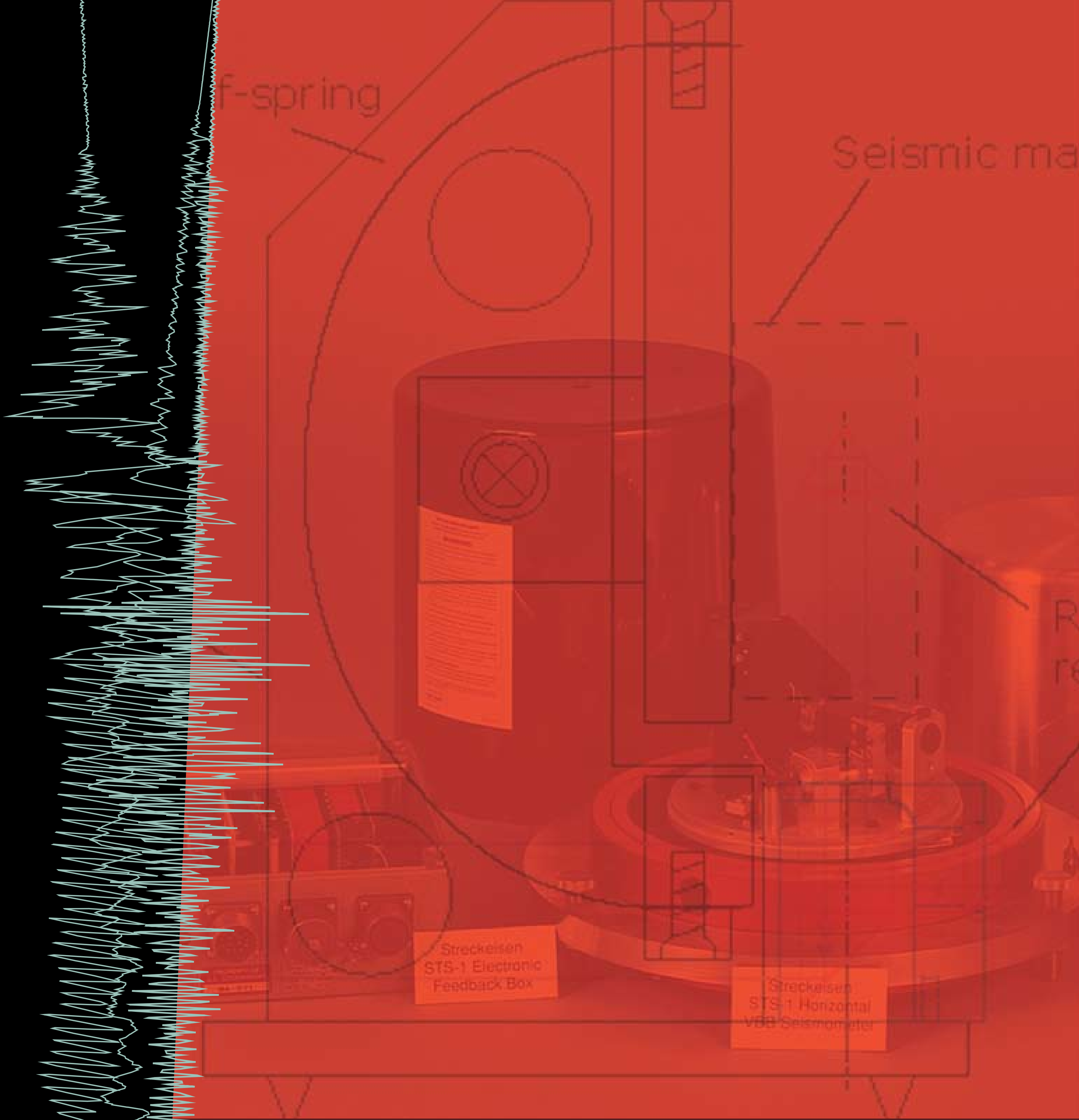


2006 Annual Report

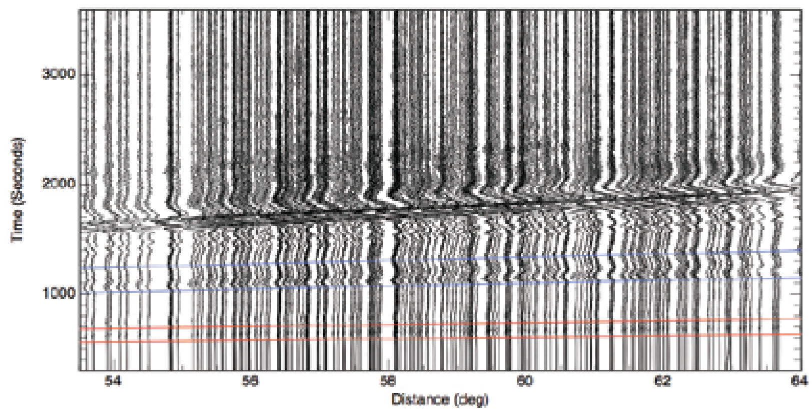
IRIS

Incorporated Research Institutions for Seismology

Statement From The Chair

Thorne Lay • University of California, Santa Cruz

The firehose is on! A recent request to the IRIS DMS for broadband seismograms for the November 15, 2006 Kurile Islands great earthquake (M_w=8.3) quickly returned data from over 500 global stations, including about 270 USArray Transportable Array stations. The latter number is growing; 200 additional TA stations are expected to be deployed by fall 2008. This onslaught of data is heart-warming to an observational seismologist like myself. Earthquake source investigations are now being performed extremely rapidly, yielding focal mechanism determinations and, for larger events, finite-faulting slip histories that quantify large ruptures robustly. Earth structure investigations are increasingly exploiting huge databases to stack and migrate large numbers of observations, extracting subtle features that had not been accessible previously, with many exciting implications. I imagine that many seismological researchers are reeling, as I am, with the challenge of coping with the long-anticipated computational and data-handling demands. It truly feels like we are riding a wave of data infusion that will lead to major advances in all areas of seismological research.



This bounty of seismic data is the product of collective effort by the seismological research community, with IRIS playing a major role. The research community is extremely well-served by the dedicated IRIS employees participating at every level in the facilities, including the new employees and contractors added in the past few years to build the USArray facilities. IRIS sustains partnerships with many universities, the USGS, UNAVCO, SCEC, CTBTO, and international membership of the FDSN, and this knits together the global coordination that underlies the whole enterprise. My second year as Chair of the IRIS Board of Directors has driven home the interconnections and mutual dependencies of our global seismological community. When cranking through a plethora of data on some exciting research endeavor, it is worth pausing to think about the contributions from many exceptional people working in this complex system that make your own accomplishments possible.

The new five-year Cooperative Agreement with NSF has now begun, following very successful review of the IRIS proposal, and the USArray component of EarthScope is on schedule and slightly under cost. Although this has been a year of tremendous accomplishment by IRIS, I still have concerns. The IRIS budget is currently flat, and some of the exciting endeavors in the five-year proposal will not be pursued at current funding levels. NSF has asked IRIS to coordinate development of a Science Plan for Seismology, which will guide NSF prioritization for funding of seismological facilities over the next decade. This plan will be a major task, and the community will have to contribute extensively. Long-term support levels for the progressive redeployment of USArray, as it sweeps across the contiguous United States and Alaska, are yet to be determined, and an operations and maintenance proposal for the first five years of this effort will have to be prepared early in 2007. Keeping the data flowing to support research applications will require your contributions to strategic planning and proposal writing efforts, and to regularly documenting the value of having centralized, open-access facilities such as IRIS.

Finally, I am concerned that the numbers of new graduate students coming into seismology to exploit the data bonanza is not all that is should be. We may need to bring IRIS Consortium energies to bear on attracting capable young researchers into our exciting discipline.

I welcome your thoughts on how this may be achieved.

Thorne Lay

The Year In Review

The IRIS Board of Directors kicked off 2006 with an important meeting with Margaret Leinen, NSF Assistant Director for Geosciences. Leinen urged the Board to look for alliances with the Office of Cyberinfrastructure, now part of the NSF Director's Office, and the NSF Social, Behavioral and Economic Science Directorate. She also encouraged IRIS to build its international activities, working with the State Department and NSF's Office of International Science and Engineering.

Two important developments early in the year were completing migration of Tier 1 data at the DMC to a disk-based system and selecting of the a next-generation data logger for the entire GSN. The disk-based data system opens the doors to an exciting range of new services when users can "look inside" of the data at the DMC. Starting installation of modern data loggers at GSN stations, with the same model of the system at all of the stations, is an important step in adapting the GSN to a sustainable mode so that it can support advances in global geophysics for the foreseeable future.

The big event for earthquake professionals in the United States this spring was the 100th Anniversary Earthquake Conference, marking the centennial of the 1906 San Francisco earthquake. IRIS itself commemorated the anniversary with an E&O poster on the history of seismology and co-sponsorship with SSA of a Distinguished Lecture by Mary Lou Zoback.

The consortium-wide efforts to prepare a visionary proposal paid off in May when the National Science Board authorized NSF to enter into a new Cooperative Agreement with IRIS, with funding at nearly the proposed level. Thanks to strong support from the research community and outstanding reviews of the planned work, IRIS can now look forward to funding to the full extent allowed by the NSF Geosciences budget.

In May and November, IRIS earned plaudits from the EarthScope Facility Executive Committee and a special NSF review committee for its continuing success in construction of USArray. The committees endorsed several initiatives suggested by the scientific community and encouraged USArray to work with regional networks to both enhance the networks' capabilities and to leave a scientifically valuable legacy of the Transportable Array. The committees also encouraged extended deployment of Transportable Array stations to achieve uniform coverage in the ANSS backbone.

IRIS international activities got a jump-start when Pete Davis and Bruce Beaudoin participated in training programs for the Indian Ocean Tsunami Warning System, supported US A.I.D. and organized by the USGS. IRIS also contributed a task description in a proposal to the UN Development Program, initiated an instrument loan program, and began preparing a briefing for State Department officials.

Year Three of EarthScope construction concluded at the end of September. IRIS reached numerous milestones on schedule for this date, including deployment at nearly half of the first-occupied sites for the Transportable Array and completion of the Reference Network, which consisted of installation and upgrades to 39 backbone stations of the ANSS.

IRIS took a step forward near the end of the year in leveraging partnerships when NSF Polar Programs funded a joint IRIS/UNAVCO MRI proposal to develop power and communication systems for remote, autonomous geophysical observations in the extreme environments of the polar regions. The project involves testing in each facility's cold chambers and field trials at test beds located locally and in Antarctica.

Statistics for each of the IRIS core programs passed round numbers during the year. The E&O Program has now placed over 100 AS-1's in schools and the MuseumLite displays now extend to the South Pole. The pool of "Texans" available for controlled-source experiments in the United States now exceeds 2000. The DMC served over one billion seismograms to users. The GSN, including affiliated stations, now includes more than 140 stations, with real-time telemetry capability from nearly every one of them. Although notable now, the progress of seismology generally, IRIS and USArray may soon make these numbers seem quaint.

The Consortium

The IRIS management structure is an interface between the scientific community, funding agencies, and the programs of IRIS. The structure is designed to focus scientific talent on common objectives, to encourage broad participation, and to efficiently manage IRIS programs.

Representatives from all of the member institutions meet annually to elect a Board of Directors, which governs IRIS. The Board of Directors appoints members to the Planning Committee, the Program Coordination Committee, the USArray Advisory Committee, and the 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.

