGE/GAGE Workshop was held in Portland, OR from October 9-11, 2019. This meeting location provided something for every geoscientist: a major subduction zone, with the remnants of oceanic crust slipping quietly beneath in episodic tremor and slip events at times and at others, through potentially destructive moderate to large earthquakes. There were several pre-workshop short courses on topics ranging from InSAR, Rapid Response to Geohazards, New Tools and More Data, to an Early Career Networking Event. Michael Poland (USGS Yellowstone Volcano Observatory) provided the keynote dinner talk, and we sent M. Meghan Miller (UNAVCO President) and Tim Ahern (IRIS Director of Data Services) off to their retirements.

The 2019 SAGE/GAGE Workshop was held right in the heart of downtown Portland, and served as a great location to ponder the big three geohazards – earthquakes, tsunamis, and volcanoes – as well as numerous other societal applications of our science. The 2019 SAGE/GAGE Workshop was an opportunity to look forward into the future of the facilities, and for scientists to come together to talk about the cutting-edge opportunities in both geodesy and seismology. The Science Planning Committee and Plenary Session Organizers worked hard to craft an agenda that represented the full realm of the sciences and the scientists who conduct the research, from both domestic and international communities, in a range of career stages and institutions.

Our understanding of fundamental Earth processes requires multifaceted investigations that span a large range of temporal and spatial scales. This workshop focused on cutting edge geophysical results of processes in the solid earth, cryosphere, oceans and atmosphere and highlighted synergies between the SAGE and GAGE communities. It is this perspective that inspired the theme of “Earth in 4D: Bridging the Timescales in Dynamic Earth Processes.”

2. Plenary Sessions

The 2019 SAGE/GAGE Workshop marked the first time in almost 15 years that the geodetic and seismic communities came together for a joint workshop. The five plenary sessions explored recent developments and advances, and examined how IRIS and UNAVCO can continue to evolve to best serve our communities. The session organizers submitted the following summaries.
**2.1 Bridging the Observational Gap in Time: Processes Today and their Relationship to the Past**

**Organizers:** Roland Bürgmann and Danny Brothers  
**Invited Speakers:** Nathan Miller, Kimberly Blisniuk, Zachary Ross, and Chelsea Scott

Recent advances in geodesy, imaging and earthquake seismology, geodynamic modeling, paleoseismology and other fields have opened new opportunities to link observations of incremental deformation events occurring on timescales of seconds to thousands of years with the integrated deformation record locked into geology and the landscape. These advances hold the potential to more completely describe how plate boundary deformation processes evolve over single to multiple earthquake cycles, and to test how well the past can inform the future. This session, “Bridging the Observational Gap in Time: Processes Today and their Relationship to the Past”, highlighted current advancements (across a range of disciplines) in linking timescales in active deformation, and provided insights on future directions for bridging the diverse timescales of earth deformation processes.

UNAVCO and IRIS have long supported integrative science aimed at improving our understanding of actively deforming plate boundary systems. Such investigations have traditionally relied on geodetic measurements of active deformation and seismic observations of small and large earthquakes. Increasingly, such geodetic and seismic measurements have been combined for an improved characterization of active faults. In this session, we emphasized the importance of considering information on active faulting spanning a wide range of temporal and spatial scales. The session also featured observations obtained by other techniques, including sea floor bathymetry, LiDAR high-resolution topography, enhanced seismicity catalogs, and chronometric dating of geologic features offset by faults. The presentations in the session provided an exciting, multi-disciplinary perspective on the research bridging the broad time scales of active tectonics at the example of the large-scale nature of active strike-slip faulting along the combined Queen Charlotte and San Andreas fault systems, the slip history of the southern San Andreas fault, the fine-scale structure of the aftershock zones of the 2019 Ridgecrest and 2013 Tottori earthquakes, and the shallow rupture zone of the 2017 Kumamoto earthquake.

In the first talk; *A characteristic scale of plate-boundary strike-slip fault obliquity and earthquake rupture*, Nathan Miller (USGS, Woods Hole Coastal and Marine Science Center) provided a large-scale perspective of faulting patterns along the ~4000-km-long zone of strike-slip deformation along the Pacific/North America boundary. New, high-resolution bathymetry data provide an astonishingly detailed view of the active strike-slip fault geometry and offset distribution along the offshore Queen Charlotte fault. Apparently, the angle of obliquity between plate-boundary faults and relative plate motion and slip rate vary along the full length of the system with a characteristic ~200 km spatial wavelength. The distance between the actual trace of these faults and small circle paths from the plate motion model varies by ~5 to 10 km at the ~200 km wavelength, producing a type of large-scale fault roughness. The scaling of this roughness appears to extend relationships established at many orders of magnitude smaller scales found in small-scale outcrops and samples. This
roughness may ultimately control earthquake rupture initiation, termination, and recurrence.

Kimberly Blisniuk (San Jose State University) explored the distribution of slip on strands of the southern Andreas fault with a focus on geologic evidence in her talk “Evidence for an alternative position for the primary active strand of the San Andreas Fault along its restraining bend in southern California”. Her team explored new multi-proxy data to better understand the past and present San Andreas fault activity. Combining data from LiDAR imagery, field mapping, sedimentary provenance analysis, detrital geochronology and a new burial dating technique using the $^{36}$Cl-in-feldspar/$^{10}$Be-in-quartz pair, she established that the Mission Creek fault strand, which is currently mapped as inactive through the restraining bend of the San Andreas Fault, is indeed active and slipping at >20 mm/y, during late-to-mid Quaternary. This result seems to support the case that continental transform faults remain relatively stable and long-lived, and deformation does not migrate between separate fault strands as rapidly as suggested by existing fault-zone evolution models. In an effort to make the tectonic geology accessible to non-experts, Kimberly provided an update on efforts to translate the classic “A streetcar to subduction and other plate tectonic trips by public transport in San Francisco” that Clyde Wahrhaftig prepared for AGU into an online, Google-Earth enabled field trip experience.

In the third talk “The structural architecture of fault zones at depth”, Zachary Ross (Caltech) used greatly enhanced and precisely relocated aftershocks of recent moderate to large earthquakes in California and Japan to illuminate the complex subsurface structure of two fault zones. The obtained characterization provides valuable information about geometric and mechanical fault zone properties that affect many aspects of earthquake physics, including the seismic energy budget, aseismic processes, and earthquake triggering potential. In the case of the 2019 Ridgecrest ruptures, the sub-surface faulting patterns compare well with those obtained from high-resolution geodetic imaging of deformation along the many surface ruptures, providing new insights into the nature and dimensions of fault damage zones, their variations with depth, and the abundance of orthogonal faulting patterns. For the 2016 Tottori, Japan sequence, the nascent fault zone narrows with depth and becomes geometrically simpler. The rupture length of the mainshock is a factor of three smaller than that of the 2004 Parkfield earthquake, which can be explained by the Tottori earthquake being ~10 times more energetically dissipative. Subsurface imaging of 3D fault structure, enabled by enhanced aftershock locations, improves our understanding of the architecture and mechanics of active fault zones and the large earthquakes they host.

Finally, Chelsea Scott (Arizona State University), provided astonishing details of the surface and sub-surface rupture of the Kumamoto earthquake in her talk, “The M7 2016 Kumamoto, Japan, earthquake: Surface strain in the damage zone and fault slip revealed by differencing near-field geodetic imagery”. This work relies on differencing high-resolution topography acquired by LiDAR measurements before and after the earthquake. These data provide a detailed image of the 3D deformation field along and adjacent to the surface rupture, filling a near-fault gap in geodetic observations of the deformation. In combination with large-scale InSAR and optical imagery observations of the coseismic surface deformation, these data allow for a detailed distributed-slip earthquake source inversion, revealing a pronounced
shallow slip deficit on the rupture. The results suggest that the missing shallow slip along the primary fault reflects shallow distributed and inelastic deformation. This has important implications for our understanding of fault mechanics and for slip rates inferred from geologic and paleoseismic records. The NSF-funded facility OpenTopography (partially operated by UNAVCO) provides on-demand vertical differencing for similar overlapping datasets to the research community and is currently adding 3D differencing. Chelsea has also developed an undergraduate topographic differencing lab where students learn about faulting processes by computing 3D surface displacements for a synthetic earthquake.

2.2 Advances in Geophysics in Extreme Environments

Organizers: Andrew Newman and Nicholas Schmerr
Invited Speakers: Erik Frederickson, Philip Wannamaker, Emily Wolin, Mark Panning

The session looked to explore the advances the geophysical community have made in instrumentation and creative new ways the community have been able to make observations in previously inaccessible, or otherwise under-sampled regions, including polar environments, ocean basins, politically unstable situations, and other worldly environments, all in the name of earth science. The speakers presented on a range of the geophysical tools we are using and developing in modern earth and planetary sciences, exploring structure and fluid processes of the interior, deformation and dynamics at the surface, and rumblings of one of our neighboring planets.

In our first talk titled “Optimizing seafloor pressure sensor networks for the detection of slow slip earthquakes in Cascadia and beyond”, Erik Frederickson (a Graduate Student at the University of Washington) summarized the types of processes seafloor geodesy is well-posed for answering. These include both interseismic and transient plate boundary signals, episodic volcanic signals, and important signals away from plate boundaries such as constraining tectonic rates of some plates, as well as flexural rigidity. He then provided details of his own research in trying to better understand seafloor pressure signatures in Cascadia. The work is motivated by our current lack of understanding of the near-trench locking behavior in subduction environments, as land-based geodetic data have been shown to yield no clear result. Assuming that the noise from seafloor pressure signals are primarily due to regionally correlated processes, including drift, oceanographic effects, and tides, Erik showed that by differencing depth-matched pressure data, he can substantially reduce noise levels in data by more than a factor of 3, bringing vertical signal RMS to less than 1 cm. Erik highlighted some recent work to improve pressure measurements to remove drift through calibration either with an internal mass or by alternating between internal ambient and external seawater pressures. Finally, he discussed other geodetic measurement methods and tools for interrogating the kinematics and subsurface changes from the seafloor. These include self-calibrating tilt accelerometers; GPS-Acoustic for measurements of horizontal displacements utilizing a combination of at least 3 seafloor transponders and a sea-surface vessel to get cm-level precision; optical fiber strainmeters for baseline strain signals to 10⁻⁸; seafloor gravimetry for 0.01 mGal precision; differential bathymetry of variable resolutions; and finally CORKs as penetrative observatories that include seismic, geodetic, fluid pressure data for sub-surface changes in the stress field.
Phil Wannamaker (University of Utah) in the second talk, “Sub-Ice thermal regime, volcanogenic processes and terrane assembly in Antarctica using magnetotellurics”, discussed the advancement of Magnetotellurics (MT), which has primarily been a land-based tool for imaging the subsurface using available passive electromagnetic (EM) methods from either solar winds (<1Hz) or global lightning activity (>1Hz). As EM methods are sensitive to conductivity within the earth, they primarily reflect physical properties such as the locations of magmatic melts, hydrous fluids, and the hydration-state of bulk rocks. Phil showed that adaptation for Antarctic environments are relatively straightforward, but required appropriate mathematical configurations for the placement of electrodes and induction coils. Field-hardening sites for wind and ample solar power were discussed. The motivations for research here include understanding processes that dictate Tran-Antarctic Mountain building, with MT results favoring a crustal flexure model over two other models currently considered in the literature. He showed some exciting research from rifting processes that host regional volcanism and earthquakes, most notably from Mount Erebus where inversion results were used to help create a rather well developed image of basanite replenishment in the magmatic plumbing system.

Emily Wolin (Albuquerque Seismological Laboratory) provided the third talk on geophysics in extreme environments. Her talk “Seismology from the Roof of the World to the Irrawaddy Delta” focused on the logistical, financial, and political challenges in developing and maintaining high-quality real-time sensor networks and the specialized staff needed to monitor local seismicity and to record and analyze strong ground motions. She discussed development of a national seismic network in Myanmar, and deployment of a low-cost Raspberry Shake sensor network in the Kathmandu Valley. These regions are both prone to large earthquakes and suffer from a local lack of knowledge and expertise on how to mitigate and prepare their populations for seismic hazards. There are also significant financial challenges in purchasing and maintaining expensive seismic equipment, and technological challenges in delivering these data to the geophysics community for analysis and interpretation. Emily focused on how low-cost sensors are revolutionizing these countries’ ability to fill in gaps in sensor technology and how outreach and education is providing opportunities to engage and inform the local citizenry on seismological hazards. She showed how a true partnership with vested local citizens is the only way such instrumentation can be deployed in the challenging political and financial situations of these countries. She also discussed some of the challenges in executing seismic science in these environments, and pointed a way forward for expanding instrument networks in other countries with similar challenges, an endeavor that will help to mitigate seismic hazard, improve forecast models, and provide new career pathways for individuals involved in the project.

The final talk rounded out the session on extreme environments by outlining the latest geophysical findings from another planet in the Solar System. Mark Panning (Caltech Jet Propulsion Laboratory) provided a talk on “Extraterrestrial Seismology: The perspective after nearly 1 year of InSight on Mars”, where he gave a broad overview of the geophysical results coming from the InSight mission to Mars, which landed in November 2018. The final talk rounded out the session on extreme environments by outlining the latest geophysical findings from another planet in the Solar System. Mark discussed results from the mission which consisted of the SEIS instrument package, a seismological suite of instruments including a very broadband seismometer and short period seismometer; HP3, a heat flow
2.3 Subduction Zones through the Lens of Seismology, Geodesy, and other Geophysical Methods

**Organizers:** Geoffrey Abers and Noel Bartlow

**Invited Speakers:** Samer Naif, William Frank, Julie Elliott, Helen Janiszewski

This session focused on subduction zone science utilizing a variety of methods in numerous subduction zones to study a variety of phenomena. The four speakers in the session captured a broad range of subduction zone studies into a single, unified session that included a discussion of techniques and ideas that are often presented separately.

Samer Naif presented the first talk titled *Electromagnetic imaging of subduction zone fluids* and more) and described two methods, Magnetotellurics (MT) and Controlled Source E&M (CSEM) for measuring subsurface porosity, and thus fluid content. Samer showed results from the SERPENT experiment, which applied both techniques to study fluids in the Nicaragua subduction zone. The CSEM results were especially impressive and found porosity signatures associated with slab bending faults on the outer rise of the incoming plate. These faults are bringing fluids deeper into the incoming plate to depths of a few kilometers. Additionally, the plate becomes more porous as it approaches the trench, resulting in more fluids being subducted than previous estimates suggested. Lastly, Samer introduced two current CSEM experiments in both New Zealand and Alaska, which should produce interesting results soon. He indicated preliminary results from the New Zealand experiment would be presented at the AGU Fall Meeting 2019.

