the IRIS CONSORTIUM

2014 IRIS Workshop

June 8–11, 2014, Sunriver, Oregon

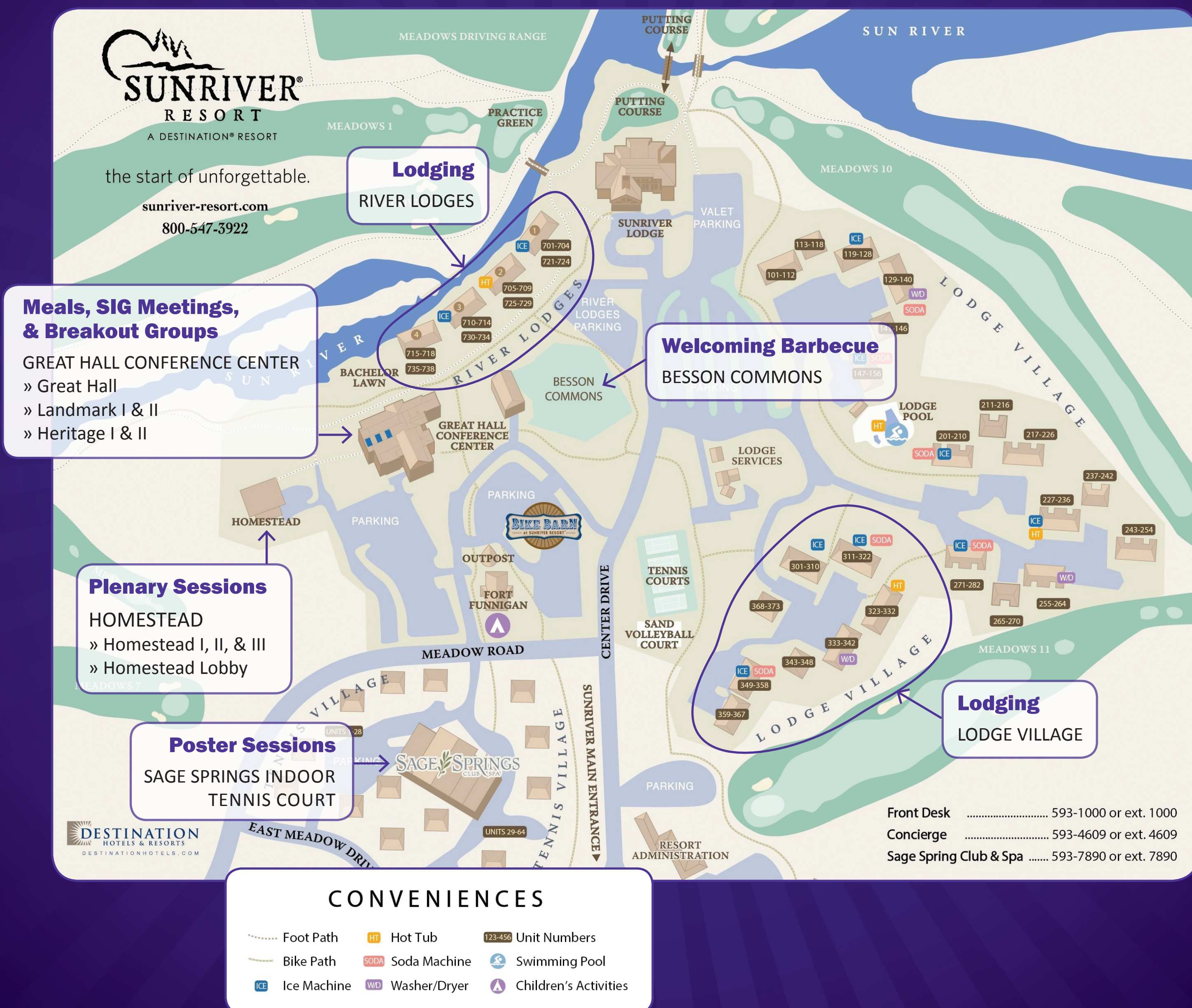
MULTI-USE FACILITIES AND DATA FOR SCIENCE AND EDUCATION

Meeting Venue

Sunriver Resort

17600 Center Drive ▪ Sunriver, OR 97707

(800) 801-8765 ▪ sunriver-resort.com



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Multiple Uses of Seismic Data

The National Science Foundation has entered into a new Cooperative Agreement with IRIS that includes initiatives to start engineering services in support of the science that we envisioned at our 2012 Workshop and described in our proposal for *Seismological Facilities for the Advancement of Geoscience and EarthScope* (SAGE). Already, the Consortium has convened meetings among tightly focused working groups to develop more specific service concepts. The 2014 IRIS Workshop – *Multi-use Facilities for Multi-use Data* – is an opportunity to explore how these concepts can be integrated and adapted to best facilitate the use of seismological and other data in research and discovery across the Earth sciences. We expect to build substantially on the community's consensus around the SAGE proposal and establish strategies to begin substantial work on initiatives for which only limited funding was included in the NSF Cooperative Agreement.

Adaptation

With its unified Cooperative Agreement running into 2018, the Consortium governs a broad range of services with the flexibility to adapt them to meet the needs of both evolving and newly emerging modes of seismological research. At the IRIS Workshop, the community will make plans to best facilitate the use of seismological and other data in research and discovery across the Earth sciences with novel service concepts such as

- Large N Initiative
- Subduction Zone Observatory
- Global Array of Broadband Arrays

Governance

One goal this year is to encourage broader engagement across the community in discussion of strategic directions for IRIS. At the Workshop, participants will be encouraged to contribute their advice related to at least one of three scientific topics areas that make use of seismological data:

- Thermo-chemical internal dynamics and volatile distribution within the Earth
- Faulting and deformation processes
- Change and interactions among climate, hydrology, surface processes, and tectonics

Services

IRIS facility activities that have significantly advanced since the 2012 Workshop include completing deployment of the **TA across the conterminous United States**, progress towards deploying **TA stations in Alaska**, and development of **OBSIP Management**.

There are also important developments in longer-standing IRIS activities – the **Global Seismographic Network**, **Portable Instrumentation**, **Data Management**, **Education & Public Outreach**, **Magnetotellurics**, **Polar Services**, and **International Development Seismology**.

Program Managers, Standing and Advisory Committees, and Working Groups are organizing SIG meetings and a section in the poster hall to highlight facility activities.

Science Program Chairs

Jeroen Ristema – University of Michigan
Elizabeth Cochran – U.S. Geological Survey
Brandon Schmandt – University of New Mexico

Special Interest Group Meetings

Meetings expected to be of special interest to groups of 10 to 50 Workshop participants are scheduled during selected time intervals of 60 or 90 minutes through the Workshop. Each SIG meeting is intended to function as a "two-way street." That is, the organizers typically make or invite a few short presentations, partly to inform the group about recent developments but also to stimulate discussion about how activities can better serve the community.

SIG meetings are not scheduled while oral sessions or poster sessions are underway, but several meetings run concurrently during each SIG interval. The program committee aims to minimize conflicts by scheduling meetings on topics likely to have overlapping participation at different times. One benefit from this is that the meeting topics during each interval are diverse, and most participants are keenly interested in at least one meeting during each SIG interval.

This year, organizers are being asked to provide reports back to the Board of Directors about an outcome from each meeting, including what the community has suggested for research and education services to advance geoscience in the future. You can help the meeting organizers represent your views in their reports by attending and actively participating in SIG meetings.

Enabling Large N

John Hole – Virginia Polytechnic Institute
Bob Woodward – IRIS Consortium

Evolving technologies will allow the deployment of seismic arrays capable of recording well-sampled wavefields, reducing or eliminating aliasing. The resulting data sets will enable new wavefield imaging methods that can transform studies of seismic sources and of Earth structure. The largest potential for new science capacity is likely to be at low frequencies to intermediate periods, which include societally relevant topics such as earthquake hazards, source discrimination, and energy. At this meeting, we will describe converging technologies for field acquisition and data analysis of full wavefields and discuss how we might move forward with creating a Large N facility to enable this vision.

Subduction Zone Observatory

Jeff McGuire – Woods Hole Oceanographic Institution
Bob Woodward – IRIS Consortium

With the successful completion of EarthScope, it will be possible to jointly leverage the USArray and PBO efforts to create an unprecedented 18,000 km long Subduction Zone Observatory along the length of the east Pacific margin. An SZO stretching from the Aleutians in the north to the tip of Tierra del Fuego in the south can enable research on all facets of subduction zone processes and facilitate a systems approach to a complex inter-linked set of processes involving deformation on times scales from seconds to millions of years and spatial scales from millimeters to thousands of kilometers. The SZO would provide unprecedented observations of deformational responses before, during and after a megathrust earthquake and other phenomena on the plate interface including slow slip events and episodic tremor. An SZO would improve our understanding of the dynamic processes in a variety of geophysical hazards, including earthquakes, tsunamis, volcanic eruptions, and landslides. The observations would be relevant to grand challenges in Earth science, including fluid flux through the crust and mantle, geochemical processes in arcs, and injection of water into the mantle. The SZO would be multidisciplinary – encompassing geodetic, seismographic, magnetotellurics, LIDAR, InSAR, and other observing systems. Our goals at this meeting are to begin identifying and compiling specific ideas and objectives for an SZO, to identify other geoscience communities with interest in SZO science, and to make progress towards an international workshop to articulate the major science objectives and required facilities.