*New Members in Bold

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Susan Beck • George Zandt

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Auburn University
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John Ebel • Alan Kafka

Boston University
Geoffrey Abers • Rachel E. Abercrombie

Brown University
Karen Fischer • Donald Forsyth

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Donald Helmberger • Thomas Heaton

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Barbara Romanowicz • Lane Johnson

University of California, Los Angeles
Paul Davis

University of California, Riverside
Stephen K. Park • David D. Oglesby

University of California, San Diego
Gabi Laske • Jon Berger

University of California, Santa Barbara
Toshiro Tanimoto • Ralph Archuleta

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Thorne Lay • Susan Schwartz

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Paul Silver • Selwyn Sacks

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Timothy Melbourne • Charles Rubin

University of Colorado, Boulder
Anne Sheehan • Mike Ritzwoller

Colorado School of Mines
Roel Snieder • Thomas Boyd

Columbia University
Arthur Lerner-Lam • Paul Richards

University of Connecticut
Vernon F. Cormier • Lanbo Liu

Cornell University
Muawia Barazangi • Larry Brown

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Susan McGeary

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Peter Malin • Eylon Shalev

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William Walter • Peter Goldstein

IGPP/Los Alamos National Laboratory
Hans Hartse • Leigh House

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University of Illinois at Urbana Champaign
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Indiana University/Purdue University at Fort Wayne
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Kansas State University
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Ross A. Black

University of Kentucky
Edward W. Woolery • Zhenming Wang

Lamar University
Joseph Kruger • James Jordad

Lawrence Berkeley National Laboratory
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Lehigh University
Anne Meltzer • Stéphane Sol

Louisiana State University
Juan Lorenzo • Roy Dokka

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John P. Craddock • Karl R. Wirth

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Tim Dixon • Falk Amelung

University of Memphis
Charles A. Langston • Jer-Ming Chiu

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Jeroen Ritsema • Larry Ruff

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University of Missouri
Eric Sandvol • Mian Liu

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Abu K.M. Sarwar

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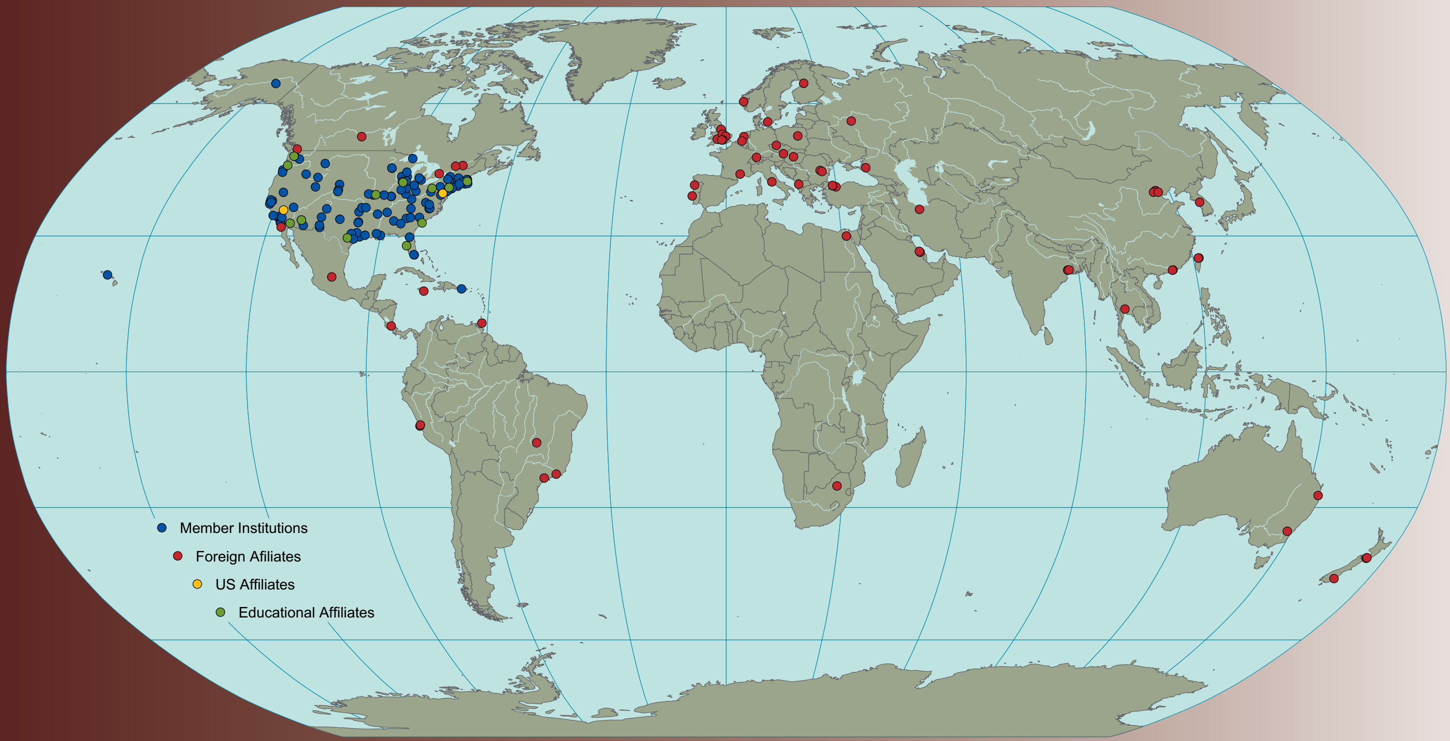

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Maryland Geological Survey
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GSN

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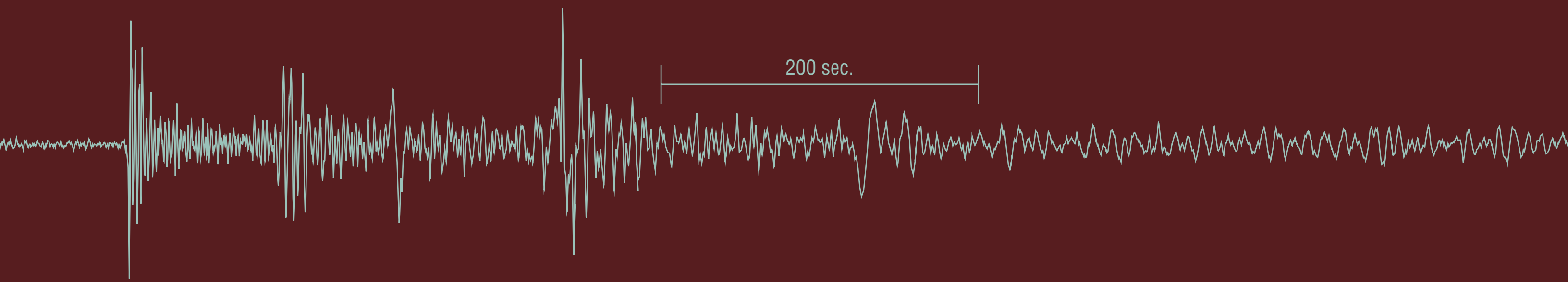
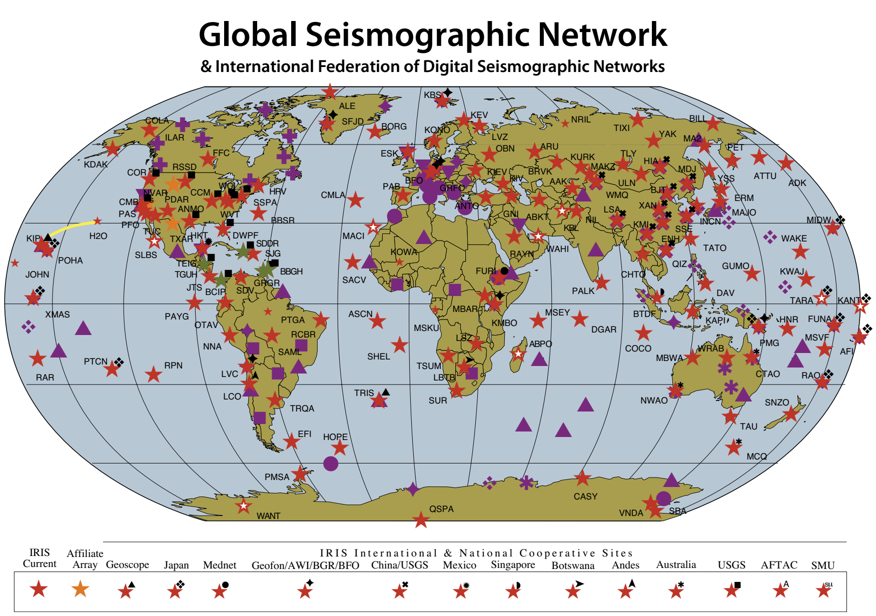
Jeffrey J. Park • Yale University



The Global Seismographic Network is a permanent network of state of the art seismological and geophysical sensors connected by available telecommunications to serve the scientific research and monitoring requirements of our national and international community. All GSN data are freely and openly available to anyone via the Internet. Installed to provide broad, uniform global Earth coverage, 143 GSN stations are now sited from the South Pole to Siberia and from the Amazon basin to islands in the Indian Ocean, in cooperation with over 100 host organizations and seismic networks in 64 countries worldwide. The GSN coordinates closely with other international networks through the Federation of Digital Seismograph Networks (FDSN), of which the IRIS is a founding member.

The GSN is primarily operated and maintained through the USGS Albuquerque Seismological Laboratory (ASL) and through the University of California at San Diego IRIS/IDA group. Eighteen GSN-Affiliate stations and arrays contribute to the network. In collaboration with the US National Earthquake Information Center, the GSN and NEIC are principal global sources of data and information for earthquake locations, earthquake hazard mitigation, and earthquake emergency response. In collaboration with National Oceanic and Atmospheric Administration (NOAA) Tsunami Warning Centers and Japanese Meteorological Agency, the GSN provides essential data for tsunami warning response globally. The GSN is an official observing system within the Global Earth Observing System of Systems (GEOSS).

Through supplemental funding in response to the 2004 Indian Ocean tsunami, this year the USGS enhanced GSN telemetry, added spare equipment, and established a new Caribbean Network whose stations join the GSN as Affiliates. New seismic stations installed in 2006 include Barbados, Honduras, Dominican Republic, Panama, and Grenada. All Caribbean sites have real-time telemetry. In 2006 the IRIS/IDA group upgraded hardware at several sites and prepared new sites in Madagascar and United Arab Emirates.



Our transition from air-mailed data media and dial-up telephone access to continuous, real-time telemetry of all GSN data is nearly complete. Only nine sites now lack real-time telemetry (~94% connectivity). Fourteen new or upgraded telemetry circuits were established in 2006. Internet connectivity to GSN stations was established by ASL in Spain and Chile, by IRIS/IDA in the South Atlantic on Saint Helena Island, and through collaboration with GSN station hosts in Singapore and Thailand. Bandwidth to our site in the Falkland Islands site was upgraded.

The GSN is working closely with the International Monitoring System (IMS) for the Comprehensive

IDA engineer Todd Johnson stands with members of the Kyrgyz Institute of Seismology during a recent visit to GSN station AAK (Ala-Archa, Kyrgyzstan)

Nuclear Test Ban Treaty Organization (CTBTO). Twenty-six GSN sites are now linked directly to the CTBTO International Data Centre, mostly via their global communication infrastructure (GCI). This shared satellite infrastructure enables remote operations, maintenance, and quality control for the IMS, and provides for real-time GSN data access for the scientific community. At eight sites, the GCI link is available as a redundant backup for GSN telecommunication infrastructure. Two new GCI VSAT links have been established this year in Peru and Uganda.

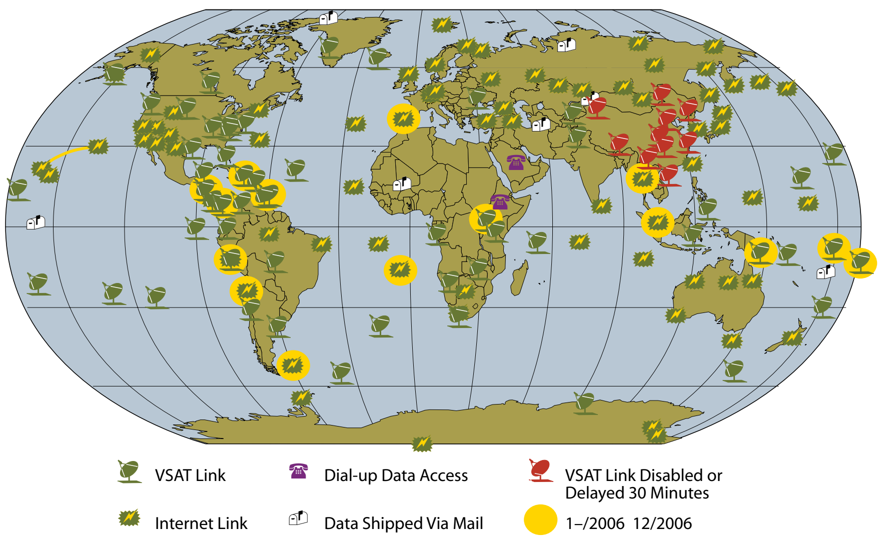
In the Pacific, close coordination with the NOAA National Weather Service (NWS) brings GSN data directly to the Oahu hub at the Pacific Tsunami Warning Center (PTWC). From PTWC, the GSN data are forwarded to the Internet. NWS is funding the satellite space-segment costs for GSN data access. Three new VSAT systems installed by USGS in the Southwest Pacific at GSN stations on Western Samoa, Tuvalu, and Papua New Guinea now augment coverage from Midway Atoll and Easter Island.