William Frank provided the second presentation on *The transient and intermittent nature of slow slip.* This talk focused on slow slip and tectonic tremor in subduction zones. William argued that the low frequency earthquakes, which make up tremor, could be used as a proxy for underlying aseismic slow slip. He demonstrated that in Mexico, separating GPS time series during a long-term slow slip event into periods, which either contain or do not contain tremor, shows that the GPS sites are show a release in strain during the tremor periods. This implies that the long-term slow slip event is really made up of many short-term slow slip events with accompanying tremor, with a return to plate interface coupling and building up of strain between the short-term events. Dr. Frank also demonstrated that in the Mexican subduction zone the slow slip moment rate can be predicted from the LFE amplitudes, and
that slow slip in the Mexican subduction zone scales with duration cubed, similar to regular earthquakes.

Julie Elliott gave the third talk, titled Geodetic Insights into Subduction Processes: The Example of Alaska. Julie introduced the Alaska-Aleutian subduction zone and illustrated its very complex kinematics as imaged by GPS data. Block models demonstrate a complex tectonic system consisting of multiple thrust and strike-slip faults within the overriding plate. Dr. Elliott went on to discuss fault coupling and earthquakes, including the 1964 Good Friday megathrust earthquake. She also showed GPS data featuring a multiyear slow slip event and GPS displacements from the 2018 Anchorage earthquake. Lastly, Dr. Elliott discussed scientific outreach activities in which she taught elementary school students about earthquakes and GPS, in addition to installing a GPS site on the school grounds.

Helen Janiszewski gave the last talk on Imaging Trans-Crustal Magmatic Systems with Receiver Functions – A Path Towards Linking Tectonic and Eruptive Processes. Helen presented a novel method for studying magmatic systems beneath subduction zone volcanoes. Her method involves separating receiver functions calculated for seismic sites near the volcano by the azimuth of the arriving teleseismic wave. Arriving waves that travel through the magmatic system demonstrate a significant change in receiver function compared to those not traveling through the magmatic system. The difference is due to a low seismic velocity body beneath the volcano, i.e. the magma chamber and/or conduits. This new method can be applied even where there are only a few seismic sites surrounding a volcano. Dr. Janiszewski demonstrated the method on both Akutan and Cleveland volcanoes and showed that magma storage extends deeper beneath Cleveland volcano.

2.4 Earth Rheology and Structure: New Approaches, Applications, and Implications for Dynamics

Organizers: Karen Fischer and Erik Ivins
Invited Speakers: Jessica Irving, Harriet Lau, Kristel Chanard, Weisen Shen

This session focused on recent and future advances related to the mechanical and rheological structure of the Earth as they pertain to contemporary geodynamic, geodetic and seismic models. Emphasis was placed on Earth models for fundamental properties, such as temperature, density and anelasticity, which both employ and, in turn, influence the interpretation of state-of-the-art observations in seismology and geodesy. The four speakers addressed widely varying aspects of 4-D Earth modeling. This session began with a discussion of recent results pertaining to the core and deep mantle, moved to models of the transition zone and finally to the shallow upper mantle, lithosphere and crust. Time scales of relevance varied in each of the four presentations.

Jessica Irving (Princeton) began the session with a talk aimed at using seismology (the Earth’s normal modes) to examine stratification at the top boundary layer of the outer core. Her method required using contemporary Equation of State theory and opened up a reexamination of the seismic and density properties of the outer core. She found that the
data permit an “E’ layer” at the top of the outer core in which P-wave velocity and density are distinct from the rest of an otherwise well-mixed outer core. The implications of such a layer are profound, for they are essential to reconstructing the history of the iron-rich fluid core, and to explaining the hydro-magnetics of time variations seen in the Earth’s magnetic field, such as magnetic jerks that occur over decades and secular acceleration. Jessica’s presentation also included the results of a new analysis with scattering of P-wave reflected phases isolated to the mantle transition zone near the 660 km depth horizon. This method demonstrates that the zone has a roughness to it that here-to-fore has neither been predicted from geodynamic theory or observed seismologically. The results open up the intriguing possibility of ponded chemical heterogeneity near 660 km depth. That the roughness is systematically connected to an inhibition of penetrating convective motions is intriguing.

Harriet Lau (Harvard, University of California, Berkeley) also spoke to the question of better deciphering the nature of the deep Earth, and in particular the physical properties of the Large Low Shear Velocity Provinces (LLVSPs) that exist beneath Africa and the western Pacific. She posed the fundamental question: Are LLVSPs positively buoyant, consistent with high temperatures, or negatively buoyant, which would imply they have a chemical origin? So far, the field seems split over the answer to this question. She proposed an entirely new imaging method, one that uses the gravitational forces of the Sun and Moon that deform the lower mantle. One data set that is sensitive to this deformation is formed by the movements of surface global GPS stations that can be analyzed at the tidal forcing period of 12 and 24 hours. Models of the 3D deep Earth structure depend on anomalous density, and elastic Lamé parameters. Model anomalous density may be set negative or positive, and the two options lead to distinctly different surface GPS-determined deformation patterns. The GPS data, in fact, reveal a preference for a positive density anomaly isolated to the volume of the LLVSP’s, hence a negative buoyancy, and chemical origin. Harriet also explored how Earth rheology can be tested over seismic (normal mode) to tidal frequencies, thereby revealing the underlying frequency-dependent mechanisms that control rheological laws.

Kristel Chanard (Institut de Physique du Globe de Paris) addressed the surface deformation that is sensitive to the mantle from the shallow asthenosphere to just above 1000 km depth. Employing a spherical earth model with layered bi-viscous rheology, she derived new constraints on the short-term viscosity of the asthenosphere by comparing observed GPS crustal displacements to those that are predicted for Earth models that are loaded by seasonal mass variations derived from the Gravity and Recovery Climate experiment (GRACE). She also showed that seasonal loading also induces stress and deformation at mantle transition zone depths and can therefore help constrain kinetics of mineralogical phase transformations. Sensitivity to deeper rheology is also revealed in the deformations associated with decadal scale polar motion and spherical harmonic degree 2,1 which are also driven by surface water and atmospheric loading.

Weisen Shen (Stony Brook University, New York) discussed recent seismological mapping of upper mantle and crustal structure in North America, Asia and Antarctica, drawing upon direct comparison between the regions. He addressed the important question of the mechanical strength of both the creeping and brittle-elastic fracturing depths of the Earth. By developing a systematic comparison of two continents (North America versus
he was able to build arguments for parameters such as geothermal heat flux and thermal boundary layer (lithospheric) thickness. He also explored how seismic wave velocities in the crust yield constraints on temperature, silica content, effective viscosity and depth to the brittle-ductile transition, and described implications from seismic tomography for rapid post-glacial uplift measured in Antarctica.

2.5 New and Exotic Approaches for Acquiring, Analyzing and Modeling in Geophysics

Organizers: Rowena Lohman and Jonathan Ajo-Franklin

Invited Speakers: Ekaterina Tymofyeyeva, Nate Lindsey, Ronni Grapenthin, Tim Clements

This session focused on recent and future advances in the methods used to analyze, acquire, and model data to solve problems of interest to a wide community of geophysicists. New geophysical observation types, new methods for getting more out of existing data, and methods for optimizing use of the rapidly growing volumes of data were the main topics covered. This session began and ended with talks about the use of very large datasets, including efforts to leverage cloud resources and processing approaches that can capitalize on large numbers of repeat observations to improve derived data products.

The session began with a presentation by Ekaterina Tymofyeyeva (JPL) who presented an example of using high resolution InSAR time series to map transient creep on the Concord Fault. Her work demonstrated how improvements in InSAR image processing are quickly advancing our capacity to accurately map large-scale deformation in time.

The next presentation by Nate Lindsey (UC Berkeley/LBNL) provided an impressive demonstration of the power of distributed acoustic sensing (DAS), a relatively new optical sensing technology, in a wide range of environments including both on land and offshore deployments. He presented new results from an offshore DAS survey in Monterey Bay demonstrating sensitivity to local earthquakes, the capacity to detect offshore faults, and measurement of a host of oceanographic processes.

Ronni Grapenthin (University of Alaska, Fairbanks) presented several examples of novel GNSS applications including the use of GNSS reflectometry to provide rapid assessments of hazards associated with volcanism such as volcanic hail. He also delved into improvements in data processing, which now allow for the accurate determination of ground displacements in the immediate aftermath of an earthquake, enhancing the ability to quickly characterize earthquake magnitude.

The last talk in this session was presented by Tim Clements (Harvard), who showed a recently completed study which utilized decades of continuous waveform data acquired on regional seismic networks in Southern California to track variations in aquifer state over time. This approach leveraged classical ambient noise techniques to image water table elevation at the regional scale through several drought cycles.
3. Poster Sessions
The workshop included two poster sessions that were each two-hours long and featured 104 presentations. Presenters chose to be available for both or only one of the sessions. These sessions, scheduled with afternoon refreshments, were well attended and prompted vigorous discussion.

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

- Bridging the Observational Gap in Time: Processes Today and their Relationship to the Past: 10 posters
- Advances in Geophysics in Extreme Environments: 3 posters
- Subduction Zones through the Lens of Seismology, Geodesy, and other Geophysical Methods: 25 posters
- Earth Rheology and Structure: New Approaches, Applications, and Implications for Dynamics: 24 posters
- New and Exotic Approaches for Acquiring, Analyzing and Modeling in Geophysics: 20 posters

There were two additional categories specific to the poster sessions, Education, Workforce, and Outreach/Community Engagement (7 posters) and Facilities, Operations, and Management (15 posters) that were showcased during the poster sessions. The posters covered a much 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 104 posters, graduate students and postdocs presented 38 and 18 posters, respectively, for a total of 56 (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 “Earth in 4D: Bridging the Timescales in Dynamic Earth Processes”, the Special Interest Groups (SIGs) were solicited widely from the community. There were 18 SIGs spread over three sessions, and each SIG session featured six concurrent meetings presented in different rooms. In order for all participants to get a glimpse of discussion at all SIGs, the SIG organizers presented a short summary at the end of the workshop and provided summaries below.

4.1 GAGE GNSS Data Products: Past, Present and Future
Organizers: Tom Herring (MIT) and David Phillips (UNAVCO)

The GAGE Facility provides a diverse suite of derived GNSS (currently GPS) data products including station position solutions, time series, velocities, coseismic offsets, time series
properties, and tropospheric (zenith delay) parameters. This SIG began with an overview of the historical evolution of these products beginning with the Plate Boundary Observatory (PBO) MREFC (2004-2008). As originally conceived and implemented, two independent Analysis Centers (AC's) at Central Washington University (CWU) and New Mexico Tech (NMT) analyzed PBO data using different software (GIPSY and GAMIT, respectively) and generated independent loosely constrained solution sets. The Analysis Center Coordinator (ACC) at the Massachusetts Institute of Technology (MIT) subsequently generated final products in constrained reference frames, including “combined” PBO (CWU+NMT) solutions. All data products were archived and distributed by UNAVCO. New and evolved data products and references frames were continuously developed and released throughout the subsequent PBO Operation & Maintenance period (2009-2013) and initial GAGE facility period (2014-2018). The number of GPS stations processed also increased continuously throughout these periods to include not only the core 1,100 PBO stations but also 500+ non-PBO stations east of the actively deforming plate boundary. A comprehensive treatment of PBO/GAGE GPS analysis methods and products was published in Reviews of Geophysics [Herring et al., 2016].

We summarized the current and anticipated future state of GAGE GNSS data products, including an overview of recent analysis changes, product releases and future plans. Analyses and products were adversely impacted at the beginning of the second GAGE facility period (2019-2023) with the discontinuation of a second analysis center (NMT). Nevertheless, two new major time-phased data product developments are anticipated in the future. First, a transition from data products based on legacy GPS observables (L1, L2, code and phase) to data products based on future GPS observables (L5, L1C, etc.) and multi-constellation GNSS observables (GLONASS, Galileo, BeiDou, QZSS, etc.). Second, the number of GNSS stations analyzed will increase from ~2,600 at present time to >10,000. In addition to these major product developments, new combination data products are being developed to facilitate comparison of results between GAGE and non-GAGE analysis centers. A series of white papers describing current and future developments, available for download from the UNAVCO website, were presented and reviewed. Recent data product updates, including the rollout of ITRF2014 products in North American and IGS reference frames including reprocessed solutions back through 1996, were described. The “past, present and future” summary was followed by online interactive demonstrations on how to access and visualize GAGE GPS data products from the UNAVCO website via FTP, the Data Archive Interface (DAI v2), and web services.

The final third of the session featured an open forum / Q&A session. Discussions topics included: Should GAGE provide separate GPS and multi-GNSS products, or only multi-GNSS products? Should products include flagged attributes, e.g., for QC parameters, and if yes, then in what format? How deep into the “weeds” do GAGE data products users really want to get, as opposed to more streamlined products? How should time information be presented in future products, e.g., what resolution and what format? Information gathered from this SIG will be used to help inform the planning and development of future GAGE GNSS data products.
4.2 What to expect from the PASSCAL Magnetotelluric facility
Organizers: Ninfa Bennington (UW-Madison) and Andy Frassetto (IRIS)

The organizers provided an update on the SAGE and NASA supported magnetotelluric activities underway at IRIS and focused discussion on the plans and current status of the MT capabilities that are being established at the PASSCAL Instrument Center in Socorro, New Mexico. SIG participants included at least 21 attendees in addition to the hosts, including 4 MT practitioners, 11 seismologists, and 6 SAGE facility staff. In his role as program manager, Andy highlighted the intended role of MT in SAGE and milestones for establishing a new pool of instruments and dirt-to-desktop workflow. Ninfa, in her role as the chair of the Electromagnetic Advisory Committee, provided a case study for using wideband MT instruments in the Aleutians to collect MT data and comparing it to a seismic dataset, and shared the results of a recent community questionnaire on the needs of Principal Investigators (PIs) considering MT.

Group discussion touched on several topics. There is recognition that MT is increasingly appreciated as a useful observation by other solid earth disciplines, which may result in opportunities to grow this relatively small (in the U.S.) research community. The practicalities of fieldwork were considered. In most applications, the magnetic field does not need to be sampled at the same density as the electric field. This is a common approach in mineral exploration cases. In addition, 2-3m long magnetic induction coils are sometimes unable to be buried vertically, reducing the number of magnetic field observations at a station. Finally, fluxgate and induction coil magnetometers have overlapping sensitivities at certain frequencies, but their power consumption and deployment characteristics differ significantly. All these factors should be considered when forming the instrument pool, and attendees emphasized the importance of maintaining a distinct pool of long-period instruments when the existing EarthScope-era MT instruments are no longer supported.

There was also concern about turning field observations into robust research results. As it does for seismic PIs, the PASSCAL Instrument Center (PIC) will train users how to properly use the MT instruments and process data into the IRIS archive, but significant consultation with the community will be needed to develop reliable and user-friendly workflows to calculate and invert transfer functions. This may eventually require facilitating access to resources for investigators to do inversions of MT datasets and joint inversions with seismic models. Some of these long-term goals are not directly supported under SAGE but should be pursued in partnership with the community. Finally, because MT has applications which extend to characterizing shallow targets, there were several comments that reemphasized the continued interest in having the SAGE facility provide capabilities for near surface geophysical investigations.

