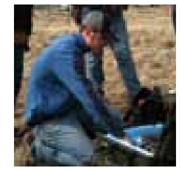
IRIS ANNUAL REPORT 2010



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***New members in bold**

Statement from the Chair

During the July 2009 to July 2010 fiscal year, IRIS and the community have been busy pushing forward on a number of exciting fronts. In June 2010, we held the IRIS Workshop in Snowbird, UT, where we recognized 25 years of "Facilitate Collaborate Educate." This 25th anniversary celebration reminded us of how much IRIS has accomplished for the seismological community and the incredible science made possible through use of the IRIS facility. Another very important accomplishment was the preparation of the NSF proposal for the IRIS core support. The proposal was strongly tied to the *Seismological Grand Challenges in Understanding Earth's Dynamic Systems* document and highlighted IRIS accomplishments as well as exciting new IRIS initiatives. I want to thank the community, the IRIS Board of Directors, the IRIS staff, and Brian Stump (Editor) for all their work on the proposal.

IRIS core programs and EarthScope are thriving. The roll out of the new Q330 data loggers at GSN stations continued at a rapid pace. GSN initiated some new and improved data quality measures to ensure that the GSN stations were producing the highest quality data possible. PASSCAL was involved in a 58-station aftershock deployment in Chile following the M_w=8.8 earthquake. These data are open and available at the DMC, and I urge everyone to use them. The E&O program supplied us with impressive teachable moments for our classrooms. The DMS program held a metadata workshop in Cairo and continued to develop new data products. The International Development Seismology Committee met with CERESIS in Peru, which has led to some to some joint activities. The IDS Committee also hosted a workshop in Miami following the devastating Haiti earthquake. Polar programs worked with international partners to deploy the Greenland Ice Sheet Monitoring Network, a real-time seismic network for studying ice sheet dynamics. EarthScope's Transportable Array is successfully moving across the country, and more and more Flexible Array deployments are in progress. Overall, it was a very successful year for IRIS and the seismological community.

I thank all of the partners that work with IRIS, committee members, IRIS staff, and NSF program managers for another successful year.

Susan Beck

Susan Beck, University of Arizona

Special Activities and Initiatives

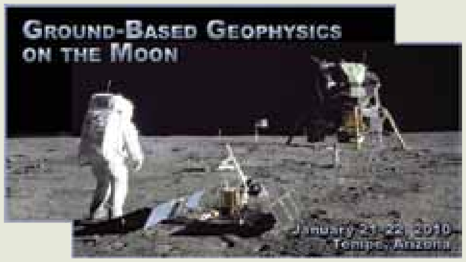
IRIS Management

Olga Cabello
David Simpson
Ray Willemann
Rob Woolley

IRIS is a university consortium sponsored by the National Science Foundation (NSF) that is dedicated to the operation of scientific facilities for the acquisition, management, and distribution of freely available seismic data. The IRIS Consortium serves as a forum for exchanging ideas, setting community priorities, and fostering cooperation. There are seven key IRIS program areas (Global Seismographic Network, Program for Array Seismic Studies of the Continental Lithosphere, Data Management System, Education and Outreach, USArray, Polar Operations, and International Development Seismology) and this report addresses each of them. Below we discuss IRIS activities and initiatives that are outside of these key program areas.

Seismic Instrumentation Technology Symposium – November 10–11, 2009

The first joint seismology/earthquake engineering/Department of Defense symposium on seismic instrumentation technology called "Spectral Extremes – Pushing the Limits of Sensing Ground Motion" was held at Miramonte Resort in Palm Springs Valley, CA, in November 2009. The symposium was sponsored by NSF, IRIS, the Network for Earthquake Engineering Simulation (NEES), and the US Geological Survey (USGS), and convened by Bob Nigbor (UCLA) and John Collins (WHOI). More information, including copies of presentations, is available at http://www.iris.edu/hq/instrumentation_meeting/.



Ground Based Geophysics on the Moon – January 21–22, 2010

IRIS co-sponsored a meeting on "Ground-Based Geophysics on the Moon" in Tempe, AZ. The meeting brought together planetary and terrestrial

Proposals Submitted:

The following table includes proposals prepared by IRIS during this fiscal year. Successful proposals are in black, unsuccessful ones in grey.

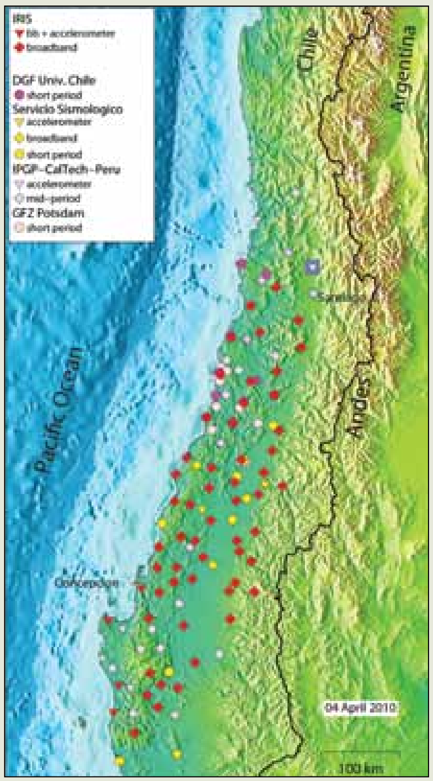
Date	Sponsor	Subject
8/09	NSF	Young Investigators Pool of Instrumentation
12/09	NSF	Mid-America Workshop (held 10/24-28/10)
1/10	NSF	Discovery Research K-12
2/10	NSF	OBS Workshop (held 9/26-28/10)
2/10	USAID	Mid-America Workshop
3/10	NSF	Haiti Workshop (held 3/22-23/10)
3/10	NSF	Chile RAPID
3/10	NSF	Pan-American Advanced Studies Institute
5/10	DOE	GSN Modernization

geophysicists to review the current state of knowledge of the Moon and past geophysical studies, to discuss current plans, and to begin planning for the future. More information is available at http://www.lpi.usra.edu/meetings/lunargeo2010/.

IRIS Community Instrument Deployment in Chile – March 20 – October 15, 2010

NSF, using its Rapid Response Research funding mechanism, supported a project to collect an open community data set from a portable seismograph deployment in an aftershock study following the magnitude 8.8 earthquake that occurred off the coast of Chile on February 27, 2010. The IRIS Consortium, on behalf of its member institutions, worked with scientists from US universities and the University of Chile to deploy 58 broadband seismic instruments to record aftershocks for approximately six months. This community-wide, coordinated approach provided a high-quality data set that was used immediately by a wide range of researchers from around the world.

Data from the Chile deployment are available at the IRIS DMC. Details can be found at http://www.iris.edu/hq/chile/data.



IRIS Workshop – June 9–11, 2010

The 2010 IRIS Workshop celebrated the 25th anniversary of IRIS—and looked ahead to an exciting future for the Earth sciences.

The workshop included plenary presentations on cutting-edge investigations related to many of the Seismological Grand Challenges, organized into sessions on:

- Exploration and Near-Surface Seismology
- The Science of Fault Slip and Earthquake Rupture
- Mantle Dynamics
- The Science and Policy of Deadly Earthquakes

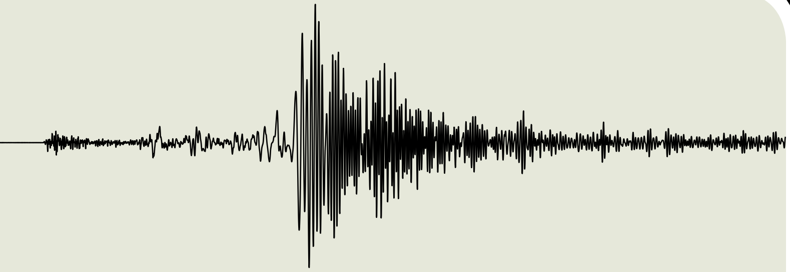
Over 225 people attended the workshop, which was organized by Mike Brudzinski, Ed Garnero, and Stéphane Rondenay.

Attendees at the IRIS Workshop held in Snowbird Resort, Utah, from June 9-11, 2010.

Publications

- IRIS Newsletter
- IRIS At a Glace

GSN



The February 27, 2010 M8.8 earthquake in Chile as recorded in Albuquerque, New Mexico, at the GSN station ANMO. The seismogram is unfiltered and is 1.5 hours long. Seismometers have been operating continuously at the ANMO location since 1961. The largest amplitude portion of the seismogram is surface waves, and provides a nice illustration of dispersion – the long period energy contained within the surface waves (wider spacing from one peak to the next) arrives at ANMO before the shorter period energy (smaller spacing between peaks).

ASL engineer upgrades GSN station in Wyandotte Cave, Indiana.

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Meredith Nettles	Lamont-Doherty Earth Obsv. of Columbia University
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IRIS Management

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The Global Seismographic Network (GSN) is a permanent network of state-of-the-art seismological and geophysical sensors connected by telecommunications to serve the scientific research and monitoring requirements of our national and international communities. All GSN data are freely and openly available to anyone via the IRIS Data Management Center. Installed to provide broad, uniform global Earth coverage, 153 GSN stations are now sited from pole to pole on all seven continents, in cooperation with over 100 host organizations and seismic networks in 70 countries worldwide. GSN coordinates closely with other international networks through the International Federation of Digital Seismograph Networks. The GSN is primarily operated and maintained through the USGS Albuquerque Seismological Laboratory (ASL) and through an IRIS subaward to the University of California at San Diego IRIS/IDA group. Twenty GSN Affiliate stations and arrays contribute to the network, including the nine-station USGS Caribbean Network. The GSN, in collaboration with the US National Earthquake Information Center (NEIC), are principal global sources of data and information for earthquake locations, earthquake hazard assessment, and earthquake emergency response. In collaboration with National Oceanic and Atmospheric Administration tsunami warning centers, the GSN provides essential data for tsunami warning response globally. The GSN participates within the Global Earth Observing System of Systems. The GSN also works closely with the International Monitoring System (IMS) for the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO). Thirty-one GSN stations and seven GSN Affiliates are now linked directly to the CTBTO International Data Centre, mostly via their global communication infrastructure.

GSN Data Quality Initiative

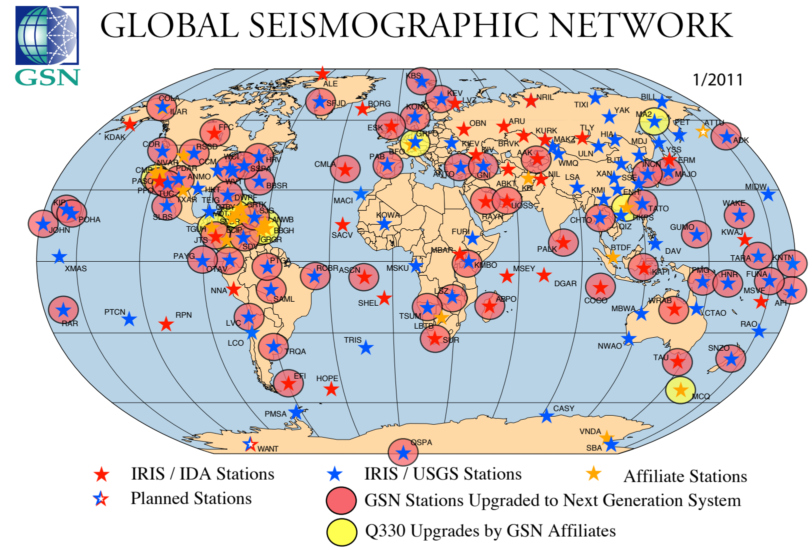
During 2010, IRIS, in collaboration with the USGS/GSN, the GSN Standing Committee, and the GSN network operators at ASL and UCSD, reviewed GSN data quality and quality-control procedures, and assessed how this information is shared within the operations community and is conveyed to the data user community. The review of current quality-control procedures included all IRIS programs (including USArray) as well those of our GSN partners at the USGS. This effort was undertaken to ensure the highest possible GSN data quality and that the quality status of each station is openly represented to the data user community.

This review was conducted this year for a number of reasons:

- Reports from the Lamont-Doherty Earth Observatory's Waveform Quality Center (WQC – Columbia University) in 2010 and studies by ASL and IDA document a number of significant problems with the long-period response of some of the aging STS-1 seismometers. The WQC reports also document a number of other problems with completeness and accuracy of metadata for some GSN stations.

Left: Staff at the UCSD IDA Facility.

Below: Staff at the USGS Albuquerque Seismological Laboratory.



GSN Network with highlighted stations upgraded to the next generation.

- With completion of the GSN's major installation phase, and receipt of funding for recapitalizing the network's recording equipment and adding secondary broadband sensors where before there were none, our ability to remotely calibrate all sensors and provide intersensor comparisons will greatly improve. Procedures are being developed to exploit this enhanced capability to routinely calibrate and report on full instrument response.
- As a result of the increasing similarities between the instrumentation technologies used by the GSN and other IRIS programs, there is an opportunity to establish "pan-IRIS" metrics and procedures for tracking and reporting on data quality.