The GSN selected the Quanterra Q330HR for use as its next-generation data acquisition system (DAS). ASL and IDA network operators are engaged in collaborative, coordinated systems integration of the new DAS to achieve a new standardized approach to GSN operations and maintenance. The GSN will begin to deploy these new units in the field beginning in 2007.

Many GSN sites have evolved into geophysical observatories. A variety of geophysical instrumentation now uses GSN logistical and telemetry infrastructure, including GPS, gravimeters, magnetometers, microbarographs, and meteorological sensors. Microbarographs were installed this year at GSN stations in Peru, Azores, in the southwest Pacific at Western Samoa and Tuvalu, and at the South Pole. The 45 microbarographs installed globally at GSN sites are the largest open data source of its kind.

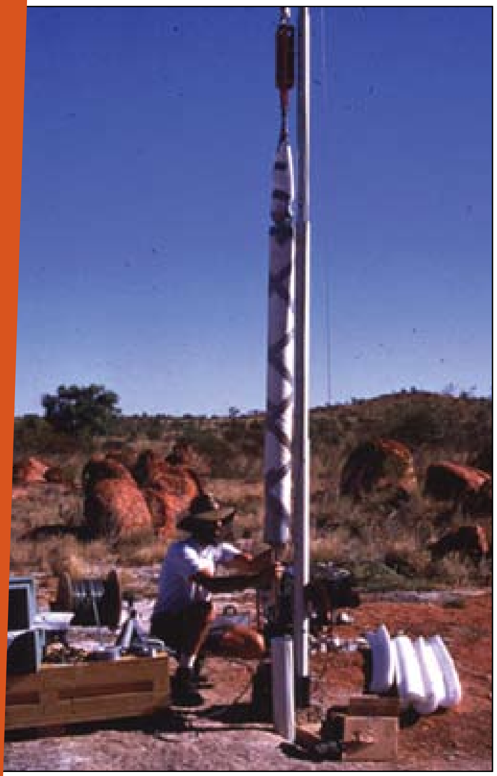
The Earthscope USArray Reference Network has been completed on time and under budget. Funded through IRIS, the work was accomplished by ASL and its Honeywell team with assistance from USGS field personnel in Golden. In total, 35 seismic stations were installed or upgraded as part of the USGS ANSS. In addition, 11 GPS monuments were collocated with the seismic stations. Four GSN-Affiliate arrays and stations also contribute to the ANSS Backbone Array, bringing the total to 39 new and upgraded sites. Under joint ANSS and GSN funding in 2006, site preparations were completed for three new Backbone stations in Montana, Utah, and Mississippi. Through December 2006, there are more than 80 ANSS Backbone stations in the conterminous United States, plus additional sites in Alaska and Hawaii.

GSN Communications

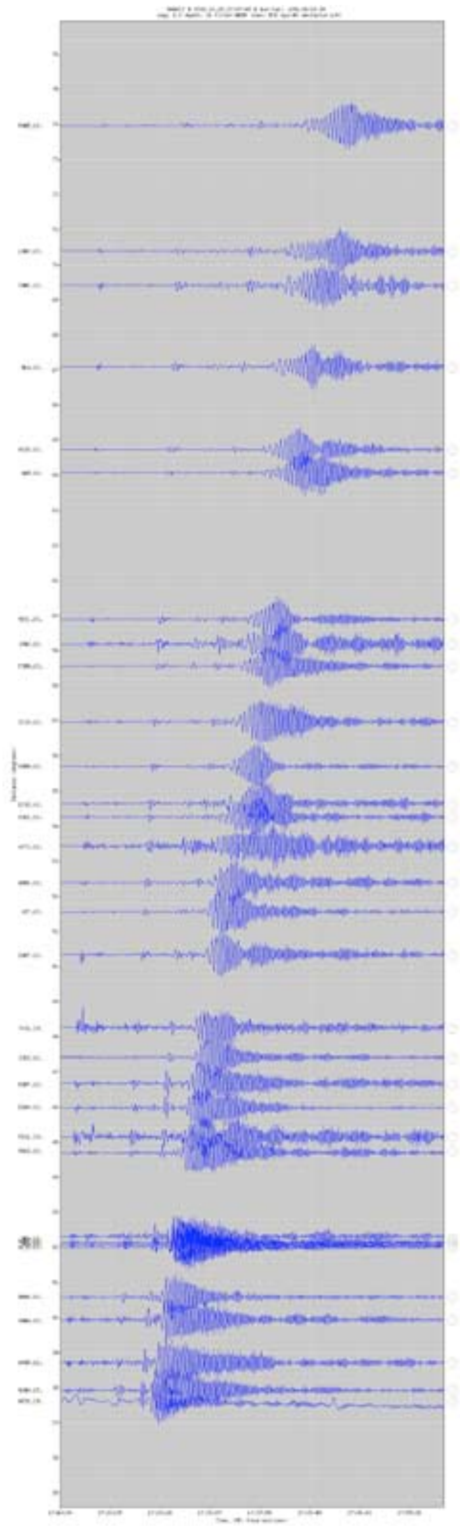


Installing the EarthScope Reference Network Seismic Stations

John S. Derr, Kyle E. Persefield, Stephen C. Roberts, Jared D. Anderson, Alena L. Leeds, Douglas G. Ford, Gary S. Gyure, Charles R. Hutt, Lind S. Gee, Kent R. Anderson



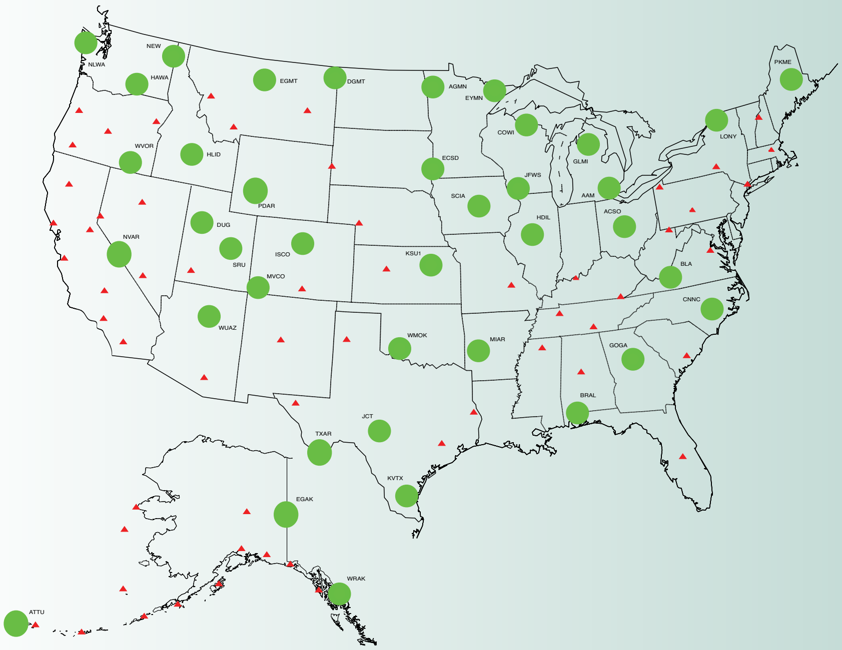
WRAB - IDA engineer Todd Johnson lowers a KS-54000 into a borehole at GSN station WRAB (Warramunga, Australia).



At midnight on September 30, Steve Roberts and Mike Busby drove into the Albuquerque Seismic Laboratory (ASL) compound. For the first time in many months, all of the USGS Albuquerque Seismological Laboratory's field vehicles were parked beside each other. Everyone was home safely: zero accidents, a couple of scrapes and bruises, but no major injuries, and 100% of the seismic stations in the USArray Reference Network were installed – on time and under budget. A team of very talented and dedicated people met the goal of installing 39 new and upgraded stations in three years. Almost all of the stations are producing excellent data, as illustrated by the records of the October 15, 2006, M6.7 earthquake in Hawaii. These stations will be a valuable contribution to the Advanced National Seismic System (ANSS) of the USGS and are a shining example of the cooperation and collaboration among the USGS, IRIS, EarthScope, and the National Science Foundation.

The Reference Network project is a combination of new and upgraded stations that both expands the ANSS Backbone national network, and provides a fiducial reference network for both the EarthScope USArray facility and the USGS Earthquake Hazards Program. Of the 39 stations in the plan for this project, 35 were actually either completely new installations or major overhauls of existing National Seismic Network (NSN) stations. They comprise 13 new surface vault stations, 12 overhauled shallow sites, 3 new borehole sites, 7 new deep vaults, all with completely new sensors, data-acquisition, power and communication systems. The remaining four stations tap into existing GSN-affiliate stations installed and maintained as part of the Comprehensive Test Ban Treaty Organization/International Monitoring System and the US Atomic Energy Detection System programs. The goal of this program was to have the Reference Network completed more than a year before the first footprint of the Transportable Array was to be moved. Therefore, the time to complete this work was under three years. With vast experience in seismic station installations and a history with the NSN, IRIS asked the USGS and its ASL and Golden, CO staff (including its prime contractor, Honeywell) to perform all this development work with confidence that the work would be completed on time.

Because every station was different, each one was an opportunity to work with new people. The project worked on public lands whenever possible, thus stations were located in national and state parks, national forests and wildlife refuges, university lands, a USGS facility, and one even on a National Guard camp. Some agencies greeted our inquiries with great interest, especially in the western United States, but some private landowners wouldn't have anything to do with the US government. In some cases, institutions requested and received IRIS museum educational displays, featuring the local seismic data, as well as recent world seismicity. Creative thinking was involved in several cases, including one site where paperwork was facilitated by a joint interest in a power cable.



Not all went smoothly, by any means. Between drilling challenges (no contractors available) and equipment shortages due to other EarthScope projects, we wondered at times how we would meet the schedule for installation of this network. Fortunately, all came together in the end and we were able to finish on time with all the equipment needed to keep the data flowing.

Overall coordination with the EarthScope and IRIS offices was very smooth, as was the support of the National Science Foundation. Monthly reports and Earned Value Management (EVM) tracking were a cooperative and complex endeavor between ASL and IRIS, but when it was all said and done, we were able to use these reports to determine when and where resources needed to be allocated to meet the tight schedule and complete the work as proposed.

The last station completed was in Conover, Wisconsin. Although it seemed a challenge to complete Conover and the other 38 stations in the short time allowed, the field crews never had a doubt that it could be done. Once again, the strong and fruitful collaboration between IRIS and the USGS has proven successful and provides yet another valuable facility to the seismological community. Moreover, one of the important by-products of the Reference Network effort was enhanced collaboration and integration between the USGS field crews in Golden and Albuquerque. Going forward, this coordinated support will continue, with both ASL and Golden personnel tasked with O&M of the network.

Acknowledgements

The authors wish to thank NAGT summer interns Mike Busby, Mike Bolz, and Ryan Davis for help with the installations. Additional expertise and assistance were contributed in various phases of the project by Jim Allen, Glenn Berwick, Steve Crawford, Jeff Fox, Jeff Grey, Jack Hennagan, Dave Ketchum, Ted Kromer, John McMillan, Dan McNamara, Mark Meremonte, Mark Robertson, Leo Sandoval, Travis Wilmoth, and Neil Ziegelman.

PA by the Numbers

Kyle Persefield (lead field engineer)

From about September 2005 through September 2006, the field crews (only three full time engineers with all the extra sets of hands we could beg, borrow or steal) were nearly out continuously. Typically, they went out in the field a month or two at a time, returning for as little as week, but no more than two weeks before heading out again. 60 to 80+ hour weeks were the norm.

There were honeymoons delayed, birthdays forgotten, holidays worked, family missed, girlfriends pining away, and weekends lost, but some of us found a little time to wet a line, catch some fish, and toss back a beer. No one will miss pulling off ticks, swatting deer flies, scratching mosquito bites, breathing in gnats, the sunscreen, the Gatorade, the cold, the heat, the rain, the snow and the mud (especially the mud).

We all survived. We are older than our years, but wiser, and everyone came back with all of their fingers and toes. It's a miracle!

118,550 miles driven; 16 new tires required; 123 cubic yards of concrete (25 yards mixed by hand); 302 purchase orders; 71 contractors; 3,736 emails; 280 lbs of explosives; 1,860 feet of conduit; 2,840 feet of lumber; 16,760 feet of cable.