4.3 Seafloor Geodesy as a Community Resource
Organizers: Noel Bartlow (UC-Berkeley), David Schmidt (Univ. of Washington), and Andrew Newman (Georgia Tech)
This SIG was organized because of a prior community identified desire for seafloor geodesy as a resource for research and it was used as an opportunity to discuss the best use of an upcoming seafloor geodetic instrument pool, funded by NSF. This community equipment pool will include 3 sea-surface, differential-GNSS-equipped Wave Gliders and ancillary components for 16 GNSS-Acoustic sites, composed of 48 cement benchmarks and 48 transponders (+3 spare), 16 of which will include pressure gauges. All of the transponders will be equipped with 10-yr batteries. Currently, no funds exist for deployment, operations and maintenance, or training. NSF is looking for community guidance on how and where the instrument pool is best utilized to meet the needs of the scientific community.

SIG attendees discussed how the community should first establish its priorities, recognizing that we should do so quickly, as the instrument pool is expected to be sea-ready by winter 2021. Several attendees voiced strong support for a dedicated workshop that should include broad participation from many fields, including non-geodesists, to help decide the best use of the pool. Many thought that this should be an independent workshop that can focus on the opportunity and technologies, and it was considered best not to align too closely with existing initiatives or groups. One possible option is to coordinate a seafloor geodetic workshop with the already funded OBS workshop in Spring/Summer 2020.

The attendees also discussed how individuals or groups might access the equipment in the pool. The group weighed the pros and cons of community experiments (e.g. Cascadia Initiative) versus PI-driven projects (i.e. proposals submitted from small PI teams). Some participants voiced how the limited-size of the pool and long-deployments would favor a community experiment for part or all of the instruments, and a community experiment would increase participation both with operations and analyzing the data. In either case, there needs to be staff assigned to maintain equipment, as the PIs cannot be expected to care for these for the duration of their deployment (found from past experience with wear and tear on OBS).

Potential scientific targets were also discussed during the SIG and how to identify a prioritized list. The solicitation for “white papers” from the community would provide a mechanism for vetting various targets. Synthetic models could be used to estimate the signal-to-noise, and this information could be used to rank proposed targets. Other positive attributes for potential targets include the presence of existing infrastructure (on land or otherwise), international collaborations, and existing cooperatives. The potential impact to our scientific understanding and the number of researchers who might participate were other important considerations when ranking potential targets. Several potential targets were mentioned during the discussion, including secular versus transient signals (i.e. slow slip) on subduction zones, enigmatic plate boundary deformation, volcanic sources (flank collapse), and non-tectonic targets (hydrocarbons, salt domes, freshwater lenses).

Workforce development was seen as an important element. The community training could include instrumentation development, data collection and management, and data analysis (the last being the component where broad participation is of greatest benefit and most accessible). Training data sets are needed (including codes) to begin preparing the community before anything goes into the water. Finally, we created a community survey that
we promoted at the SIG, during the summary session, and promoted through the UNAVCO-list serve asking many of the questions we discussed during the meeting. This will help initiate discussions in a near-future workshop.

4.4 Broadband Sensor Direct Burial, Appropriate Uses, Results from Recent Experiments and Best Practices in Terrestrial and Polar Environments

Organizers: Christian Stanciu (University of Oregon) and Lara Wagner (Carnegie Institution for Science)

The Direct Burial SIG meeting was a big success with over 60 participants plus significant community interest. Geoff Abers, Karen Fischer, Kevin Nikolaus, Justin Sweet, Tim Parker, and Lara Wagner provided presentations. Overall, there was a great deal of interest in the use of new direct-bury sensors (DBS) to facilitate broad- and intermediate period seismic deployments in a wide range of environments.

Our first two presenters, Geoff Abers and Karen Fischer, compared three different styles of broadband station installations: 1) traditional vault, 2) direct-bury using Guralp CMG-3T (non-DBS) with 5 meter plastic bags for protection, and 3) direct-bury using the new Nanometrics Trillium 120 PHQ (DBS) during a recent deployment in Alaska. Vault installations were the most time consuming. One major point was that the Guralp CMG-3T sensors were not designed for direct burial, and deployments that used direct burial of these instruments resulted in high rates of failure. When DBS were available, direct burial installations were the fastest and produced comparatively high data return rates. For the deployments discussed by Geoff and Karen, data quality was as good or better for direct bury sites as for vault sites. In some cases, direct bury sites rivaled nearby TA stations. Overall, local site geology played a far greater role in controlling station noise than installation style. The community expressed interest in having access to a greater number of direct burial systems through the PASSCAL Instrument Center.

The third speaker, Kevin Nikolaus, discussed the use of direct burial in polar environments. These instruments made the deployments lighter, easier, and less expensive. Flexible aluminum conduit was used to protect the cable. Tiles and thermal foam were used for initial leveling. There was some concern about tilting, especially in shifting ice. There was also some concern with the smaller Trillium Compact sensors that the weight of the cable compared to the light weight of the sensor made installation, particularly leveling, a bit of a challenge. To facilitate instrument removal he suggested placing a piece of plywood above the sensor so it would be clear when you were close to the instrument when digging.

Justin Sweet and Tim Parker gave the last two presentations. Sweet presented noise comparisons for collocated CMG-3T (non-DBS) direct burial and FlexArray-style vault installation from the IDOR experiment. For the longest periods, the FA style vault was noisier than the TA average, but the direct burial site had a noise level comparable to or below the TA-style vault. These results reinforce direct burial as a good option and were confirmed in experiments at Poker Flats, AK, with the additional constraint that the deeper the station is deployed, the less noisy it will be. Tim Parker presented suggestions for the deployment of DBS. There was discussion about the use of sand versus clay to level and install DBS. Parker
expressed concern about sand causing tilting, whereas others expressed concern over clay for both tilt and station removal. Good coupling is important in either case, as is a burial depth of at least 0.5 meters to the top of the instrument, though deeper is better.

Looking forward, Lara Wagner presented advancements for the other end of the sensor cable in the form of a lightweight, compact quick deploy box capable of holding the power source, digitizer, and a compact solar panel for easy shipping, transportation, and deployments.

4.5 Network of the Americas: The Current and Future State of the Network

Organizers: Karl Feaux (UNAVCO), David Mencin (UNAVCO), Kathleen Hodgkinson (UNAVCO), Ken Austin (UNAVCO), Chris Walls (UNAVCO), and Tim Dittmann (UNAVCO)

This SIG was well attended, with over 30 participants. Dr. Glen Mattioli opened the session, introducing the Network of the Americas (NOTA) and the GNSS station decommissioning plan. NOTA is a federation of 3 large NSF-funded networks of geophysical instrumentation, including the EarthScope Plate Boundary Observatory (U.S.), COCONet (Caribbean), and TLALOCNet (Mexico). NOTA consists of 1278 GNSS stations, 255 meteorological instruments, 82 borehole strainmeters, 83 borehole seismometers, 25 tiltmeters, and 2 tide gauge sensors. As instructed by the NSF, UNAVCO developed a ~10% station reduction plan through an iterative process with the community with final approval of the UNAVCO Geodetic Infrastructure Advisory Committee. This plan includes either the transfer of ownership and responsibility of specific NOTA stations to institutions that have expressed interest or to decommission a total of 128 existing GNSS stations within the NOTA network. The period of public comment was extended to October 31, 2019.

Karl Feaux presented a summary of the recent GNSS station upgrades with respect to the receiver and antennas. Currently, 486 NOTA stations have receivers and antennas capable of full GNSS tracking. Another 52 stations need receivers only and 90 need antenna replacement to become to be capable of GNSS tracking. All GNSS station upgrades are funded either through NSF support of the GAGE Facility, USGS support of UNAVCO as a partner in the ShakeAlert project, or through a pilot project to receive funding from commercial interests to reinvest into NOTA operations.

Ken Austin presented a summary of the recent GNSS station upgrades with respect to data communications. The addition of expanded-constellation receivers, stakeholder demand for real-time data, and more frequent requests for high rate data all contribute to higher bandwidth requirements that have been addressed within available funding/resources and supplemental projects. During the July 2019 Ridgecrest earthquake sequence, no NOTA stations went offline during shaking or during the ensuing high-rate data downloads, although some latencies were affected for low bandwidth hardware and aging VSAT systems. Overall, the hardware resiliency, GNSS observation quality and dataflow performance of stations proximal to the Ridgecrest earthquake sequence were a direct result of telemetry upgrade efforts and station hardening that have been in evolution since the close of construction and continue today as budget and resources allow.
Kathleen Hodkinson presented a summary of the performance of the real-time GNSS data processing center at UNAVCO during the Ridgecrest earthquake sequence. At the time of the Ridgecrest sequence, 220 NOTA GNSS stations, nine NOTA borehole strainmeter, and ten NOTA seismometers were operational within 250 km of the epicentral area. The peak ground displacements in the real-time GNSS solutions indicated this was a M6.9±0.4 at 13 seconds and M6.9±0.2 at 23 seconds after the event.

There was a short Q&A session after the main presentations ended. These discussions began with some comments on the limitations of satellite telemetry for real-time applications, including earthquake early warning. This led to a discussion about the USGS plan for robust, redundant backhaul from NOTA stations. Brendan Crowell reiterated that his analysis of the Ridgecrest event using geodetic data identified a M7.0 within 14s. There was overall support for the plan to densify the GNSS network in Oregon, which UNAVCO will begin in FY2020 as a component of the USGS ShakeAlert project.

4.6 Social Media for Hazard Scientists  
Organizers: Wendy Bohon (IRIS) and Beth Bartel (UNAVCO)

Wendy Bohon and Beth Bartel led a session on Social Media for Hazards Scientists. Twenty-five meeting attendees participated. Topics of focus included general best practices for science communication using social media, the ways that the communication landscape has changed due to social media and the implications that has for communicating via this interface, the importance of source credibility and trust, the way trust is built and the timescales over which trust can change, the value of consistent messaging and the importance of empathy and compassion when communicating about ongoing hazards situations. There was an interesting and insightful Q&A at the end of the session where participants discussed the best social media platforms for science communication, the ways individual scientists can work with official agencies during ongoing situations and how to best deal with internet trolls and other online “bad actors”.

4.7 Geodetic data and products sharing: enable the future with web services?  
Organizers: Elisabetta D'Anastasio (GNS Science), David Phillips (UNAVCO), Chad Trabant (IRIS) and Mike Floyd (MIT)

This SIG focused on how to deal with the current explosion of geodetic data, new data handling technologies and the need of expanding current metadata standards. Legacy and insecure technologies are widely used by the geodetic community to share geodetic data, metadata and derived products. UNAVCO, Geoscience Australia, EPOS/EUREF, and NASA-JPL have started to provide web services, but there is a need to coordinate efforts towards international standards that facilitate federation and interoperability and to promote those initiatives within the community. FAIR principles (Wilkinson et al, 2016) can guide these efforts. The seismological community has been using web services for many years, and IRIS shared their experiences and lessons learned with web service evolution and
standardization. The International Federation of Digital Seismograph Networks (FDSN) standardized data and metadata formats and a variety of request mechanisms, and federated four data repositories’ services. Some recommendations from this experience: 1) the migration of users and data centers is challenging and need compelling reasons; 2) community support, tools development and allowances are necessary to overcome the divide created by web technologies and their overwhelming norms; 3) allowing a wide variety of use cases is a foundation for all other access; 4) priority should be given to simple interfaces, powerful and usable by non-technologists; 5) human readable documentation is very important; 6) standardized interfaces and formats are crucial to allow federation across different data centers.

The SIG had a very good attendance and many interesting discussion points were raised: 1) an open source community approach, driven by champions, would be more sustainable than a single entity driven approach. Data centers like UNAVCO can act as enablers and nexus for community contributions; as tools/formats/standards evolve, UNAVCO could help provide outreach resources and activities; 2) an open source approach might help to facilitate mixed networks and datasets; 4) where they do exist, current initiatives and standards shall be adopted: GeodesyML, ISO 19115:2014 (Geographic Information – Metadata - Part 1: Fundamentals), ISO 19157:2013 (Geographic Information – Data Quality), and the Open Geospatial Consortium.

Attendees provided recommendations and use cases: 1) could/should GNSS data be treated as “channels”, as it is done in seismology? 2) how can data quality be described and “flagged”? (time series quality, Quality Assessment parameters, derived products from different analysis centers); 3) most users do not want to become “ML experts” or dedicate resources to developing software and prefer formats that are human readable; 4) data providers need mechanisms in place to ensure data completeness and file delivery verification; 5) improving Metadata management is a common need across different network operators. Validation and interoperability are especially widespread desires; 6) data provenance and DOI support is a major community need.

4.8 Preparing for future controlled-source seismic experiments that will use thousands of nodal seismometers

Organizing Committee: David Okaya (University of Southern California), Beatrice Magnani (Southern Methodist University), Marianne Karplus (University of Texas El Paso), Lindsay Worthington (University of New Mexico), Donna Shillington (LDEO), Stephen Veitch (University of Texas El Paso (UTEP)), and Thom Luckie (University of Southern California)

Within a few years, controlled-source seismic experiments will be able to use a PASSCAL pool of one-to-a-few thousand seismic node instruments, with a related phase-out of the RT-125 "Texan" pool. These node instruments are also popular for ambient noise and seismicity field studies. The purpose of the SIG was to have a community discussion regarding how we will scale up to use thousands of nodes, building on the experiences from smaller controlled-source node experiments already completed (50-400 node range). The two objectives of this
SIG were to identify (a) future adjustments to field procedures and experiment planning, and (b) recommendations to PASSCAL management and standing committee regarding procedures and pool expansion from a controlled-source seismic perspective.

The SIG was attended by approximately 40 persons (2/3 early-to-mid career) of which 1/3 had used node equipment before. Early-career scientists Stephen Veitch and Thom Luckie moderated this session.

Presentations began with a short introduction by David Okaya followed by status reports on the PASSCAL nodal pool by Kent Anderson and Bruce Beaudoin from the PASSCAL Instrument Center (PIC). The PASSCAL pool has 633 nodes available for general use plus another 400 for Polar research. These nodes are three-component, 5-Hz Fairfield Zland2 with ancillary charging and download systems. PH5 is used for node data archive. PIC plans to test nodes from other vendors (e.g., a possible 5 second-to-150 Hz node). Galen Kaip (UETP) then gave an update on the Seismic Source Facility including examples of a new P/S wave source that offers potential to carry out 9-component data collection.

Andy Nyblade (Penn State) gave a summary of a high-resolution seismic experiment that targeted the weathering layer at the Susquehanna Shale Hills Critical Zone Observatory via video conferencing. Penn State deployed 2100 Texan instruments and used hammer and shotgun sources; then deployed 50-60 nodes twice for one-month ambient noise recording. Scaling upward, the estimated deployment time would be approximately the same for 4000 Texans or 4000 nodes; however, the suite of possible analyses is greater for the node data.