Arrays for Global Seismology

Keith Koper – University of Utah
Colleen Dalton – Brown University

We plan to discuss envisioned complementary international contributions to build arrays for global seismology. There could be numerous benefits from such systems – both for Earth science and for broader society – but a strategic science goal could guide an effective design process without detracting from other benefits. Building partly on work at the 2013 "Arrays in Global Seismology" (http://www.iris.edu/hq/arrays_workshop) we plan to review

- Instrument response, array aperture, and other requirements to resolve structures related to alternative goals
- Observational evidence that coherent processing is possible across the required apertures
- Geodynamic arguments suggesting how many arrays would be necessary for different goals
- Impacts from the possibility that ocean arrays may be prohibitively expensive
- Further advances in data processing and waveform simulation would be needed

USArray in Alaska

Doug Christensen – University of Alaska Fairbanks
Katrin Hafner – IRIS Consortium
Frank Vernon – University of California, San Diego

Beginning in 2014 and accelerating during 2015 and 2016, the Transportable Array will be deployed as a single footprint in Alaska and northwestern Canada. These TA stations will be arranged in a grid-like pattern spaced at ~85 km, covering all of interior Alaska and adjacent areas. IRIS is working with the Alaska Earthquake Center, Alaska Volcano Observatory, and the Alaska Tsunami Warning Center to upgrade and leverage existing seismic infrastructure and permitting wherever possible. Installation will be complete by late 2017. TA stations are operated at least two years until removed. While no firm date has been set for removal, its expected to begin in 2019. Flexible Array deployments are also expected in Alaska, and at least one project is already funded to study the Cook Inlet Basin. Other FlexArray deployments might be focused in the active arc for volcanic processes, earthquake processes, and active tectonic processes, rapid mobilizations of instruments for post-earthquake studies, or other projects limited only by the imagination of the community. IRIS management and governance have been working to scale the TA in Alaska Project to awarded budgets and forecasts as these total 15% less than proposed over five years. We describe the need for changes, and the approach used to rescope the deployment. We want to discuss this with science community so they can appreciate the schedule and potential impacts and, in particular, to extend community discussion of science objectives – including new objectives presented by the geophysical setting and possible impacts to rescoping choices. Many of the scope adjustments are limited in the first year or so, and so clarity on objectives will continue to guide further steering in the next year or so as the effects of changes accumulate in later years. In general, the deployment will shrink from ~294 stations to about ~262 stations, with interspersed stations dropped from the grid in the northern and western periphery and in Canada, and the effort on continuous real-time telemetry and station construction costs will be scaled back 10%.

Current and Future States of PASSCAL

Seth Moran – U.S. Geological Survey
Bob Woodward – IRIS Consortium

Since its inception 25+ years ago, the IRIS PASSCAL program has evolved in ways large and small to meet the evolving needs of the PI community. In this SIG meeting, we will briefly describe the different ways that PASSCAL provides service to investigators, and provide updates on service levels to be provided under the SAGE budget. We will also review the current state of health of the PASSCAL instrument pool, including presenting findings from the PASSCAL Sustainability Working Group that has been looking into various questions regarding the sustainability of the instrument pool. We encourage any and all potential users of the PASSCAL program to come learn about how PASSCAL works and discuss some of the challenges facing the program as we move into SAGE.

High Performance Computing

Carl Tape – University of Alaska Fairbanks
Rengin Gok – Lawrence Livermore National Lab

The infrastructure available today for collecting, exchanging, and comparing multiple types of geophysical data is advancing rapidly: sensors are becoming less expensive to acquire and more readily deployed in large numbers, while the capacities for data telemetry and storage increase. These developments create opportunities for cutting-edge computational facilities to facilitate rapid advances in deep and broad understanding of many Earth processes, with benefits extending to broader society. The United States has committed to developing exascale computing, and hardware with vastly greater capabilities have been created – yet none of the systems are configured or managed with the requirements of Earth science research as a consideration. Efficient use of a shared computing would require adoption of community data and software, but the Earth science community is already pursuing this course even while very few joint teams of software engineers and discipline scientists are even aware of the distinct requirements of Earth science research. We will describe efforts to improve this situation and seek community input on how they envision using advanced computing capability and features that would facilitate their use of such services.

Volume Velocity Inversions and Converted-Wave Migrations: Uncertainties & Uniqueness

Ken Dueker – University of Wyoming
Rick Aster – Colorado State University

Seismic and seismically derived inverse models of Earth structure are cornerstone contributions of seismology to Earth sciences. However, their use is subject to over interpretation and/or misrepresentation, particularly by non-specialists. At this meeting, we plan to discuss ways in which we might more adequately and accurately portray and convey uncertainty and non-uniqueness issues within the seismological community and with peer geoscientists from other areas of specialization. We invite practitioners and users of seismic velocity models to participate broadly in this discussion. Possible topics might include tools for more completely investigating resolution, examination of regularization or other biasing methodologies, dissemination of models, normative expectations for peer-reviewed manuscripts presenting and/or utilizing velocity models, and issues related to their interpretation in terms of mappings of temperature, attenuation, mineralogy, phase, etc.

IRIS Support for Early Career Scientists

Tim Ahern – IRIS Consortium
John Taber – IRIS Consortium

Are you unsure about which tool is the best for you to access data and data products from the IRIS DMC? Then come join this SIG, which will focus on tools and services for early career scientists. It will begin with a short summary of the various client applications and web services that scientists can use to easily access time series and products available from the IRIS DMC. The majority of the SIG will be for interactions between early career scientists and IRIS staff, to discuss research needs and potential data access and data product solutions. Among the tools discussed will be WILBER3, IEB, jWeed, and several powerful PERL and shell scripts available from the IRIS DMC. Additionally, the interfaces to MatLab and ObsPy will be presented, along with hints for accessing information directly using standard Internet tools such as wget and curl.

Increasing Seismometer Presence in the Oceans: Identification of Scientific Needs

Brent Evers – IRIS Consortium

The Ocean Bottom Seismograph Instrument Pool (OBSIP) is soliciting input from the seismology community to identify the key concerns and services that OBSIP should provide in the future. OBSIP has recently expanded our instrument fleet and added pressure gauges to many of the existing instruments. Recent community experiments provide an opportunity for OBSIP to expand the OBS user base and encourage use of OBS data. This SIG will give an overview of recent changes in the OBSIP facility and focus on identifying the OBS community's needs for the future.

Real-Time Seismic Data from the Oceans

Gabi Laske – Scripps Institute of Oceanography
Frederik Simons – Princeton University
Guust Nolet – Géoazur

Two new developments in ocean seismology offer methods of extending the Global Seismographic Network into the oceanic domain: wave gliders coupled acoustically to ocean bottom seismometers (ADDOSS) and the recording of seismic P waves by untethered low-cost floats in the water column (MERMAID). We will start this meeting with summaries of what has been accomplished so far, then discuss a number of important questions. What are the design goals of an Ocean GSN? What are the possibilities, advantages, and drawbacks of each system? What synergies can be obtained with other disciplines beyond seismology? Should the seismic community start a worldwide effort like the FDSN, or leave it to individual PIs to launch such instruments? What role can IRIS play in these initiatives?

IRIS Government Communications

Ray Willemann – IRIS Consortium
Anne Meltzer – Lehigh University

Apart from its role as facility operator, the IRIS Consortium of U.S. universities is an advocate for government policies and funding that support geoscience research, emphasizing the use of seismological data to address a wide range of objectives with benefits to broader society. IRIS works to inform members of Congress and administration officials about how seismology and related fields of geophysics contribute to tsunami early warning, earthquake rapid alerts and early warning, earthquake hazard mitigation, underground nuclear test monitoring, exploration and evaluation of energy and mineral resources, mapping hydrologic and other near-surface resources, and documenting selected aspects of the state of the ocean and of glaciers. At this meeting, we will provide a summary of recent IRIS activities in this area, and solicit community input on prioritizing future activities.

Undergraduate Curriculum

Michael Hubenthal – IRIS Consortium
Derek Schutt – Colorado State University
John Taber – IRIS Consortium

Would you like to add some new seismology exercises into your intro classes? Do you need some ideas and resources for upper level seismology courses? Are you interested in getting involved in education research? This meeting will begin with an overview of a recently developed and tested set of intro undergraduate activities that are based on the grand challenges in seismology. The activities are designed to be integrated into your existing courses, while also conveying the latest seismological research to your students. This will be followed by a discussion on a developing project to provide a shared repository of higher-level course materials (PowerPoint files, homework, labs, etc.) from individual faculty members. Feedback is needed from the community as to how to organize and curate such a collection, and to define what is most needed. The meeting will conclude with a discussion of the spectrum of opportunities for the IRIS community to increase their involvement in geoscience education research.

Commonalities between Exploration and Academic Seismology

Emily Brodsky – University of California, Santa Cruz
Bob Woodward – IRIS Consortium

Recent technical developments bring together seismologists from industry and academia in a variety of ways. Autonomous seismic exploration acquisition equipment allows the economic collection of continuous passive seismic data that is not normally acquired in conjunction with controlled-source seismic exploration. This passive data records naturally occurring signals (ambient noise, micro-earthquakes, and teleseismic events) that can provide additional understanding of the subsurface. Recent advances in seismic data analysis can utilize these naturally occurring signals to complement and enhance subsurface images from active source seismic surveys. These advances incorporate techniques that cross-over between exploration and earthquake seismology, and are being applied to 3D and 4D active source surveys. We seek community involvement in emerging topics of common interest that include applications and algorithms, instrumentation and sensors, using dense arrays in both active and passive source applications, multi-use data sets, managing large data sets, and developing the workforce of the future.