The Hailey Experience

Jared D. Anderson

Many extremes, one station. During the installation of the Reference Network station in Hailey, Idaho, we faced many challenges. At the summer installation, the heat added fun to the 130 bags of concrete (~ 4 yd) that had to be hand mixed up the side of a very steep mountain! No access to water resulted in several grueling trips up and down the mountain to keep the pour going. Talk about putting in a full hot summer day.

Upon return in the winter to install the electronics, 4 ½ feet of snow had fallen. That was a workout—snowshoeing up and down that hill with tools and equipment in below freezing weather. Man, oh man; that was some experience!

Yukon Experience

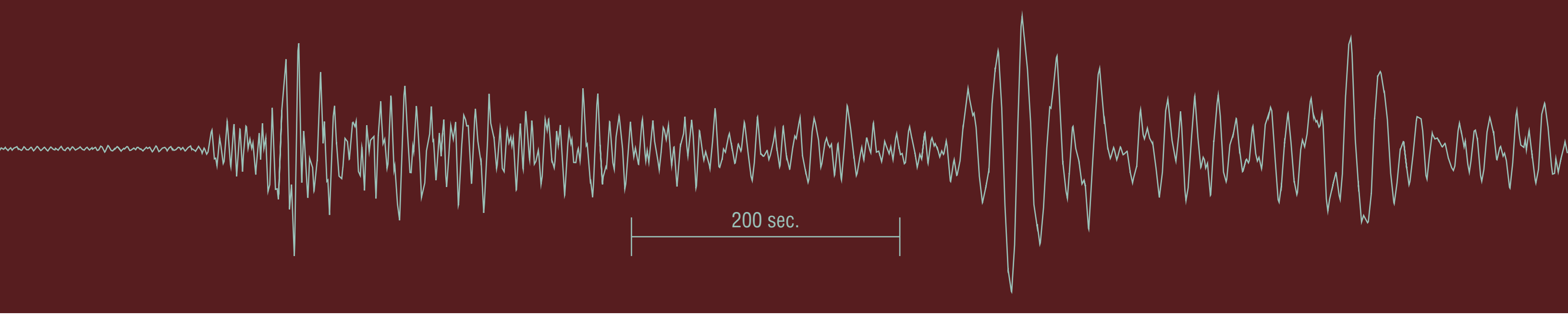
Steve Roberts

My trip to Alaska basically defines the entire two years of travel while working on these installations. Hurry and get to Fairbanks only to learn that part of the shipment is delayed; no big deal, just go fishing for Arctic grayling and northern pike in the many rivers in lakes around Fairbanks, making sure to not go the way you'll be traveling when the shipment does arrive. Those trails will be explored along the way to Eagle. By the way, where is Eagle? It is at the end of the road of course!

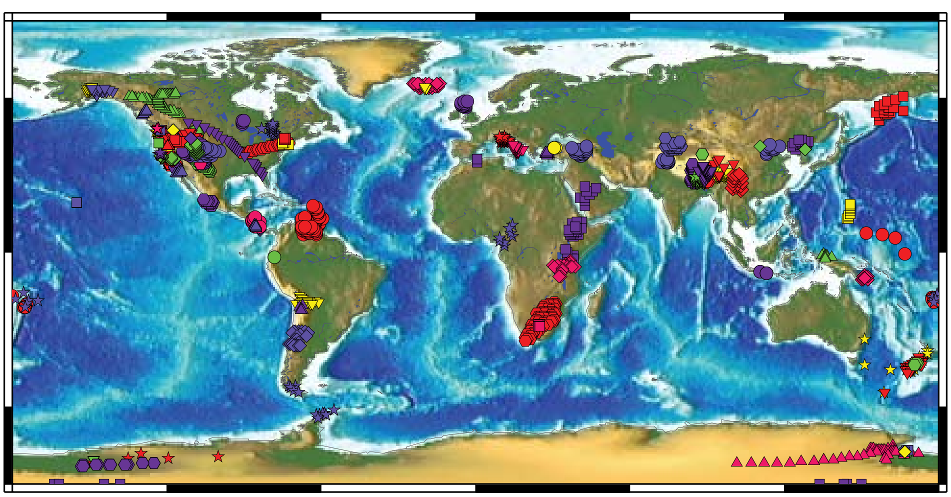
Dig a big hole in Eagle, fill it full of concrete and seismic equipment then hope the mail flight will get your satellite dish and radio to you before the day arrives for the ten-hour drive back to Fairbanks to catch the plane to Wrangell. Leaving Friday? No problem, we'll have the dish to you Thursday afternoon. It's a good thing the sun never sets in Alaska in the summertime! Work all through the night Thursday, finish the station Friday afternoon, drive the 10 hours to Fairbanks, arrive at the hotel 2 AM, leave for the airport 6 AM Saturday morning, arrive in Wrangell late that afternoon. As the sun circles around into Sunday morning it is a beautiful sunshiny day (I'm told it is one of the very few all summer) and no one will work with us until Monday morning. A much welcome day off is in the plans.

PASSCAL

Jim Fowler • IRIS Consortium



PASSCAL facilitates portable array seismology worldwide with end-to-end experiment support services, state-of-the-art portable seismic instrumentation, and advanced field and database management tools. Over its history, PASSCAL has supported more than 550 deployments to image plate boundaries, cratons, orogenic systems, rifts, faults, and magmatic systems. The instruments have also been essential in a variety of environmental research projects, including volcanic system imaging, fault-zone studies, basin-related seismic hazard, hydrologic studies, and recently climate and glacial processes. This year, the program supported a total of 70 experiments, of which 45 are new in 2006. Of these experiments, 28 are broadband, 22 are short period passive experiments, and 20 are controlled source experiments, 7 of which employed "Texan" single-channel recorders while 13 used multichannel recording systems. This translates into over 500 new stations shipped not including controlled source experiments. In addition to these efforts, the PASSCAL Instrument Center (PIC) supported four USArray Flexible Array experiments (two continuing and two new, 70 stations shipped) and shipped 158 installations and 206 constructions in support of USArray Transportable Array efforts.



The PASSCAL Virtual Network includes all PASSCAL stations for which data are available at the DMC and consists of 3905 stations.

The PASSCAL broadband pool increased by roughly 25 sensors, partially offset by attrition due to an aging instrument pool. To help PIC counter the increase maintenance, we have arranged training with sensor manufactures for our staff. Six new multichannel dataloggers were added to the existing four units to offer a total of 336 channels of recording capability.

PASSCAL's Texan pool remained stable at 950 units, now consisting of roughly 400 of the older RT125 units and 550 of the new RT125A units. The new Texans have four times as much memory–256 Mbytes–which allows higher sample rates, longer recording times, and more shots per deployment. Yet, they can be redeployed more quickly than the old Texans thanks to an even greater increase in data upload speed. The new units are designed with a user interface similar to the original units, which facilitates using both units in the same experiment. Usage of the Texan pools was down this year with the equipment in-house for roughly half of the year, in part due to several experiment cancellations or delays.

PASSCAL provides services to support each phase of an experiment, including pre-proposal consultation and advice on experiment design, as well as pre-deployment training in use of the instrument hardware and software for data recording, QC, and archiving. PASSCAL usually makes arrangements for shipping instruments both to the field area and back to the instrument center. The instruments and field computers

Staging of equipment for a Flexible Array deployment in Washington State (CAFE). Principle Investigators, their students, and engineers from the PASSCAL Instrument Center test and assemble all the components required for a broadband seismic network. One of the main purposes of this experiment is to study the recently discovered Episodic Tremor and Slip phenomena beneath Cascadia. Over 60 narrowly spaced portable stations were deployed throughout Washington state within the larger footprint of the Transportable Array for a period of two years.

are configured with a variety of custom software to support efficient operations, and PIC personnel provide assistance by telephone and e-mail. Post-deployment services include software for data format conversion, data verification, and initial processing for both active and passive experiments.

The PIC software and data group continues to improve and develop tools for in-house and user communities. Recent advancements include all aspects of PASSCAL activity from field tools for users, to data handling utilities that facilitate archiving with the DMC, to in-house inventory and maintenance tools. Highlights for this year include the release of a new multi-platform version of the PASSCAL data viewing program PQL, an RT125A field programming interface, tools to improve data delivery to the IRIS DMC, creation of a PASSCAL virtual network, and continued improvement to our in-house inventory and maintenance database. In addition to these achievements, PIC is working closely with the DMC to prototype a new archiving format for active source data, with the objective of decoupling the metadata from the waveforms to avoid delays in submission of active-source data and enhance more general long-term use of these data.

EarthScope/USArray

Now in the third year of operation in the significantly expanded PASSCAL facility at New Mexico Tech, the Array Operations Facility provides maintenance and logistical support to USArray, which involves instrument purchasing, acceptance testing, final assembly, and shipping. To date, over 300 data acquisition systems, 290 broadband sensors, and 150 power and sensor vault systems have been commissioned for use on the Transportable Array. Standardization of equipment and installation techniques have led to advances that produce very high quality broadband seismic stations.

The Flexible Array is a pool of instruments available for principal-investigator-driven studies, designed to augment imaging of key targets at higher resolution than other components of USArray. Modeled after the existing PASSCAL program, the Flexible Array provides additional data processing support and station construction materials to the principal investigator to help hasten data archiving and enhance data quality.

The Flexible Array procurement plan was changed to accommodate the higher demand for broadband instruments, now specifying 291 broadband stations, 120 short period stations, and 1700 active source stations. The new instrument mix will allow the Flexible Array to better service the research community, which was reviewed by the PASSCAL Standing Committee, USArray Advisory Committee, and IRIS Workshop participants before IRIS submitted the change order.

This year, two new Flexible Array broadband experiments were deployed: “CAFÉ” in Washington and “Wallowa” in Oregon. Continuing experiments from last year are the “PASO TRES” in Parkfield and “SNEP” in the Southern Sierra Nevada Mountains. The “CAFÉ” project consists of 62 stations, of which 10 stations are deployed in two real-time arrays designed to record the Cascadian episodic tremors. The Wallowa experiment is designed to image the source of the Columbia River Basalts. The entire set of broadband of 120 stations in the current Flexible Array pool is deployed in these four experiments.

RETREAT: Seismological Investigation of Northern Apennines

Vadim Levin • Rutgers University; Jeff Park • Yale University

An international passive seismic data collection effort was recently completed in the northern Apennines of central Italy. The deployment included Liguria, Tuscany and Emilia-Romagna regions. The project involved collaboration among US, Italian, and Czech institutions, integrating sites occupied by portable equipment with permanent observatories. This project constitutes one component of a five-year long multidisciplinary research program aimed at understanding mountain-building processes in central Italy.

While the Apennines inspired early ideas of modern earth science, their existence as a high mountain chain, roughly parallel to relative motion between Africa and Europe, remains poorly understood. The acronym of the project, RETREAT, stands for "REtreating-TRench, Extension and Accretion Tectonics," after the geodynamic concept widely believed to be at work here. In the retreating-trench scenario, a downgoing plate in a subduction zone behaves like a towel thrown into a pool–the place where the towel (and the plate) drops from the surface migrates backwards. Consequently, mountains formed above the line of convergence between two plates do not stay in place–a fate suffered by Apennines over the course of their existence.