Rufus Catchings (USGS) also presented via video conferencing the results of a comparison of Fairfield and new DTCC SmartSolo nodes as used in his field deployments this year, including surveying of the 2019 Ridgecrest earthquake. These two types of nodes have similar response characteristics. The SmartSolo node is designed as two pieces with its battery separable from the DAS and sensors, facilitating battery recharge and in-field swapping. This node has a locally cordless on/off design and portable packaging for the programming and charging systems. Regardless of the type of node, field download of thousands of nodes will require mass storage on computers with fast connections (e.g., Thunderbolt instead of USB).

Jenny Nakai (University of New Mexico) presented data acquisition during the 2019 Alaska Amphibious Community Seismic Experiment at Kodiak Island. The controlled-source seismic portion was a seismic onshore-offshore deployment using 400 nodes from PASSCAL and University of Utah for one month of continuous recording in order to listen to R/V Langseth airgun sources. Lessons from this experiment: Mixing node pools makes the subsequent data merge not easy due to different formats and system metadata. Pre-defining field metadata prior to being in the field limits flexibility in moving instrument sites. Changes to local site conditions and vegetation growth can obscure individual node sites upon retrieval. The current availability of nodes is not sufficient yet for controlled source experiments such as BIGHORNS or ENAM. Instrument cleaning for return shipping can consume significant time and effort and needs to be planned for.
Galen Kaip (UTEP) presented results of source tests in Colorado using Texans and nodes, and in Antarctica, using Geode multichannel cable systems and nodes. Node pros: The Texans could record continuously for only 2.5 days compared to the nodal 30 days. A smaller field crew can be used to deploy nodes over longer time due to the longer battery charge. The nodes offer more flexibility for redeploys. Node cons: The Fairfield system requires an ESRI license whose database tools are used for field geometry both prior to shipping and after the experiment. In Antarctica, the Fairfield nodes were susceptible to lose orientation due to tilting of the top-heavy design.

The SIG ended with questions and discussion among all participants. For Vibroseis surveys, the source sweeps can be saved within nodal auxiliary channels. Lithium battery shipping was identified as a logistical issue. Helpful hints for finding buried nodes were discussed. Identified topics that need further community discussion included homogeneous nodal pool (same vendor/model) versus mixed types, and how large of a pool IRIS should own versus contracting when needing several thousand+ nodes. A recommendation was defined that PASSCAL should test some of the newest node models that are now available.

4.9 Designing a Subduction Zone Observatory Initiative: Community Input to the SZ4D Research Coordination Networks
Organizers: Harold Tobin (Univ. of Washington) and Diego Melgar (Univ. of Oregon)

In late 2018, NSF funded three linked Research Coordination Networks (RCNs) for the Subduction Zones in Four Dimensions (SZ4D) effort. The objective of all is to convene a broad spectrum of the research community to shape plans for a potential interdisciplinary, multi-agency, and international decadal scale research effort as a potential “next big thing” in the post-Earthscope, post GeoPRISMS era. The SZ4D Umbrella RCN is to develop community consensus and design a viable plan for a significant infrastructure program (new field campaigns at a large scale on- off-shore), a P.I.-enabling coherent and focused science program crossing geoscience disciplines, and a research network with effective outreach. The Modeling Collaboratory for Subduction (MCS) RCN is charged with developing an organized modeling community around SZ4D themes and developing the elements of the infrastructure/science program that rely on simulation. Finally, the CONVERSE RCN (Community Network for Volcanic Eruption Response) is specifically tasked to develop researcher response capability for volcanic events and a coherent suite of response tools. The goal of this SIG will be to inform the SAGE/GAGE community of recent developments in the SZ4D RCN activities and solicit input into the planning process.

4.10 Updating Design Goals for the Global Seismographic Network (GSN) to Enable New Discoveries
Organizers: Katrin Hafner (IRIS), Peter Davis (University of California - San Diego), and Dave Wilson (USGS Albuquerque Seismological Laboratory)
The Global Seismographic Network (GSN) is just beginning the process of updating the network’s design goals, which were last revised in 2002. The SIG was convened to solicit community input on the next-generation GSN Design Goals, intended to reflect evolving basic scientific research and earthquake monitoring needs. Twenty-one workshop participants attended the SIG.

A summary on the past development of GSN Design Goals was presented. The current status of the GSN relative to the 2002 design goals was reviewed, i.e. 150+ stations with a Global distribution, High dynamic range, Very Broadband (hrs to ~10 Hz), with real-time telemetry. The 2002 design goals have largely been met, except in the oceans, where seafloor stations are absent. Adam Ringler (Albuquerque Seismological Laboratory) presented “Revisiting Long-Period Horizontal Observations” to emphasize the continued need to record very high-quality data below 1 mHz for understanding horizontal Earth tides and the background Earth hum.

A working group on GSN Design Goals has recently been formed, with Miaki Ishii (Harvard University) serving as the chair. The working-group plans to hold additional SIGs on design-goal topics at the annual meetings of the AGU and EGU, that will expand on ideas brought up by the participants of this SIG. Key points brought up during the discussion were: 1) the GSN should recommit to broadening the range of physical phenomena measured (air pressure, magnetic field, wind) with the aim of empirically correcting for bias from these effects on seismic data; 2) Extend the frequency band of recording to longer periods (even DC) to collect more information on earth structure from free oscillations and tides; and 3) Work more closely with the geodetic community particularly for establishing geophysical observatories in the oceans.

4.11 Emerging applications for UAS (uncrewed aerial systems)
Organizers: Chris Crosby (UNAVCO), Chelsea Scott (Arizona State University), and Keith Williams (UNAVCO)

The use of small Uncrewed Aerial Systems (sUAS) as platforms for data capture in the geosciences has rapidly increased in recent years. Lower-cost hardware, smaller and lightweight sensors, the availability of flight planning and data processing software, and increasing clarity in national and international aviation regulations have driven adoption. sUAS have several advantages when compared to other “traditional” data collection methods: (1) the ability to collect higher spatial and or temporal resolution data; (2) a reduced impact on sensitive environments being monitored; (3) lowered risks to workers and equipment involved in data collection in dangerous environments; (4) a flexible platform from which a wide range of parameters might be monitored simultaneously, and (5) access to data that what would otherwise be practically inaccessible, all (6) often at a significantly lower cost than traditional methods might incur. This session reviewed the current state of facility support for sUAS in support of geodetic and geoscience research, highlighted emerging applications and recent science results enabled by sUAS, and offered the community an opportunity to discuss future needs, opportunities, and challenges.
Six lightning talks were used to summarize the current state of facility support for sUAS, community experiences and example applications, and to motivate group discussion. Christopher Crosby and Keith Williams (UNAVCO) introduced the SIG and provided an overview of current GAGE capabilities in terms of sUAS platforms and payloads. Keith also showed two recent sUAS projects conducted by UNAVCO, one focused on rock glacier dynamics in Colorado, and another to survey an Adélie penguin colony in Antarctica. Christopher presented a summary of a recent UNAVCO community sUAS survey to capture community requirements for future GAGE sUAS support, including types of potential sensor payloads (e.g., multispectral, hyperspectral, lidar, thermal). Peter La Femina (PSU) presented a summary of applications of UAS to volcano monitoring, and spoke about plans for UAS as part of NSF’s Volcano Rapid Response Research Coordinated Network (CONVERSE) project. Chelsea Scott (ASU) highlighted her recent work on automatic approaches for mapping fault scarps from UAS high-resolution topography (HRT) in the volcanic tablelands of eastern California. Jayne Bormann (UNR) discussed lessons learned from acquiring and operating a UAS lidar system at CSU Long Beach. She highlighted challenges related to the complexity and size of the system, as well as coordination among research groups and insurance. Finally, Christopher, presenting on behalf of Beth Pratt-Sitaula (UNAVCO), provided an update on the GETSI field project, which features modules on GPS/GNSS, and high-resolution topography (HRT) with TLS and SfM. The latter module includes content and curriculum on UAS-based data collection and analysis.

The session concluded with approximately 45 minutes of discussion around the following questions:

- Would easy access to small Unmanned Aircraft Systems (sUAS) improve your research?
- What types of sensors would you like to have access to (e.g., lidar, hyperspectral, multispectral, thermal, etc)?
- What are current barriers to your use of sUAS in your research?
- Do you see opportunities / needs for training and best practices in sUAS?
- Are you interested in integrating sUAS into education and outreach? Challenges?

There is considerable opportunity and enthusiasm for UAS for optical, 3D (i.e., lidar and SfM), thermal, hyperspectral, and sampling applications. However, there is presently easy access to low-cost UAS for photogrammetry that enables PI’s to use this technology without facility support. There is broad demand in the GAGE community for more sophisticated sensors (e.g., lidar, hyperspectral), but the complexity and cost of these systems/sensors makes them prohibitive without support from a facility such as GAGE. There is also an opportunity for facilities to provide data processing expertise and data archiving in support of FAIR UAS data.

4.12 Integrating geophysics methods into undergraduate courses
Organizers: John Taber (IRIS) and Beth Pratt-Sitaula (UNAVCO)

This session was organized to give participants an opportunity to learn about and provide input regarding ongoing UNAVCO and IRIS undergraduate geophysics curriculum
development efforts related to teaching field geophysics and situating it in a societal context. The session began with an overview of some existing and planned geophysics teaching resources. UNAVCO’s GETSI (Geodesy Tools for Societal Issues) resources were described first, including both classroom modules and field modules. GETSI has developed a dozen modules using geodesy to address critical societal issues such as climate change, natural hazards, water resources, and environmental management for both classroom and field courses. Then, IRIS’s new effort to develop introductory urban and environmental geophysics modules, IGUANA (Introducing Geophysics for Urban and Near-surface Applications), was introduced. A key goal is to engage freshman and sophomores in questions or problems in their communities that can be addressed with geophysical approaches. The modules will be designed to engage a broader audience of students, particularly those from groups that have been traditionally underrepresented in geosciences. The modules will use a variety of near-surface geophysical techniques to image and interpret shallow subsurface structure and processes.

After a short online poll of the participants’ teaching practices, and field equipment usage and interests, the majority of the session was spent in small group discussions, providing feedback on discussion questions, which included:

- Would the proposed urban and environmental geophysics topics, techniques and module structure be appropriate and useful for you? What suggestions do you have to broaden their applicability?
- What approaches have you used in the past to attract a more diverse group of students to your courses and/or institution, and what are barriers to engaging a diverse audience?
- Are there other local or regional urban and environmental issues that could be addressed in an intro geophysics course using seismic reflection/refraction, resistivity, GPR? Are there other tools/techniques we should be considering?

Much of the discussion centered around barriers to engaging students from groups underrepresented in geosciences and approaches to overcoming those barriers. Key points included the need to:

- Capture students’ attention sooner
- Provide clear career options and diverse role models
- Provide modules that are small enough to be easily inserted in existing courses
- Include virtual field work or prepared data set options
- Offer sufficient mentoring

4.13 SAGE/GAGE Common Data Access Point (CDAP)
Organizers: David Phillips (UNAVCO) and Rob Casey (IRIS)

The goal of this SIG was to gather ideas and requirements from seismic and geodetic data users for a notional common interface for access to data provided both at UNAVCO and IRIS data service infrastructures. The ‘charge’ of the Common Data Access Point (CDAP) was presented, which is to allow a user to download data from both centers through a single web
service call. Diagrams of two separate communities served by IRIS and UNAVCO were presented, using powerful tools that allow discovery and data access at each center. Attendees then contemplated and provided feedback on how a unified community could use these tools from both data centers.

One concept was of data products that could be pre-built from events, such as earthquakes, expressing specific measurements of joint geophysical significance. Special datasets, animations, and expert interpretations could be documented online and made available for example as tutorials and reference datasets. Some products would be of educational benefit while others could serve as a temporary ‘most-frequently accessed’ collection of data, ready for download, minimizing the strain on the custom assembly infrastructure.

A need for geodetic and seismic time series data to be aligned to the same (or comparable) sample rate was discussed, though the only data format that was recognized as suited to both seismic and geodetic data was GeoCSV (which has limitations). The group recognized that even as CDAP may seek to find a shared homogeneous output format with common scale, specific research applications along with decades of specialized applications and user knowledge would still require the ability to gather data in domain-specific formats.

It was observed that a common search interface would be very helpful if it kept the user apprised of the volume and count of data their search would return. Another idea was to allow users to ask for only what is new or what has changed.

The SIG was unified in recognizing the importance of maintaining attribution to the sources of data pulled through CDAP. Good data tracking and persistent digital object identifiers (DOIs) must be employed judiciously to enable any data used to be easily citable and discovered by others.

An issue that arose was the notion of unique identifiers for data streams. CDAP would need to be able to unambiguously reference instrumentation from either center, so a shared system of Universal Resource Names (URNs) would need to be introduced. QA flagging of datasets would help users to select only research-ready data. Search parameters across data types will require the use of a common vocabulary and it was recognized that seismic and geodetic metadata do not use the same terms, or the same terms to mean the same thing.

Finally, support for linking other data centers into a second tier federation to feed to CDAP was discussed as a way to broaden the field of accessible data. Both UNAVCO and IRIS have federated data access in play, so the CDAP design will need to consider how to conjoin these groups of data centers in a sustainable way.

In the end, the attendees generally agreed that powerful discovery and visualization tools, allowing dataset request assembly using open standards, followed by powerful programmatic data access, would provide the most well-rounded model for a CDAP implementation.
**4.14 The Big Data Exchange: How?**
Organizers: Nate Lindsey (UC-Berkeley), Chad Trabant (IRIS), and Chris Crosby (UNAVCO)

A growing number of geophysical data sources are beginning to generate terabytes of data per experiment (e.g., seismic nodes, fiber-optic distributed acoustic sensing, InSAR, HD video, hydroacoustic sensors). Critical, community-level bottlenecks already faced by some research groups are the management, sharing and archiving of these very large data sets. This SIG focused on: 1) identifying and sharing current strategies used by the UNAVCO and IRIS research communities, and 2) identifying strategies used or being adopted in non-geoscience communities (i.e. astronomy, biology) to address big data exchange. We invited large volume data wranglers to describe their current and future approaches to these challenges.

We began with a short series of lightning talks targeting particular projects in order to demonstrate the different types of challenges that are experienced today across both geodesy and seismology. Speakers included Chad Trabant (IRIS), Tim Clements (Harvard University), Jonathan Ajo-Franklin (Rice University), Scott Baker (UNAVCO), and Bill Barnhart (University of Iowa).

Several themes emerged through the question-and-answer portion following each speaker’s presentation, which we expanded upon during a breakout session for the second half of the SIG. When defining “Big Data” for geophysics problems, we identified that it was at the multi-terabyte level or multi-terabyte per day level when thinking about the challenge for continuously operating experiments that geophysicists begin to face logistical issues with data management. It was clear that many in the room faced this problem on a daily basis in their research. A couple of common strategies for dealing with big data were also discussed. These included moving the data as little as possible, and generating derivative smaller products to mitigate big data problem. Continuation of this discussion will be important in the future as new needs arise and data product needs change.