The review team was comprised of representatives from GSN, PASSCAL, DMS, and USArray, as well as ASL and NEIC. The report (issued in August 2010) was approved by the GSN Standing Committee and was presented to the IRIS Board of Directors and the GSN Data Quality Review Panel. This panel, consisting of members of the GSN data user community (including past Board of Directors and GSN Standing Committee chairs), reviewed this document and is working with the Quality Assessment Team to establish or update procedures and reporting mechanisms for GSN data quality to benefit GSN operators and users. Development of implementation plans for these new procedures is underway. Information and updates on the GSN Quality Initiative can be found at http://www.iris.edu/hq/programs/gsn/quality.

Next Generation Upgrades

The GSN is continuing the major overhaul and upgrade of the stations and field equipment. Begun last year, the network upgrade is now over 53% completed (see map) and we expect to have most of the network improved to next generation equipment by the end of 2013. The systems installed across the network are based on the Quanterra Q330HR (high resolution) acquisition system and marks a new era in the GSN with standardized data collection systems between the network operators of the GSN. Both UCSD IDA and USGS ASL have collaborated in the design and development of standard interface boxes for both sensor interfaces and power distribution subsystems. These upgrades are complemented by Q330 installations by GSN Affiliates. In addition to NGS upgrades, the GSN has used the opportunity afforded by these visits to maintain critical infrastructure, repair sensors, install or repair secondary broadband and strong-ground motion sensors and microbarographs, and embark on a systematic analysis of sensor calibration and azimuth. Supplementing yearly relative calibration procedures, network operators now measure in situ calibrations with portable equipment verifying sensor and system responses, orientation, and location of deployed GSN sensors.

The GSN and Large Earthquakes

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Since 1984, global ground motions recorded by the GSN have led to improved images of Earth's interior, the quantification of seismic source parameters for hundreds of thousands of events (USGS), the estimation of source mechanisms for more than 30,000 earthquakes (Global Centroid-Moment-Tensor Project), and the identification of unusual climate-related signals. The GSN has recorded more than 120 large ($M_w \geq 7.5$) earthquakes, including recent megathrust events near Sumatra and along the coast of central Chile. GSN data provide an essential resource for ongoing and future studies of Earth's interior, tectonics, and earthquake processes, and serve as primary signals for global earthquake monitoring operations of the USGS and the National Oceanic and Atmospheric Administration tsunami warning centers, and complement the nuclear test monitoring operations of the International Monitoring System.

A long-standing challenge for earthquake scientists is the rapid assessment of large earthquake rupture characteristics as necessary for timely appraisal of the event's likely societal impact. Earthquake location, seismic magnitudes measured over a range of periods, faulting geometry, and slip distribution are key inputs for rapid estimation of ground shaking that underlie impact assessments. The expansion of GSN's real-time telemetry (and complementary digital seismic networks) over the past 25+ years and parallel advances in rapid seismological analysis have enabled faster, more detailed, and more accurate characterization of earthquakes. This has been transformative for earthquake monitoring operations, with society now receiving far more quantitative information about large events soon after they occur than was possible just a few decades ago. GSN observations also provide the basis for detailed follow-up studies by the research community, which play an important role in fundamental investigations of the tectonic processes and earthquake physics.

GSN installation occurred at an opportune time with regard to the natural fluctuations of large-earthquake activity. During the early 1980s, as the analog WWSSN was phased out and the GSN was planned and deployment was begun, large earthquakes occurred globally at a lower rate than had been experienced in the previous five decades. As the GSN approached its design goal for number of stations, there was a steady increase in the number of large earthquakes, with the last decade having a higher rate of great events than at any prior time in the seismological record. The data collected during this recent active period provide a wealth of information on large-earthquake processes, including patterns of slip distribution, rupture propagation, and earthquake interactions such as triggering. The network has also provided information on special classes of events, such as the deep Bolivia and Tonga earthquakes of 1992, great earthquakes rupturing within subducting plates in the trench-wall/outer-rise region, and the slow-rupturing tsunami earthquakes.

Tsunami earthquakes are a class of events that rupture the shallow regions of subduction zone plate boundaries, producing much larger tsunami than would be expected based on the event's standard body- and surface-wave magnitudes. Unusually low rupture speed and low moment-scaled energy release are common attributes of these events, accounting for relatively low magnitudes measured with shorter-period waves. Examples include the September 1992 Nicaragua and July 2006 Java earthquakes, both of which produced weak ground shaking on nearby coasts, but large and deadly tsunami. The most recent tsunami earthquake occurred off the coast of

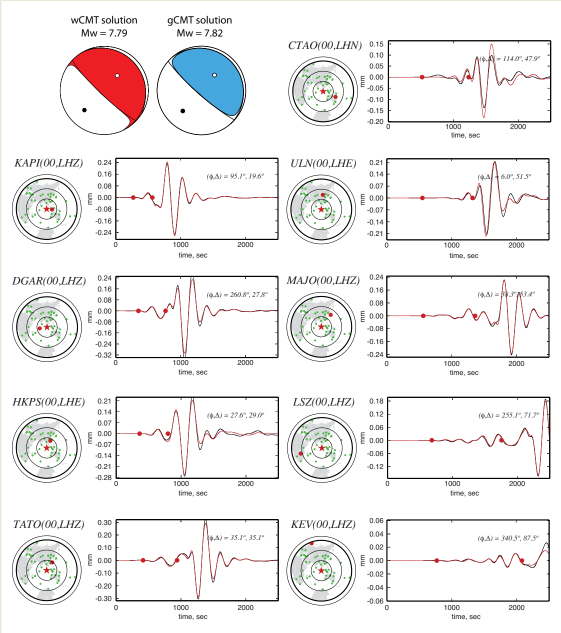

Figure 1: W-phase source inversion results for the 10/25/2010 Mentawai earthquake offshore Sumatra. W-phase CMT (red) and global CMT (blue) solutions (top left) are very similar. Examples of observed waveforms (black lines) and corresponding predictions (red) computed for the W-phase solution are shown for a selection of representative, globally distributed stations, listed by station name, channel and component. The station azimuth and epicentral distance are listed; the W-phase time window is indicated and bounded by the red circles.

Sumatra on 25 October 2010. A key strategy to quickly identify such earthquakes is to use long-period seismic observations, which convey information regarding the complete seismic moment, rather than just short-period characteristics of the rupture. Typically, however, long-period surface waves travel slowly compared to short-period body waves, thus their use in analyzing tsunami earthquakes is delayed. A recent effort to reduce the time for such characterizations involves W-phase inversion. The W-phase, first identified after the 1992 Nicaragua tsunami earthquake, is very long-period energy. It arrives during the body waves and has high group velocity surface wave overtones. The long-period energy propagates predominantly through the mantle, thus it is insensitive to shallow heterogeneity. These qualities make the W-phase ideal for rapid and accurate characterization of the earthquake centroid moment tensor, especially for extremely large events such as the 2004 Sumatra earthquake for which ordinary surfaces waves go off scale and are unusable (Figure 1). W-phase inversion can exploit the GSN global station distribution and reliability estimate the seismic moment tensor for large events within 15 to 30 minutes, and has now been used in real-time operations at the USGS for over two years. Combined with other measures such as traditional seismic magnitudes, the tsunami-generating potential of large events, including tsunami earthquakes, can be rapidly assessed.

Rapid event characterization and timely hazard assessment are only the initial use of GSN data for earthquake quantification. Research efforts that use all seismic signals, combined with other information such as geodetic, geological, and tsunami records, are subsequently pursued to characterize the source process. Short-period and broadband signals are used to image the rupture-front propagation and the space-time variability in slip along the fault. Figure 2 shows the slip distribution estimated using teleseismic body and surface waves radiated from the 25 October Sumatra tsunami earthquake. The observations favor a low rupture propagation speed, similar to other tsunami earthquakes. Comparison of the 2010 slip region to those of two large earthquakes in 2007 shows that the ruptures are adjacent, with little overlap. Establishing kinematic constraints on ruptures and the relationships between ruptures are important steps toward understanding the dynamics of subduction earthquakes and earthquakes interactions in general.

Looking forward, the long-term continued operation, archiving, and open access of GSN (and many other network) observations are important tasks facing earthquake seismologists. Many fundamental discoveries may only yield to future investigations based on the growing archive of seismic observations provided by the GSN and similar seismic networks that it helped inspire.

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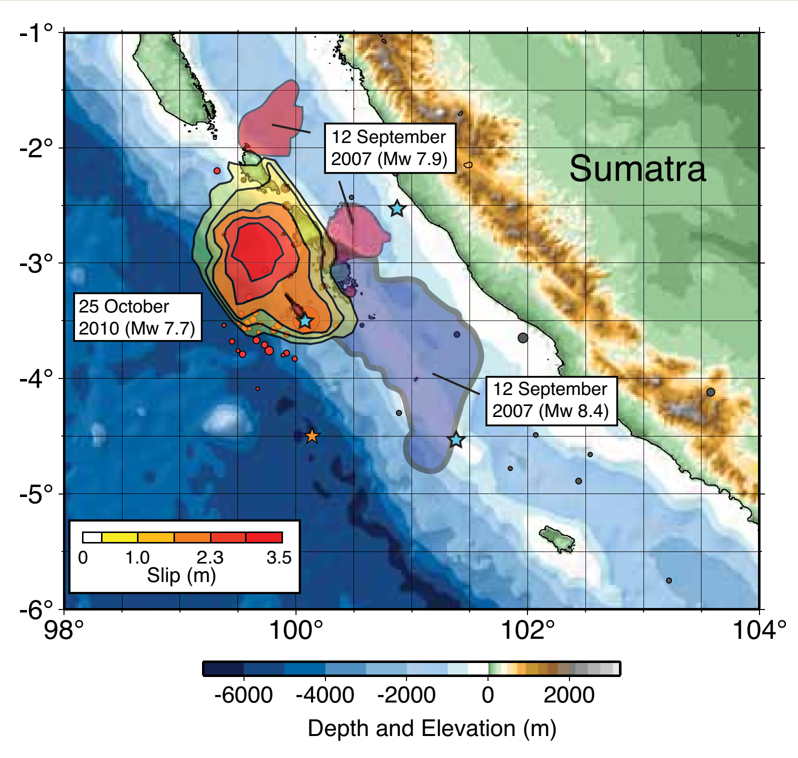
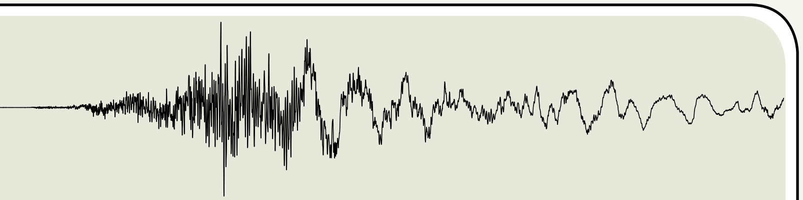


Figure 2: Map showing slip distribution of the Mentawai earthquake (yellow-red shading, scaled by slip magnitude), obtained by the inversion of P, SH, and R1 source time functions. The base map shows the large-slip regions of the 12 September 2007 Kepulauan (pink) and Sumatran (blue) earthquakes, overlain on the source region bathymetry and topography. Blue stars show the epicentral locations of each event, and red circles show aftershocks of the 2010 earthquake. The orange star depicts the upper left corner of the fault model.

PASSCAL



Recording of an aftershock of the great Maule, Chile, earthquake of 2010. The recording was made as part of the IRIS CHAMP deployment—an NSF-RAPID-sponsored community effort that deployed 58 seismic stations in Chile in the weeks following the February, 2010 M8.8 Chile earthquake. The recording shown here was made at station QC10 just 16 days after the mainshock, at which point 13 of the 58 CHAMP stations were already installed and recording data. The CHAMP stations were installed by PASSCAL staff along with volunteers from the US and Chilean scientific communities. The stations used a combination of PASSCAL and EarthScope Flexible Array instrumentation managed by the PASSCAL Instrument Center, and recorded thousands of aftershocks during their seven-month deployment in Chile. The aftershock shown here was an M6.1 event, just 190 km from the station. The seismogram is 200 seconds long and is unfiltered.