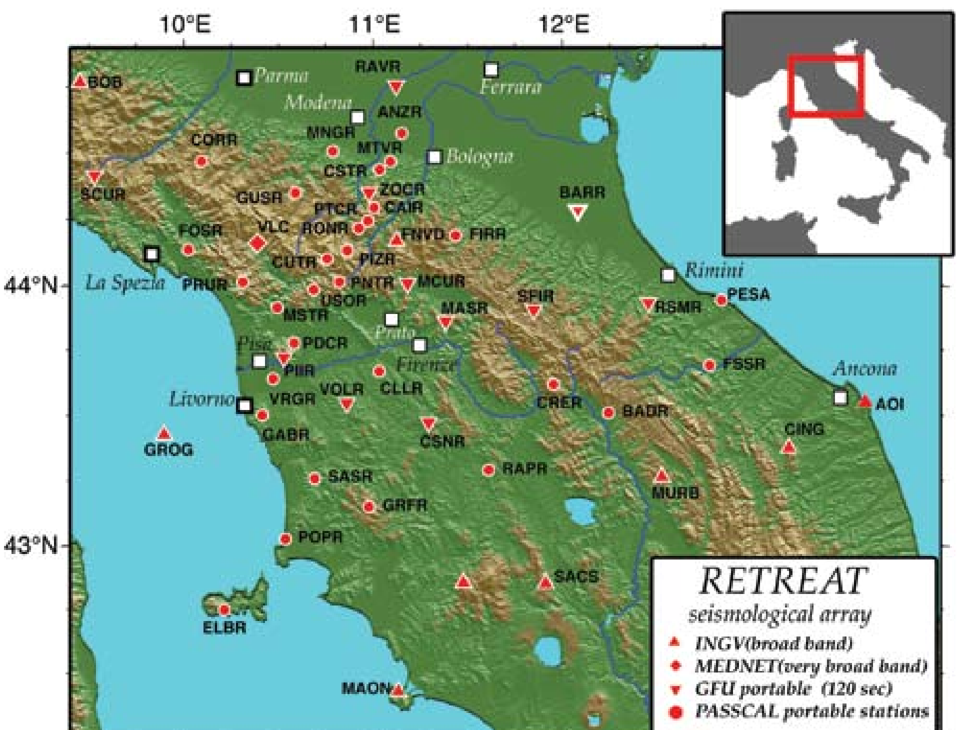
To unravel a complicated tectonic picture in the northern Apennines, the RETREAT project applies multiple techniques, many aimed at constraining past and present rates of surface uplift. Reproducing this uplift with computer simulations requires good constraints on crustal structure, and also on forces applied to the crust. Thus, the objectives of the seismological study in the framework of RETREAT were crustal and uppermost mantle structure, and mantle flow patterns.

Institutions involved in the seismological component of RETREAT are Yale and Rutgers Universities in the United States, the National Institute of Geophysics and Volcanology (INGV) in Italy, and the Geophysical Institute of the Czech Academy of Science (GFU). Funding for US participants, and for the bulk of field operations, came from NSF Continental Dynamics. INGV offered extensive support in terms of personnel, equipment (especially field vehicles), use of facilities and, very importantly, the imprimatur of legitimacy in dealing with local authorities. The Czech Academy of Sciences provided support for personnel, and supplied equipment.

Seismic Deployment and Operations

The needs of other disciplines were critical in the design of the portable deployment. The array combined a relatively dense (~10 km spacing) linear transect across the mountains with a broader, sparse two-dimensional backbone. The duration of observations at individual sites varied from about a year to three years. The longer observing period is essential for the success of analysis methods that seek directional variations in teleseismic signals. Overall, the array included 25 sets of portable equipment from PASSCAL (both STS-2 and CMG-40 sensors), 10 sets of portable equipment from GFU (STS-2 sensors), and up to 10 permanent installations of the Italian national seismic network (Trillium sensors).

Over three years we had a number of sites covering the region. They collected between two and three years



Peter Ulbricht advises Lucia Margheriti (center) and Silvia Pondrelli about installation of PASSCAL data loggers.

of data, and additionally we observed two linear arrays with approximately one year of data collection along each.

During the initial deployment of PASSCAL hardware we had expert guidance and invaluable help from PASSCAL engineer Peter Ulbricht. Peter's ability to repair a STS-2 sensor in the field was essential, and his creativity in setting up sensor enclosures contributed to the data quality.

Most of the service for the array, for both data retrieval and maintenance, was carried out by our Italian colleagues, with help from the Czech group. Removable flash cards used by both Reftek 130 data loggers and GFU "GAIA" recorders make data retrieval very simple. Permanent sites of the Italian network broadcast their data via a satellite uplink. Nearby clusters of sites were visited by one or another of our Italian colleagues during a day trip, with data subsequently accumulating in the INGV facility in Bologna. All transfers of data between our project and IRIS facilities (PASSCAL and DMC) were done via the Internet.

Fieldwork in Europe: Pleasure, With Some Minor Hiccups

It is hard to expect sympathy to hardship when you tell people that your "field area" overlaps Florence and Pisa. Indeed, operating in Italy was largely a gratifying experience. Earthquakes are a familiar bane in Italy, thus seismologists are received warmly by residents. Locating a suitable sites in a region as densely populated and cultivated as Tuscany was a challenge, handled admirably by our colleagues from INGV. As anywhere, equipment security was a concern, requiring lockable doors to ward off curious humans and, in one instance, wild boar.

Operating in a heavily touristed region can lead to surprising trouble, such as having one's US credit card blocked after a purchase of 10 car batteries from a home-goods store. Travel between sites, even closely spaced, was often complicated by rush-hour traffic and (frequent) railway strikes, which put many more cars on the roads. Cell phone service was disrupted a few times, interrupting state of health messaging and causing alarms.

Data Diplomacy

A remarkable amount of energy went to forestalling unintended misunderstandings about procedures assumed to be "natural" by different groups participating in the project, especially in approaches to storage, archival, and subsequent access to data. Procedures promoted by IRIS (including preservation of continuous data, full documentation, and common site archival) are not as common in Europe. Early on we found it necessary to develop a common policy on data issues for the group, and to have it reviewed periodically. The data policy covered mundane matters of where to store the data and how to get them, but also a much more difficult matter of who gets access to data, and under what conditions. The effort invested in defining the policy paid off well, with a resulting data set from all 45 nodes that made up our array being archived in IRIS under the common network code (YI 2003-2006), and with a common "exclusive use" period of two years (from October of 2006).

Early Science Results

As our data collection effort lasted three years, we had time to analyze and publish some early results. Initially, we focused on data that would serve as a mantle-flow proxy–seismic anisotropy. Three papers already published document the extreme complexity of the upper mantle deformation field. We infer sharp changes in the mantle flow (or else in its frozen texture) associated with the crest of the Apennines, and we also see evidence for vertical changes in texture in some places. On the whole, the emerging picture is not consistent with the scenario of ongoing trench retreat. Alternative views, such as stalled subduction and/or incipient slab detachment, pose intriguing challenges to observations derived from surface geology. While a final interpretation is far from settled, seismologists involved in RETREAT are progressively more doubtful that the acronym of the project faithfully reflects the underlying geodynamics.

RETREAT Seismology Team

The effort to deploy and operate the network in Northern Apennines involved numerous groups and individuals. Without their support this project could not become such a success and US members of the RETREAT seismology team are extremely grateful to these participants:

Istituto Nazionale de Geofisica e Vulcanologia:
Alessandro Amato, Nicola Piana Agostinetti, Luciano Giovani, Francesco Pio Lucente, Lucia Margheriti, Davide Piccinini, Silvia Pondrelli, Simone Salimbeni

Geophysical Institute of Czech Academy of Sciences:
Vladislav Babuska, Petr Jedlicka, Jaroslava Plomerova

Laboratorio sismologia Genova:
Elena Eva, Marco Pasta, Stefano Solarino, Enzo Zunio

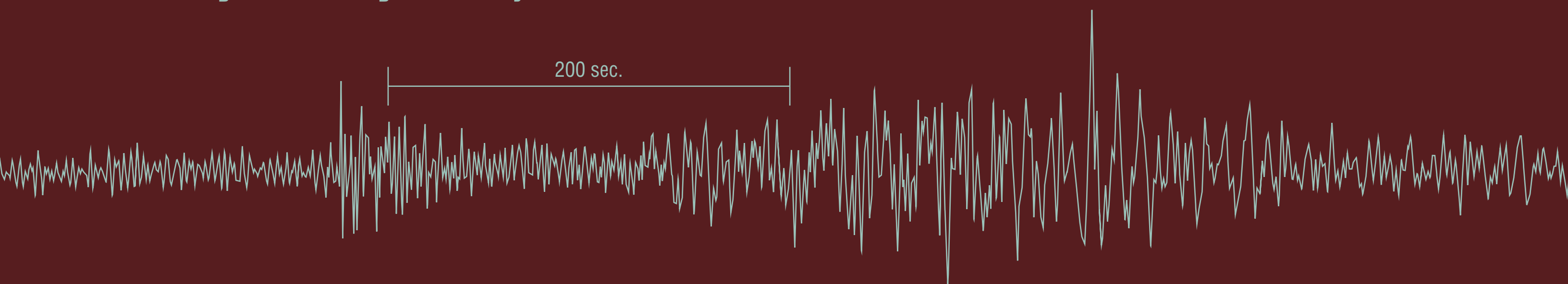
Istituto Geofisico Toscano:
Andrea Fiaschi

Centro Recherche Brasimone:
Bruno Carpani

DMS Standing Committee	
Douglas Wiens (Chair)	Washington University, St Louis
Chaitan Baru	University of California, Santa Cruz
Emily Brodsky	University of California, Santa Cruz
Paul Earle	USGS, Denver
Megan Flanagan	Lawrence Livermore National Laboratory
John Hole	Virginia Polytechnic Institute
Keith Koper	Saint Louis University
Suzan van der Lee	Northwestern University
Timothy Ahern	DMS Program Manager

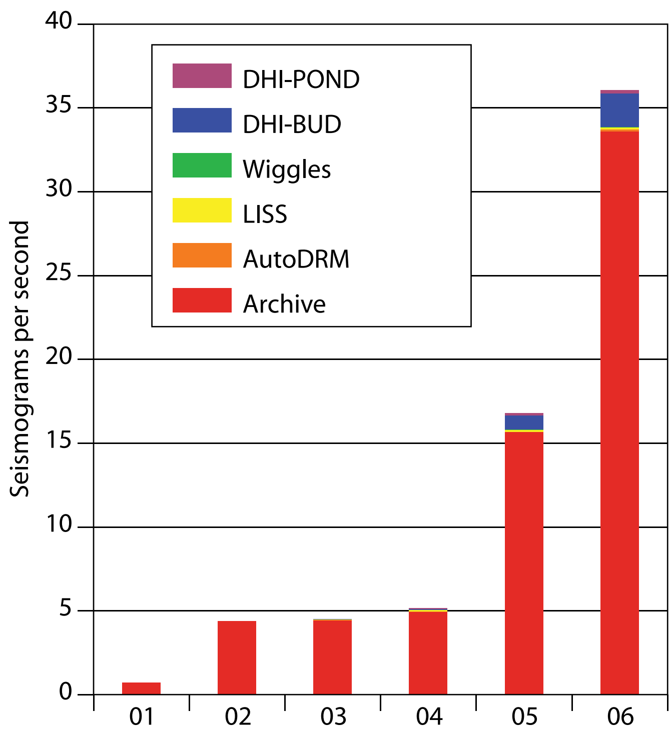
DMS

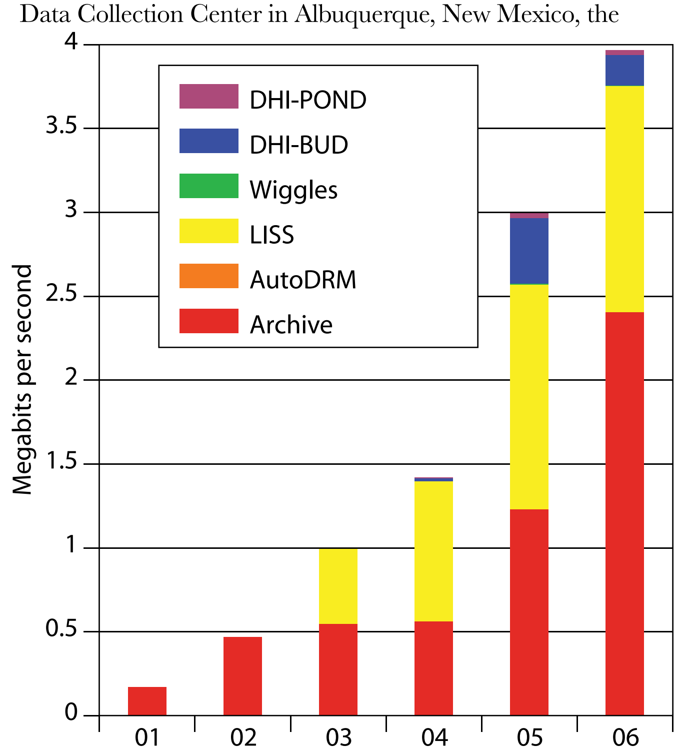
Tim Ahern, Rick Benson, and Rob Casey • IRIS Consortium
Doug Wiens • Washington University in St. Louis