The SIG was also an opportunity to begin to vocalize community needs, which over the coming decade will likely become more apparent. The needs discussed included: 1) have an affordable mechanism for very deep cold storage of raw data, which includes building and developing a clear path to infrastructure. This is presently unclear for facilities like UNAVCO and IRIS. A second need was: 2) to address the lack of common framework/approaches for workflow execution in HPC/cloud environments.

**4.15 Low-Cost Sensors**
Organizers: James Foster (University of Hawaii) and John LeBrecque (UT-Austin)

The slow, long-term reduction in price point for science-grade instrumentation has experienced a dramatic surge in recent years, driven partly by the recognition that large volumes of relatively low accuracy observations can be more powerful in addressing some science goals than sparsely recorded, higher accuracy, observations. This recognition has
coincided with the rapid movement of technology towards the “Internet of Things.” Types of sensors that used to have limited economic potential are now being mass-produced and integrated into mass-market electronic devices, with smart phones being the most notable. The economies of production for these devices mean that there is a burgeoning new range of low-cost sensors that are making it possible to do new science, as well as doing traditional science in a different way. Especially relevant to the IRIS and UNAVCO communities is the recent availability of low-cost, low-power, high-resolution accelerometers with integrated digitizers, and dual-frequency GNSS chips and wireless communications. These sensors are available for only a few dollars and are integrated into some of the latest Smartphone ranges.

We had two initial presentations to highlight current work and capabilities

1. Dr. Ben Brooks, USGS, presented “Smart-Phone Based Earthquake Early Warning”; work leading the application of smartphones for Earthquake Early Warning. He demonstrated that the on-board accelerometers on smartphones are sufficiently accurate for these phones to participate as sensors in early warning networks. In addition, low-cost GNSS boards can be attached that are able to characterize the static motions from large earthquakes, potentially improving rapid magnitude estimation for earthquake and tsunami warning efforts.

2. Dr. Brendan Crowell presented Dr. Jianghui Geng, Wuhan University, work on “Six-degree-of-freedom Seismogeodesy using Android GNSS, accelerometer and gyroscope data for Rapid Earthquake Response”. This work performed investigations and calibrations of smartphone data streams to form seismogeodetic timeseries. It was demonstrated that, with some care, these data are sufficiently accurate and reliable to support event and hazard response applications.

Community members provided information about two specific sensors: an inexpensive MEMS accelerometer developed at SIO, and a low-cost GNSS hardware solution tinyPC/3-LC developed by GFZ, Germany.

A large and engaged turnout for this session confirmed that our communities are interested in the potential of these new developments, but it was clear that the limiting factor for adoption was lack of information about the capabilities, accuracies and reliabilities of these sensors. Our discussion period was therefore organized around responding to four key questions:

Q1.Identify the science & applications that could be enabled/augmented by low-cost sensors
   a. These sensors are particularly suited to short baseline in high strain environments so environmental noise is mitigated as a common mode influence.
   b. Rapid response campaigns e.g. capture dense spatial imaging of post-seismic transients
   c. Volcano response in hazardous zones; for both ground motion, seismicity, and atmospheric refractivity.
   d. Structural health monitoring for buildings, bridges, dams etc.
Q2. What barriers exist to adopting/implementing low-cost sensor solutions?
a. Unknown biases and/or lack of calibration of sensors: systems may not be reliably deployable off the shelf.
b. Some data streams are/may be the result of unknown internal “black-box filtering/processing”
c. Capabilities not clear for many traditional science targets and a change of mindset may be required to approach data collection from a new, high spatial density, but high-noise, perspective.

Q3. What technological (hardware/software/infrastructure?) developments would further enhance capabilities for science?
   a. Temperature tolerance (Dr Brooks noted that smartphones are limited in the field due to thermal issues)

Q4. What support and/or facilities could ease adoption of low-cost solutions in the community?
   a. Clearly documenting sensor capabilities
   b. Github repository for relevant software
   c. Documentation of data/work flow & components.
   d. Forum/workshops for training and distributing information & capabilities

4.16 Don’t Let Sediments Cover All the Good Geophysics Below
Organizers: Wang-Ping Chen (China University of Geosciences, Wuhan and formerly of University of Illinois, Urbana-Champaign), Yong Zheng (China University of Geosciences, Wuhan) and Dun Wang (China University of Geosciences, Wuhan)

Sedimentary cover is ubiquitous near the Earth’s surface. While it contains invaluable resources to our society, it often obscures key features that are essential for understanding the Earth’s inaccessible interior. In addition, because of amplification of ground motions, properties of the sedimentary cover are also important for the mitigation of seismic hazard. For example, effects of this layer can simply manifest themselves as static corrections for travel-time tomography. However, in many cases, reverberations in this layer of low seismic speed overwhelm subtle signals upon which very popular techniques such as crustal receiver functions (RF) and other variants of receiver-side scattering rely.

1. Dr. Vera Schulte-Pelkum (University of Colorado) focused on the RF using both synthetic and observed seismograms. There are also several recent publications on this subject, devising filters to minimize the effects caused by the sedimentary cover. The fundamental difficulty lies in that the signal of receiver functions is typically smaller than the noise caused by near-surface reverberations.

2. Dr. Weisen Shen (Stony Brook University) presented perspectives from surface wave studies. The best resolution comes from combining dispersion curves, the ratio of horizontal and vertical components of particle motion, and RF. The spatial resolution of surface waves can become too large, if data are from a closely spaced array.

3. Dr. Wang-Ping Chen (on behalf of Dr. Chunquan Yu, who joined via a voice-link from Southern University of Science and Technology, China) advocated the alternative approach
of using reflections under the free surface generated by large earthquakes as a virtual source. These sources produce very strong reflections whose large amplitude is much less susceptible to all noise. There are examples using post-critical, pre-critical and critical reflections to study the basement under the sedimentary cover, the Moho, and intra-crustal interfaces. For critical reflections, the sedimentary cover even enhances multiples of the $Pn$ phase, which, in turn, offers constraints on bulk crustal properties and the sedimentary cover itself.

Because other information, such as well-logs or even drill cores, may be available for the sedimentary cover, there is a need to understand what seismology is detecting in geological terms. Given the fact that the IRIS PASSCAL Instrument Center is acquiring equipment for magnetotellurics (MT), it behooves our community to consider the role MT plays in the topic of this SIG. Since the MT community is very small in the U.S., the opinion of the international community could be valuable. For instance, if enough contrast in electrical resistance exists at the base of a clay-rich sedimentary layer, audio-frequency MT may offer enough information, in a couple of hours, about basic properties of this layer.

4.17 Synthesis of Syntheses: A Retrospective and Results of EarthScope Workshops
Organizer: Kasey Aderhold (IRIS)

- Evolution of North America – Heather Ford (University of California Riverside)
  - Challenges in connecting surface geological expressions to seismological observations of EarthScope – scale and resolution, time aspect, current observations vs. tectonic processes over the geophysical record
  - Resulted in discussions of what EarthScope 2 would look like and a publication
- Wyoming Craton – Heather Ford (University of California Riverside)
  - Many more geologists/geochemists, eye-opening for both sides - developed knowledge/respect for what each are capable of observing and background
  - Discussions on what seismologists/geophysicists can contribute to understanding these long time scale events, how is de克拉tonization handled
- SAFOD – Cliff Thurber (University of Wisconsin – Madison)
  - Brought PIs of SAFOD together, renewed connections to community
  - Relating earthquake studies observations at depth, results from cores, how SAFOD related to other “current” science topics, key science outcomes
  - Discussion of SAFOD Phase IV - follow on to fill in missing piece
- Cascadia – Kathy Davenport (Oregon State University)
  - Brought early career scientists together with participants with long histories with Cascadia
  - Discussion of how to bring together familiar results/observations with things we do not know as well, used by researchers not contributing models
  - Focused on strategizing how to evaluate differences between models, where are there still gaps in the knowledge and what observations would be needed
  - Did not do breakout groups, the discussions in the full group were productive
Continuing to build the model with workshop participants, USGS - maintenance is another consideration of future work, incorporating old and new data, logistics for making a single community model happen - dedicated person or team?

- Synthesis Workshops, in general – Jeff Freymuller (Michigan State University)
  - Many workshops were regionally focused - not intended but good for organizing
  - Outcomes were diverse and included things like publications in science or news, special issues, meeting sessions, collaborations between participants
  - All workshops had materials submitted in advance and made available, also have workshop reports available on the EarthScope website
  - Final synthesis workshop on Alaska, broadening to disciplines like space weather, atmospheric; in tandem with another workshop in Canada

- “Lessons Learned”
  - Should prioritize small workshops for engaging other communities early on in a program (i.e. geologists, geochemists) - head off skepticism and dismissal
  - Community regional models are an ideal place for synthesis
  - Difficulty conveying uncertainties of models/observations across fields
  - Small meetings that still included a lot of diversity in background/fields
  - Funding is still available for workshops, submit to the main programs
  - The synthesis is not over for EarthScope!

4.18 Communication, Education, and Outreach with the ShakeAlert Earthquake Early Warning System
Organizers: Danielle Sumy (IRIS) and Robert-Michael de Groot (USGS-Pasadena)

The U.S. Geological Survey (USGS), in partnership with the emergency management agencies, state geological surveys, and academic partners in Washington, Oregon, and California, are in the first phase of operations of the ShakeAlert Earthquake Early Warning System for the West Coast of the United States. ShakeAlert requires the necessary technical expertise, but also needs well-informed feedback into the System’s human interface and how ShakeAlert will be an effective tool in reducing earthquake risk for its end users including people receiving individual alerts and systems performing automated actions.

The SIG began with an information session where both conveners gave a brief overview of the ShakeAlert project and its current status when it comes to educational development with the IRIS Consortium. A question and answer session then allowed us to gauge the general response to the educational materials in development, and allowed ample time for feedback. We discussed common public misconceptions related to earthquake science, especially in light of the 4 July 2019 M6.4 and 5 July 2019 M7.1 Ridgecrest, CA earthquakes. During the Ridgecrest, CA earthquake sequence, the ShakeAlertLA app did not provide warning because while the magnitude threshold was set at an M5, the intensity threshold was set to an MMI IV, which was not reached within Los Angeles County. This example sheds light on the fact that the public does not understand the difference between earthquake magnitude and intensity, and led Los Angeles County to lower the thresholds. The public perception of
earthquakes to include their education and knowledge of earthquake mechanics and behavior intertwined with the social science implications of not providing warning is a subject of current research.

A lengthy discussion occurred about how to properly disseminate results to the public and how to do so in a manner that was fitting to a variety of diverse audiences. One of the major topics was the diversity of voices heard narrating IRIS animations and how to get a better breadth of narrators to appeal to different audiences. We also discussed other common misconceptions in earthquake science, like how intensity of shaking is related to distance away from the source rupture and not just the epicenter itself.

5. Acknowledgements

The success of the workshop depended on contributions from IRIS staff, UNAVCO representatives, and consortium members alike. Krystin Poitra and Danielle Sumy from IRIS handled the behind-the-scenes logistics and planning for the SAGE/GAGE Workshop, with support from Jaime Magliocca and Donna Charlevoix from UNAVCO. Krystin Poitra, Candy Shin, Marlo Swanson, Taunia Medina, and Melissa Weber handled many of the onsite tasks and registration. The workshop science committee, Bill Barnhart, Colleen Dalton, Donna Shillington, Cliff Thurber, Laura Wallace, and Terry Wilson, worked diligently to develop the workshop program and plenary session topics. They coordinated with a plethora of plenary session conveners who organized speakers and helped bring the plenary session topics to life.

The workshop is based upon work supported by the National Science Foundation (NSF) under Cooperative Agreements 1724794 for the GAGE Facility and 1724509 for the SAGE Facility.
# Appendix A: Workshop Program

## Day 0: Tuesday, October 8th

*Tuesday, October 8th, 2019, 8am–5pm*

<table>
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<tr>
<th>Time</th>
<th>Event</th>
<th>Room</th>
<th>Description</th>
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| 8:00 am  | **InSAR Data Interpretation and Analysis for Nonspecialists**       | Broadway I (Plaza Level)    | **Description:** The expansion of cloud-based routine processing efforts accompanying the Sentinel-1 mission, and in anticipation of the forthcoming NISAR mission, have dramatically expanded the volume of processed InSAR data in the public domain, providing access to InSAR data products without the need to learn InSAR processing. This workshop is targeted at researchers who would like to use these processed products effectively. In this full-day short course, we will focus on the interpretation of processed InSAR data and how these data can be analyzed and modeled. Topics to be covered include: background theory and processing methodology, data errors and common issues, satellite missions and processed data repositories, time series analysis, data interpretation and ingesting data into modeling efforts.  

To register or ask questions, please contact Kristy Tiampo at kristy.tiampo@colorado.edu |

| 1:00 pm  | **Rapid Response to Geohazards Mini-Workshop**                      | Broadway III & IV (Plaza Level) | For more information or to register, please visit this [link](#). Please contact Justin Sweet (justin.sweet@iris.edu) with questions. |

| 2:00 pm  | **New Tools and More Data from the IRIS DMC and Beyond**            | Broadway II (Plaza Level)      | **Description:** IRIS Data Services will conduct a short course in conjunction with the Workshop. The discussion will be informal, but we will demonstrate and discuss a variety of topics including the latest developments and tools that DMC’s users should know about.  