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University of Colorado PI Anne Sheehan buries a Texan geophone for the Bighorn Arch Seismic Experiment (BASE). The data logger is bagged and also buried to reduce temperature fluctuations inside the unit. This seismometer is powered by two D-cell batteries. (Photo: Anne Sheehan)

Jeremy Silver (CU) digging a trench for the short period seismometer's cables. The seismometer, in the pink box, will be buried at the end of the trench. The battery, GPS, and data logger are in the box with the solar panel and will be left on the ground all summer. (Photo: Anne Sheehan)

The ability to configure portable sensors as networks and arrays anywhere in the world has enabled seismologists to focus measurements on specific sources of interest and bring scientific understanding of Earth to new levels. The Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL) facilitates geophysical investigations by supporting a pool of portable seismographic instrumentation for loan to diverse scientific and educational communities. Access to professionally supported state-of-the-art equipment and standardized archived data has revolutionized the way US investigators conduct seismological research. PASSCAL provides turnkey instrumentation and data services, including the integration of experiment planning, logistics, training, and field support. Its staff also provides hardware, software, and engineering services, which enable the seismological community to conduct numerous customized scientific investigations each year. Over its history, PASSCAL has supported more than 600 deployments to image plate boundaries, cratons, orogenic systems, rifts, faults, and magmatic systems.

PASSCAL experiments range from small classroom exercises to large-scale global investigations. Collaborative studies like the Bighorn Arch Seismic Experiment (BASE), and program-level efforts such as PASSCAL Polar activities, demonstrate how PASSCAL exceeds the data-collection capability of any individual research group. Scientists and project teams can focus on optimizing science productivity, rather than supporting basic technology and engineering. Departments and institutions of various sizes and capacities can compete on equal footing in seismic instrumentation and measurement capabilities. Because of PASSCAL's experiment support, scientists working outside of traditional seismological subfields can undertake new and multidisciplinary investigations. PASSCAL continues to play a substantial roll in enabling international seismologists to collaborate

BASE project members on the east side of the Bighorns lived in a five-bedroom rental house on the outskirts of Buffalo, WY. Photo shows stacks of geophones on the porch. (Photo: Anne Sheehan)

Volunteers spent one to two weeks helping BASE by deploying portable seismometers in and around the Bighorn Mountains of northern Wyoming. Along with other field adventures, volunteers helped program the seismometers, and in pairs deployed 30-40 seismometers per day. Shown here is a completed broadband installation. (Photo: Anne Sheehan)

and to facilitate studies by either initiation or augmentation of experiments.

PASSCAL supports an open data policy, and the principal investigators agree to archive all data collected with PASSCAL instruments at the IRIS Data Management Center (DMC) within a prescribed period. Standardized equipment and data formats greatly advance long-term data archiving and data re-use for novel purposes. Many groups in the United States have adopted the IRIS standards for instrumentation facilities, data archival, and the open exchange of information. The scientific success of “open exchange” by seismological networks has inspired other US data collection groups to embrace the open data culture. As a result, obligatory data archival requirements and standards have increasingly been stipulated by federal agencies.

During the 2010 field season, PASSCAL supported 70 new experiments and 40 ongoing experiments carried over into 2010 from previous years. Experiments recording natural sources amounted to roughly 1175 broadband and short-period stations (PASSCAL: 480 broadband, 280 short-period, and 45 polar broadband; USArray Flexible Array: 220 broadband and 150 short-period). Ten experiments used single-channel “Texans” to record man-made sources, accounting for over 5000 stations deployed in 2010. PASSCAL Instrument Center (PIC) staff sent to the DMC for archiving over 4 TB of data from 51 unique PASSCAL-supported experiments.

In 2010, PASSCAL Polar Support Services supported 19 new and ongoing experiments in the Antarctic and Arctic. PASSCAL Polar Support Services continues to provide support for the POLENET and AGAP stations that comprise a total of 46 broadband stations. These two networks operated year-round for three years with better than 90% data return. This year also marks the first field season for the Greenland Ice Sheet Monitoring Network (GLISN), with the acquisition, fabrication, and installation of seven new seismic stations. PIC staff is providing network installation, monitoring, and data archiving support for a portion of GLISN. The Polar Support Services group has also worked closely with the ANDRILL project and RefTek to develop two hydrophones that were successfully deployed under the Ross Ice Shelf, Antarctica.

A solar panel provides sufficient power to keep the seismometer and telecommunications working, even in cold weather. (Photo: Anne Sheehan)

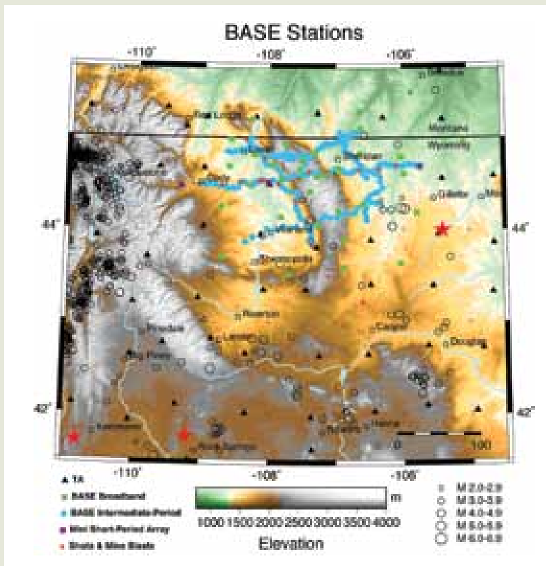
The PIC supported the NSF-funded Rapid Array Mobilization Program (RAMP) response to the magnitude 8.8 earthquake that occurred off the coast of Chile on February 27, 2010. PASSCAL staff provided logistics, field, and data support for the 60-station broadband array. The project collected an open, community data set that is available from the DMC.

The Bighorn Arch Seismic Experiment (BASE):

A Multifaceted Investigation into Foreland Arches

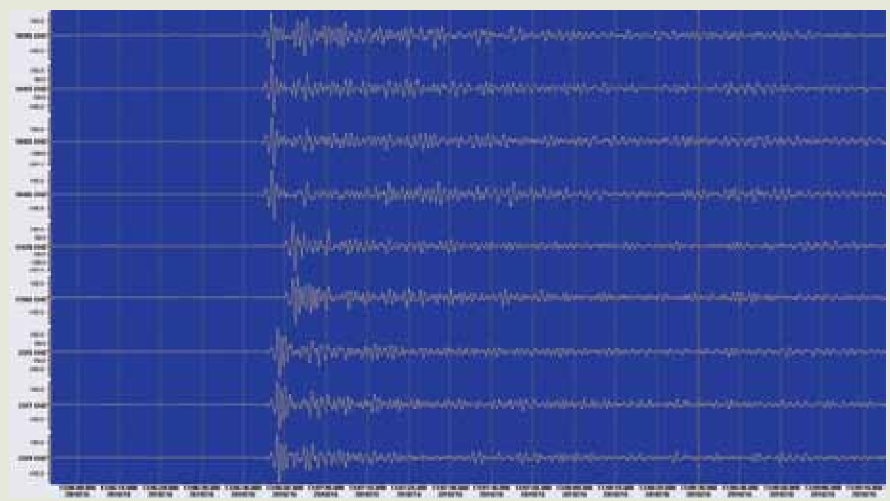
Melissa Dozier and Will Yeck, University of Colorado

Many a happy family vacation has begun by packing up the station wagon and traveling west along I-90 from the eastern plains. Excited to leave the plains and explore the beautiful topography of the western United States, these families are first greeted by the magnificent Big Horn Mountains of north central Wyoming. A precocious and budding young geologist in the back seat might raise the question: "how could the Big Horn range form not only so far away from a tectonic margin, but so distinctly from the rest of the Rocky Mountains?" Though she probably gets punched by her brother, she raises one of the fundamental questions that the Bighorn Arch Seismic Experiment (BASE) was designed to untangle. The Big Horn Mountains are a Laramide foreland arch whose formation history, like most basement-controlled foreland arches, remains mysterious. BASE combines structural studies with both passive- and active-source seismic experiments in an effort to understand the tectonic processes that control the formation of these basement-cored arches, and the formation of foreland arches worldwide.

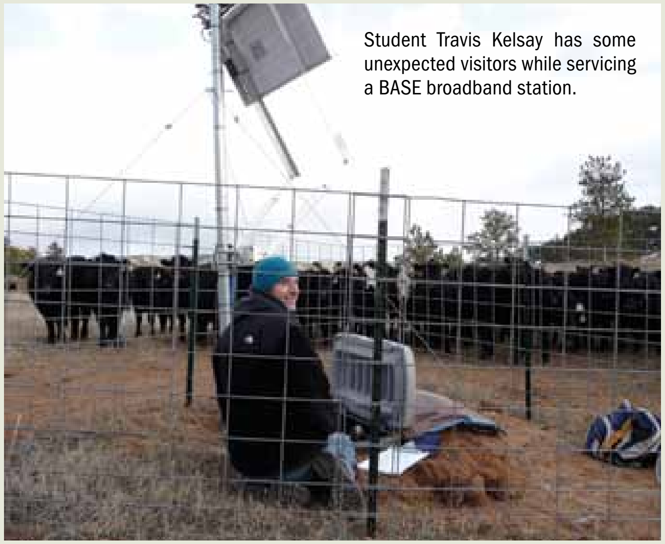


Map of BASE-deployed three-component instruments. Green squares show broadband stations emplaced to densify the preexisting Transportable Array backbone. Blue dots represent intermediate-period station placement along five main transects. Purple squares show locations of five-station short-period mini arrays.

BASE commenced answering this question in the summer of 2009 by densifying the region's extant USArray Transportable Array grid with 38 broadband stations. These stations remained in place until the fall of 2010. One hundred seventy-two intermediate-period stations (CMG40T-1s and L22) were deployed in the spring of 2010 along five transects that cut across and alongside the Big Horns. These instruments were spaced at intervals ranging from 4–10 km. The primary purpose of the intermediate-period stations was to ensure quality, 2D cross sections of the Big Horns' subsurface structures. This large-scale deployment of intermediate-period instruments was made feasible by PASSCAL's development of quick-deploy boxes. Each box is shipped with all of the necessary equipment for a station to run, including a RefTek RT130 data logger, solar panel, GPS, seismometer (depending on type), and power regulator. All that the user needs to do is direct bury the sensor, place the solar panel

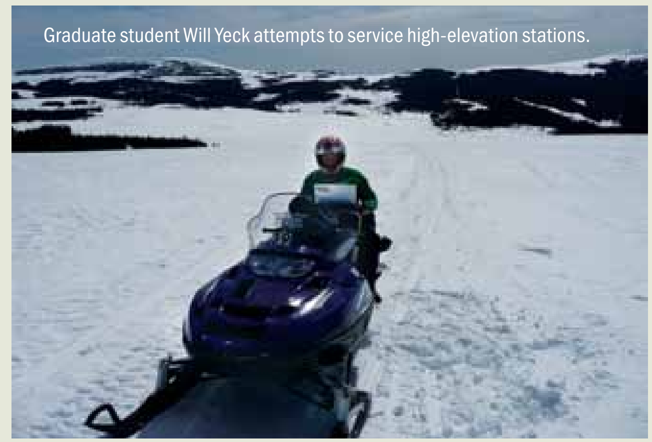


P-wave arrivals from a magnitude 6.4 Alaskan earthquake were clearly recorded across the entire passive Texan array. Filtering showed clear teleseismic arrivals on Texan instruments.


Student Travis Kelsay has some unexpected visitors while servicing a BASE broadband station.


Quick-deploy boxes allowed fast intermediate-period deployment as well as gave stations a low profile.


PI Anne Sheehan and student Jeremy Silver search for a Texan instrument.


Graduate student Will Yeck attempts to service high-elevation stations.

on the top of the box, add a battery, connect some cables, and start the RT130. With this all-in-one technology, experienced deployers could install or remove a station in less than an hour. Three collocated five-instrument, intermediate-period arrays were additionally installed by Los Alamos National Laboratory for discrimination studies. Wyoming coal mines produce around 40% of the United State's coal, and provided a plethora of local blast sources that will add to our already large data pool. In total, BASE installed 210 three-component seismometers.

BASE didn't stop there, though. Over four weeks beginning in July 2010, we deployed nearly 2000 single-component geophones, recording 24 active-source blasts, and two weeks of continuous passive-source recording. Texan recorders with 4.5-Hz geophones were deployed along the same five transects as the intermediate-period stations, with spacings of 500 m and 1 km. This labor-heavy deployment required such a large number of volunteers that our project doubled the population of Shell, Wyoming, the small town where we based our project. Over 40 volunteers converged in Shell and Buffalo from schools around the country, including Keck consortium students, IRIS interns, and mentored undergraduate students. Keck students performed both structural geology and seismic studies. Students have and will continue to play a key role in BASE.

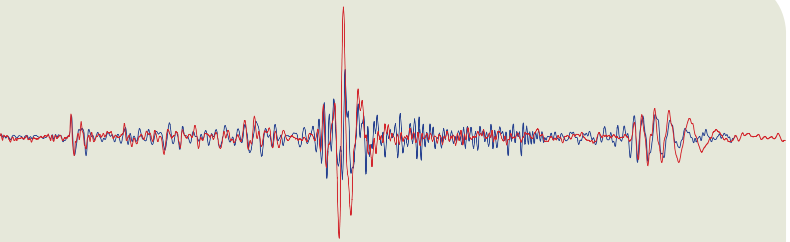
The deployment of Texans for a passive-source experiment is an innovative use of these instruments, which are more commonly used for short, active-source deployments. Texan instruments were deployed for two weeks and captured both regional and teleseismic events, including a magnitude 4.8 earthquake in Jackson Hole, Wyoming, and a magnitude 6.4 Alaskan earthquake. By incorporating these teleseismic events with active shots, it will be possible to use tomography to delve deeper into the structure of the Big Horns.