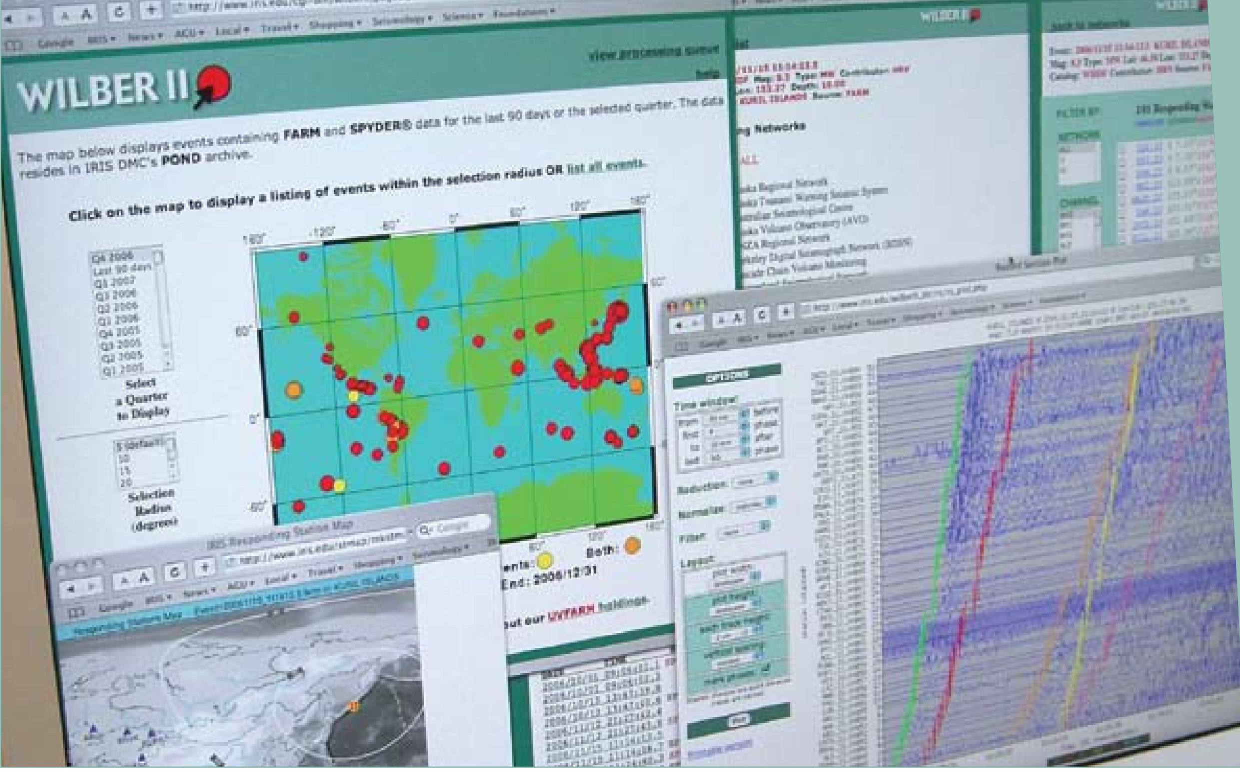
After 18 years, the Data Management Center was finally able to implement an archive storage architecture that relies on disk storage. The transcription of roughly 50 terabytes of data from a Powderhorn Tape based mass storage to online RAID was completed early in 2006. An Isilon IQ6000i cluster storage server now holds all of the Tier 1 data managed at the DMC. The Powderhorn Robot continues to act as a near-line backup for all of the data in the Isilon as well as the only storage for Tier-2 data, those that are less frequently accessed or too costly to store on very large disk systems. For example, we treat the very-high-sampling-rate data from numerous strong motion sensors throughout the Factor Building at UCLA as Tier 2 data. The DMC archive currently holds a total of about 52 terabytes of Tier 1 and Tier 2 waveform data (Note: since the move to the Isilon we no longer maintain a dual sorted archive and the archive size now reflects only a single copy of the data). The archive is growing at a rate of 14 to 15 terabytes per year with much of the new growth coming from EarthScope data.

The Data Management System has primary nodes that consist of the DMC in Seattle, Washington, the USGS Data Collection Center in Albuquerque, New Mexico, the





Left: About 36 seismograms per second (1.1 billion seismograms per year) left the DMC on their way to a researcher during 2006, roughly twice the rate during 2005. Right: During 2006, data left the DMC at a rate of 4 megabits per second (15.6 terabytes per year).



The Wilber II system provides a simple mechanism for discovering records from large earthquakes that are available from the DMC, viewing the data as record sections and station maps, and then downloading the waveforms best suited for any particular research project.

International Deployment of Accelerometers Data Collection Center in La Jolla, California–and it is these three components that directly manage the data flow from the GSN. The PASSCAL Instrument Center in Socorro, New Mexico, provides a similar quality assurance function for PASSCAL data before it is forwarded to the DMC. The DMS also supports activities at three US universities and one data center in Almaty, Kazakhstan. Quality-control-related activities at Columbia University and the University of Washington add to the thorough quality control data at the DMC receive. The University of South Carolina will continue to lead the FISSURES software development effort for one more year. The Kazakh National Nuclear Center continues to insure that data from stations in Kazakhstan flow to the international community through the DMC.

One Billion Seismograms Served

The research community continues to make heavy use of the DMC. It was only in 2005 that the DMC surpassed 500 million seismograms shipped to the research community. Yet, already in 2006, partly due to the improved access to data through the online RAID system, the DMC shipped more than 1 billion seismograms to the research community. While BREQ_FAST continues to be the most frequently used tool to request data from the DMC archive, we are now starting to see increasing use of direct access through the FISSURES Data Handling Interface (DHI) beginning to increase in terms of the amount of data sent to the community in this manner. Data shipments from the DMC continue growing in terms of seismograms per second as well as the steady state dataflow rate in megabits per second. The DMC is presently sending 36 seismograms per second with a data rate of 4 megabits per second to the research community in response to their data requests. While most data still comes from the archive, the growth in the amount of data from the near-real-time system (BUD) through the DHI is now at a level of roughly 7% of the total and increasing. About 73% of the requests from the archive are BREQ_FAST requests and in 2006 16% of requests to the archive came from DHI client applications such as JWEED, VASE, and SOD.

Continued Expansion of Data Sources

During 2006, stations PSI on Sumatra and PATS in Pohnpei, Micronesia, from the Pacific-21 network started telemetering data to the IRIS DMC in real time using ORB-ORB protocol between JAMSTEC and IRIS. The DMC receives data from a total of nine JAMSTEC stations. Also, of the 41 total Geoscope stations for which the DMC archives data, the number of sending real time data to the DMC increased from three to five.

Data from the CTBT International Monitoring system now reach the DMC through a connection from NEIC. The DMC receives data from all of the US-operated IMS seismographic stations and arrays: ATTU, ILAR, PDAR, TXAR, NVAR. In addition, IRIS now has agreements in place with Australia to access their IMS seismographic station and array data via the NEIC circuit and is receiving Warramunga Array and Alice Springs Array data in real time. Also in partnership with NEIC, the DMC continued to re-archive USNSN data. Steady progress during 2006 took the process nearly to the end of data from 1991, and further work is planned for all USNSN data through the year 2002.

Data-Related Services

The DMC held a tremendously successful network data management workshop in Sao Paulo, Brazil, attended by a total of 45 students. The workshop was fortunate to have worldwide experts volunteer their time to lecture at the workshop, including Erhard Wielandt, Göran Ekström, Joachim Wassermann and Reinoud Sleeman. The Local Organizing Committee of Jesus Berrocal, Marcelo Assumpcão and others at the University of Sao Paulo provided a great venue. Thanks to collaboration between Juan Gomez of UNAM and Rick Benson at the workshop, the DMC already has data from a station in Mexico, something that has been in the works for years.

IRIS finalized the SAC license agreement with the University of California. The DMC can now provide SAC to all legitimate seismological users at no cost and the source code will remain open, allowing the USGS and FDSN members to gain access to the code.

DMC Highlights

Tim Ahern and Chad Trabant • IRIS Consortium; Doug Wiens • Washington University in St. Louis

EarthScope

The IRIS DMC archives and provides access to nearly all time-series data collected as part of EarthScope. We now have data from the following USArray components: Transportable Array, Flexible Array, Reference Network and Magnetotelluric data. The Array Operations Facility in Socorro, New Mexico, provides data download and quality control for Flexible Array data before they are transmitted to the DMC, analogous to the role of the GSN data collection centers.

The Plate Boundary Observatory (PBO) provides access to most of their time-series data through the DMC as well. These data include borehole strainmeter data, laser strainmeter data, and borehole seismic data. The DMC also acts as a backup archive facility for all GPS data collected by PBO.

SAFOD data are of three types: 1) real-time monitoring data from 1–2 sensors from the Pilot and Main SAFOD boreholes at a sample rate of 250 samples per second, (2) 20 second event windows for identified SAFOD events at a sampling rate of 4000 samples per second, and (3) the continuous borehole sensor data at 4000 samples per second are stored as Tier -2 data in the DMC's Powderhorn robot. The DMC presently has about 4.5 terabytes of EarthScope data and we have already shipped a total of over 0.5 terabytes of EarthScope data to end users.

The Metadata Aggregator

The DMC developed some very compelling tools that we believe will help provide researchers easy access to useful data about all the seismic networks whose data are managed at the DMC. The MetaData Aggregator (MDA) can be found at *http://www.iris.edu/mda*. This tool allows one to very quickly determine key information related to seismic networks including stations in the network, their locations, instrumentation installed at a station, channels being recorded, instrument responses, sample rates, and a variety of other useful metadata. We encourage you to spend a few minutes to find out for yourself how easy to use and powerful the MDA is.

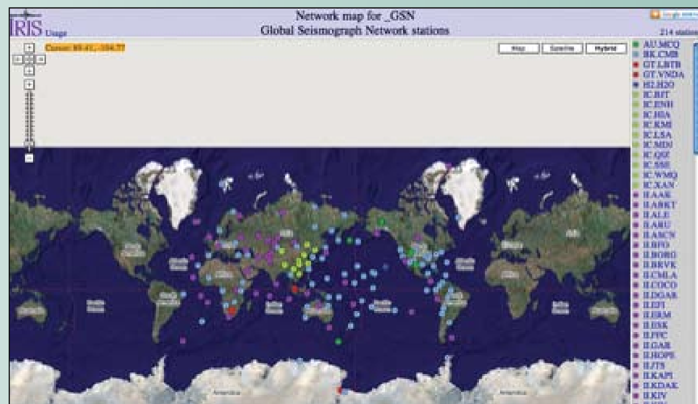
The MDA fully supports access to information about seismic networks using the two character FDSN network code (such as IU, II, and XA) but perhaps even more powerfully it supports the use of the virtual networks defined at the DMC. More information about virtual networks can be found at *http://www.iris.edu/vnets*. For instance, if one wishes to determine information about the Global Seismic Network (GSN) they would have to know which stations from ten different actual networks (AU, BK, GT, H2, IC, II, IM, IU, MS, TS) make up the GSN. The DMC maintains a virtual network called '_GSN' which allows one to easily access the full GSN description with almost no complexity. The MDA description of the GSN is invoked by linking to *http://www.iris.edu/mda/_GSN*.

Google™ Earth screenshot showing earthquakes from the USGS (yellow circles) superimposed with EarthScope station locations. These EarthScope stations include the Reference Network (orange pushpins) the Transportable Array (white circles), Flexible Array stations (blue, pink, red, green, and light blue circles), PBO strain and borehole seismic stations (dark blue circles) and the SAFOD Pilot Hole.

Google Mapping Support

Maps showing the stations in a real or virtual network are available from the MDA page. Clicking on the link to "Google Maps" produces a Google™ Map, such as the one shown on the next page, for the GSN. All of the capabilities of Google™ Maps are available to the user including zooming, re-centering, satellite imagery and hybrid maps. Display of station coverage during specific time spans is also possible using the Google™ mapping capabilities. For more information about the Google™ Map support available through the DMC, refer to *http://www.iris.edu/gmap*.

On the upper right hand corner of the IRIS Google™ Map Displays one also sees a link to Google™ Earth. Clicking on the Google™ Earth logo will result in the displayed network information being reformatted into a Keyhole Markup Language (KML) file. These are network links that will be updated periodically and it helps insure that dynamic networks like the EarthScope/USArray Transportable Array are routinely refreshed. Google™ Earth is available from Google™ as a free application at *http://earth.google.com/*.



Google™ Map showing GSN stations.