Please register at [here](#). Questions? Please contact Chad Trabant at chad@iris.washington.edu |

| 3:00 pm  | **Early Registration and Poster Set-Up**                           |                             |                                                                                                                                         |

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Day 0: Tuesday, October 8th

*Tuesday, October 8th, 2019, 8am–5pm*

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<tr>
<th>Time</th>
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| 6:00 pm - 7:00 pm | Early Career Networking Event  
**Room:** Atrium Ballroom  
Please contact Wendy Bohon (bohon@iris.edu) and/or Beth Bartel (bartel@unavco.org) for more information and to register. |

Day 1: Wednesday, October 9th

*Wednesday, October 9th, 2019, 7:30am–9:00pm*

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<th>Time</th>
<th>Event</th>
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| 7:00 am | Early Career Networking Breakfast  
**Room:** Atrium Ballroom  
Space is limited! Please register with Danielle Sumy (danielle.sumy@iris.edu). |
| 7:30 am | **Beverage Service** - Coffee & Tea |
| 8:00 am | **WELCOME**  
- Cliff Thurber and Laura Wallace, Workshop Program Committee  
- Bob Detrick, IRIS President, and Chuck Meertens, UNAVCO Acting President  
- Maggie Benoit and Mike Jackson, National Science Foundation |
| 8:30 am | **PLENARY SESSION:** Bridging the Observational Gap in Time: Processes Today and their Relationship to the Past  
**Plenary Session Organizers:** Roland Bürgmann (UC-Berkeley) and Danny Brothers (USGS - Santa Cruz)  
**Plenary Session Speakers:**  
- 8:30-8:55 AM: Nathan Miller, USGS - Woods Hole Coastal and Marine Science Center  
  - A characteristic scale of plate-boundary strike-slip fault obliquity and earthquake rupture ([abstract](#)) |
Day 1: Wednesday, October 9th

Wednesday, October 9th, 2019, 7:30am–9:00pm

- 8:55-9:20 AM: Kimberly Blisniuk, San Jose State University
  - Evidence for an alternative position for the primary active strand of the San Andreas Fault along its restraining bend in southern California (abstract)
- 9:20-9:45 AM: Zachary Ross, California Institute of Technology
  - The structural architecture of fault zones at depth (abstract)
- 9:45-10:10 AM: Chelsea Scott, Arizona State University
  - The M7 2016 Kumamoto, Japan, Earthquake: Surface Strain in the Damage Zone And Fault Slip Revealed By Differencing Near-Field Geodetic Imagery (abstract)
- 10:10-10:30 AM: Panel Discussion

10:30 am | COFFEE BREAK

11:00 am | Technical Topic Sessions/Special Interest Groups

- GAGE GNSS Data Products: Past, Present and Future
- What to expect from the PASSCAL Magnetotelluric facility
- Seafloor Geodesy as a Community Resource
- Broadband Sensor Direct Burial, Appropriate Uses, Results from Recent Experiments and Best Practices in Terrestrial and Polar Environments
- Network of the Americas: The Current and Future State of the Network
- Social Media for Hazard Scientists

12:00 pm | GROUP PHOTO & LUNCH

2:00 pm | PLENARY SESSION: Advances in Geophysics in Extreme Environments

Plenary Session Organizers: Andrew Newman (Georgia Tech) and Nicholas Schmerr (Univ. of Maryland)

Confirmed Plenary Session Speakers:

- 2:00-2:20 PM: Erik Frederickson, University of Washington
  - Optimizing seafloor pressure sensor networks for the detection of slow slip earthquakes in Cascadia and beyond (abstract)
Day 1: Wednesday, October 9th

**Wednesday, October 9th, 2019, 7:30am–9:00pm**

- 2:20-2:40 PM: Philip Wannamaker, University of Utah  
  o [Sub-Ice Thermal Regime, Volcanogenic Processes and Terrane Assembly in Antarctica Using Magnetotellurics](abstract)
- 2:40-3:00 PM: Emily Wolin, USGS Albuquerque Seismological Laboratory  
  o [Seismology from the Roof of the World to the Irrawaddy Delta](abstract)
- 3:00-3:20 PM: Mark Panning, JPL  
  o [Extraterrestrial Seismology: The Perspective After Nearly 1 Year of InSight on Mars](abstract)
- 3:20-4:00 PM: Panel Discussion - "New directions for community science, engineering, and education in extreme environments"

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>4:00 pm</td>
<td><strong>BREAK</strong></td>
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<tr>
<td>4:30 pm</td>
<td><strong>POSTER SESSION</strong></td>
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<td>Poster size is 4' high x 8' wide</td>
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<tr>
<td>6:30 pm</td>
<td>Celebration of Tim Ahern's (IRIS) and Meghan Miller's (UNAVCO) Achievements and Retirements</td>
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<td>9:00 pm</td>
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Day 2: Thursday, October 10th

**Thursday, October 10th, 2019, 7:30am–8:30pm**

- 7:30 am | **Beverage Service** - Coffee & Tea
- 8:00 am | **Daily Announcements**
- 8:05 am | **PLENARY SESSION**: Subduction Zones through the Lens of Seismology, Geodesy, and other Geophysical Methods
Day 2: Thursday, October 10th

Thursday, October 10th, 2019, 7:30am–8:30pm

Plenary Session Organizers: Geoffrey Abers (Cornell Univ.) and Noel Bartlow (UC-Berkeley)

Plenary Session Speakers:

- 8:05-8:30 AM: Samer Naif, Lamont-Doherty Earth Observatory - Columbia Univ.
  - Electromagnetic imaging of subduction zone fluids (& more) (abstract)
- 8:30-8:55 AM: William Frank, University of Southern California
  - The transient and intermittent nature of slow slip (abstract)
- 8:55-9:20 AM: Julie Elliott, Purdue University
  - Geodetic Insights into Subduction Processes: The Example of Alaska (abstract)
- 9:20-9:45 AM: Helen Janiszewski, Carnegie Institution of Science DTM
  - Imaging Trans-Crustal Magmatic Systems with Receiver Functions – A Path Towards Linking Tectonic and Eruptive Processes (abstract)
- 9:45-10:05 AM: Panel Discussion

10:05 am | COFFEE BREAK

10:30 am | Technical Topic Session/Special Interest Groups

- Geodetic data and products sharing: enable the future with web services?
- Preparing for future controlled-source seismic experiments that will use thousands of nodal seismometers
- Designing a Subduction Zone Observatory Initiative: Community Input to the SZ4D Research Coordination Networks
- Updating Design Goals for the Global Seismographic Network (GSN) to Enable New Discoveries
- Emerging applications for UAS (uncrewed aerial systems)
- Integrating geophysics methods into undergraduate courses

12:00 pm | LUNCH
Day 2: Thursday, October 10th

Thursday, October 10th, 2019, 7:30am–8:30pm

1:30 pm  PLENARY SESSION: Earth Rheology and Structure: New Approaches, Applications, and Implications for Dynamics

Plenary Session Organizers: Karen Fischer (Brown Univ.) and Erik Ivins (Jet Propulsion Laboratory)

Plenary Session Speakers:

- 1:30-1:55 PM: Jessica Irving, Princeton University
  - Behavior at the boundaries of our world: What can we learn about core and mantle dynamics from long and short period seismology? (abstract)

- 1:55-2:20 PM: Harriet Lau, University of California Berkeley
  - Investigating Earth’s deep mantle buoyancy and frequency dependent behavior using Earth tides (abstract)

- 2:20-2:45 PM: Kristel Chanard, Institut de Physique du Globe de Paris
  - Rheological constraints on time scales of a few decades or less derived from the Earth’s response to surface mass redistribution (abstract)

- 2:45-3:10 PM: Weisen Shen, Stony Brook University
  - Strength and rheology of continental lithosphere: A perspective from some recent seismic investigations (to large arrays in North America, Asia and Antarctica) (abstract)

- 3:10-3:30 PM: Panel Discussion

3:30 pm  POSTER SESSION

- Poster size is 4' high x 8' wide
- NOTE: We will discard any poster not removed by 6 PM

5:30 pm  Technical Topic Session/Special Interest Groups

- SAGE/GAGE Common Data Access Point (CDAP)
- The Big Data Exchange: How?
- Low-Cost Sensors
- Don’t Let Sediments Cover All the Good Geophysics Below
- Synthesis of Syntheses: A Retrospective and Results of EarthScope Workshops
Day 2: Thursday, October 10th

Thursday, October 10th, 2019, 7:30am–8:30pm

- Communication, Education, and Outreach with the ShakeAlert Earthquake Early Warning System

6:30 pm  BREAK

7:00 pm  DINNER with Guest Speaker, Dr. Michael Poland, Scientist-in-Charge, Yellowstone Volcano Observatory, introduced by Dr. Wes Thelen, Research Seismologist, Cascades Volcano Observatory

Science F(r)iction: Challenges and opportunities for science communication in a world that’s gone bonkers

Over the past decade, the landscape of science communication has evolved in dramatic ways. Traditional media interviews have been supplemented, and in some ways supplanted, by social media, and it has become harder to convey clear messages about Earth processes. The lust for attention and profit can result in the intentional misuse of scientific information, which creates headaches for researchers regardless of their institutional origin. How can geoscientists, who are often reluctant participants in this communication game, hope to ensure clarity of message and develop trust with the public? Experience gained from social and traditional media interactions related to volcanism in Hawaiʻi and Yellowstone provides some insights—foremost among them that awareness and engagement are key components to successful messaging. Knowing that scientific information is being misrepresented is a key call to action in which the entire scientific community can play a role. Even if the science that is being misrepresented is not “your” work, mutual support among scientists is key for building public consensus. The path is not without its bumps, and social media can be an especially fickle companion, dispensing all manner of judgement in response to apparently inconsequential stimuli. Persistence is critical, however, as scientific truth will outlast false claims, and expert assessments will ultimately win the day.

Day 3: Friday, October 11th

Friday, October 11th, 2019, 7:30am–12:10pm

7:30 am  Beverage Service - Coffee & Tea

8:00 am  Daily Announcements
### Day 3: Friday, October 11th

*Friday, October 11th, 2019, 7:30am–12:10pm*

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<th>Session</th>
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<tr>
<td>8:05 am</td>
<td><strong>Technical Topic Session/Special Interest Group SUMMARIES</strong></td>
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<tr>
<td>9:20 am</td>
<td><strong>Discussion of Future Management Models for Geodetic and Seismic Facilities</strong></td>
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<td>- Maggie Benoit, NSF</td>
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<td>- Bob Detrick, IRIS President</td>
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<td>- Chuck Meertens, UNAVCO Acting President</td>
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<tr>
<td>10:00 am</td>
<td><strong>BREAK</strong></td>
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<tr>
<td>10:30 am</td>
<td><strong>PLENARY SESSION:</strong> New and Exotic Approaches for Acquiring, Analyzing and Modeling in Geophysics</td>
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<td><strong>Plenary Session Organizers:</strong> Rowena Lohman (Cornell University) and Jonathan Ajo-Franklin (Rice University)</td>
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<td><strong>Plenary Session Speakers:</strong></td>
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<td></td>
<td>- 10:30-10:55 AM: <strong>Ekaterina Tymofyeyeva</strong>, JPL</td>
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<tr>
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<td>- <a href="abstract">High resolution InSAR time series of transient creep on the Concord Fault, Eastern Bay Area</a></td>
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<td>- 10:55-11:20 AM: <strong>Nate Lindsey</strong>, UC-Berkeley</td>
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<td></td>
<td>- <a href="abstract">Crossing the shoreline with fiber-optic Distributed Acoustic Sensing (DAS) in Monterey Bay</a></td>
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<td>- 11:20-11:45 AM: <strong>Ronni Grapenthin</strong>, University of Alaska Fairbanks</td>
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<td>- <a href="abstract">Yet More GNSS Applications: Volcanic Hail Detection and Instantaneous Velocities for Rapid Earthquake Characterization</a></td>
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<td>- 11:45-12:10 PM: <strong>Tim Clements</strong>, Harvard University</td>
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<td>- <a href="abstract">Ambient Noise Monitoring of the Near-Surface at Scales</a></td>
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<tr>
<td>12:10 pm</td>
<td><strong>Formal Conclusion of Workshop</strong></td>
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</tbody>
</table>
Appendix B: Poster Presentations

Bridging the Observational Gap in Time: Processes Today and their Relationship to the Past

1. **Modeling of co- and early postseismic deformation due to the 2019 Ridgecrest earthquake sequence**
   Kang Wang, Berkeley Seismological Laboratory, University of California Berkeley; Roland Bürgmann, Berkeley Seismological Laboratory, University of California Berkeley

2. **Earthquake Magnitudes from Dynamic Strain: the 2019 Ridgecrest Sequence**
   Andrew Barbour, United States Geological Survey, Menlo Park, CA

3. **Postseismic deformation as recorded by PBO borehole strainmeters following principal events of the 2019 Ridgecrest, California earthquake sequence**
   Evelyn Roeloffs, United States Geological Survey

4. **Meers Fault; Inactive, Creeping, or Sleeping Monster Fault**
   Mortaza Pirouz, University of Texas at Dallas; Robert J. Stern, University of Texas at Dallas

5. **GPS Imaging of Crustal Uplift in the High Plains Aquifer, Central United States**
   Justine Overacker, University of Nevada, Reno; William C. Hammond, University of Nevada, Reno; Geoffrey Blewitt, University of Nevada, Reno; Corné Kreemer, University of Nevada, Reno

6. **Drought Induced Groundwater Loss in and Around Great Salt Lake, Utah, Inferred from 3D GPS Displacements**
   Zachary Young, University of Nevada, Reno; Corné Kreemer, University of Nevada, Reno; Geoffrey Blewitt, University of Nevada, Reno

7. **Unravelling the strain rate field of Arizona using a regional densification of the Plate Boundary Observatory**
   Rick Bennett, University of Arizona; James Broermann, University of Arizona; Corné Kreemer, University of Nevada, Reno; Geoffrey Blewitt, University of Nevada, Reno; Phil Pearthree, Arizona Geological Survey

8. **Large and fragmented lithospheric velocity variations in the Northern Canadian Cordillera imaged by ambient noise tomography**
   Derek Schutt, Colorado State University; Robert W., Porritt, University of Texas Institute for Geophysics; Richard C., Aster, Colorado State University; Jeffrey T., Freymuller, Michigan State University; Joel F., Cubley, Yukon College

9. **GPS Imaging of Mantle Flow and Flexural Uplift of the Apennines, Italy**
   William Hammond, University of Nevada, Reno; Nicola D'Agostino, Instituto Nazionale di Geofisica e Vulcanologia

10. **Raton Basin induced seismicity from 2016-2019 reveals short length-scale faults**
    Margaret Glasgow, University of New Mexico; Brandon Schmandt, University of New Mexico; Ruijia Wang, University of New Mexico; Sarah Rysanek, University of New Mexico; Ryan Stairs, University of New Mexico

**Advances in Geophysics in Extreme Environments**

11. **Shallow 2-D Active-Source Seismic Imaging of Old Faithful Geyser in the Upper Geyser Basin of Yellowstone National Park**
    Jordan Caylor, University of Texas at El Paso; Marianne Karplus, University of Texas at El Paso; Juan Pablo Exparza, Tarrant County College; Jamie Farrell, University of Utah; Julien Chaput, University of Texas at El Paso; Stephen Veitch, University of Texas at El Paso; Galen Kaip,
12. **Tidally induced icequake swarms at the grounded margins of the Ross Ice Shelf, Antarctica**
   Hank Cole, Colorado State University; Richard C. Aster, Colorado State University; Michael Baker, Colorado State University; Julien Chaput, University of Texas El Paso; Peter D. Bromirski, Scripps Institution of Oceanography; Peter Gerstoft, Scripps Institution of Oceanography; Ralph A. Stephen, Woods Hole Oceanographic Institution; Andrew Nyblade, Pennsylvania State University; Douglas A. Wiens, Washington University in St. Louis

13. **Constraining the thickness of Europa’s ice shell with observations of Rayleigh and flexural wave dispersion: Insights from synthetic waveform modeling**
   Ross Maguire, University of New Mexico and University of Maryland; Nicholas Schmerr, University of Maryland; Vedran Lekic, University of Maryland; Terry Hurford, NASA Goddard Space Flight Center