Early Career: Work/Life Balance

Harmony Colella – Miami University
Danielle Sumy – University of Southern California
Andy Frassetto – IRIS Consortium

New faculty members and researchers have commitments spread across research, teaching, service, student advising, family, etc. This SIG meeting will be split into two parts. First, we will be introduce the incoming Chair of the Working Group and discuss the current needs of the ECI community. Second, a panel of seasoned members of the community will profile their career paths and be available to answer questions from early career scientists. We encourage all members of the IRIS community to attend and participate in this SIG. Perspectives and mentorship from more senior members of the IRIS community are particularly welcomed.

Agenda

SUNDAY, JUNE 8

3:00 PM – 7:00 PM	**REGISTRATION**	Homestead Lobby
6:30 PM – 8:30 PM	**WELCOMING BARBECUE**	Besson Commons

MONDAY, JUNE 9

7:00 AM – 8:00 AM	**BREAKFAST**	Great Hall
7:00 AM – 5:00 PM	**REGISTRATION**	Homestead Lobby
8:00 AM – 8:30 PM	**INVITED TALK** – Jim Whitcomb	Homestead
8:30 AM – 10:00 AM	**PLENARY SESSION: SCIENCE GRAND CHALLENGES** **Grand Challenges and Scientific Themes** – Anne Meltzer **Thermo-Chemical Internal Dynamics and Volatile Distribution** – Jeroen Ritsema & Colleen Dalton **Faulting and Deformation Processes** – Mark Simons & Eric Dunham	Homestead
10:00 AM – 10:30 AM	**COFFEE BREAK**	Homestead Lobby
10:30 AM – 12:00 PM	**PLENARY SESSION: SCIENCE GRAND CHALLENGES (continued)** **Change and Interactions Among Climate, Hydrology, Surface Processes and Tectonics** – Sridhar Anandakrishnan & Eric Kirby **Discussion Period with Committee Panel**	Homestead
12:00 PM –1:00 PM	**LUNCH**	Great Hall
1:00 PM – 3:00 PM	**PLENARY SESSION: VERY WIDE APERTURE ARRAYS – PBO, USARRAY AND OTHERS** **Insights into Fluids and Melt in the Crust and Mantle from 3D Inversion of EarthScope MT Data** – Gary Egbert **Wave Propagation Across the US: Exploiting the Quality of USArray Data** – Göran Ekström **Exploring Pragmatic to Esoteric Applications of PBO High-Rate Geodetic Data to Constraining Fault Slip** – Joan Gomberg **Hi-Net is Great!** – Hitoshi Kawakatsu	Homestead

3:00 PM – 4:30 PM	**POSTER SESSION WITH REFRESHMENTS**	Sage Springs Indoor Tennis Court
4:30 PM – 6:00 PM	**SPECIAL INTEREST GROUP MEETINGS: SESSION A**	
	USArray in Alaska – Doug Christensen, Katrin Hafner, & Frank Vernon	Heritage I
	Enabling Large N – John Hole & Bob Woodward	Heritage II
	Arrays for Global Seismology – Keith Koper & Colleen Dalton	Landmark I
	IRIS Government Communications – Ray Willemann & Anne Meltzer	Landmark II
6:30 PM – 8:30 PM	**DINNER IN RECOGNITION OF DAVID SIMPSON**	Great Hall

TUESDAY, JUNE 10

7:00 AM – 8:00 AM	**BREAKFAST**	Great Hall
8:00 AM – 8:30 PM	**CHALLENGES AND OPPORTUNITIES FOR IRIS** – Bob Detrick	Homestead
8:30 AM – 9:30 AM	**PLENARY SESSION: DIRT, DATA, DESKTOP, DISSEMINATION**	Homestead
	Do Scientific Breakthroughs Come from Large Programs? – Geoff Abers	
	Imaging a Crustal Magma Body at Newberry Volcano: A Feasibility Study that Justifies Large N – Emilie Hooft	
	Lessons Learned from 24 Years of Collecting and Processing Broadband Array Data – Gary Pavlis	
9:45 AM – 10:45 AM	**BREAKOUT GROUPS: WHAT DO WE NEED?**	Heritage I & II Landmark I & II
11:00 AM – 12:00 PM	**PLENARY SESSION: REPORTS FROM BREAKOUT GROUPS**	Homestead
12:00 PM – 1:00 PM	**LUNCH**	Great Hall
1:00 PM – 2:30 PM	**SPECIAL INTEREST GROUP MEETINGS: SESSION B**	
	Velocity Models – Ken Dueker & Rick Aster	Heritage I
	Subduction Zone Observatory – Jeff McGuire & Bob Woodward	Heritage II
	Undergrad Curriculum – Michael Hubenthal, Derek Schutt, & John Taber	Landmark I

2:30 PM – 3:30 PM	**SPECIAL INTEREST GROUP MEETINGS: SESSION C**		
	Industry Relations – Emily Brodsky & Bob Woodward		Heritage I
	Real-Time Seismic Data from the Oceans – Gabi Laske, Frederik Simons, & Guust Nolet		Heritage II
	High Performance Computing – Carl Tape & Rengin Gok		Landmark I
	Early Career Work/Life Balance – Harmony Colella, Danielle Sumy, & Andy Frassetto		Landmark II
3:30 PM – 5:00 PM	**POSTER SESSION WITH REFRESHMENTS**		Sage Springs Indoor Tennis Court
5:00 PM – 6:00 PM	**SPECIAL INTEREST GROUP MEETINGS: SESSION D**		
	Current and Future States of PASSCAL – Seth Moran & Bob Woodward		Heritage I
	Increasing Seismometer Presence in the Oceans – Brent Evers		Heritage II
	Support for Early Career Scientists – Tim Ahern & John Taber		Landmark I
6:30 PM – 8:00 PM	**DINNER – INCLUDING A TRIBUTE TO JIM FOWLER & SPECIAL THANKS TO RICK ASTER**		Great Hall

WEDNESDAY, JUNE 11

7:00 AM – 8:00 AM	**BREAKFAST**	Great Hall
8:00 AM – 10:00 AM	**PLENARY SESSION: UNEXPECTED SCIENCE – NEW APPROACHES TO USING CONTINUOUS ARRAY DATA**	Homestead
	Multi-Parameter Waveform Inversion of Low-Frequency, Wide-Angle Active Surface Seismic Data – René-Édouard Plessix	
	New Developments in Ambient Noise Imaging – Victor Tsai	
	Detection of Gravity Waves and Infrasound Signals at the USArray – Catherine de Groot-Hedlin	
	The Ubiquity of Seismology – Rick Aster	
10:00 AM – 10:30 AM	**COFFEE BREAK**	Homestead Lobby
10:30 AM – 12:30 PM	**PLANNING FORUM**	Homestead
12:30 PM – 1:30 PM	**LUNCH & ADJOURN**	Great Hall

» NOTE: POSTERS MUST BE REMOVED FROM BOARDS BY 12:00 PM ON WEDNESDAY «

Science Grand Challenges

Organizers: **Jeroen Ritsema – University of Michigan**
Jeff McGuire – Woods Hole Oceanographic Institution
Beatrice Magnani – Southern Methodist University

It has been five years since the publication of *Seismological Grand Challenges in Understanding Earth's Dynamic Systems*. This session is intended to evaluate progress toward the Grand Challenges goals and the newest developments in seismology. As we are planning for the 2018 proposal, it is important to discuss whether IRIS is well aligned with our science goals. Which adjustments in existing IRIS programs and which new facilities are necessary to maximize IRIS's impact on seismological and interdisciplinary Earth science research? Why is IRIS indispensable in the next decade? The IRIS Board of Directors has organized science committees around three major scientific themes:

- Thermo-chemical internal dynamics and volatile distribution
- Faulting and deformation processes
- Change and interactions among climate, hydrology, surface processes, and tectonics

The science committees are charged to "…ensure alignment of the facilities with the scientific goals of the consortium." This session is intended to introduce these committees and to review our science goals and the structure of future IRIS programs.

PRESENTATIONS

Board Chair Anne Meltzer will open the session by summarizing the Board's expectations for the science committees. Members of the three committees will discuss the scientific themes and the critical roles that IRIS is playing or can play in our science.

Grand Challenges and Scientific Themes

Anne Meltzer – Lehigh University

Thermo-Chemical Internal Dynamics and Volatile Distribution

Jeroen Ritsema – University of Michigan
Colleen Dalton – Brown University

Faulting and Deformation Processes

Mark Simons – California Institute of Technology
Eric Dunham – Stanford University

Change and Interactions Among Climate, Hydrology, Surface Processes, and Tectonics

Sridhar Anandakrishnan – Pennsylvania State University
Eric Kirby – Oregon State University

DISCUSSION

The session will conclude with an open-microphone forum to engage the community in these discussions and to shape the work of the IRIS science grand challenges committees.

Very Wide Aperture Arrays: PBO, USArray, and Others

Organizers: Lara Wagner – University of North Carolina
Peter Shearer – University of California, San Diego

We will convene in plenary to explore what recent groundbreaking geophysical investigations tell us about how recently implemented services and major facility projects have facilitated research. The questions that each of us might ask ourselves as we listen to presentations and discuss them include:

- Among all of the activities that comprise EarthScope – SAFOD, PBO, USArray (including TA, FA, MT, DMS, EPO) – which features were most effective at promoting scientific advances?
- What scientific progress was facilitated by the combination of SAFOD, PBO, and USArray? What further progress might have been possible if there had been a contemporaneous InSAR mission?
- Have complementary lessons been learned from the Cascadia Initiative and other very wide aperture arrays, such as in China?
- Does development of a de facto array across all of Europe arising from independent investments by different countries offer lessons about the importance of unified planning to achieve efficiency or scientific gains?