Geoscience Web Services

The DMC participates in the Geoscience Web Services (GeoWS) effort (*www.geows.org*). This collaboration among the Lamont Doherty Earth Observatory (LDEO) of Columbia University, the UNAVCO Consortium, and IRIS brings distributed Web Mapping Services to our user communities. Each of the three groups operates an Open Geospatial Consortium (OGC) standards-based Web Mapping server, producing information that can be combined and viewed within a single Web Mapping Services Client. For instance, LDEO supplies bathymetry, ship tracks, and other marine geological and geophysical information, UNAVCO provides GPS station locations, and the DMC provides locations of seismographic stations and earthquakes. In addition, the DMC provides locations for some products, such as moment tensors, that are managed by SPADE–a product management system that the DMC developed for the USArray component of EarthScope.

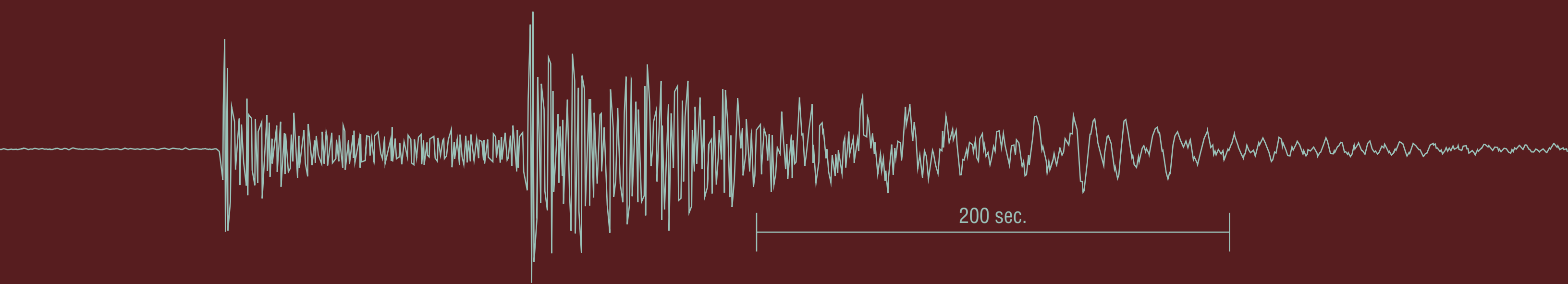
To tie all of these data together, a client program pulls back a reference map from a freely available web mapping service and facilitates latitude and longitude selections from the map itself. The GeoWS data providers then independently deliver online “web feature services” (WFS). A “feature” is a data point on the map that indicates location and basic identification as well as a link to more information if the user selects the item. The WFS can provide a series of these feature points, which are then overlaid on a base map as a “layer.” Users can selectively turn data layers on and off so they only see the information that they want to.

While initially simple, use of Web services enables extension of GeoWS to incorporate search criteria to other types of metadata. The capabilities of these compatible services are demonstrated in the GeoWS tool. Currently available as a prototype, this tool allows discovery from all three data centers using a simple map interface and allows users to search by latitude and longitude ranges; elevation and time range criteria will be added in future releases. The design of GeoWS is purposefully extensible, since it is intended to be a common interface that other data centers can adopt and provide an easy access mechanism for data centers to offer data discovery from their peer organizations.

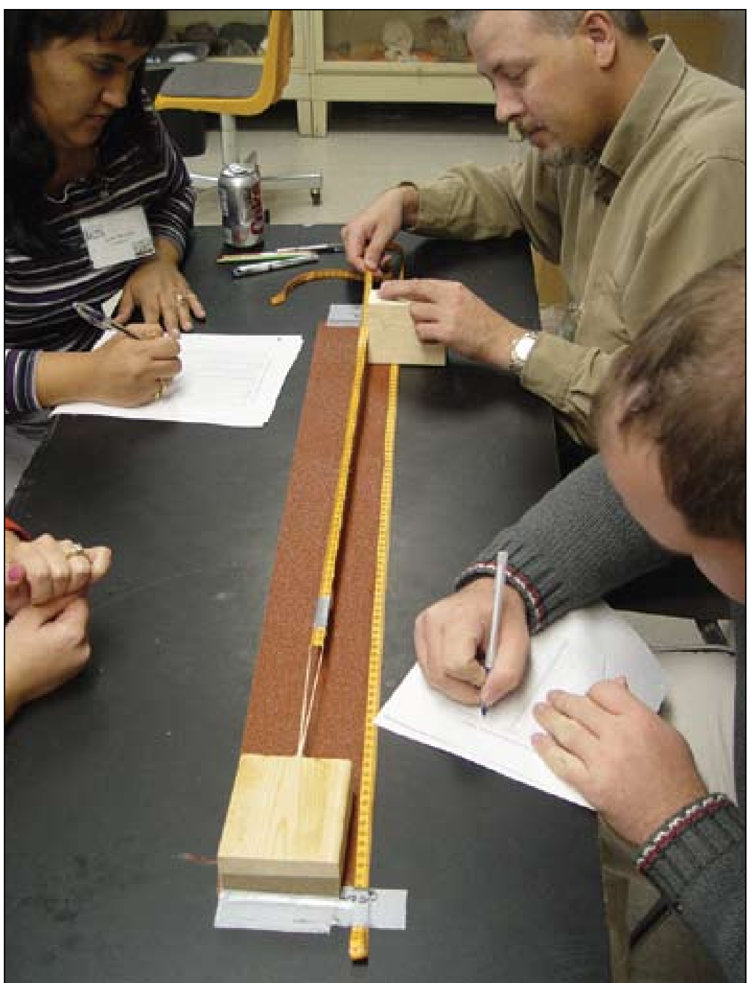
A world map displayed in the freely available OGC-compliant GIS client uDig shows FDSN stations (orange), GSN stations (red), and USArray stations (blue-green). Operating stations of the Transportable Array portion of USArray are clustered in the western United States. The dark green squares represent locations of events that have CMTs managed by the SPADE system.

E&O

John Taber, Michael Hubenthal • IRIS Consortium



The Education and Outreach (E&O) Program is committed to using seismology and the unique resources of the IRIS Consortium to make significant and lasting contributions to science education, science literacy, and the general public's understanding of the Earth. The E&O program has continued its development and dissemination of a well-rounded suite of educational activities designed to impact a spectrum of learners, ranging from 5th grade students to adults. These learning experiences transpire in a variety of educational settings ranging from self-exploration in front of one's own computer, to the excitement of an interactive museum exhibit, a major public lecture, or in-depth exploration of Earth's interior in a formal classroom.



The efforts of the IRIS E&O program during the past year have been focused on the refinement and enhancement of ongoing core activities, and the expansion of their impact. The museum program highlights these efforts, with millions of people potentially interacting annually with the IRIS/USGS museum displays, many of them at the American Museum of Natural History and the Smithsonian Institution National Museum of Natural History. A new smaller, more flexible version of the museum display has been tested at eight sites in the past year as well as being installed at the South Pole station and provided to the host of a USArray Reference Network station. The display is based on an evaluation of our large displays, which showed that audiences are particularly interested in the presentation of near-real-time seismic information. Served via a Web browser, the display is customizable for each museum and touch screens provide an interactive experience.

Another program aimed at general audiences is the IRIS/SSA Distinguished Lectureship Series. This was the fourth year of the series, and our three speakers presented a total of 17 lectures at major museums and universities throughout the country to audiences of up to 400 people. A new poster, titled A Century of Earthquakes, was developed to commemorate the 1906 San Francisco earthquake centennial and to accompany the Distinguished Lectureship.

The E&O Program continues to refine its highly effective set of professional development experiences designed to support the background and curricular needs of formal educators. Leveraging the expertise of Consortium members, IRIS delivers content such as: plate tectonics, propagation of

Yuma, AZ teachers engaged in the "Plate Puzzle" exercise as part of a multi-year professional development effort designed around the specialized needs of the district.

seismic waves, seismographs, earthquake locations, and Earth's interior structure, in workshop formats ranging from one-half to three days. A one and one-half day focused workshop was also offered this year to teachers who use AS1 seismographs in their classroom that they received through the IRIS seismographs in schools program. There are now more than 100 such seismographs in use by schools around the United States. Other new sessions this year included half-day tutorials for teachers at the EERI/SSA 1906 centennial meeting and a three-day workshop held in collaboration with Penn State and North Carolina A&T as part of the AfricaArray project.

The second in a series of professional development sessions for high school and middle school teachers in Yuma, AZ was conducted over three days this year. The effort, designed in collaboration with the Yuma Union High School District is part of a systemic reform endeavor, which supports the district's need to prepare its earth science teachers to adequately address the newly adopted Arizona state science standards, as well as developing a scope and sequence of resources to support all of the district's earth science teachers.

The Educational Affiliate membership category and the Undergraduate Internship program have increased IRIS' impact among their respective audiences of undergraduate faculty and students. The objective of Educational Affiliate membership is to cultivate a base of non-research colleges and universities committed to excellence in undergraduate geoscience education through the co-development of E&O activities designed to address their needs. Our summer internship program was expanded this year through a Research Experiences for Undergraduates grant from NSF. Students began the summer with a one-week orientation hosted by New Mexico Tech. The week provided a chance for the students to bond together as a group and to provide a common starting point for them. The nine undergraduates then spent the rest of the summer engaged in research at nine different IRIS institutions, where they kept in touch with each other via Internet blogs and discussion boards. Through their participation in the program, these students gain experience in and exposure to earth science as a potential career path.

The E&O Web pages remain a primary means of dissemination of information and resources. The Seismic Monitor is the most popular IRIS Web page and we continue to add new material. Ongoing collaboration with University of South Carolina and the Digital Library for Earth System Education (DLESE) has led to the refinement of the Rapid Earthquake Viewer (REV). REV is a simple, real-time Web interface for viewing and exploring the seismic data that are available via the IRIS Data Management Center.

Students engage in a seismic refraction experiment during the 2006 summer intern orientation at New Mexico Tech.

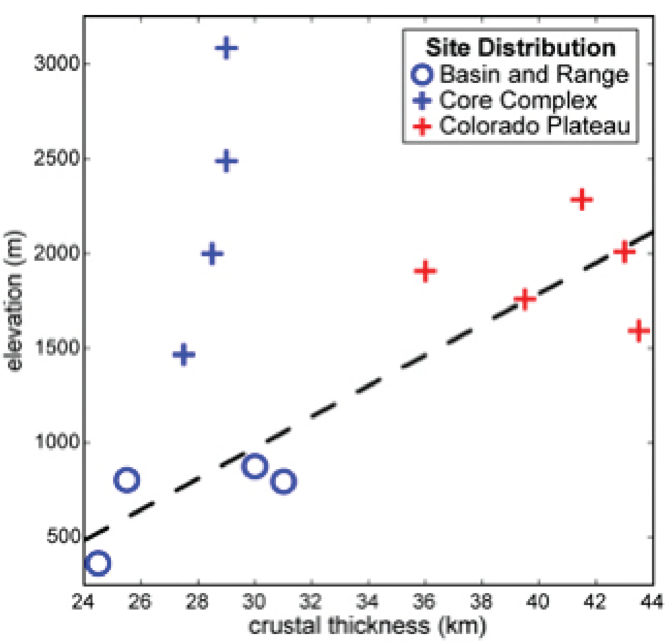
Additional audiences are reached via collaboration with other regional and national geoscience programs. For example, 15,000 copies of a REV activity were provided this year for AGI's Earth Science Week packets along with an earthquake activity in the Earth Science Week calendar. We also leverage our resources by providing materials for workshops organized by other organizations. EarthScope related activities are and will continue to be an important focus and we are working closely with both EarthScope and UNAVCO E&O programs to maximize our impact.