In addition to seismic data, we continue to collect structural data in order to learn more about Big Horn deformation history and ensure that subsurface interpretations correlate with surface observations. The combination of these techniques will greatly add to the understanding of base-cored foreland arches and, hopefully, satisfy the curiosity of future visitors to the western United States and basement controlled foreland arches around the world.

For more photos and PI contact information, go to: http://www.bighorns.org.

PIs for the Bighorn Project include Anne Sheehan (University of Colorado), Kate Miller (Texas A&M), Eric Erslev (University of Wyoming), and Christine Siddoway and Megan Anderson (Colorado College).

DMS



M7.6 2009-09-30 10:16:17 UTC, southern Sumatra, Indonesia
IU ANMO: recorded (blue) and Princeton 3D synthetic (red).

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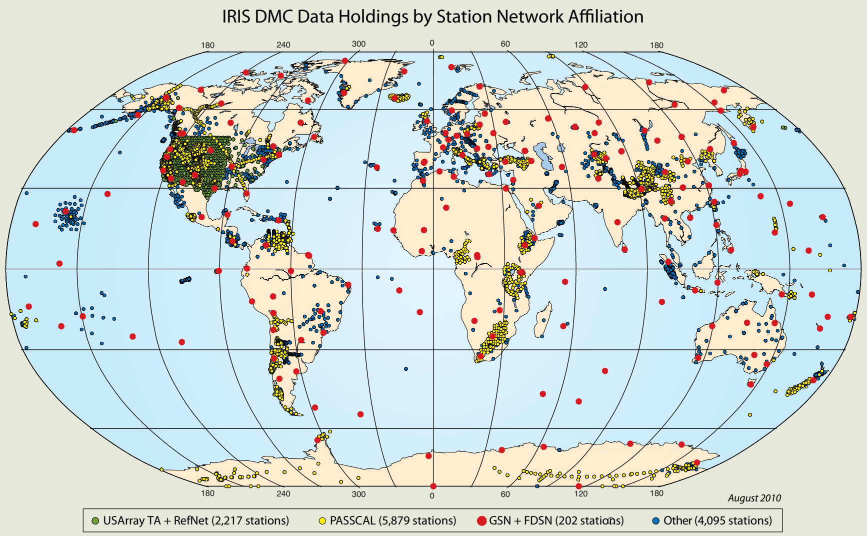


Figure 1. This map shows all of the stations that have contributed data to the IRIS DMC in SEED format and covers the time range 1970 until present. The color coding is green for USArray stations, yellow for PASSCAL stations, red for GSN and FDSN stations, and blue for all other stations. There are a total of 14,000 stations that have data at the DMC.

DMS Core Services

The heart of the Data Management System (DMS) is the Data Management Center (DMC) located near the University of Washington in Seattle. The DMC has evolved into the largest seismological data center of its kind in the world. Central to the DMC is the large archive of waveform data. Figure 1 shows the locations of all stations that have contributed data to the IRIS DMC. The DMC archive includes data from 127 permanent networks and, perhaps more impressively, 288 temporary experiments from programs such as PASSCAL (USA), SEIS-UK (United Kingdom), SEISMOB-FR (France), as well as the Ocean Bottom Seismometer Instrumentation Program OBSIP (USA). As of July 1, 2010, the DMC managed approximately 120 TB of waveform data (Figure 2) and it was growing at about 20 TB per year.

Unlike many scientific data centers, a large international community actively uses the IRIS DMC. In fact, 4.5 times more data are distributed each year than new data received from operating networks. In 2010, the DMC shipped more than 90 TB of data to data requestors (Figure 3).

Regional Exchange of Earthquake Data (REED)

For the past three years, the DMS has been developing the REED project. This project focuses on helping seismic networks acquire the capability to transmit data in real time to neighboring countries and to international data centers such as the DMC. Generally, the REED project supports networks' acquisition of telemetry equipment or, in some cases, the small costs of data telemetry. During the 2010 fiscal year, the REED project supported data exchange from the Tajik

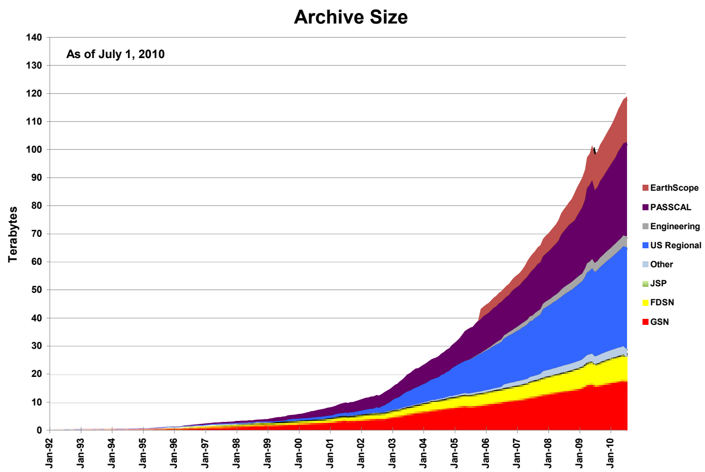


Figure 2. The DMC archive. The archive grew to just under 120 TB by the end of June 2010. The contributions are from the bottom to the top: (1) GSN, (2) FDSN, (3) JSP, (4) miscellaneous networks, (5) US regional networks, (6) engineering Networks, (7) PASSCAL and other temporary networks, and (8) EarthScope. The largest data contributors are US regional networks funded primarily by the USGS.

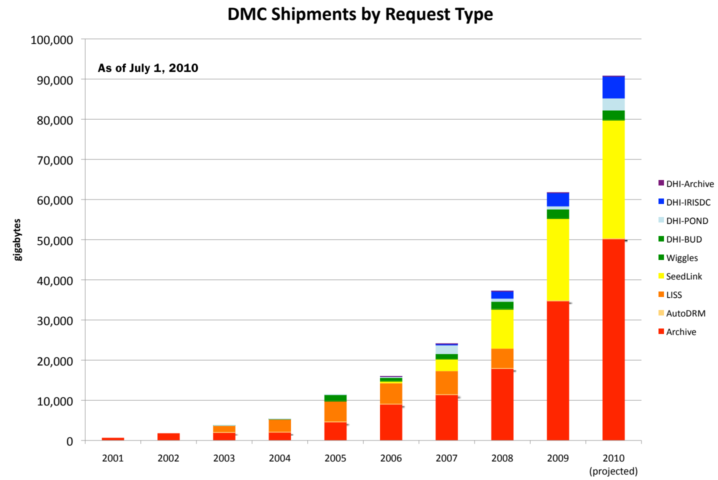


Figure 3. Volume of data shipped from the DMC. The DMC shipped roughly 90 TB of waveform data in 2010 to thousands of seismologists worldwide. Fifty TB were sent via traditional request mechanisms such as NetDC and BreqFast, 30 TB were sent using SeedLink real-time feeds, and roughly 10 TB were sent using the Data Handling Interface (DHI) and through web services.

National Seismic Network (TJ), the Kazakh National Network (KZ), and the new Kyrgyz National Network (KR). The next focus area for the REED project is in the Southwest Pacific as island nations in that region are interested in data sharing and data management, usually through the DMC. Interested groups include Vanuatu, New Caledonia, and Tonga, and some data exchange has already started. The REED project helps make valuable data available to the seismological research community.

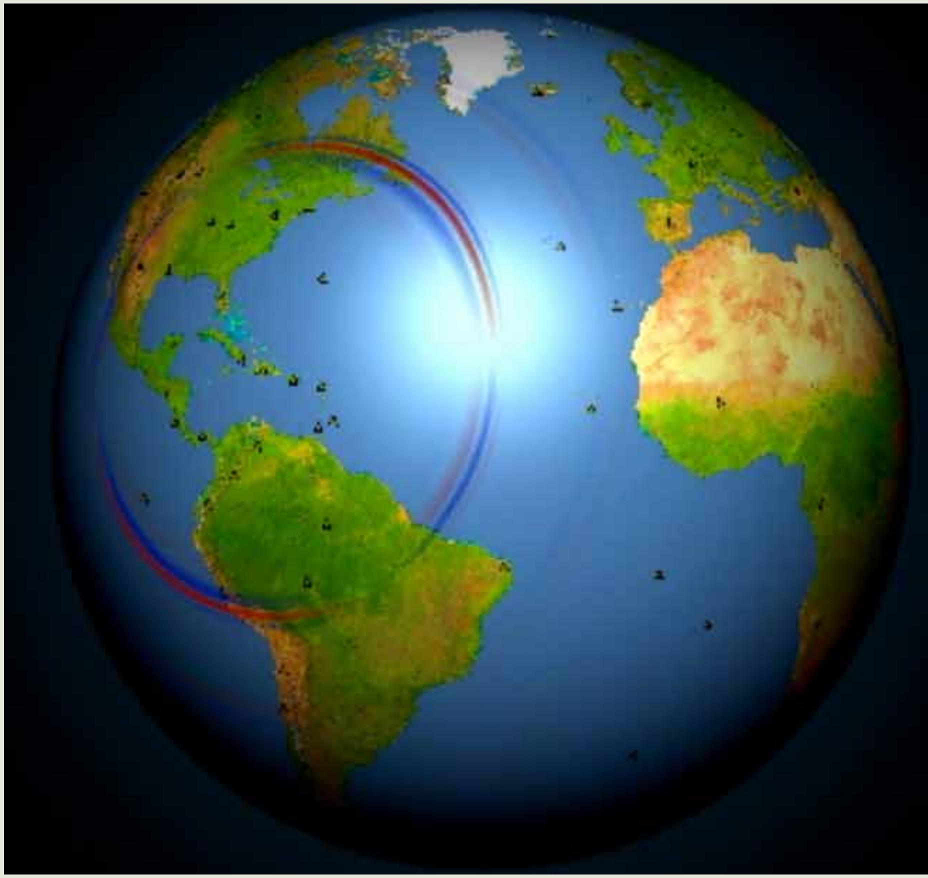
Products and Services

The DMC now offers higher-order data products that complement the raw time-series data traditionally managed by it. These data products are either submitted by the community to the DMC or generated at the DMC. The nomenclature for data products includes: Level 0 – raw waveforms, Level 1 – quality assured data, Level 2 – derived information (noncontroversial processing), Level 3 –seismological research products, and Level 4 – integrated research products. While Level 0 and 1 products have been the traditional output of the DMC, Levels 2–4 are new. Level 2 products include such things as Ground Motion Visualizations, event plots (a suite of figures automatically generated following all M6.0+ events, including phase-aligned record sections, global body wave envelope stacks, and regional-scale vespagrams) receiver functions from the University of South Carolina-developed EARS (EarthScope Automated Receiver Survey) system, calibration information for GSN stations, USArray magnetotelluric transfer functions, USArray phase picks, global CMTs, and SAFOD spectrograms. Level 3 products include tomographic models with visualization capability and synthetic seismograms computed as part of Jeroen Tromp's research efforts at Princeton University (see pages 16–17). The DMC developed a system to manage these various products. The Searchable ProdUct Depository (SPUD) is the DMC's answer to product management and discovery. SPUD can be accessed at http://www.iris.edu/spud. These higher-level products are expected to become available in 2011, but much of the groundwork has been done this year. As the type and number of products continue to grow at the DMC, we believe SPUD will become a valuable resource that will enable research within the Earth science community.

The DMC has also been actively working on the development of a variety of web services, including data access services that will allow programmatic access to waveforms, metadata about the waveforms, as well as event information from USGS and ISC catalogs. The DMC is also developing processing services that will enable users to preprocess waveforms through digital signal processing techniques such as filtering, instrument correction, and rotation of components. More information about these web services can be found at http://www.iris.edu/ws. While these services are intended to be accessed by client applications, for small requests they can be accessed through a web browser.

Synthetic Seismograms for Global CMT Earthquakes

Jeroen Tromp, Princeton University, Department of Geosciences and Program in Applied & Computational Mathematics



Snapshot of a spectral-element simulation of the January 12, 2010, M_w = 7.1 Haiti earthquake. The near-real-time system produces animations of all earthquakes reported by the Global CMT Project. The animations show the velocity wavefield on Earth's surface as a function of time. Red: upward motion; Blue: downward motion.