PRESENTATIONS

Insights into Fluids and Melt in the Crust and Mantle from 3D Inversion of EarthScope MT Data
Gary Egbert – Oregon State University

Wave Propagation across the United States: Exploiting the Quality of USArray Data
Göran Ekström – Columbia University

Exploring Pragmatic to Esoteric Applications of PBO High-Rate Geodetic Data to Constraining Fault Slip
Joan Gomberg – U.S. Geological Survey

Hi-Net is Great!
Hitoshi Kawakatsu – University of Tokyo

Insights into Fluids and Melt in the Crust and Mantle from 3D Inversion of EarthScope MT Data

Gary Egbert – Oregon State University

Long period (10–20,000 s) magnetotelluric (MT) data are being acquired in large-array footprints across the continental USA on a quasi-regular grid (nominal ~70 km spacing, as for the seismic TA) as a part of the USArray component of EarthScope. These data are highly sensitive to fluids, melts, and other orogenic indicators, and thus provide a valuable complement to other observational components of EarthScope. Prior to the first deployments of the "MT TA" in 2006, no MT arrays of this spatial scale had been deployed. Indeed, up to this point, MT data were generally acquired in much denser 2D profiles, typically a few hundred kilometers or so in length. When first proposed, the wide site spacing of the MT TA, required for a quasi-uniform grid covering a large area, raised serious concerns about effects of near-surface static distortion and aliasing due to undersampling. However, in combination with newly available practical 3D inversion codes, this large-array quasi-uniform sampling strategy has proven to be highly valuable, providing the first large-scale views of electrical resistivity variations beneath a continent, and ultimately generating new insights into magmatic and tectonic processes. In this talk, I will show results from the two footprints completed between 2006 and 2013, focusing on the 325 site Pacific Northwest (PNW) array, for which interpretation is fairly mature, and briefly discuss preliminary results from the 235 site Mid-Continent Rift (MCR) array. Our emphasis will be on surveying some broad variations in subcontinental resistivity, the imaging of which has been enabled by the large-scale sampling strategy employed by the IRIS facility. Some specific examples include: (1) 3D inversions of the MT TA provide a broad view of high conductivity layers in the lower crust and uppermost mantle, revealing how ubiquitous these features are in tectonically active (but not stable) continental areas. The imaged spatial patterns provide further evidence that these conductive features are caused by melt and magmatic fluids. (2) The very large aperture of the MT TA allows resolution of large scale variations in upper mantle conductivity (down to ~400 km), suggesting large scale variations in aesthenospheric water content, and possibly providing clues to melting and/or hydration history. (3) Coherent conductive features, extending through the crust and well into the mantle lithosphere, often mark sutures that bound stable cratonic blocks, and provide a record of continental assembly that may be otherwise cryptic. We will also touch on how availability of other resources, including freely available 3D inversion codes and searchable databases of MT transfer functions hosted by IRIS, can contribute to broader application of EM geophysical methods in interdisciplinary Earth science research.

Wave Propagation across the US: Exploiting the Quality of USArray Data

Göran Ekström – Lamont-Doherty Earth Observatory, Columbia University

As the Transportable Array (TA) has made its way across the lower forty-eight, its unique characteristics have encouraged the application of many new and old methods of analysis to investigate surface-wave propagation across the continent. One of the most unexpected and useful applications of the TA is the mapping of crustal structure using surface-wave signals extracted from seismic noise. None of three community articles that formulated the case for constructing USArray (*Ekström et al.*, 1998; *Levander et al.*, 1999; *Meltzer et al.*, 1999) mentioned continent-scale crustal mapping as a goal, much less achieving such a goal by analyzing noise. The modern methodologies of cross-correlating continuous seismic signals for structural information were, of course, not developed until the early 2000s. The TA, with its 70 km station spacing and sliding deployments on a regular grid, turned out to be ideal for this application and has spurred the rapid development of many noise-tomography techniques and models. The uniform high-quality instrumentation and installation of the TA has also enabled several types of investigations of the surface-wave wavefield that extend beyond those anticipated and described in the planning and design documents. In particular, the high-accuracy orientation of the horizontal components to within one or two degrees and amplitude calibration at the level of one or a few per cent, make possible investigations of wavefield polarization, focusing, and local waveform distortion that are not typically possible with sparse or temporary arrays. In my talk, I will describe some empirical measurements that illustrate the high quality of TA data and present the results of investigations that map surface-wave characteristics across the footprint of the array.

Ekström et al., 1998. USArray – Probing the continent, *IRIS Newsletter, 16*, 2–9.

Levander et al., 1999. Proposed project would give unprecedented look under North America, *Eos, Trans. AGU, 80*, 245–251.

Meltzer et al., 1999. USArray initiative, *GSA Today, 9*, 8–10.

Exploring Pragmatic to Esoteric Applications of PBO High-Rate Geodetic Data to Constrain Fault Slip

Joan Gomberg – U.S. Geological Survey
Collaborators: David Schmidt, Sarah Minson, Evelyn Roeloffs, Jessica Murray, John Langbein, Brendan Crowell, Ilya Zaliapin

New high-rate PBO geodetic data hold promise to find elusive answers to how faults slip. In addition, near-real-time availability of these data provides opportunities to deliver earthquake information with resolution and speed not possible with traditional monitoring with only seismometers. Prior to the installation of the PBO strainmeters, tiltmeters, and GPS receivers, most deformation measurements were limited to daily sampling, such that constraining the evolution of fault slip at higher rates was the exclusive domain of seismology. However, seismic instruments only capture slip in the passband of hundredths to hundreds of seconds. High-rate geodetic data may fill the gap in the period range between the hundreds of seconds (or less) sampled by seismology and daily or longer periods sampled by most traditional geodetic data. In addition to the promise of filling this gap in temporal scale, GPS systems can record motion of unlimited amplitude, unlike seismometers that can saturate and distort when measuring strong shaking. This attribute has enormous potential pragmatic benefits. When available with latencies of seconds or less, high-rate GPS measurements are particularly useful for rapid estimates of the size and even the geometry of the largest earthquakes, for which alert rapidity depends on the shortest possible travel times and thus would be in the region with the large amplitude displacements.

We present examples of high-rate strainmeter and GPS data to address scientific questions about fault slip, focusing on scaling between the duration of transient slip events and scalar moment. We explore limitations of strainmeter, GPS, and seismic data imposed by the instrumentation and by the Earth, using some simple models and observations. To fill observational gaps relevant to constraining this scaling, we search for transient strains and displacements indicative of aseismic slip surrounding shallow seismic swarms, and present some preliminary findings. We also review some of the pragmatic applications of high-rate GPS data used in earthquake monitoring, from the literature and our own work. These employ GPS data alone and GPS and seismic data together.

Hi-Net Is Great!

Hitoshi Kawakatsu – Earthquake Research Institute, University of Tokyo
(currently at Institut de Physique du Globe de Paris)

Hi-net consists of nearly 700 short period three-component seismometers buried in deep boreholes at around a depth of 100 m, to cover the Japanese islands with the designed spacing of 20 km (Okada et al., 2004, *Earth Planet. Sci.*). Thanks to the high-fidelity recordings with a dense and uniform coverage, Hi-net has provided unprecedented quality dataset to unravel properties of the Japanese subduction zone, for example, the discovery of the non-volcanic deep tremors (Obara, 2002, *Science*), as well as to probe other parts of Earth as a seismic array (e.g., Ishii et al., 2005, *Nature*). Hi-net is operated by the National Research Institute for Earth Science and Disaster Prevention (NIED), and is also equipped with tiltmeters that can be used as a network of horizontal broadband seismometers (e.g., Tono et al., 2005, *J. Geophys. Res.*; Tonegawa et al., *Earth Planet. Sci.*, 2006; Nishida et al., 2008, *J. Geophys. Res.*). In this review talk, I will present some of notable researches conducted using Hi-net (and F-net) data, especially focusing on my own work related to the subduction of the Pacific Plate (Kawakatsu and Watada, 2007, *Science*; Kawakatsu et al., 2009, *Science*; Kawakatsu and Yoshioka, 2011, *Earth Planet. Sci. Lett.*), as well as the real time monitoring the long-period seismic wavefield (Kawakatsu, 1998, *Bull. Earthquake Res. Inst.*; Tsuruoka et al., 2009, *Phys. Earth Planet. Int.*; Kawakatsu and Montagner, 2008, *Geophys. J. Int.*). I hope to give some perspectives on what the future generation seismic networks might be able to provide.

Dirt, Data, Desktop, Dissemination

Organizers: Suzan van der Lee – Northwestern University
Susan Schwartz – University of California, Santa Cruz

Dirt: What new instrumentation is needed to advance science? When is this work best done by PI-led groups of students and other researchers, and when are professional teams more effective?

Data: What are the field requirements for high-quality data acquisition? Which metrics do data providers and users use to improve data? What services from the DMC are required to work more efficiently?

Desktop: What services complement data? Data system products? Open-source and community software? High performance computing resources? Visualization tools?

Dissemination: How are the data used in a project or publication documented? How are research products linked with data? How does the community evaluate and adopt new field practices, data processing algorithms, and analysis methods?