**Subduction Zones through the Lens of Seismology, Geodesy, and other Geophysical Methods**

14. **Multi-parameter Volcano Monitoring from Space: Recommendations from the USGS Powell Center Volcano Remote Sensing Working Group and Beyond**
   Michael Poland, United States Geological Survey; Matt Pritchard, Cornell University; Kevin Reath, Cornell University; Ben Andrews, Smithsonian Institution; Marco Bagnardi, NASA; Juliet Biggs, University of Bristol; Simon Cam, Michigan Tech; Diego Coppola, University of Turin; Susana Ebmeier, University of Leeds; Maria Furtney, Washington Geologic Survey; Tarsilo Girona, JPL; Julie Griswold, USGS; Taryn Lopez, University of Alaska Fairbanks; Paul Lundgren, JPL; Sarah Ogburn, USGS; Michael Pavoloni, NOAA; Elise Rumpf, USGS; Greg Vaughan, USGS; Christelle Wauthier, Penn State; Rick Wessels, USGS; Rob Wright, University of Hawaii; Kyle Anderson, USGS; Grace Bato, JPL; Alberto Roman, JPL

15. **Path-averaged seismic attenuation in southeast Alaska from USArray Transportable Array**
   Jenny Nakai, University of New Mexico; Lindsay Lowe-Worthington, University of New Mexico

16. **Joint Inversion of Body-wave Arrival Times and Surface-wave Dispersion in Alaska**
   Avinash Nayak, University of Wisconsin Madison; Clifford Thurber, University of Wisconsin Madison

17. **The 30 November 2018 Mw7.1 Anchorage Earthquake**
   Michael West, University of Alaska Fairbanks; Adrian Bender, U.S. Geological Survey; Matthew Gardne, University of Alaska Fairbanks; Lea Gardne, University of Alaska Fairbanks; Kara Gately, NOAA; Peter Haeussler, U.S. Geological Survey; Wael Hassan, University of Alaska Anchorage; Franz Meyer, University of Alaska Fairbanks; Cole Richards, University of Alaska Fairbanks; Natalia Ruppert, University of Alaska Fairbanks; Carl Tape, University of Alaska Fairbanks; John Thornley, Golder Associates Inc.; Rob Witte, U.S. Geological Survey

18. **Along-strike segmentation of intermediate-depth seismicity along the Alaska Peninsula**
   S. Shawn Wei, Michigan State University; Sydney Gable, Michigan State University; Natalia Ruppert, University of Alaska Fairbanks; Haijiang Zhang, University of Science and Technology of China

19. **Slow slip and tectonic tremor episodes on south-central Alaska megathrust**
   Baptiste Rousset, University of California Berkeley; Yuning Fu, Bowling Green State University; Noel Bartlow, University of California Berkeley; Roland Bürgmann, University of California Berkeley

20. **Completion of AACSE: The Alaska Amphibious Community Seismic Experiment**
   Geoffrey Abers, Cornell University; Aubreya Adams, Colgate College; Anne Bécel, Lamont-
21. **Seismic evidence for geologic influence on seismicity during the April 1, 2014 Pisagua, Chile Earthquake**
   Kathy Davenport, Oregon State University; Anne Tréhu, Oregon State University

22. **Local Earthquake Tomography of the Central Oregon Forearc using a large-N, short duration, nodal seismic dataset**
   Audrey Dunham, University of Arizona; Eric Kiser, University of Arizona

23. **Does Subslab Buoyancy Govern Segmentation of Cascadia's Forearc Topography?**
   Miles Bodmer, University of Oregon; Douglas Toomey, University of Oregon; Josh Roering, University of Oregon; Leif Karlstrom, University of Oregon

24. **Characterize the Propagation of Seismic Waves along the Cascadia Subduction Zone through Seismic Interferometry**
   Xiaotao Yang, Harvard University; Zhitu Ma, Tongji University - China; Marine Denolle, Harvard University

25. **A long-term view of Episodic Tremor and Slip in Cascadia**
   Noel Bartlow, University of California Berkeley

26. **Structural constraints on non-volcanic tremor along the Cascadia margin**
   Jonathan Delph, University of Oregon; Amanda Thomas, University of Oregon; Alan Levander, Rice University

27. **10-minute slow slip subevents and atmospheric modulation: Assessing fault zone processes**
   Jessica Hawthorne, University of Oxford; Baptiste Gombert, University of Oxford

28. **Crustal deformation on quaternary fault zones near the Mendocino Triple Junction inferred from GPS-derived strain rate maps**
   Carolyn Nuyen, University of Washington; David Schmidt, University of Washington

29. **Three-Dimensional Magnetotelluric Imaging of the Cascadia Subduction Zone with an Amphibious Array**
   Gary Egbert, Oregon State University; Bo Yang, Zhejiang University; Dean Livelybrooks, University of Oregon; Paul Bedrosian, USGS, Denver; Kerry Key, Columbia University; Adam Schultz, Oregon State University; Blake Parris, University of Oregon; Anna Kelbert, USGS, Golden

30. **Seismic evidence for subduction-induced mantle flows underneath Middle America**
   Hejun Zhu, University of Texas at Dallas; Robert Stern, University of Texas at Dallas; Jidong Yang, University of Texas at Dallas

31. **Ground Motion Prediction Derived from Interseismic Locking Models for the Subduction Zone in Nicoya, Costa Rica**
   Suli Yao, The Chinese University of Hong Kong; Hongfeng Yang, The Chinese University of Hong Kong

32. **Transitions in the Banda Arc-Australian Continental Collision Revealed by Surface Wave Tomography**
   Ping Zhang, Australian National University; Meghan S. Miller, Australian National University

33. **Slip transient pattern changes: external perturbation or intrinsic interaction with earthquakes**
   Yingdi Luo, California Institute of Technology; Zhen Liu, JPL, Caltech
34. **Seismic signatures of trench rupturing megathrust earthquakes: effects of accretionary-wedge structures**
   Jiuxun Yin, Harvard University; Marine Denolle, Harvard University

35. **A New Map of Crustal Velocities in Myanmar from GPS: Understanding Strain Partitioning**
   Eric Lindsey, Earth Observatory of Singapore; Rishav Mallick, Earth Observatory of Singapore; Lujia Feng, Earth Observatory of Singapore; Wang Yu, National Taiwan University; Lin Thu Aung, Earth Observatory of Singapore; Saw Myat Min, Yangon University; Win Pyae Htet, Myanmar Earthquake Committee; Aung Moe, Myanmar Survey Department; Than Khaing, Myanmar Survey Department; Oo Than, Myanmar Department of Meteorology and Hydrology; Myo Thant, Yangon University; Kyle Bradley, Earth Observatory of Singapore; Roland Burgmann, University of California Berkeley; Emma Hill, Earth Observatory of Singapore

36. **Detect slow slip events in ocean bottom pressure data using machine learning**
   Bing He, University of Rhode Island; Meng Wei, University of Rhode Island; D. Randolph Watts, University of Rhode Island; Kathleen A. Donohue, University of Rhode Island; Karen L. Tracey, University of Rhode Island; Yang Shen, University of Rhode Island

37. **Seismic velocity model of the northern Hikurangi margin, New Zealand from combined active and passive sources: Initial results from the Seismogenesis at Hikurangi Integrated Research Experiment (SHIRE)**
   Thomas Luckie, University of Southern California; Andrew Gase, The University of Texas at Austin Institute for Geophysics; Malcolm White, University of Southern California; Katrina Jacobs, GNS Science; Stuart Henrys, GNS Science; David Okaya, University of Southern California; Harm Van Avendonk, The University of Texas at Austin Institute for Geophysics; Nathan Bangs, The University of Texas at Austin Institute for Geophysics; Daniel Barker, GNS Science; Daniel Bassett, GNS Science; Shuichi Kodaira, JAMSTEC; Ryuta Arai, JAMSTEC; Gou Fujie, JAMSTEC; Yojiro Yamamoto, JAMSTEC

38. **A time dependent inversion of onshore geodetic data for the 2019 Hikurangi subduction zone slow slip event**
   Katherine Woods, Victoria University of Wellington; Laura Wallace, GNS Science, New Zealand and Institute for Geophysics, University of Texas at Austin; Martha Savage, Victoria University of Wellington; Spahr Webb, Lamont-Doherty Earth Observatory, Columbia University; David Chadwell, Scripps Institution of Oceanography, University of California San Diego; Yoshihiro Ito, Kyoto University; Kimihiro Mochizuki, University of Tokyo; Charles Williams, GNS Science; Ian Hamling, GNS Science

**Earth Rheology and Structure: New Approaches, Applications, and Implications for Dynamics**

39. **Trans-dimensional Bayesian inversion of subsurface density structure and its geometry using gravity data**
   Surya Pachhai, University of Utah; Michael Thorne, University of Utah; Christian Hardwick, Utah Geological Survey

40. **Mineral Exploration Applications for EON-ROSE and other large geophysical programs**
   Katherine Boggs, Mount Royal University; Martyn Unsworth, University of Alberta; David Eaton, University of Calgary; Fiona Darbyshire, Université du Québec à Montréal; Keith Benn, Terracognita Geological Consulting Inc.

41. **Hydration State of the Upper Mantle in Subduction Arc-Backarc Regions from Magnetotellurics Using the Western U.S. as an Example**
   Philip Wannamaker, University of Utah; Virginie Maris, University of Utah; Kevin Mendoza, University of Utah; John Booker, University of Washington
42. A mid-crustal channel of radial anisotropy beneath the northeastern Basin and Range and its metamorphic core complexes
Justin Wilgus, University of New Mexico; Chengxin Jiang, Harvard University; Brandon Schmandt, University of New Mexico

43. Surface-wave Radial Anisotropy Illuminates Magma Storage and Migration at Okmok caldera, Alaska
Ninfa Bennington, University of Wisconsin-Madison; David Miller, University of Wisconsin-Madison; Matthew Haney, USGS Alaska Volcano Observatory; Paul Bedrosian, USGS; Kerry Key, Lamont-Doherty Earth Observatory; Clifford Thurber, University of Wisconsin-Madison; Laney Hart, University of Wisconsin-Madison; Summer Ohlendorf, National Tsunami Warning Center

44. Shear Wave Splitting across the Mackenzie Mountains
Andrew Bolton, Colorado State University; Derek Witt, SWIIM System Ltd., Derek Schutt, Colorado State University; Rick Aster, Colorado State University; Jeffrey Freymueller, Michigan State University; Joel Cubley, Yukon College

45. Tectonic inheritance via the influence of crustal composition and deformation fabric on deformation response and the geometry of faults and anisotropic shear zones in California
Vera Schulte-Pelkum, University of Colorado Boulder; Sarah Brownlee, Wayne State University; Kai Wang, University of Toronto; Chengxin Jiang, Harvard University; Zachary Ross, California Institute of Technology; Yehuda Ben-Zion, University of Southern California

46. Crustal deformation in southern California constrained by radial anisotropy from ambient noise adjoint tomography
Chengxin Jiang, Harvard University; Kai Wang, University of Toronto; Yingjie Yang, Macquarie University; Vera Schulte-Pelkum, University of Colorado Boulder; Qinya Liu, University of Toronto

47. Characterizing lithospheric structure beneath Connecticut using Sp receiver functions
Gillian Goldhagen, University of California, Riverside; Heather A. Ford, University of California, Riverside; Maureen D. Long, Yale University

48. Complex shear-wave splitting implies simple anisotropy in the lithosphere and asthenosphere beneath the eastern U.S.
Karen Fischer, Brown University; Julia G. MacDougall, Carnegie Institution for Science; Yichen Geng, Carnegie Institution for Science; Lara S. Wagner, Carnegie Institution for Science; Robert B. Hawman, University of Georgia

49. Imaging and modelling the titled Yellowstone Plume
Peter Nelson, University of Texas at Austin; Bernhard Steinberger, GFZ German Research Centre for Geosciences; Stephen P. Grand, University of Texas at Austin

50. An Updated View of the Australian Lithosphere
Andrew Birkey, University of California Riverside; Heather A Ford, University of California Riverside; Page Dabney, Eckerd College; Gillian Goldhagen, University of California Riverside

51. Seismic-Wave Attenuation and the Grain-Boundary Sliding Rheology: A Test for the MLD and the LAB
Jeffrey Park, Yale University; Tolulope Olugboji, University of Rochester; Shun-Ichiro Karato, Yale University

52. The Distribution of Mid-Lithospheric Discontinuities on Precambrian Continents
Hannah Krueger, Brown University; Karen Fischer, Brown University; Isabella Gama, Brown University; Junlin Hua, Brown University; Zachary Eilon, University of California - Santa Barbara
53. **Mantle Transition Zone velocity jump and sharpness study using a compilation of temporary seismic arrays**
Brandon Schmandt, University of New Mexico; Margaret Glasgow, University of New Mexico;

54. **Prominent thermal anomalies in the Mantle Transition Zone beneath the Transantarctic Mountains, Antarctica**
Erica Emry, New Mexico Tech; Andrew A. Nyblade, Penn State University; Alan Horton, New Mexico Tech; Jordi Julià, Universidade Federal do Rio Grande do Norte; Samantha E. Hansen, University of Alabama; Sridhar Anandakrishnan, Penn State University; Richard C. Aster, Colorado State University; Audrey D. Huerta, Central Washington University; Douglas A. Wiens, Washington University in St. Louis; Terry J. Wilson, Ohio State University; J. Paul Winberry, Central Washington University

55. **Investigating Ultra-low Velocity Zones in the Southern Hemisphere using an Antarctic Dataset**
Samantha Hansen, University of Alabama; Sarah E. Carson, University of Alabama; Edward J. Garnero, Arizona State University; Shule Yu, Arizona State University; Sebastian Rost, University of Leeds

56. **Recent glacial isostasy and new constitutive approaches to the spectrum of low frequency geodynamics**
Erik Ivins, JPL-Caltech; Lambert Caron, JPL-Caltech; Eric Larour, JPL-Caltech; Surenda Adhikari, JPL-Caltech; Helene Seroussi, JPL-Caltech; Mirko Scheinert, Technical University of Dresden; Martin Horwath, Technical University of Dresden; Andrew Lloyd, Washington University of St. Louis; Douglas Wiens, Washington University of St. Louis

57. **Composition of deep crust imaged by USArray**
Siyuan Sui, Stony Brook University; Weisen Shen, Stony Brook University

58. **Crustal architecture beneath eastern China revealed by receiver function analysis**
Lingli Li, Stony Brook University; Weisen Shen, Stony Brook University; Siyuan Sui, Stony Brook University

59. **Array-based earthquake detection with multiple techniques**
Qiushi Zhai, Georgia Institute of Technology; Zhigang Peng, Georgia Institute of Technology; Zefeng Li, California Institute of Technology; Chenyu Li, Georgia Institute of Technology; Liang Zhao, Chinese Academy of Sciences

60. **Seasonal seismicity in the Western Branch of the East African Rift System**
Liang Xue, Bowling Green State University; Christopher W. Johnson, University of California San Diego; Yuning Fu, Bowling Green State University; Roland Bürgmann, University of California Berkeley

61. **Variation of the mode of slip along the Blanco Transform Fault, NE Pacific**
Vaclav Kuna, Oregon State University; John Nabelek, Oregon State University; Jochen Braunmiller, University of South Florida