Prompted by a notification from the Global Centroid Moment Tensor Project (globalCMT.org; Dziewoński et al., 1981), Princeton University now routinely calculates normal-mode synthetic seismograms for the Preliminary Reference Earth Model (PREM; Dziewoński and Anderson, 1981) and spectral-element synthetic seismograms for 3D mantle model S362ANI (Kustowski et al., 2008), in combination with crustal model Crust2.0 (Bassin et al., 2000). One- and three-dimensional synthetics for more than 1800 seismographic stations operated by members of the International Federation of Digital Seismograph Networks (FDSN) are provided via the Internet (http://global.shakemovie.princeton.edu; Tromp et al., 2010) and will soon also be available via the IRIS DMC. The record length is 100 minutes for earthquakes with magnitudes less than 7.5, such that the first-arriving Love and Rayleigh waves are included at all epicentral distances. For earthquakes with magnitudes of 7.5 and greater, the record length is 200 minutes, thereby incorporating one complete surface-wave orbit at all epicentral distances. The synthetic seismogram data base currently contains more than 1000 events.

For PREM, the system calculates normal-mode synthetics accurate at periods of 8 s and longer (e.g., Gilbert, 1971; Dahlen and Tromp, 1998). Three-dimensional synthetics for mantle model S362ANI in combination with Crust2.0 are calculated based on a spectral-element method (SEM; Komatitsch and Vilotte, 1998; Komatitsch and Tromp, 1999, 2002a,b; Chaljub et al., 2003). SEM synthetics are accurate between periods from 17 s to 500 s. Simulations incorporate effects due to attenuation, rotation, and self-gravitation in the Cowling approximation. The spectral-element mesh honors all first- and second-order mantle discontinuities in 1D reference model STW105 (Kustowski et al., 2008). Ellipticity is accommodated by transforming all first- and second-order discontinuities in the 1D reference model into ellipsoids. Surface topography and bathymetry are incorporated in the mesh using model ETOPO1 (Amante and Eakins, 2009), which has a resolution of one arc minute.

Lateral variations in crustal thickness are provided by model Crust2.0 (Bassin et al., 2000), a 2° × 2° block model that is smoothed with a 1° Gaussian cap. The crust of the 1D reference model is removed and replaced by mantle, which is subsequently overprinted by Crust2.0. Sedimentary layers in Crust.2.0 are incorporated if sediment thickness is 2 km or greater. The spectral-element mesh honors the Moho if crustal thickness is less than 15 km (oceans) or greater than 35 km (continents). In transition regions, the Moho runs across the mesh and is captured by the numerical integrations points, as in a finite-difference method.

In addition to synthetic seismograms, the system produces a number of earthquake animations, as well as various record sections comparing simulated and observed seismograms. The duration of the animation scales linearly with the size of the earthquake. The movies show the velocity wavefield on Earth's surface as a function of time, as illustrated by the snapshot shown in Figure 1 for the January 12, 2010, Haiti earthquake.

Time permitting, the system will be used to analyze past earthquakes. The CMT catalog contains tens of thousands of entries, and any available spare compute cycles will be used for the analysis of past events, such that, ultimately, 1D and 3D synthetics for all earthquakes in the CMT catalog will be available. When the Global Centroid Moment Tensor Project "upgrades" to a new 3D model, so will the near-real-time system. Soon synthetics will also be available from the IRIS DMC via the same request and access mechanisms as recorded data.

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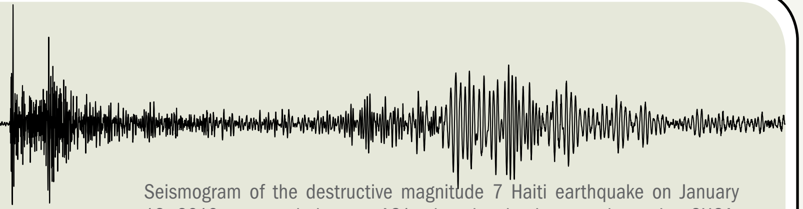
E&O



Seismogram of the destructive magnitude 7 Haiti earthquake on January 12, 2010 as recorded on an AS1 educational seismograph, station CHCA, at Calavera Middle School, Carlsbad, CA. The earthquake focused global attention on the need to provide seismic hazards education.

Standing Committee

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Juan Lorenzo	Louisiana State University
Gary Pavlis	Indiana University
Wayne Pennington	Michigan Technological University
Suzan van der Lee	Northwestern University
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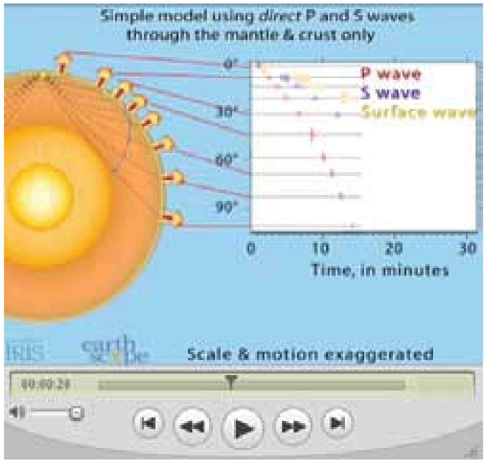
IRIS Management

John Taber



Simple animations help teachers and college faculty convey complex topics.

Using a hammer seismograph at the Intern orientation.

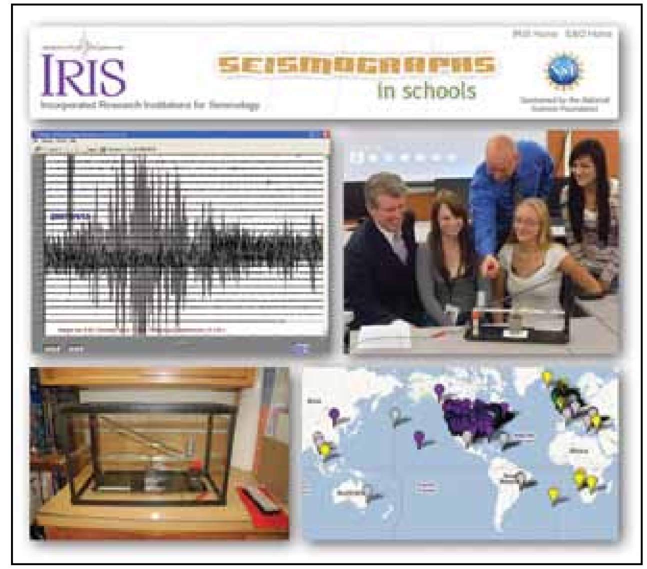
The IRIS Education and Outreach (E&O) program is committed to advancing awareness and understanding of seismology and Earth science while inspiring careers in geophysics. The E&O program develops and disseminates a suite of educational activities designed to have an impact on 5^{th} grade students to adults in a variety of settings, ranging from self-exploration in front of one's own computer, to the excitement of an interactive museum exhibit, to a major public lecture, or to in-depth exploration of Earth's interior in a formal classroom.

In the past year, the efforts of the E&O program have focused primarily on expanding the impact of existing activities. A major new addition is the production of Teachable Moment (TM) presentations following major earthquakes. TM presentations, produced in collaboration with the University of Portland, are generally posted to the IRIS web site within 24 hours of the event. Each presentation is formatted in a way that allows a middle school through college educator to tailor the materials to their particular audience and time frame. Common elements include USGS earthquake and volcano information, plate tectonic and regional tectonic maps and summaries, custom-generated computer animations, seismograms, photos, speaker notes, and other event-specific information, some of which is contributed by IRIS consortium members.

Our summer internship program (14 students in 2010) continues to thrive via a Research Experiences for Undergraduates grant from NSF and through positions funded by IRIS community research programs (see pages 20–21). IRIS is a partner with UNAVCO's RESESS program that is designed to provide multiyear research experiences for students from underrepresented groups, with some students joining the IRIS student cohort in their final year. IRIS interns began the summer with a one-week orientation hosted by New Mexico Tech and then spent the rest of the

Left: Teachers conduct an experiment modeling the recurrence behavior of earthquakes.

Images at right: Educational seismographs have been provided to schools throughout the United States, where they often attract the attention of the community. The web interface allows educational stations and networks throughout the world to share data and ideas.



Classroom photo courtesy of *Times-News*, Twin Falls.

summer engaged in research at 12 different IRIS institutions, where they kept in touch with each other via Internet blogs and discussion boards. Of the 99 students who have participated in the program since 1998, over 85% of those who have completed their undergraduate degree have gone on to graduate school in the geosciences, often at school where they did their internship.

The E&O web pages are the primary means of dissemination of information and resources and we continue to add new material, with an emphasis on animations and short instructional videos. A significant increase in the number of visitors to the site has been achieved by examining all of the delivery venues for educational content, followed by revisions and reorganizations across the web site, increased use of social networking sites, and encouraging other groups to link to our materials. Our newest poster featuring wave propagation across the USArray Transportable Array is also linked to a new student-centered web entry point.

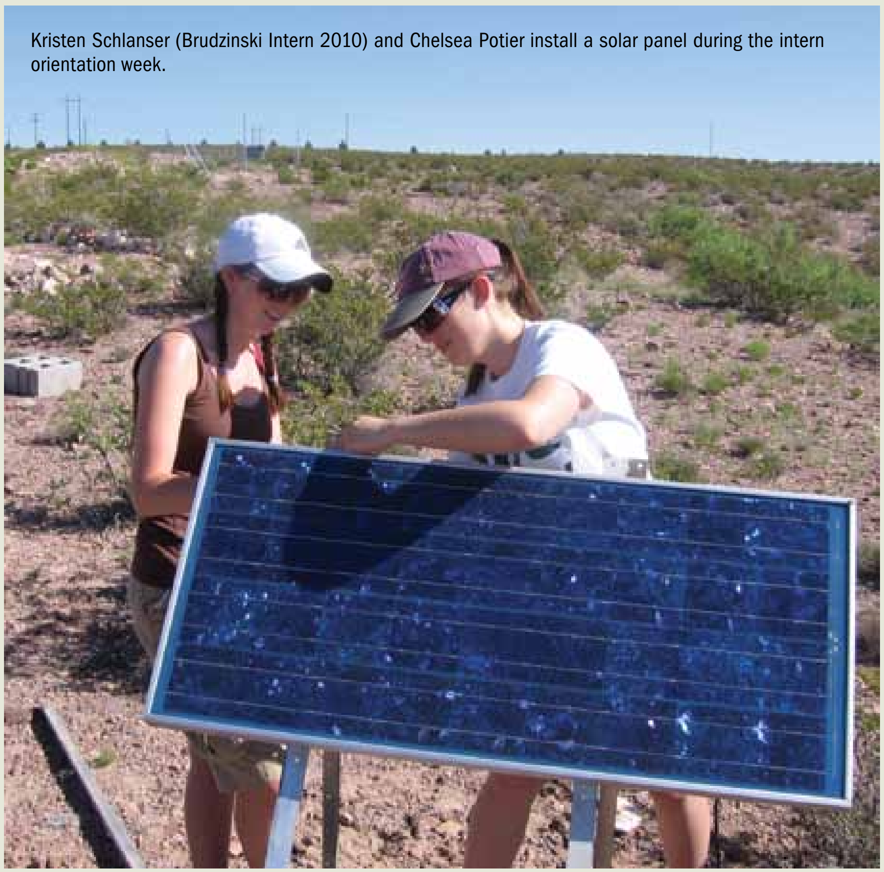
Millions of people have interacted with IRIS/USGS museum displays, many of them at the American Museum of Natural History in New York and the Smithsonian Institution National Museum of Natural History in Washington, DC. However, a growing number of people explore seismological concepts through our newest display, the Active Earth Display (AED). The AED is a smaller, more flexible version of the museum display, and is now in use at universities and visitor centers throughout the United States. Served via a web browser, the display is customizable and the software is available to anyone who applies via the IRIS E&O web pages. Touch screens provide an interactive experience and new content continues to be developed, including a new set of pages focusing on the Basin and Range region. Another program aimed at general audiences is the IRIS/SSA Distinguished Lecture Series, where two speakers are selected each year from a pool of nominees generated from the IRIS community. These lectures reach a broad sector of the public through venues that often have a well-established lecture series.

The E&O program provides professional development experiences designed to support the needs of formal educators. For example, a 2.5-day workshop is held in collaboration with Penn State and North Carolina A&T as part of the AfricaArray project. In addition, a series of short workshops are held each year as part of the National Science Teachers Association annual meeting and a 2.5-day operators workshop is offered to teachers who use AS1 seismographs in their classroom. More than 170 such seismographs have been distributed by IRIS E&O to schools around the United States, and over 375 users of educational seismographs from 42 states and 16 countries have at some time registered their station in the IRIS Seismographs in Schools database. The Seismographs in Schools web site helps teachers make use of seismic data and communicate with the growing global community of educational seismograph users.