PRESENTATIONS

On Tuesday morning three speakers will present on-going research, and describe how new services might facilitate several phases of the projects:

Do Scientific Breakthroughs Come from Large Programs?
Geoffrey Abers – Columbia University

Imaging a Crustal Magma Body at Newberry Volcano: A Feasibility Study that Justifies Large-N
Emilie Hooft – University of Oregon

Lessons Learned from 24 Years of Collecting and Processing Broadband Array Data
Gary Pavlis – Indiana University

BREAKOUT GROUPS

After the presentations, workshop participants will be asked to discuss "*What do we need?*" What programs and facilities can most effectively enable investigators to address Grand Challenges in the Earth Sciences? The small breakout groups provide opportunities for individual comments; each group is free to discuss any discipline of Earth science and any type of facility. Topics of discussion might include:

- Community experiments – for example, the Subduction Zone Observatory and Arrays for Global Seismology, that have been broadly discussed and newly envisioned experiments
- Coverage in the gaps – in the ocean, in the Arctic and Antarctic, and in other environmentally and politically challenging locations
- Multidisciplinary challenges – science goals that cannot be met with seismological research alone

Informed in part by the presentations with which the *Dirt*, *Data*, *Desktop*, *Dissemination* session began, the breakout groups could consider any category of resources, including:

- Instrumentation requirements – both the number and the specifications of instruments that are required by the array of grand challenges
- Data formats and products – to efficiently re-use seismological data for new purposes, to reliably share seismological results with other Earth scientists, and for seismologists to integrate outcomes from other disciplines into their own results
- Community software and computing resources – to facilitate wide and timely adoption of best practices and advances in data analysis, Earth models, and numerical simulation

- Education and outreach – to develop support among broader society for decision making that is well informed by Earth science and to develop the work force needed for robust research and good use of new knowledge

REPORTS IN PLENARY

The leaders of each breakout group will compile a summary of discussion during their session and report to the plenary session that immediately follows. The re-assembled group is scheduled to meet for a full hour to allow time for comparison of and commentary on points raised in different groups.

Do Scientific Breakthroughs Come from Large Programs?

Geoff Abers – Lamont-Doherty Earth Observatory, Columbia University

Government-sponsored science has become increasingly the province of large facilities, targeted funding programs and "community" led endeavors. These are seen as a way to accomplish expensive things that could not be done by individual investigators, and have led to a large amount of time being devoted to planning activities (like this Workshop). But do they deliver on their promise of transformative science? Several large facilities and initiatives have sought to encourage scientific advance in seismology in the last decade, most obviously IRIS and EarthScope, but also programs such as GeoPRISMS/MARGINS (where I have devoted much energy), Continental Dynamics, CSEDI, and SCEC.

It is instructive to investigate the relationship between some of the last decade's major advances in seismology, and these programs. For example, the discovery of a correlated ambient noise wavefield has provided a powerful new imaging tool at scales previously difficult. While the seminal papers were based on small numbers of stations in permanent networks, this advance completely depends upon the ability to record, store and access vast streams of continuous data, through facilities such as the IRIS DMC. The USArray then showed that these signals can reveal new things about the nature of the crust and uppermost mantle. Second, the discovery of episodic slip and non-volcanic tremor has opened up a huge new, unexpected field of transient deformation. The tremor was first discovered by a dense, permanent and low-noise array in Japan, followed quickly its linkage to deformation transients in the Pacific Northwest. Again, large easily accessible streams of continuous data have made this discovery possible. Discovering tremor and slow slip have motivated a host of new efforts, with programs like GeoPRISMS/MARGINS to provide a vehicle to understand the physical processes behind this phenomenology. Finally, a large uptick in earthquakes in the central and eastern US has led to the inference that high-volume injection wells may be inducing earthquakes in many areas. The serendipitous passage of the TA during much of this activity, 2009–2011, has led to a number of discoveries about the location, depth and spatial patterns of the seismicity, greatly increasing the confidence with which induced earthquakes can be identified. IRIS also provides rapid array mobilization (RAMP) that has allowed the earliest stages of some of these earthquake sequences to be characterized in an unprecedented manner, as in Oklahoma in 2011. The high waveform quality and uptime of the TA has made it possible to utilize waveform-matching techniques to identify much smaller earthquakes than previously, showing that dynamic triggering takes place at induced earthquake sites as well as natural sites of high fluid pressure. Such observations have helped motivate longer-term monitoring via the CEUSN. In all of these cases, large facilities and programs in geoscience were not built with these specific discoveries in mind. Rather, the best are designed to promote discovery and make serendipity possible. They also rely both on high-quality data collection and large, organized and open data facilities, demonstrating the value of a dirt-to-desktop philosophy to major programs.

Imaging a Crustal Magma Body at Newberry Volcano: A Feasibility Study that Justifies Large-N

Emilie Hooft – University of Oregon
Collaborators: Douglas Toomey, Matthew Beachly, Benjamin Heath, Gregory Waite

To understand the magma plumbing system beneath Newberry Volcano, Oregon, we tested an experimental design that densely sampled the seismic wavefield along a well-instrumented profile. The resulting data were used to constrain the sub-caldera magma chamber structure.

DIRT: We deployed 81, three-component, L-22D short period (2 Hz) sensors at a station spacing of 300 m and 800 m within the caldera and on the volcano flanks, respectively. PASSCAL suggested an unusual power source: 8 D-cell air-alkaline batteries wired to provide 12 V and 180 Ah, which powered the sites for almost 4 weeks. Though non-rechargeable, these light, easily carried batteries facilitated deployment of a large number of stations. Fieldwork was done with volunteer teams of community college, undergraduate, and graduate students as well as with community members from Bend. Volunteers were led by one PASSCAL representative (Steve Azevedo), the PIs, and experienced graduate students. This cost-effective approach involved the local public, provided valuable research experiences, and resulted in good quality data collection.

DATA: Newberry was an ideal target for a feasibility study because it allowed us to piggyback on the westernmost explosive shot of the NSF-funded High Lava Plains experiment and because there are extensive legacy datasets from two USGS active source experiments conducted in the 1980s. The legacy data were recovered from the IRIS DMC archive and were essential to our tomographic studies. Since our feasibility study recorded continuously for several weeks, we also observed 21 teleseismic events, at distances from 38° to 92°.

DESKTOP: Several complementary analyses were used to constrain the structure of the magmatic system beneath Newberry, including first-arrival travel time tomography of all active source data, joint inversion of active-source travel times and relative delay times of teleseismic data, finite difference modeling of primary and secondary arrivals, and receiver functions. Broadly speaking, all time-based tomographic methods result in a 3D image of a volume of anomalously low velocities beneath the caldera that is consistent with a magma body. However, finite difference modeling shows that the tomographic models do not fully predict the arrivals and amplitudes of the full seismic wavefield. Predicted waveforms for 2D models that include more pronounced low-velocity bodies yield magma chamber models that comprise a much narrower range of melt volumes (1.6–8.0 km^3) than could be constrained by tomography alone (~70 km^3).

DISSEMINATION: In addition to presenting our results through the usual scientific channels (e.g., M.Sc. theses, peer-reviewed journals, and scientific conferences), we also generated a 10-minute video that has been used in university classrooms, public schools, the UO website, and is available on YouTube. As of May 1, 2014, this video will also be featured at the Lava Lands visitor center run by the US Forest Service. Preparation of the video was a collaborative effort between the Digital Arts and Geological Sciences department at UO.

In the future, dense sampling of the seismic wavefield in 3D will allow us to image heterogeneous, small-scale structure at volcanoes. Such experiments will require on the order of 10^3 seismometers that are capable of being deployed easily for several months. Analysis of these large datasets will require industry-level, full-waveform inversion methods, high-performance computing facilities, and advanced visualization.

Lessons Learned from 24 Years of Collecting & Processing Passive Seismic Array Data

Gary L. Pavlis – Department of Geological Sciences, Indiana University

Having been involved nearly continuously in one or more portable array deployment since 1990, I will begin this talk from a historical perspective on the "four Ds" that are the topic of this session. For each of the Ds I will aim to address where we are and my perspectives on where attention is needed. My end point for each will be recent experiences with the ongoing Ozark Illinois Indiana Kentucky (OIINK) Flexible Array experiment and/or experiences with data from the TA used for plane wave migration imaging. ***Dirt.*** I will review the development of the telemetry system that is the foundation of the TA. Many of the concepts that made the TA possible were developed under the IRIS Joint Seismic Program in the 1990s. I will show how the use of cell phone telemetry in OIINK has led to data recovery rates similar to the TA while stand-alone stations in the same experiment have had typical PASSCAL style recovery rates. Telemetry has saved our project a large amount of money by reducing the required site visits in half. I will also review the history of broadband vault construction and emphasize a factor that was once well known but seems to have been lost in recent years. That is, it was recognized in the first, dense portable broadband experiment at Pinyon Flats in 1991 that long period noise on horizontal components is totally uncorrelated from station to station and is tilt noise induced by processes in soil that are not fundamentally understood. Direct burial installations and the small Flexible Array vaults are always very noisy at long periods because the soil is always moving from local pressure and temperature fluctuations. In OIINK, we were fortunate enough to be able to replace 30 Guralps in FA vaults with 30 Trillium posthole sensors when the array was moved from Illinois to Kentucky. On the positive side this was a huge improvement in field procedure. A crew of two people could install three stations from start to finish in a single day compared to multiple visits with a conventional concrete pad and vault procedure. Data quality, however, is comparable to FA vault with comparably high tilt noise at periods longer than 30 s on all horizontals. We presume this is because we installed these sensors in shallow (1 m) deep postholes. This is further evidence that soil is always an unstable medium. Sites requiring superior long period noise will likely only be possible by emplacing sensors within a borehole drilled into rock and at a minimum depth that is currently not established. ***Data.*** I will preach that a further important benefit of telemetry is reduced effort in assembling data. The ideal future system should aim to use online storage only as the backup of last resort. Experiment costs and time to scientific results would be reduced significantly if automated systems handled all data in real time. ***Data*** and ***Desktop*** share a common problem we all experience daily because of the staggering pace of technical developments in information technology and computer hardware. In the 24-year history in my title desktop computing system speeds have increased by about orders of magnitude while high performance systems have advanced to the order of 10^{13} flops. Furthermore, HPC systems now commonly have scratch file systems with storage capacities of multiple petabytes where the entire DMC's holdings would hardly be noticed. David Hale said it perfectly at the 2009 USArray Data Processing courses: "Factors of 1000 are hard on assumptions." I will argue the largest barrier to progress in much of seismology is a combination of using archaic algorithms where implicit assumptions are no longer valid and archaic software frameworks (e.g., SAC) that are completely incapable of massive data processing. Experience teaching the USArray data processing short course the past 4 years had made it clear that there is an overwhelming need for a standard, well-supported framework for data handling. Furthermore, it is questionable that the existing models for data delivery by the IRIS DMC are optimal in the world of exascale computing. I will describe recent experiences I have had with using IRIS web services to obtain data from the TA. This has revealed a number of strengths and weaknesses of this system. Finally, for ***dissemination*** I will stress the critical recent changes in the affordability of 3D graphics visualization. Early work we did in this area in the 1990s was challenging due to the cost of the hardware and software. Today open source software and modern GPU chips make 3D visualization universally affordable. The main barrier is inertia of publishers and the community. I will illustrate modern capabilities with results from the TA and OIINK.