62. **Surface-wave constraints on upper mantle petrofabric and flow beneath ~40 Ma seafloor in the south Pacific**
Joshua Russell, Lamont-Doherty Earth Observatory at Columbia University; James B. Gaherty, Lamont-Doherty Earth Observatory at Columbia University; Zachary Eilon, University of California, Santa Barbara; Donald W. Forsyth, Brown University; Göran Ekström, Columbia University
New and Exotic Approaches for Acquiring, Analyzing and Modeling in Geophysics

63. **Toward Creating a Subsurface Camera**
   Sili Wang, University of Georgia; Wenzhan Song, Georgia State University; Fangyu Li, University of Georgia; Maria Valero, University of Georgia

64. **IRIS DMC’s Latest Data Products**
   Manochehr Bahavar, IRIS DMC; Chad Trabant, IRIS DMC; Robert Weekly, IRIS DMC; Mick Van Fossen, IRIS DMC; Jerry Carter, IRIS DMC

65. **HPC Workflow Management in Seismology: Global CMT 3D Inversion**
   Lucas Sawade, Princeton University; Wenjie Lei, Princeton University; Frederik Simons, Princeton University; Jessica Irving, Princeton University; Jeroen Tromp, Princeton University

66. **A deep neural network approach to seismic event discrimination and phase identification**
   Nishath Ranasinghe, Prairie View A & M University; Nalinda Kulathunga, Texas Southern University;

67. **Overtone Interference in Fundamental-Mode Rayleigh Wave Phase and Amplitude**
   Anant Hariharan, Brown University; Colleen Dalton, Brown University; Zhitu Ma, Tongji University; Göran Ekström, Lamont-Doherty Earth Observatory of Columbia University; Donald Forsyth, Brown University

68. **Improved Upper Mantle Seismic Imaging Beneath the Pacific Northwest Interior**
   A. Christian Stanciu, University of Oregon; Eugene Humphreys, University of Oregon

69. **Exploration of end-member models for inverting 1D InSAR data for 3D displacements: Application to deformation at a groundwater entrainment site in the Coachella Valley**
   Kyle Murray, Cornell University; Rowena Lohman, Cornell University; Jeonghyeop Kim, Stony Brook University; William Holt, Stony Brook University

70. **Characterizing Time-Dependent Deformation Processes in Imperial Valley, California**
   Junle Jiang, Cornell University; Rowena Lohman, Cornell University

71. **Leveraging an operational archive of ARIA standard InSAR products for higher level time-series generation**
   David Bekaert, Jet Propulsion Laboratory (JPL); Simran Sangha, JPL and University of California; Emre Havazza, JPL; Brett Buzzanga, Old Dominion University; Mohammed Karim, JPL; Justin Linick, JPL; Hook Hua, JPL; Namrata Malarout, JPL; Marjorie Lucas, JPL; Piyush Agram, JPL; Heresh Fattahi, JPL; Susan Owen, JPL; Judy Lai-Norling, JPL; ARIA Team, JPL

72. **Kinematic magma volume accumulation at Westdahl volcano, Alaska, from 1992 to 2019**
   Xueming Xue, Michigan State University; Jeff Freymueller, Michigan State University

73. **High spatial resolution 2D wetland surface water flow modeling in the Everglades, Florida, constrained by interferometric SAR observations**
   Heming Liao, Florida International University; Reinaldo Garcia, Florida International University and Hydronia, LLC; Shimon Wdowinski, Florida International University

74. **Probabilistic Mapping of August 2018 Flood of Kerala, India, Using Space-borne Synthetic Aperture Radar**
   Sonam Sherpa, Arizona State University; Manoochehr Shirzaei, Arizona State University; Chandrakanta Ojha, Arizona State University; Susanna Werth, Arizona State University

75. **Widespread Subsidence and Carbon Emissions across Southeast Asian Peatlands**
   Estelle Chaussard, University of Oregon; Alison M. Hoyt, Massachusetts Institute of Technology and Max Planck Institute for Biogeochemistry; Sandra S. Seppalainen, University of Oregon;
76. Comparing InSAR, microwave, and optical measurements of soil moisture in hyper-arid regions.
Paula Burgi, Cornell University; Rowena Lohman, Cornell University

77. Soil moisture impacts on InSAR.
Rowena Lohman, Cornell University; Paula Burgi, Cornell University

78. Detecting microearthquakes with template matching and deep learning around the 2009 Typhoon Morakot in Taiwan.
Zhigang Peng, Georgia Tech; Qiushi Zhai, Georgia Tech; Lindsay Y. Chuang, Georgia Tech; Lijun Zhu, Georgia Tech; James McClellan, Georgia Tech; Shimon Wdowinski, Florida International University

79. Numerical Modeling of Earthquake Triggering Due to Erosion Unloading in Central Taiwan.
Shanshan Li, Florida International University; Shimon Wdowinski, Florida International University; Gregory Ruetenik, University of Wisconsin Madison; Ken Ferrier, University of Wisconsin Madison

80. Automating the Detection of Dynamically Triggered Earthquakes via a Deep Metric Learning Algorithm.
Vivian Tang, Northwestern University; Prem Seetharaman, Northwestern University; Kevin Chao, Northwestern University; Bryan A. Pardo, Northwestern University; Suzan van der Lee, Northwestern University

81. Stormquakes.
Wenyuan Fan, Florida State University; Jeffrey McGuire, USGS; Catherine de Groot-Hedlin, SIO; Michael Hedlin, SIO; Sloan Coats, WHOI; Julia Fiedler, SIO

82. 25-Second Determination of 2019 M7.1 Ridgecrest Earthquake Coseismic Deformation from Global GNSS Seismic Monitoring.
Tim Melbourne, Central Washington University; Walter Szeliga, Central Washington University; Marcelo Santillan, Central Washington University; Craig Scrivner, Central Washington University

Facilities, Operations, and Management

83. Rebuilding the Western Canada Deformation Array and Canadian National Seismograph Network.
Lisa Nykolaishen, Natural Resources Canada; Henry Seywerd, Natural Resources Canada; Yuan Lu, Natural Resources Canada; Joseph Henton, Natural Resources Canada

Jianghui Geng, Wuhan University; Guangcai Li, Wuhan University; Kai Liu, Wuhan University; Qiang Wen, Wuhan University; Enming Jiang, Wuhan University

Jayne Bormann, University of Nevada, Reno; Graham Kent, University of Nevada, Reno; Neal Driscoll, University of California, San Diego; Ken Smith, University of Nevada, Reno; Mark Williams, University of Nevada, Reno; Gabe Plank, University of Nevada, Reno; David Slater, University of Nevada, Reno; Doug Toomey, University of Oregon; Leland Driscoll, University of Oregon

86. New Instrumentation for Rapidly Responding to Geohazards.
Justin Sweet, IRIS; Kent Anderson, IRIS; Bob Woodward, IRIS
87. **Expanding Magnetotellurics at IRIS - Continuing Surveys of North America and Establishing New Portable MT Capabilities**
   Andy Frassetto, IRIS; Adam Schultz, Oregon State University; Bruce Beaudoin, IRIS
   PASSCAL/New Mexico Tech; Justin Sweet, IRIS; Kent Anderson, IRIS; Bob Woodward, IRIS

88. **EarthScope Alaska Transportable Array: Transition and Conclusion**
   Robert W. Busby, IRIS; Robert L. Woodward, IRIS; Kasey Aderhold, IRIS; Ryan Bierma, IRIS;
   Doug Bloomquist, IRIS; Jeremy Miner, IRIS; Molly Staats, IRIS; John Soderquist, IRIS; Frank L.
   Vernon, UCSD

89. **The Impact of USArray on Earthquake Monitoring in Alaska**
   Natalia Ruppert, University of Alaska Fairbanks; Michael E. West, University of Alaska Fairbanks

90. **Ongoing Modernization of Global Seismographic Network (GSN) Stations**
    Katrin Hafner, IRIS; Peter Davis, IDA/UCSD; David Wilson, ASL/USGS; Kasey Aderhold, IRIS;
    Carl Ebeling, IDA/UCSD; Andy Frassetto, IRIS; Adam Ringler ASL/USGS

91. **Installation and Performance of a Small Aperture Posthole Array at Albuquerque Seismological Laboratory**
   Robert Anthony, United States Geological Survey; Adam Ringler, United States Geological Survey;
   David Wilson, United States Geological Survey; Rebecca Rodd, KBR Wyle; Joseph Maharrey, KBR Wyle

92. **Validating Regional Station Performance Using Teleseismic Event Stacks**
    Adam Ringler, United States Geological Survey; Rebecca Rodd, KBR, Albuquerque Seismological Laboratory;
    Andrew Holcomb, KBR, Albuquerque Seismological Laboratory

93. **Geodetic network expansion during the 2018 Kilauea eruption**
    Sarah Conway, USGS-Hawaiian Volcano Observatory; Ingrid Johanson, USGS-Hawaiian Volcano Observatory;
    Asta Miklius, USGS-Hawaiian Volcano Observatory; Brian Shiro, USGS-Hawaiian Volcano Observatory;
    Brian Meyers, USGS-Cascades Volcano Observatory; Rebecca Kramer, USGS-Cascades Volcano Observatory

94. **Introduction to Anubis software for GNSS quality control in the GAGE facility and NOTA**
    Christine Puskas, UNAVCO; Charles M. Meertens, UNAVCO; David A. Phillips, UNAVCO;
    Frederick Blume, UNAVCO; Mike Rost, UNAVCO

95. **GAGE Facility GNSS Data Archives and Products**
    Kelly Enloe, UNAVCO; David Phillips, UNAVCO; Charles Meertens, UNAVCO; Dan Reiner, UNAVCO;
    David Maggert, UNAVCO; Christine Puskas, UNAVCO; Michael Rost, UNAVCO;
    Michael Marquez, UNAVCO; Susanna Gross, UNAVCO

96. **UNAVCO Support to the NASA Global Geodetic Network and Space Geodesy Project**
    Sarah Doelger, UNAVCO; Jacob Sklar, UNAVCO; David Stowers, NASA Jet Propulsion Laboratory;
    Freddy Blume, UNAVCO; Glen Mattioli, UNAVCO; Chuck Meertens, UNAVCO

97. **UNAVCO Network of the Americas Performance During 2019 Ridgecrest Earthquake Sequence**
    Christian Walls, UNAVCO; Doerte Mann, UNAVCO; David Mencin, UNAVCO; Kathleen Hodgkinson, UNAVCO;
    Christine Puskas, UNAVCO; Shawn Lawrence, UNAVCO; Andre Basset, UNAVCO; Ryan Turner, UNAVCO;
    Karl Feaux, UNAVCO; Glen Mattioli, UNAVCO

**Education, Workforce, and Outreach/Community Engagement**

98. **Martian InSight Data Access for Researchers and Educators**
    Tammy Bravo, IRIS; Rick Benson, IRIS; Mladen Dordevic, IRIS; John Taber, IRIS

99. **Assessing and Communicating Risk from Low-Activity Faults in British Columbia, Canada**
    Tiegan Hobbs, Natural Resources Canada; Murray Journey, Natural Resources Canada;
100. **Community Science Liaison Program: Transforming scientific outreach by connecting K-12 Citizen Science Groups with EON-ROSE scientists**
Katherine Boggs, Mount Royal University; Kevin O’Connor, Mount Royal University; Robert Sharp, Yukon Education (retired); Marina Clark, Calgary Board of Education; Hersh Gilbert, University of Calgary; Jason Droboth, EON-ROSE Executive; David Eaton, University of Calgary

101. **Engaging undergraduates using animations to demystify science concepts**
Jenda Johnson, IRIS; Robert Butler, University of Portland; Wendy Bohon, IRIS; Michael Hubenthal, IRIS; John Taber, IRIS

102. **From Data Visualization to Geoscience Visual Storytelling**
Ning Wang, University of Texas at Dallas; Robert J Stern, University of Texas at Dallas

103. **Geodesy Data-rich Undergraduate Teaching Materials and Instructor Professional Development**
Beth Pratt-Sitaula, UNAVCO; Bruce Douglas, Indiana University; Becca Walker, Mt San Antonio College; Benjamin Crosby, Idaho State University; Kristin O’Connell, SERC; Donna Charlevoix, UNAVCO

Michael Hubenthal, IRIS; John Taber, IRIS
Appendix C: Post Workshop Survey

The 2019 SAGE/GAGE Workshop organizers conducted a post-workshop survey to assess the effectiveness of the workshop. We garnered a response from 86 of the ~304 workshop attendees, for a 28% response rate.

Demographics and Workshop Funding
Information about the gender, career level, and ethnicity of respondents is summarized below. To the question on gender, 82 respondents (95% of total respondents) provided information and showed that the workshop was very close to gender parity (50% male, 42% female, and 8% chose to not disclose). 5% of the 72 people who responded to the question on disability status identified a disability. Of the 76 respondents who answered the question on which groups they identify with, three respondents (4%) identified as Hispanic/Latinx and two respondents (3%) identified at Native Hawaiian or Pacific Islander. 17% of the 84 respondents attended the 2019 SAGE/GAGE Workshop through scholarship support, another ~30% on IRIS/SAGE support, and an additional ~12% on UNAVCO/GAGE support. Another 8% and 12% attended through a PI/Advisor grant or through their own personal grant, respectively. 4% attended the workshop at their own personal expense.
Workshop Survey Results
In the survey, responders were able to choose multiple reasons as to why they attended the 2019 SAGE/GAGE Workshop and what they hoped to get out of it. For the 83 respondents to this question, 97% indicated the purpose of attending was to network with others. 38% of these respondents strongly agreed that they were able to network with peer researchers and ~84% either agreed or strongly agreed that they established new professional connections. Almost an equal amount of respondents (72% and 68%, respectively) wanted to learn more about research directly related to their own work, or more about fields unrelated to their own work. Approximately 47% wanted to receive feedback about their own research.

Ninety-five percent of 86 survey respondents rated the science content of the workshop as either ‘good’ or ‘excellent’. Of the 17 respondents who answered the open-ended part of the survey question in regard to plenary sessions of note, six responded that they appreciated the career and demographic variety of the workshop plenary presenters, to include early career researchers and gender and employment diversity. Approximately 88% of 85 respondents rated the structure and effectiveness of the technical topic sessions/special interest group breakout sessions as ‘good’ or ‘excellent’. From the open-ended response section of this question, respondents felt the technical sessions were too short, that there were multiple or overlapping sessions that could have pertained to the same audience, and/or that there were too many sessions scheduled at the same time. Others felt that these sessions are some of the best parts of the workshop because of the discussions,
communication, and opportunities to connect with others who work on the same or similar issues.

In regard to the poster sessions, approximately 92% of the 86 respondents rated the value and format of the poster sessions as either ‘good’ or ‘excellent’. For the open-ended survey response, respondents requested more time for posters and that the aisles in the poster room were too narrow.

In response to other open-ended response questions on how to better enhance the exchange between the geodesy and seismology communities, several responded to have short courses focused on educating the seismology community on geodetic related topics, and vice versa. Brief overviews on topics and techniques unfamiliar to the individual communities could be useful for future workshops.