The Symbiosis Between the IRIS Internship and Faculty Hosts

Mike Brudzinski, Miami University of Ohio

The IRIS Research Experiences for Undergraduates (REU) program, while focused on the needs of students, also provides benefits to faculty at various stages in their career. I have become quite familiar with this program in the time since Miami University was first selected as a host institution in 2007, as I have had an opportunity to serve as an intern research advisor in each year since. The most distinguishing aspect of this program is that it does not simply collect student applicants and place them with research advisors. Instead, the program provides a critical week-long classroom and field orientation created with seismology researchers, a cyberinfrastructure developed to maintain a cohort of students conducting research at geographically separated institutions, and the opportunity to present their research at the annual fall AGU meeting. Together, these features generate an undergraduate research experience that goes well beyond the typical summer project an individual researcher like me can provide.



Kristen Schlanser (Brudzinski Intern 2010) and Chelsea Potier install a solar panel during the intern orientation week.

One of the most important issues facing geosciences and science in general is the growing disparity between the workforce needs and our ability to produce well-trained students. Current trends indicate a remarkable 20% growth in employment opportunities over the next 10 years, while the number geosciences and science graduates is expected to stay flat. The IRIS REU is clearly one of most creative and effective ways to engage and retain college undergraduates in geosciences. I have been extremely fortunate to be part of this program in my first few years as a pre-tenure faculty when recruiting students is particularly difficult. In fact, my experience is similar to others who have had students enjoy the experience so much that they decide to continue the research either in subsequent summers or as graduate students. Two of my current graduate students are former interns (I hosted one of them), and my two other former interns are both in graduate seismology programs after continuing their undergraduate research with me in subsequent summers.

As a program host, I have offered students the opportunity to work in the emerging field of episodic tremor and slip (ETS). Thanks to the discovery of ETS less than a decade ago, there have been many aspects of tremor and slip in need of investigation, as well as nearby earthquakes and plate boundary structure, that allow undergraduates to contribute to the leading edge of science. My IRIS interns have contributed to both field and lab studies each summer, including work on tremor detection, locating earthquakes near ETS, tomography of ETS zones, and tremor location in several subduction zones. These studies have built fundamental aspects of my research program, such that the IRIS REU has been just as instrumental in my career as it has been for the interns.

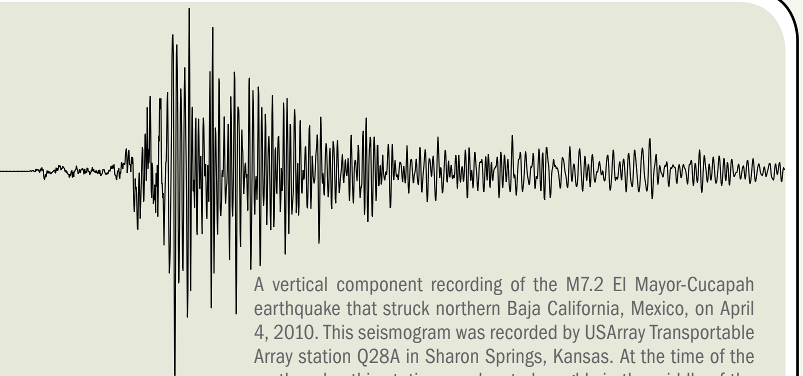
To expand my own undergraduate research initiatives and to help support the IRIS REU, I submitted an NSF CAREER proposal to support two undergraduates annually, one selected from Miami University and one from the IRIS REU applicant pool. Both students are integrated into the orientation, online discussions, subsequent AGU presentations, and overall structure of the IRIS REU. The IRIS REU–Miami University collaboration leverages the infrastructure developed to serve undergraduates through IRIS REU site funding as well as the in-kind contributions of the IRIS E&O staff to manage and staff the program, and senior scientists from within the IRIS community to provide instruction during the week–long orientation. The extra funding at Miami University ensures that the student cohort can grow to impact a larger set of undergraduates, and serves as a model for other research universities and institutions. This past summer marked the first year of implementing this approach, and I'm happy to report that both students successfully presented new observations of tremor in Mexico and Alaska at the fall AGU meeting while enjoying the camaraderie of their fellow interns.

Mike Brudzinski with grad students Hector Hinojosa-Prieto and Devin Boyarko and summer intern Stefany Sit (now a grad student with Brudzinski) taking a break from Cascadia Subduction Zone field work to pose for pictures at Crater Lake.

Above: IRIS Interns set off to make connections between the macroscale processes being studied in the classroom and the local- and regional-scale geology visible from the peaks along the Rio Grande Rift.

Right: New Mexico Tech faculty lead a field trip to the Socorro Fault.

USArray



A vertical component recording of the M7.2 El Mayor-Cucapah earthquake that struck northern Baja California, Mexico, on April 4, 2010. This seismogram was recorded by USArray Transportable Array station Q28A in Sharon Springs, Kansas. At the time of the earthquake, this station was located roughly in the middle of the Transportable Array's rolling 400 station footprint. The seismogram shows an unfiltered long-period recording 1,800 seconds long.

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Karl Karlstrom	University of New Mexico
Charles Langston	The University of Memphis
Maureen Long	Yale University
Guy Masters	University of California, San Diego
David Snyder	Geological Survey of Canada
Joann Stock	Caltech
Rob van der Hilst	Massachusetts Institute of Technology
Chester Weiss	Virginia Tech

IRIS Management

Bob Busby
Katrin Hafner
Bob Woodward

Station B27A in Glenburn, North Dakota, was the 812th Transportable Array station commissioned. The station was installed in September 2009. This marks the half-way point of the Transportable Array in the contiguous United States.

USArray, the seismic and magnetotelluric component of EarthScope (http://www.earthscope.org), continued to make significant progress in the past year. At the end of June 2010, the Transportable Array had commissioned about 950 seismic stations, more than half the stations planned for the contiguous United States, and was operating in a region extending from North Dakota south to Texas. Approximately 500 locations had been vacated. The legacy of the Transportable Array also expanded with the adoption of about 10 additional stations, bringing the total to more than 40 transfers through the NSF-approved "Adopt A Station" program. Field crews continued to work at full operational levels, constructing, installing, and removing about 18 stations each month. With additional funding from the National Science Foundation, the Transportable Array also returned to Cascadia in FY2010. A total of 27 Transportable Array stations were deployed that will operate for five years and will complement other geophysical instruments being installed both onshore and offshore.

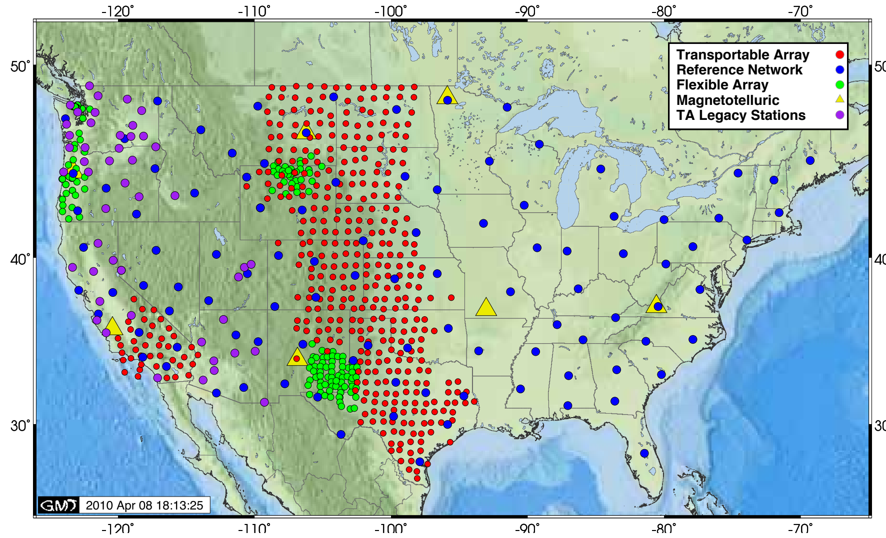
Several enhancements were introduced to the Transportable Array station design, including a package of basic environmental monitoring sensors and a vault interface enclosure that provides power regulation, protection for electronics, and uniform cable connectors. Station reliability and data quality have remained high as the array moves into different geologic regions. Transportable Array construction and data collection and distribution from the network depends on a wide range of dedicated personnel from IRIS as well as from Honeywell Technology Solutions Inc., Coastal Technologies, the Transportable Array Coordinating Office (at New Mexico Tech), the Array Operations Facility (at New Mexico Tech), the Array Network Facility (at the University of California, San Diego) and the IRIS Data Management Center.

Demand for USArray data by scientists from the United States and throughout the world has grown considerably. All USArray data, as well as PBO and SAFOD seismic data, are archived at the IRIS Data Management Center and are freely available to scientists and the public via the Internet. Nearly 27 TB of EarthScope data have been archived to date, and about 8.5 TB of data have been shipped in the past year.

The Transportable Array Student Siting Program continues to be a successful way to engage students in EarthScope. This summer, student teams identified about 130 sites for future stations on the eastern side of the Mississippi River. Since 2005, about 970 Transportable Array sites in 26 states have been identified by approximately 100 students from more than 35 universities. USArray also conducted a data processing short course for 22 advanced graduate students. Hosted by Northwestern University, the week-long course delved into the history, intricacies, and current practices for seismic data processing and examined the handling of large volumes of data from USArray stations.

The Siting Outreach component of USArray facilitates siting of USArray stations and works with numerous state and local organizations to raise awareness of EarthScope and USArray. For instance, many universities participating in the Student Siting Program have issued a news release about their role in EarthScope. In the past year, this has generated nearly two dozen stories in local newspapers and on local and regional television programs. In April, the project was featured in a USA Today

A student team installs a transportable magnetotellurics system in the shadows of the Grand Tetons during the 2009 summer field season.



article. Other outreach activities and products include the development of regional content sets for the Active Earth Display in partnership with EarthScope and UNAVCO, the creation of wave visualization movies, and a publication for landowners issued twice per year.

The Flexible Array, consisting of about 326 broadband, 140 short-period, and 1700 active-source instruments, continued to be fully utilized by principal investigators to conduct high-resolution studies that address EarthScope's scientific goals. At the end of June, there were more than 500 Flexible Array stations in the field actively recording data for six experiments. This spring, the Bighorns teams used the Flexible Array's new integrated enclosures for the deployment of 170 short-period instruments, enabling them to install as many as 14 stations in a day. These "quick-deploy" enclosures, used for both shipping and deployment, contain an entire short-period station within a single box. For deployment, the seismometer is moved outside the box and buried. The enclosures were based on a design developed by the IRIS Polar Operations team and were fabricated by the Array Operations Facility. These "quick-deploy" boxes are expected to be heavily used in future Flexible Array experiments.

The seven stations comprising the permanent magnetotelluric (MT) observatory were equipped with telemetry systems that send raw data in near-real time to the MT facility at Oregon State University. MT systems measure the natural electric and magnetic fields at Earth's surface that are caused by electromagnetic waves radiated from the sun and from distant electrical storms. These observations constrain the electrical conductivity of Earth's lithosphere and asthenosphere, and provide an excellent complement to the seismic tomography of the structure beneath North America. During the 2009 summer field season, crews placed the 20 campaign MT instruments in more than 50 locations across Montana and Wyoming. Sites were located on a 70-km × 70-km grid and were occupied for two to three weeks before being moved to the next site. More than 220 temporary sites have been occupied during the past four summers. The 2010 field campaign has already begun and will cover northern California, Nevada, and Utah.

The first Bighorns short period station was installed in April 2010 using a "quick-deploy" box. These boxes greatly reduced the time needed to deploy a station.

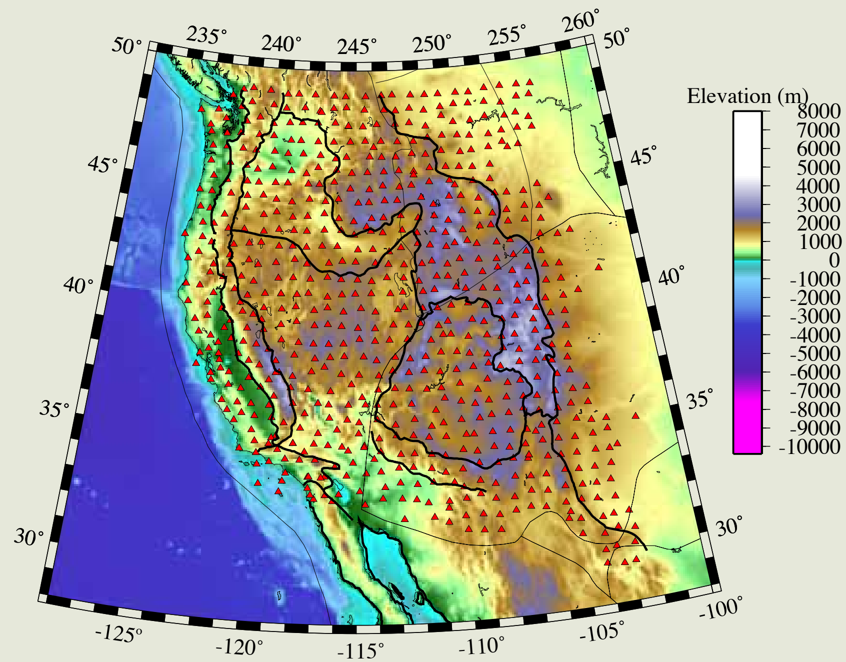
Imaging Lithospheric Structure in the Western United States Using S Receiver Functions

Meghan S. Miller, University of Southern California • Alan Levander, Rice University

A fundamental concept of plate tectonics is the presence on Earth of a strong, largely coherent outer layer, the lithosphere, moving over a weaker layer, the asthenosphere. The lithosphere forms the outer chemical, mechanical, and thermal boundary layer(s) of the convecting mantle. Both the thickness of the lithosphere and how the lithosphere is modified over time by tectonic processes are under widespread investigation. To address the debate over the lithosphere-asthenosphere boundary's (LAB's) existence and true definition, this study used signals from distant earthquakes, as recorded by the USArray Transportable Array, to create images of the LAB.