Unexpected Science: New Approaches to Using Continuous Array Data

Organizers: Heather DeShon – Southern Methodist University
Carl Tape – University of Alaska Fairbanks

We will explore the implications of data coming now from thousands of sensors recording continuously. In four independent presentations, researchers with extensive experience from diverse disciplines of geoscience motivated by questions such as

- What previously unrecognized Earth structure or processes can we see?
- What types of exploratory research, such as new approaches to modeling or visualization, are revealing previously unsuspected patterns in the data?
- What new science is emerging from use of seismic data to monitor time-dependent changes of structures or of exotic sources in the solid Earth and atmosphere?

There will be ample time for discussion after each presentation, with an intention to draw lessons that are useful in a planning forum that will follow.

PRESENTATIONS

Multi-Parameter Waveform Inversion of Low-Frequency, Wide-Angle Active Surface Seismic Data
René-Édouard Plessix – Royal Dutch Shell

New Developments in Ambient Noise Imaging
Victor Tsai – California Institute of Technology

Detection of Gravity Waves and Infrasound Signals at the USArray
Catherine de Groot-Hedlin – Univ of California, San Diego

The Ubiquity of Seismology
Rick Aster – Colorado State University

Multi-Parameter Waveform Inversion of Low-Frequency, Wide-Angle Active Surface Seismic Data

René-Édouard Plessix – Shell International Global Solutions

Proposed by Tarantola almost 35 years ago, seismic (full) waveform inversion consists of minimizing the misfit function between observed and computed data. Though this is a relatively simple and natural formulation, the practical application remains a challenge. One of the main conceptual difficulties resides in the propagative and oscillatory behavior of the seismic waves. The events are localized in the seismic traces and matching the correct phases between the observed and modeled data is crucial. Because the data misfit function oscillates, the propagation model has to be known "up to a wavelength" otherwise cycle skipping occurs. This leads to a rather complicated minimization scheme to converge to a realistic realization of the earth model. Another difficulty lies in the multiple parameters (velocities, attenuation coefficients, density) required to describe the wave propagation in the earth. Many parameter realizations can explain the seismic data. The solution of the so-called inverse or imaging problem is not unique and trade-offs exist between parameters. From a numerical point of view, solving the wave equations is rather expensive, especially when thousands of wave equation solutions are required to generate a modeled data set. This forces us to employ a so-called gradient-based optimization that can be problematic with an oscillatory data misfit, and consequently to develop inversion strategies depending on the seismic data, especially on the wavenumber information content of the data. However, waveform inversion has a large potential to reveal earth structures by processing a large amount of data without a too large human intervention.

To partially tackle the difficulties mentioned above, several approaches have been proposed. We can manually or automatically identify some of the seismic events and only invert the waveforms of these selected events. We can simplify the wave equations by making some assumptions on the nature of the earth, of the selected seismic events, to speed-up the numerical solutions and reduce the number of parameters. With active data, we can tailor the seismic acquisition. In this presentation, I shall focus on the waveform inversion applications in exploration geophysics and more specifically in oil and gas applications. The active data sets have nowadays a spectrum between roughly 2 and 80 Hz and the record length is around 8 to 16 s. We are interested in the first ten kilometers of the earth. Except for so-called near-surface applications when we image the first let say 10 to 100 m of the subsurface, we principally interpret the acoustic pre-and post-critical reflected and transmitted waves of the data. For large 3D applications, we then make the acoustic assumption. The misfit data minimization behaves differently with transmitted and reflected waves. Depending on the objectives and the data we focus on, there are currently two main applications of waveform inversion. The first one consists of inverting broadband reflection data to obtain a high resolution image, notably of the reservoirs. This approach requires an initial velocity that precisely represents the kinematics of the acoustic propagation in the frequency range of the data. The second application aims at determining intermediate wavelength-scale (i.e., 100 to 1000 m) variations of the earth model that are sometimes difficult to obtain by ray-based methods. These variations can correspond up to a 50% change from the initial earth model. Here we focus the inversion on the diving/transmitted events and we use a multi-scale (frequency continuation) approach to mitigate the dependency on the initial model. We then rely on low-frequency and wide-data sets. I shall focus the presentation on this second application and discuss the new acquisition development, the data pre-processing and the imaging strategy that includes a multi-parameter waveform inversion. I shall also detail some of the challenges we face. The presentation will be illustrated by waveform inversions of marine and land data sets.

New Developments in Ambient Noise Imaging

Victor Tsai – California Institute of Technology

Imaging Earth structure using ambient seismic noise has been exploited since the 1950s, but it was not until the last decade that it has flourished, with an exponential growth in the number of studies utilizing such ambient noise methods. While most applications of ambient noise imaging were and still are for surface-wave travel-time tomography, in the past couple of years there have been a number of new developments in both the types of applications and the theory behind the various approaches. In this presentation, I will summarize some of the recent exciting developments in noise imaging. These applications range widely from body-wave imaging of deep Earth structure with array interferometry and using full tensor correlations, to robustly constrain short-period amplitudes, to tracking short-time-scale variability in a variety of geophysical systems, including volcanoes and the hydrosphere. Improvements in theory have also helped clarify the degree to which noise imaging results on Earth faithfully record the quantities of interest and to what degree there is bias due to the interferometry or the specific methodology utilized. Finally, the fact that a number of phenomena produce seismic “noise” energy implies that this energy can be used to infer quantitative constraints on these physical processes. Examples will be given of using “noise” to image landslides, debris flows, fluvial sediment transport, sea ice, and hurricanes.

Detection of Gravity Waves and Infrasound Signals at the USArray

Catherine de Groot-Hedlin – University of California, San Diego

The seismo-acoustic USArray Transportable Array (TA) allows for enhanced observations of pressure variations at the Earth's surface associated with infrasound and other atmospheric phenomena. I present novel techniques that make use of the relatively close spacing of stations within the TA – about 70 km – to detect and track the progress of pressure disturbances across the TA. The method has been applied both to the detection of atmospheric gravity waves having periods from 40 minutes to 8 hours, and to the detection of 1–3 Hz infrasound energy generated by meteoroids.

The TA is sufficiently dense that gravity waves with wavelengths from tens to hundreds of kilometers are coherent between neighboring stations, but is too large for coherence across the entire network. To examine the characteristics of gravity waves propagating across the network, the TA is divided into a large number of elemental, triangular, sub-arrays consisting of three neighboring stations. Coherent analysis of the data at each triad provides a robust estimate of the signal's direction and speed. The results from all triads are combined to follow the progress of a gravity wave as it propagates across the TA. This method allows for observation of fine-scale variations in the speed, direction and amplitude of long period signals across the TA. It allows study of the statistics of these waves.

The method was used to follow the progress of gravity waves that originated near a severe storm system in the southern US and propagated across the TA in late April 2011. A large, high-amplitude gravity wave, spanning an area over 200,000 km^2, was observed moving to the NNW away from tornadic storm region. Other gravity waves with lower amplitudes and smaller spatial extent propagated southward along the gulf coast, away from the storm region. Satellite data for the same date detected large gravity waves with similar spatial patterns within the stratosphere, suggesting that barometric pressure data from the TA have application to basic atmospheric research.

The method described above has been modified to detect pressure disturbances with wavelengths much less than the inter-station spacing. In this case, the waveform data is appropriately bandpassed and an STA/LTA filter is applied to form envelopes of the data. Coherent analysis is then performed on the data envelopes at each triad rather than the waveforms; in other respects the analysis is similar to that described above. This method has been applied to infrasound generated by the terminal burst of meteors in order to infer the trajectory of several small bolides, and the location of their terminal burst.

The Ubiquity of Seismology

Rick Aster – Colorado State University

The IRIS community was a global leader in early efforts to record, archive, and broadly facilitating new scientific uses of continuous seismic data. The prescient recognition of the deep value of continuous recordings of Earth's seismic wavefield has led to the discovery of a bestiary of new seismogenic processes as well as to the development of powerful new analysis methods. In this talk, I will summarize historic and recent intriguing results from research that lies generally outside the realm of traditional earthquake/monitoring-based seismology. These include studies of atmospheric (e.g., industrial accidents, bolides), glaciological (iceberg and glacial sources), volcanic (tremor, very-long-period events), and fluid wave and transport (fluvial and microseism seismology) sources and processes. I will also note attendant methods that have been utilized and developed to analyze these "unusual" signals, and have been used extract source and structural information at a wide range of spatial scales. Finally, I will note some recently emerging opportunities to advance in extracting yet more information from the ever-growing trove of continuous and non-transient seismic data.

Planning Forum

Organizers: **Anne Meltzer – Lehigh University**
Bob Detrick – IRIS Consortium

The IRIS Board of Directors and the Consortium's new President, Bob Detrick, are convening a Planning Forum to discuss next steps in setting a strategic agenda to develop post-SAGE services to facilitate Earth science research.

PRESENTATIONS

Presentations are not the principal mode of work at the Forum. As a prelude to discussion, however, the organizers have invited brief summaries of discussion at Special Interest Group meetings during the Workshop.

Recording the Full Seismic Wavefield: Large N and Commonalities with Exploration Seismology
John Hole – Virginia Tech

Seismology in the Oceans: OBSs, Gliders, and Floaters
Guust Nolet – Geosciences Azur

Beyond Data: High Performance Computing and Earth Models
Carl Tape – University of Alaska Fairbanks

Trans-National Initiatives: Subduction Zone Observatory and Arrays or Global
Keith Koper – University of Utah

Seismology Presentations also will be invited about work over the coming year, based partly on presentations and discussion at the Workshop, from each of the three Science Grand Challenges Committees:

Thermo-Chemical Internal Dynamics and Volatile Distribution
To be named

Faulting and Deformation Processes
John Vidale – University of Washington

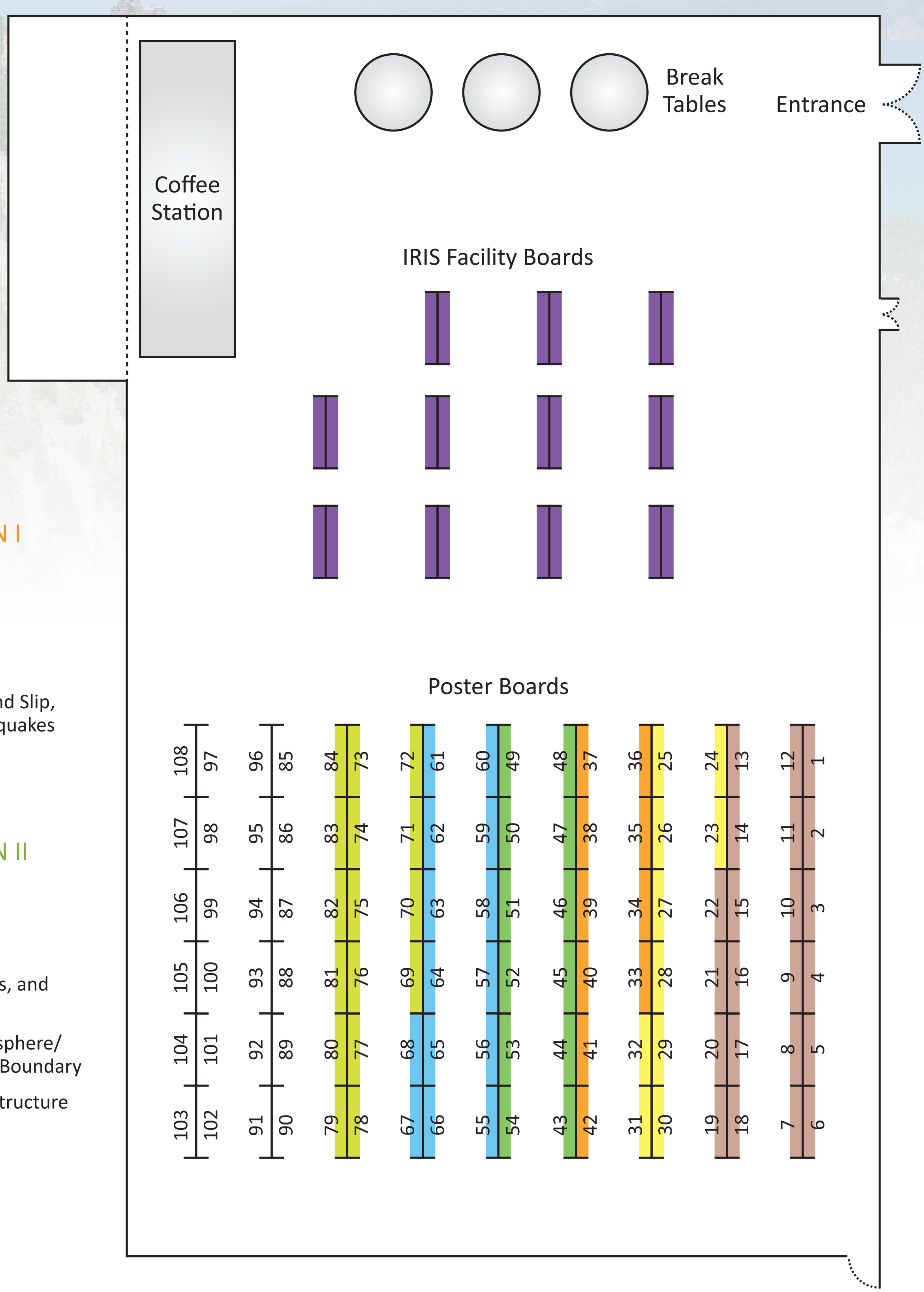
Change and Interactions Among Climate, Hydrology, Surface Processes, and Tectonics
Eric Kirby – Oregon State University

DISCUSSION

Questions and discussion are welcome after each of the brief presentations. After all of the presentations, Bob Detrick, Anne Meltzer, and Michael Wysession will act as a panel to facilitate broad discussion and respond to or re-direct questions. To conclude the session, Anne Meltzer will summarize the lessons that she sees for the Board of Directors.

Poster Sessions

Sage Springs Indoor Tennis Court



POSTER SESSION I

Monday, June 9
3:00–4:30 PM

- IRIS Facilities
- Crustal Structure
- Episodic Tremor and Slip, Triggered Earthquakes
- Other

POSTER SESSION II

Tuesday, June 10
3:30–5:00 PM

- IRIS Facilities
- Faults, Earthquakes, and Other Sources
- Lithosphere, Lithosphere/ Asthenosphere Boundary
- Mantle and Core Structure and Dynamics

POSTER SESSION I

Monday, June 9
3:00–4:30 PM

Author(s)/Title	Poster #
CRUSTAL STRUCTURE	
3-D Crustal Velocity Structure of Central Idaho/ Eastern Oregon using Ambient Seismic Noise and Joint Inversion of Rayleigh Wave Group and Phase Velocities: Results from the IDOR Project *Paul Bremner (Univ. of Florida), Mark Panning (Univ. of Florida), Ray Russo (Univ. of Florida), Victor Mocano (Univ. of Bucharest), Adrian Stanciu (Univ. of Florida), Megan Torpey (Univ. of Florida), Sutatcha Hongsresawat (Univ. of Florida)*	1 *
Seismic Velocity Reduction Following the September 5, 2012, Mw = 7.6 Nicoya Costa Rica Earthquake from Ambient Noise Correlations *Esteban J. Chaves (Univ. of California Santa Cruz), Susan Schwartz (Univ. of California Santa Cruz)*	2 *
Low Wave Speed Zones in the Crust Beneath SE Tibet Revealed by Ambient Noise Adjoint Tomography *Min Chen (Rice Univ.), Hui Huang (Massachusetts Inst. of Technology), Huajian Yao (Massachusetts Inst. of Technology), Rob Van Der Hilst (Massachusetts Inst. of Technology), Fenglin Niu (Rice Univ.)*	3 *
Removing Source-side Scattering for Virtual Deep Seismic Sounding (VDSS) *Chun-Quan Yu (M.I.T.), Robert Van Der Hilst (M.I.T.), Wang-ping Chen (Ocean College, Zhejiang Univ., China)*	4
Contrasting Crust Across the Cratonic Margin in Idaho-Oregon: Preliminary Results of the EarthScope IDOR Controlled-Source Seismic Survey *Kathy Davenport (Virginia Tech), John Hole (Virginia Tech), Steve Harder (Univ. of Texas at El Paso), Basil Tikoff (Univ. of Wisconsin – Madison)*	5 *
Shear-Wave Velocity Structure of the Anatolian Plate and Surrounding Regions *Cemal Biryol (Univ. of North Carolina), Susan Beck (Univ. of Arizona), George Zandt (Univ. of Arizona), Kevin Ward (Univ. of Arizona), Jonathan Delph (Univ. of Arizona)*	6 *
Sedimentary Basin Seismic Amplification Using the Ambient Seismic Field *Marine Denolle (IGPP, Scripps Inst. of Oceanography, UCSD), Hiroe Miyake (Earthquake Research Inst., Univ. of Tokyo), Gregory Beroza (Stanford Univ.)*	7 *
Lg Attenuation of the United States *Andrea Gallegos (New Mexico State Univ.), Nishath Ranasinghe (New Mexico State Univ.), James Ni (New Mexico State Univ.), Eric Sandvol (Univ. of Missouri)*	8 *
Joint Tomography of Newberry Volcano *Douglas Toomey (Univ. of Oregon), Emilie Hooft (Univ. of Oregon), Ben Heath (Univ. of Oregon), Maximiliano Bezada (Univ. of Oregon)*	9 *

*Student/Postdoc Presentation

*Student/Postdoc Presentation

Seismic Imaging of the Magmatic Underpinnings Beneath the Altiplano-Puna Volcanic Complex from the Joint Inversion of Surface Wave Dispersion and Receiver Functions — 21 *
Kevin Ward (The Univ. of Arizona), George Zandt (The Univ. of Arizona), Susan Beck (The Univ. of Arizona), Douglas Christensen (The Univ. of Alaska Fairbanks), Heather McFarlin (The Univ. of Alaska Fairbanks)