The western United States is divided into a small number of physiographic provinces (Basin and Range, Cascadia, Sierra Nevada, Colorado Plateau, and the Rocky Mountains), and each of them owes at least their most recent structure to Mesozoic-Cenozoic interactions of the Farallon, Pacific, and North American plates. However, significant deformation of these provinces has resulted from processes that deviate greatly from simple models of plate interactions. The late Cenozoic history of the western United States was shaped by the transition to transform motion (plates sliding past one another) following the northward migrating Mendocino Triple Junction and the subduction of the young Gorda and Juan de Fuca plates to the north. Southern California and the Basin and Range have experienced various degrees of extension as a result of orogenic collapse and the transition of the plate boundary from convergence to transform motion. Deformation and volcanism still occur at great distances from the plate boundary, through the Basin and Range, around the edges of the Colorado Plateau, and in the Rocky Mountains.

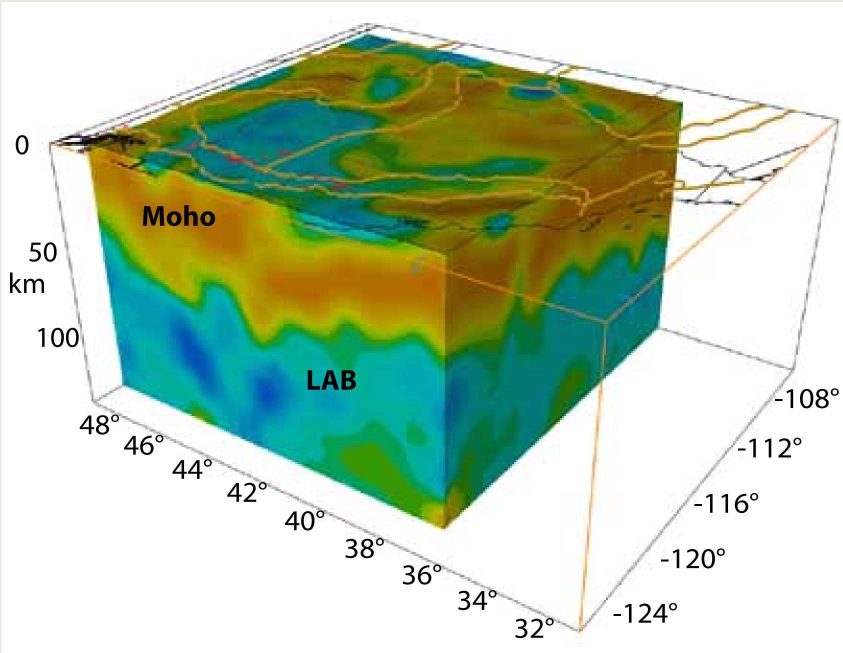
We produced common conversion point (CCP) S receiver function image volumes of the lithosphere beneath the western United States using teleseismic data recorded by the USArray Transportable Array. The S receiver functions were made from 57 earthquakes at $55° < \Delta < 85°$; the data were recorded at 556 stations from 2005 to 2009. S receiver functions are well suited to the study of the LAB, more so than conventional P-receiver functions (PRFs), because the latter often suffer from strong crustal multiple reflections following the P arrival. The use of S receiver functions



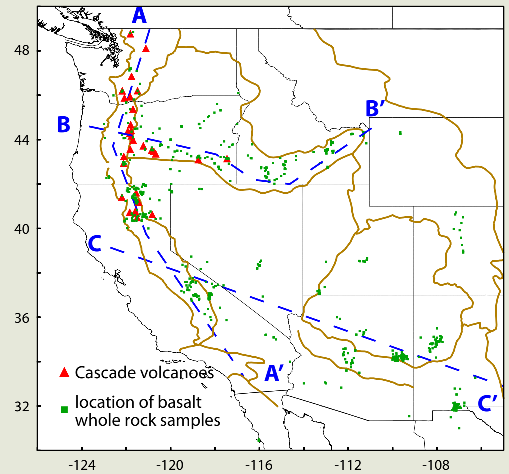
Transportable Array stations (red triangles) used to study lithospheric structure in the western United States. The dark black lines outline the major physiographic provinces.

alleviates concerns about crustal reverberations and allows for interpretation of boundaries in the depth range expected for the bottom of the lithosphere.

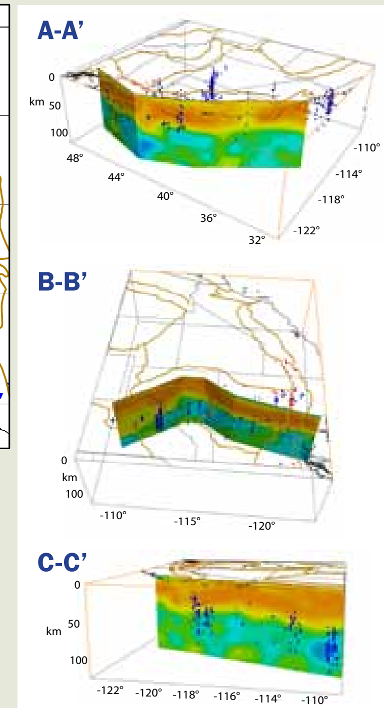
The receiver function image volumes are bounded by the Pacific coast to the west, by the longitude of central Colorado to the east, and by the Canadian and Mexican borders to the north and south, respectively. The large area allows us to investigate the



Receiver function volume beneath the western United States. The warm (red-orange) colors show positive signals indicative of wave conversion at the crust-mantle (Moho) boundary. The cool (green-blue) colors show negative signals indicative of wave conversion at the LAB. The Moho forms a nearly continuous boundary at depths of ~22–52 km. In contrast, the LAB varies in depth from ~45–150 km and is intermittent.



Map of the western United States showing the location of three profiles through the stacked receiver functions. Rock samples taken at the locations indicated by the green symbols on the map provide additional, independent estimates of LAB depth (as indicated by the blue symbols on the profiles on the right).



structure of a variety of tectonic provinces influenced by Farallon plate subduction and its aftermath. The stacked receiver function volumes clearly image the Moho (the discontinuity between the crust and upper mantle) as a positive amplitude (red-orange) signal, where the S wave converts to P at the crust-mantle high-to-low velocity discontinuity. We interpret the LAB as the negative (blue) signal, where the S-to-P wave conversion occurs at this high-to-low seismic velocity discontinuity. The Moho forms a nearly continuous surface, between ~22–52 km, under most of the western United States, except in the coastal regions and areas experiencing convective removal of the lowermost crust and upper mantle. In contrast, the LAB has significant depth variation (~45–150 km) and cannot be described as a single continuous surface.

As the volume we are imaging is large, it is useful to create cross sections through a few areas of interest. We interpret areas of bright negative amplitudes as regions of partial melt in the asthenosphere. We see a strong correlation between analyses of primitive basalt whole rock samples (Lee et al., 2009; NAVDAT database: http://www.navdat.org) and our LAB depths beneath the southern Basin and Range, Colorado Plateau, Cascadia, and the Snake River Plain. The depth estimates from the geochemistry data provide an independent estimate on LAB depth that compares well with our receiver function estimates.

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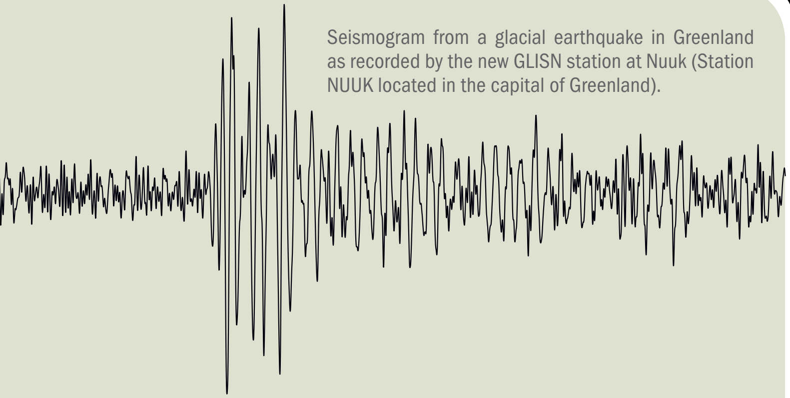
Polar Operations



Seismogram from a glacial earthquake in Greenland as recorded by the new GLISN station at Nuuk (Station NUUK located in the capital of Greenland).

Fishtail Point, Antarctica (Photo by Gut Tytgat, PIC)

POLENET station at Lone Wolf, Antarctica. (Photo by Gut Tytgat, PIC)

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IRIS Management

Kent Anderson

IRIS has long recognized the extra effort and specialized equipment required to field temporary and permanent seismic experiments successfully in the Arctic and Antarctic, and continues to develop and expand its capabilities in the world's coldest regions through the Polar Operations Group (POG). Through support of permanent observatories (GSN) in the polar regions for the past 20 years and the buildup of portable polar instrument support (PASSCAL) over the same time frame, the POG brings together the technical and managerial expertise required for these unique environments. The result is a vast improvement in IRIS facility capabilities, allowing the seismological community to record high-fidelity, robust data sets from these extreme environments. The POG consists of a pan-IRIS management team, with the primary implementation of engineering and fieldwork accomplished by PASSCAL Polar Support Services (PSS) at the PASSCAL Instrument Center. The new capabilities IRIS has developed provide the ability to study, with high resolution, seismological phenomena associated with the delicate polar regions, allowing further understanding of bi-polar climate-related seismological phenomena as well as improving constraints on shallow and deep structure in these sparsely covered areas of Earth.

During 2010, the POG staff supported 19 PI-lead projects in the polar regions (more details are provided in the PASSCAL section of this report). In addition to supporting individual PI work, the POG is tasked with installing and operating a permanent network in Greenland, with the joint goals of monitoring glaciogenic and tectonic seismicity and improving knowledge of seismic structure beneath the ice sheet. At the request of the community, IRIS has been asked to establish and operate the Greenland Ice Sheet Monitoring Network (GLISN; http://www.iris.edu/hq/programs/glisn). This past year, the POG worked with international partners to install seven stations in Greenland (Thule, Narsarsuaq, Nuuk, Tasiilaq, Ittoqoortoormiit, Daneborg, and Station Nord), and our Swiss colleagues installed a station in Nuugaatsiaq. With contributions from all our international partners, there are now 27 stations on and around Greenland contributing data to the IRIS DMC under the _GLISN virtual network.

While the POG has enhanced the IRIS facility for polar-related work, we continue to coordinate and take guidance from the seismological community on their scientific requirements for these new capabilities. The polar community is represented through two advisory committees: (1) the Polar Network Science Committee (reporting to both the IRIS and UNAVCO Boards of Directors), and (2) the GLISN Science Advisory Committee. The POG also interacts with the GSN and PASSCAL standing committees and provides status reports to the IRIS Board of Directors.

The emphasis on supporting climate research has created a new need for seismic instrumentation that can work in cold regions, and function in the wet environments found in the ablation zone of Earth's polar regions. In addition, work on rapidly moving ice requires equipment to operate in highly tilting environments. Developments to address these requirements are underway and will continue in the coming years. Complementing our wet-system development, we continue to update and refine our designs for enclosures, power systems, and real-time telecommunications.

The workshop "Rebuilding for Resilience: How Science and Engineering Can Inform Haiti's Reconstruction" was organized by IRIS IDS and cosponsored by the US Department of State, the US Agency for International Development, and the United Nations International Strategy for Disaster Reduction. It was held at the University of Miami on its Coral Gables, Florida, campus.