Inferring Crustal Anisotropy by Joint Interpretation of Radial and Azimuthal Anisotropy — 22 *
Jiayi Xie (Univ. of Colorado Boulder), Michael Ritzwoller (Univ. of Colorado Boulder), Sarah Brownlee (Wayne State Univ.), Bradley Hacker (Univ. of California, Santa Barbara)

EPISODIC TREMOR AND SLIP, TRIGGERED EARTHQUAKES

Micro Earthquakes Detected Using a Small Dense Array — 23 *
Blaine Bockholt (Center for Earthquake Research and Information), Charles Langston (Center for Earthquake Research and Information)

New Families of Low Frequency Earthquakes Beneath the Olympic Peninsula, WA — 24 *
Shelley Chestler (Univ. of Washington), Kenneth Creager (Univ. of Washington)

Low-Frequency Earthquake Source Scaling — 25
Ken Creager (Univ. of Washington), Justin Sweet (Univ. of Washington)

Tremor in San Andreas Fault Near Parkfield Imaged by a High Resolution Mini Seismic Array — 26
Abhijit Ghosh (Univ. of California, Riverside)

Very Low Frequency Earthquakes (VLFE) in Cascadia — 27
Abhijit Ghosh (Univ. of California, Riverside), Eduardo Huesca (Univ. of California, Riverside), Emily Brodsky (Univ. of California, Santa Cruz), Yoshihiro Ito (Kyoto Univ.)

Data Products from the PBO Borehole Network — 28
Kathleen Hodgkinson (UNAVCO), David Phillips (UNAVCO), David Mencin (UNAVCO), Brent Henderson (UNAVCO), Warren Gallaher (UNAVCO), Wade Johnson (UNAVCO), Chad Pyatt (UNAVCO), Liz Van Boskirk (UNAVCO), Otina Fox (UNAVCO), Chuck Meertens (UNAVCO), Glen Mattioli (UNAVCO), Mike Gottlieb (UNAVCO)

Hurricane Irene's Impacts on the Aftershock Sequence of the 2011 M_w5.8 Virginia Earthquake — 29 *
Xiaofeng Meng (Georgia Inst. of Technology), Hongfeng Yang (Georgia Inst. of Technology), Zhigang Peng (Georgia Inst. of Technology), Stephen Allman (Randolph College)

Precursory Slow Slip and Tremor Leading up to the September 5, 2012, M_w 7.6 Nicoya, Costa Rica Earthquake — 30
Susan Schwartz (UCSC), Stephanie Taylor (UCSC), Rocco Malservisi (USF), Tim Dixon (USF), Zhigang Peng (Georgia Tech)

Initiation and Propagation Phases of Northern Cascadia Episode Tremor and Slip Events — 31 *
Carl Ulberg (Univ. of Washington), Kenneth Creager (Univ. of Washington)

Systematical Search for Remotely Triggered Earthquakes in the Tibetan Plateau — 32 *
Dongdong Yao (Georgia Tech), Zhigang Peng (Georgia Tech), Xiaofeng Meng (Georgia Tech), Abhey Bansal (Georgia Tech)

*Student/Postdoc Presentation

OTHER

*Student/Postdoc Presentation

POSTER SESSION II

Tuesday, June 10
3:30–5:00 PM

Author(s)/Title	Poster #
FAULTS, EARTHQUAKES, AND OTHER SOURCES	
Seismogenic Landslides *Kate Allstadt (Univ. of Washington)*	43 *
Understanding Distribution of Strength in the Gorda Plate Subduction System *Xiaowei Chen (Woods Hole Oceanographic Inst.)*	44 *
Source Processes of Global Major Deep-Focus Earthquakes *Yu Chen (Stony Brook University), Lianxing Wen (Stony Brook Univ.), Chen Ji (UC Santa Barbara)*	45 *
Examining Induced Seismicity in SE New Mexico in the Vicinity of the Waste Isolation Pilot Plant *Edel Stanislav (New Mexico Inst. Of Mining and Technology), Susan Bilek (New Mexico Inst. of Mining and Technology), Shange Ingate (New Mexico Inst. Of Mining and Technology)*	46 *
Exploring Finite-Slip Inversion with Near-Field Seismic Data *Wenyuan Fan (Scripps Inst. of Oceanography, UC San Diego), Peter Shearer (Scripps Inst. of Oceanography, UC San Diego), Peter Gerstoft (Scripps Inst. of Oceanography, UC San Diego)*	47 *
Infrasound Data Analysis Results Using Portable and KMA's Infrasound Networks *Young Soo Jeon (KMA)*	48
Modeling Observed Aftershock Sequences with an Earthquake Simulator *Kayla Kroll (Univ. of California, Riverside), Keith Richards-Dinger (Univ. of California, Riverside), James Dieterich (Univ. of California, Riverside), Heming Xu (San Diego Supercomputing Center)*	49 *
Systematic Re-analysis of Volcano-Seismic Waveform Data *Robin Matoza (UC San Diego), Peter Shearer (UC San Diego)*	50 *
Seismic Moment Tensor in Southern Alaska Derived from Body and Surface Waves *Vipul Silwal (Univ. of Alaska Fairbanks), Carl Tape (Univ. of Alaska Fairbanks)*	51 *
Preliminary Results on Attenuation and Shear-Wave Splitting for the November 2011 M5.7 Prague, Oklahoma, Earthquake *Danielle Sumy (Univ. of Southern California), Elizabeth Cochran (United States Geological Survey), Katie Keranen (Cornell Univ.), Corrie Neighbors (Univ. of California – Riverside), Gail Atkinson (Univ. of Western Ontario), Fred Aminzadeh (Univ. of Southern California)*	52 *
Repeating Glacier Earthquakes *Paul Winberry (Central Washington), Howard Conway (Univ. of Washington), Michelle Koutnik (Univ. of Washington)*	53

*Student/Postdoc Presentation

LITHOSPHERE, LITHOSPHERE/ASTHENOSPHERE BOUNDARY

*Student/Postdoc Presentation

MANTLE AND CORE STRUCTURE AND DYNAMICS

*Student/Postdoc Presentation

*Student/Postdoc Presentation

IRIS FACILITIES POSTERS

Monday, June 9 3:00–4:30 PM	and	Tuesday, June 10 3:30–5:00 PM

Author(s)/Title

IRIS staff members will be available to share literature and discuss IRIS facilities during the poster session on both days at these and other posters.

Latest Developments at the IRIS/IDA DCC
Peter Davis (UCSD), Jon Berger (UCSD)

Seismic Noise Analyses and Event Quality Assessment for EarthScope Transportable Array Stations in Alaska
Andrew Frassetto (IRIS), Bob Busby (IRIS), Katrin Hafner (IRIS), Bob Woodward (IRIS), Luciana Astiz (Array Network Facility, Univ. of California-San Diego), Gillian Sharer (IRIS), Allan Sauter (PASSCAL Instrument Center, New Mexico Tech)

USArray – The First 10 Years
Bob Woodward (IRIS), Bob Busby (IRIS), Katrin Hafner (IRIS), Andy Frassetto (IRIS), Adam Schultz (Oregon State Univ.)

Recent Work at the Albuquerque Seismological Laboratory
Lind Gee (USGS Albuquerque Seismological Lab.), Tyler Storm (HTSI, Albuquerque Seismological Lab.), Adam Ringler (USGS Albuquerque Seismological Lab.), Bob Hutt (USGS Albuquerque Seismological Lab.), David Wilson (USGS Albuquerque Seismological Lab.)

Developing Worldwide Capacity for Analysis of Broadband Seismic Data
Ray Willemann (IRIS Consortium), Susan Beck (Univ. of Arizona), Jay Pulliam (Baylor Univ.), Eric Sandvol (Univ. of Missouri), Anne Meltzer (Lehigh Univ.), Mike Pasyanos (Lawrence Livermore National Lab.), John Louie (Univ. of Nevada, Reno), Ray Russo (Univ. of Florida)

USArray Siting Outreach: Activities in the Lower 48 and Alaska
Perle Dorr (IRIS Consortium), John Taber (IRIS Consortium), Patrick McQuillan (IRIS Consortium), Robert Busby (IRIS Consortium), Katrin Hafner (IRIS Consortium), Carl Tape (Univ. of Alaska Fairbanks), Lea Gardine (Univ. of Alaska Fairbanks)

Animating Seismology for Novice Learners and Undergraduate Students
Jenda Johnson (Volcano Video & Graphics (animation contractor for IRIS), Robert Butler (Univ. of Portland, OR)

EarthScope Chronicles: Sharing Scientist's Stories and Media-Rich Earth Science Investigations
Carla McAuliffe (TERC), Erin Bardar (TERC), Lois McLean (McLean Media), Rick Tessman (McLean Media)

USArray Data Processing and Analysis Short Course
Robert Porritt (Univ. of Southern California), Andrew Frassetto (IRIS), Meghan Miller (Univ. of Southern California), Michael Brudzinski (Miami Univ. of Ohio), Suzanne Van Der Lee (Northwestern Univ.), Gary Pavlis (Indiana Univ.), John Taber (IRIS)

Visualizing Seismicity with the Updated IRIS Earthquake Browser
Russ Welti (IRIS), Bruce Weertman (IRIS), John Taber (IRIS), Tim Ahern (IRIS)

Repeating Glacier Earthquakes
Paul Winberry (Central Washington), Howard Conway (Univ. of Washington), Michelle Koutnik (Univ. of Washington)

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