International Development Seismology

IRIS Management

Olga Cabello
Ray Willemann

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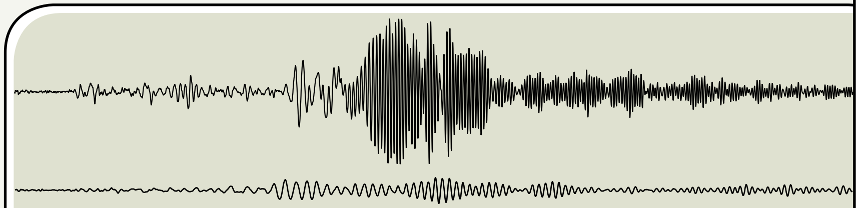


Recordings of two devastating earthquakes that occurred in 2010. The recordings were made at GSN station KMBO, Kilima Mbogo, Kenya. The top recording is from the February 27, 2010 M8.8 earthquake in Chile. The bottom recording is from the January 12, 2010 M7.0 earthquake in Haiti. Both earthquakes were located roughly 11,000 km from Kenya. The seismograms are unfiltered, 1.5 hours long, and are plotted on approximately the same amplitude scale—illustrating the dramatic difference in energy radiated from a M8.8 earthquake relative to a M7.0 quake. However, the smaller earthquake had a much greater human impact, due to the characteristics of man-made structures in the region of the epicenter.

International Development Seismology (IDS) constitutes an interface between the IRIS NSF-sponsored scientific mission and the need to ensure that scientific progress enables socially important outcomes. This effort responds to the recognized importance of developing the partnerships, technical infrastructure, and human capacity required for effective international cooperation as an instrument to accelerate scientific progress through collaboration with technologically equal partners, and as an essential element of various other modes of US foreign engagement, including foreign assistance and science diplomacy. NSF-sponsored IDS activities serve as seeding efforts or pilot projects targeted toward achieving two synergistic goals: to aggressively promote strategies that support fundamental research and exploration through wide and reliable geographic coverage, and to contribute to reducing global population exposure to seismic hazards through broad education of scientific and technical principles that have an impact on societal resilience through increased awareness, preparedness, and accountability.

IDS initiated activities in September 2009. Through June 2010, these activities have included exploratory meetings, collaborative projects, and multidisciplinary activities in response to destructive earthquakes. One of these activities was a joint meeting of the Centro Regional de Sismología para América del Sur (CERESIS) and the IRIS IDS Committee in Lima, Peru. The outstanding finding was the remarkable heterogeneity of conditions for conducting geophysical research, as well as earthquake monitoring and preparedness, among individual countries in South America, suggesting that effective seismological development in the region requires strategies tailored to these unique national conditions.

The devastating earthquakes in Haiti and in Chile in 2010 dramatically highlighted the significance of socially responsible scientific foreign engagement. In light of the enormous post-earthquake challenges in Haiti, the US National Science and Technology Council's Subcommittee on Disaster Reduction requested IRIS assistance in convening an international, multidisciplinary and cross-sector workshop to outline the role of science and engineering in reconstruction efforts. Another significant achievement was an agreement for free and open access to data from multinational deployments in response to the Chile earthquake. IDS contributed to this aftershock monitoring effort by securing supplemental support from the US Department of Defense Southern Command in the form of no-cost transportation of equipment, and assisting with in-field logistic arrangements during service runs.

IRIS received support through the NSF RAPID funding mechanism to install a portable network of 60 stations in the aftershock zone of the Chile earthquakes and closely collaborated with Chilean, French, German, and British groups in coordinating site selection and data exchange. IDS Director Olga Cabello and George Slad during service run.

The main focus of IDS is to support and facilitate activities of transitional nature between scientific progress, impact, and development. This requires the consolidation of resources derived from diverse stakeholders, and is consistent with current emphasis in scientific capacity as an integral component of economic development.

Financial Overview

Budget and Finance Subcommittee

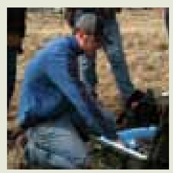
Steve Grand (Chair)	University of Texas at Austin
Don Forsyth	Brown University
Doug Wiens	Washington University in St. Louis
Ray Willemann	IRIS
Candy Shin	IRIS

Program Coordinating Committee (CoCOM)

Jim Gaherty (Chair)	Lamont-Doherty Earth Obsv. of Columbia University
Richard Allen	University of California, Berkeley
Matt Fouch	University of Arizona
Keith Koper	Saint Louis University
Xiodong Song	University of Illinois, Urbana Champaign
Glenn Kroeger	Trinity University
Robert Busby	IRIS
Rhett Butler	IRIS
James Fowler	IRIS
Candy Shin	IRIS
David Simpson	IRIS
John Taber	IRIS
Robert Woolley	IRIS
Bob Woodward	IRIS
Timothy Ahern	IRIS





The Incorporated Research Institutions for Seismology (the IRIS Consortium) is a 501(c)(3) nonprofit consortium of research institutions founded in 1984 to develop scientific facilities, distribute data, and promote research. IRIS is incorporated in the State of Delaware.

GSN

The Global Seismographic Network is operated in partnership with the USGS. Funding from NSF for the GSN supports the installation and upgrade of new stations, and the operation and maintenance of stations of the IDA Network at University of California, San Diego, and other stations not funded directly within the budget of the USGS. Operation and maintenance of USGS/GSN stations is funded directly through the USGS budget. Subawards include the University of California, San Diego, the University of California, Berkeley, the California Institute of Technology, Columbia University, and the USGS (Albuquerque Seismological Laboratory).

PASSCAL

Funding for PASSCAL is used to purchase new instruments, support the Instrument Center at the New Mexico Institute of Mining and Technology,

2010

IRIS Budgets

Core program budgets*
(July 1, 2009-June 30, 2010)

	FY2010	Augmentation	Total
GSN	2,652,627	4,671,795	7,324,422
PASSCAL	3,343,165	500,000	3,843,165
DMS	3,157,954		3,157,954
E&O	731,253		731,253
Community Activities	474,207		474,207
Indirect Costs	1,640,794	331,445	1,972,239
Total	12,000,000	5,503,240	17,503,240

* Budgets are for core IRIS programs from the NSF Earth Sciences Division Instrumentation & Facilities Program, and does not include additional funding from other sources, such as NSF Polar Programs, DOE, CTBTO, SCEC, JPL, etc.

2010

EarthScope Awards

(Oct. 1, 2009 - Sept. 30, 2010)

USArray (O&M Year 7)	12,438,286
EarthScope Science Plan Workshop	175,952
Cascadia (Year 1)	1,670,009
Indirect Costs	1,733,603
Total	16,017,850

train scientists to use the instruments, and provide technical support for instruments in the field. Subawards include the New Mexico Institute of Mining and Technology (New Mexico Tech), and University of Texas at El Paso.

DMS

Funding for the Data Management System supports data collection, data archiving, data distribution, communication links, software development, data evaluation, and web interface systems. Major subawards include the University of Washington, the University of California, San Diego, Columbia University, and the Institute for Geophysical Research, Kazakstan.

Education and Outreach

Funding for the Education and Outreach Program is used to support teacher and faculty workshops, undergraduate internships, the production of hardcopy, video and web-based educational materials, a distinguished lecturer series, educational seismographs, and the development of museum displays. Subawards are issued to IRIS institutions for software and classroom material development and support of educational seismology networks.

EarthScope

EarthScope awards include funding for USArray activities. Subawards include the University of California, San Diego, New Mexico Tech, Oregon State University, and other siting and partnership subawards. Contracts for USArray Transportable Array station construction and installation are to Honeywell and Coastal Technical Services.

Indirect Expenses

Costs include corporate administration and business staff salaries; audit, human resources and legal services; general headquarters and Seattle office expenses; insurance; and corporate travel costs.

Other Activities

Other activities include IRIS workshops, publications, and International Development Seismology.

A complete copy of IRIS' financial statements and auditor's reports are available from the IRIS business office by contacting admin@iris.edu.

Staff

IRIS Headquarters

1200 New York Ave. NW, Suite 800
Washington, DC 20005
Telephone (202) 682-2220 · Fax (202) 682-2444 · www.iris.edu

Josephine Aka	Business Analyst
Robert Austin	Business Analyst - Purchasing
Mary Baranowski	Meeting Planner
Arlene Bloom	Sr. Human Resources Specalist
Tammy Bravo	Education and Outreach Specialist
Olga Cabello	Director of International Development Seismology
Rick Callender	Media and Graphics Specialist
Perle Dorr	Public Outreach Manager
Lisa Green	Senior Budget Analyst
James Gridley	PASSCAL Program Manager
Michael Hubenthal	Education Specialist
Shanna Huddleston	Staff Accountant
Leslie Linn	Executive Assistant
Patrick McQuillan	Education and Outreach Specialist
Robin Morris	Business Projects Manager (EarthScope)
Aubrey Patsika	Web Developer
Teresa Saavedra	Office Manager/Receptionist
Candy Shin	Director of Finance and Administration
David Simpson	President
Ruth Sobel	Business Projects Manager (Core Programs)
John Taber	E&O Program Manager
Nicole Tatro	Accounting Manager
Matt Toigo	Web Developer
Russ Welti	Software Engineer - Education and Outreach
Ray Willemann	Director of Planning
Robert Woodward	USArray Director
Rob Woolley	Director of Program Support and Special Projects

Kent Anderson	GSN Operations Manager
Rhett Butler	GSN Program Manager

Robert Busby	Transportable Array Manager
Anthony Gonzales	USArray Lead Construction Engineer
Katrin Hafner	Transportable Array Chief of Operations
Howard Peavey	Station Specialist
Graylan Vincent	Transportable Array Reconnaissance Specialist

Data Management Center

1408 NE 45th Street, Suite 201
Seattle, Washington 98105-4505
Telephone (206) 547-0393 · Fax (206) 547-1093

Timothy Ahern	Program Manager
Manochehr Bahavar	Product Specialist
Rick Benson	Director of Operations
Rick Braman	UNIX Systems Administrator
Rob Casey	Director of Software Engineering
Mary Edmunds	Data Control Technician
Gale Eschete	Office Manager (travel questions)
Alexander Hutko	Product Specialist
Un Joe	Data Control Technician
Peggy Johnson	USArray Data Control Analyst
Lonny Jones	USArray Systems Administrator
Richard Karstens	Software Engineer
Tim Knight	Information Services Coordinator/Webmaster
Chris Laughbon	Senior Software Engineer
Anh Ngo	Operations Programmer
Thani Phongsuwan	Data Control Technician
Juan Rodriguez	Software Engineer
Sue Schoch	Senior Software Engineer (database specialization)
Gillian Sharer	USArray Lead Data Control Analyst
Ashley Spencer	Data Control Technician
Sandy Stromme	Software Engineer
Yazan Suleiman	Software Engineer
Mary Templeton	USArray Data Control Analyst
Chad Trabant	Director of Projects
Inge Watson	Administrator
Bruce Weertman	Software Engineer
MaryAnn Wood	Data Control Technician

PASSCAL

New Mexico Tech
100 East Road
Socorro, NM 87801
Telephone (505) 835-5070 · Fax (505) 835-5079

Marcos Alvarez	Deputy Program Manager
James Fowler	Program Manager

IRIS collaborates with the US Geological Survey (www.usgs.gov) on operation of the GSN.

The following IRIS partners operate major facilities with separately employed staff:

New Mexico Tech (http://www.passcal.nmt.edu)

Project IDA (http://ida.ucsd.edu)

The USArray Network Facility (http://anf.ucsd.edu)

The USGS Albuquerque Seismological Laboratory (http://earthquake.usgs.gov/regional/asl)

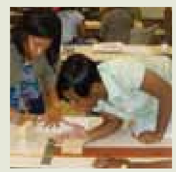
The IRIS mission, actively supported by each Member and Affiliate Institution, is to:

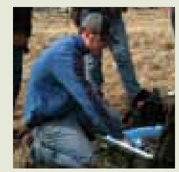
- Facilitate and conduct geophysical investigation of seismic sources and Earth properties using seismic and other geophysical methods
- Promote exchange of geophysical data and knowledge, both through use of standards for network operations, data formats and exchange protocols, and through pursuing policies of free and unrestricted data access
- Foster cooperation among IRIS Members, Affiliates, and other organizations in order to advance geophysical research and convey benefits from geophysical progress to all of humanity

The Board of Directors, selected by the Voting Members of IRIS in annual elections, is vested with full power in the management of IRIS's affairs. The Board appoints members to the Planning Committee, the Program Coordination Committee, the USArray Advisory Committee, and four Standing Committees that provide oversight of the Global Seismographic network (GSN), the Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL), the Data Management System (DMS), and the Education and Outreach Program (E&O). For special tasks, the Board of Directors or President may convene special advisory committees and working groups, which currently include the Instrumentation Committee and working groups for the Transportable Array and the Magnetotellurics components of USArray. IRIS committees and working groups develop recommendations for consideration by the Board of Directors.

The Annual Report was assembled by Rick Callender, Perle Dorr, and Ellen Kappel.





IRIS

Founded in 1984 with support from the National Science Foundation, IRIS is a consortium of over 100 US universities dedicated to the operation of science facilities for the acquisition, management, and distribution of seismological data. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and the verification of a Comprehensive Test Ban Treaty.

IRIS is a 501 (c) (3) nonprofit organization incorporated in the state of Delaware with its primary headquarters office located in Washington, DC.

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