Tectonics of the Basin and Range Province and the Colorado Plateau

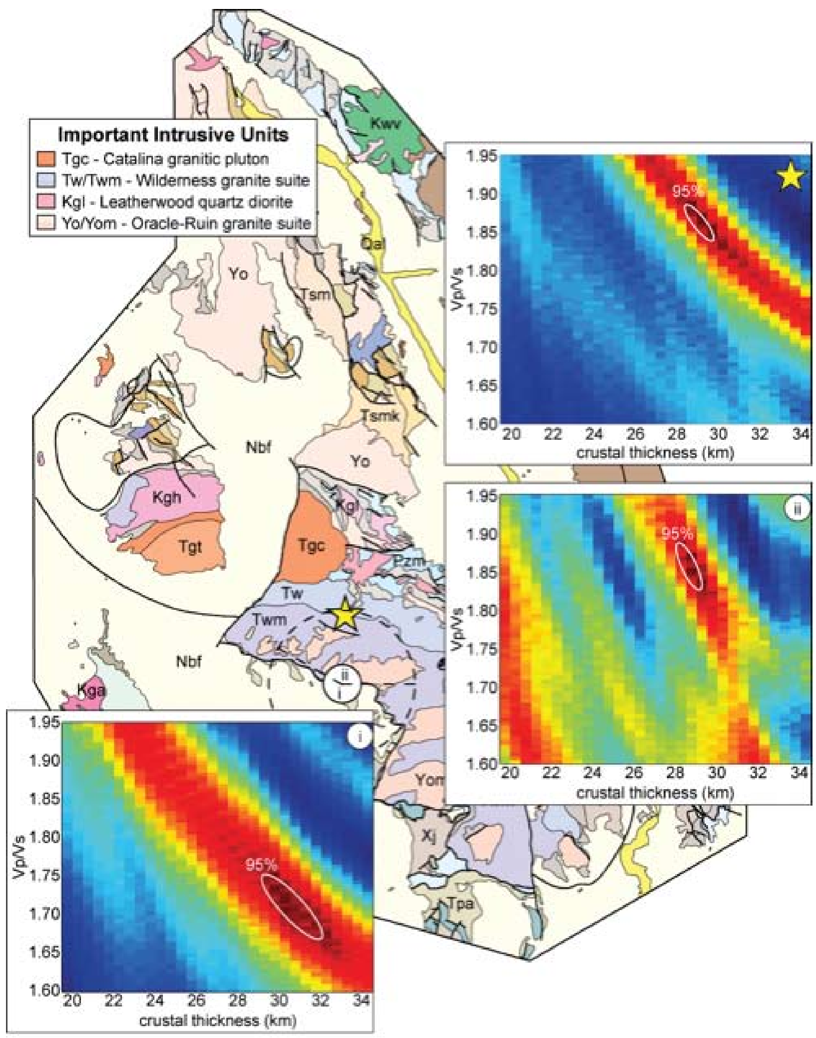
Andy Frassetto • University of Arizona

During the summer of 2003, I was a recipient of an IRIS Undergraduate Internship, allowing me the opportunity to spend ten weeks at the University of Arizona working with my now-PhD advisors George Zandt and Susan Beck. Conducting an independent study far from my familiar environment at the University of South Carolina proved to be a challenging, frustrating, but rewarding time. The internship proved to be a turning point in my academic career, an opportunity which pushed forward my understanding and appreciation of seismology and drew my interest to further exploring the research questions associated with Cordilleran tectonics. The initial internship experience, which began as a simple summer project, expanded into an AGU fall meeting abstract and then senior thesis before finally culminating in a peer reviewed article [Frassetto et al., 2006]. From a personal standpoint it has been exciting to see an initially small aspect of my undergraduate degree expand into an important cornerstone of my graduate education. My experience and the stories from other interns with whom I have interacted convince me that these internships provide an unparalleled opportunity to learn and appreciate seismology as an undergraduate. In my case, it set me on a journey that continues today.

My internship project focused on examining variations in the crust and upper mantle using data from the recently deployed Consortium for an Arizona Reconnaissance Seismic



Relationship of elevation and crustal thickness as estimated from receiver functions. A least squares trend-line is fit to all stations with the exclusion of those atop metamorphic core complexes. The departure of core complexes from the trend-line shows their deviation from a traditional isostatic relationship between increasing elevation and thickening crust that is evident elsewhere throughout the COARSE survey area.



The map shows the locations of the COARSE station atop the Catalina metamorphic core complex as yellow star and of the GSN station TUC as a divided circle in the Catalina foothills. The receiver function stack labeled with a yellow star shows the crustal thickness-Vp/Vs "bull's eye" for the COARSE station. The other receiver function stacks are of arrivals at TUC from (i) the southwest and (ii) the northeast. The division of the circle in the map shows the azimuthal limits for the two TUC stacks. An ellipse representing greater than 95% of the maximum stacked amplitude is applied to represent uncertainty of the measurement. These stacks show a crust of equal to lesser thickness with substantially greater Vp/Vs beneath the high elevations of the Catalina core complex range. Such a large increase in Vp/Vs is rarely seen, and indicative of a confined but significant change in the crustal composition and density within the Catalina core complex.

Experiment (COARSE) broadband network. These broadband instruments, managed primarily by my advisors Matt Fouch at Arizona State and Hersh Gilbert (now at Purdue), were spread across central and southeastern Arizona and formed a dataset that sampled several previously unstudied regions of the Basin and Range province and the Colorado Plateau. Working with George Zandt and Hersh Gilbert, my role as an intern and now graduate student has been to characterize the structure and composition of the crust and upper mantle using P-wave to S-wave converted phases generated by discontinuities in the lithosphere beneath a broadband station. These converted phases and their multiples appear prominently in receiver functions, created by removing through deconvolution the source and instrument response from three-component broadband records for large earthquakes at teleseismic distances [e.g., Langston, 1979]. Receiver functions respond most sensitively to variations in the thickness and S-wavespeed of individual layers and, if a P-wavespeed for a layer (e.g., the crust) is estimated, receiver function traces can be stacked in the thickness-Vp/Vs domain to constrain the crustal thickness and composition (as a function of Vp/Vs) [Zhu and Kanamori, 2000].

Receiver function analyses show that the southern Basin and Range province has a relatively thin crust of ~28 km thickness, versus the ~40 km thick crust of the Colorado Plateau. These results are consistent with the tectonically extended vs. unextended nature of the two geologic provinces. A proportional relationship between elevation and crustal thickness can be viewed for most stations throughout the COARSE array. However, the absence of a crustal thickness increase beneath the high metamorphic core complexes in the Basin and Range province lead us to further explore these highly extended and uplifted sections of the middle crust which have Vp/Vs of 1.79-1.87. This value is higher than the global average for Vp/Vs of 1.73 in Cenozoic and Mesozoic orogenic belts [Zandt and Ammon, 1995]. In particular, two seismic stations near Tucson and in proximity to the Catalina metamorphic core complex show a significant local increase in Vp/Vs beneath the core complex. Forward models created to constrain crustal composition and isostatic compensation using the seismically determined Vp/Vs, crustal thickness, and the Bouguer/isostatic gravity field reveal that core complexes in this region are supported by relatively buoyant segments of crust that are rich in plagioclase and poor in quartz. Additionally, in the case of the geologically well-mapped Catalina core complex, these zones of high Vp/Vs coincide with a compositionally distinct series of intrusions that were emplaced during late Cretaceous magmatism. These findings have broader implications for the manner in which the low-angle extension that formed core complexes was distributed during Tertiary orogenic collapse in southern Arizona. For a more detailed explanation of this study, please see the original publication.

The benefits of my internship experience with IRIS reach beyond research results. The fieldwork aspect of COARSE project prepared me for working on extensive seismic deployments as a graduate student in the Coast Mountains of British Columbia, the Sierra Nevada of California, and the Olympic Mountains of Washington. Most recently, Michael Hubenthal and John Taber invited me to serve as a mentor to the most recent group of IRIS interns. This involved me giving two presentations on my internship experiences and graduate school at the Internship Orientation Workshop in Socorro, NM in May 2006. Additionally, throughout the summer I served as a remote resource for interns with issues and questions as well as an advisor based on my experiences as a researcher in seismology. IRIS not only invigorated an interest in seismology and provided a broad and interesting research topic that I continue to explore, but also allowed me to gain valuable field experience and recently afforded me the opportunity pass on my enjoyment of seismology to other interns and hopefully impact those who are in the same important stage of their lives that I found myself during the summer of 2003.

Andy Frasetto at a seismic station in the Coast Mountains of British Columbia.

ACKNOWLEDGEMENTS

Aibing Li (Univ. of Houston) and Steve Grand (Univ. of Texas-Austin) loaned broadband instruments used during this experiment and Tom Owens (Univ. of South Carolina) helped get it all started.

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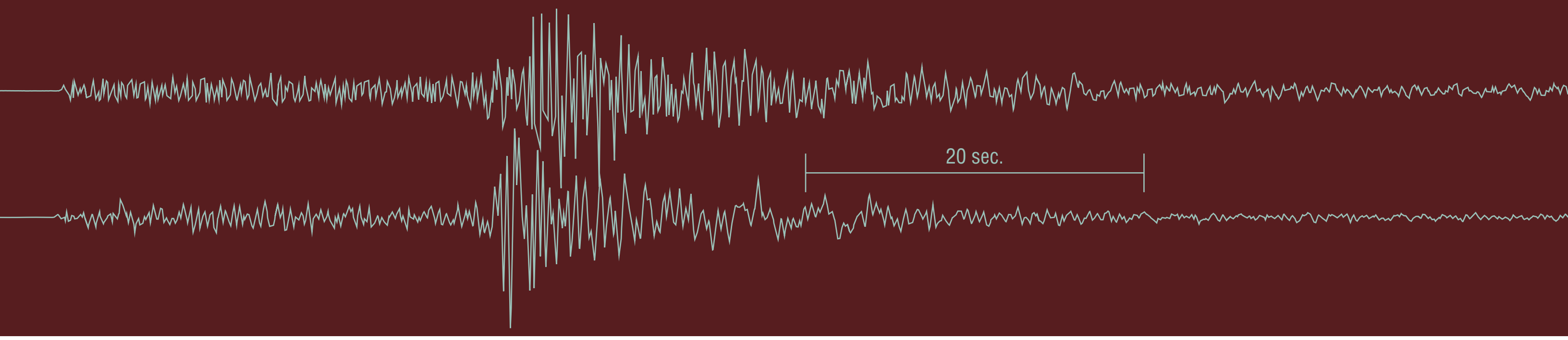
G. Zandt and C.J. Ammon (1995), Continental crust composition constrained by measurements of crustal Poisson's ratio, Nature, 374, 152-154.

L. Zhu, H. Kanamori (2000), Moho depth variation in southern California from teleseismic receiver functions, J. Geophys. Res., 105, 2969-2980.

Transportable Array Working Group	
Gary Pavlis (Chair)	Indiana University
Matt Fouch	Arizona State University
John Collins	Woods Hole Oceanographic Institute
Egill Hauksson	California Institute of Technology
Suzan van der Lee	Northwestern
Michael Ritzwoller	University of Colorado
Hersh Gilbert	University of Arizona

TA

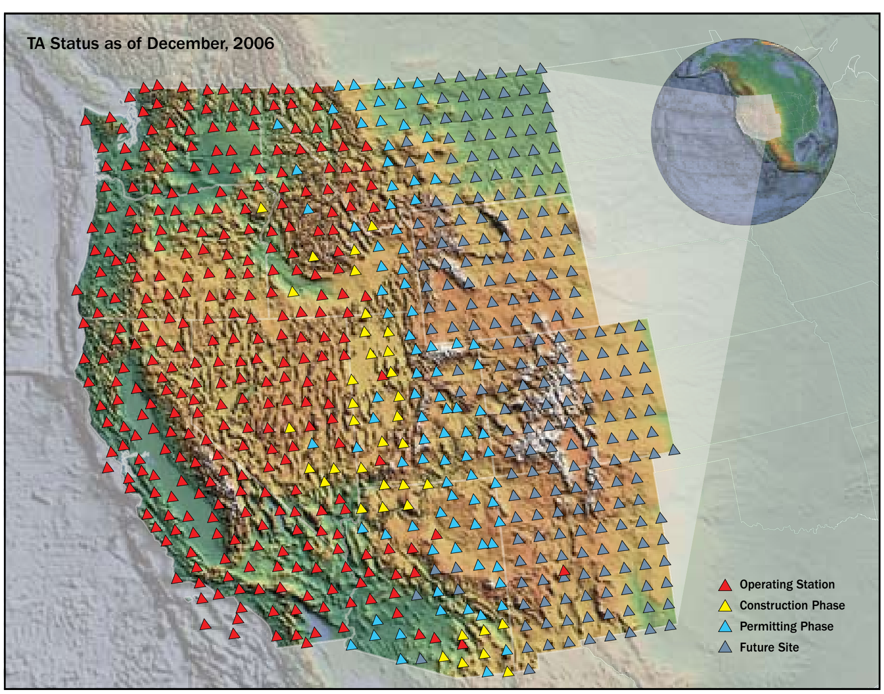
Bob Busby • IRIS Consortium



The Transportable Array is a dense array of broadband seismographs that is being installed across the continental United States and Alaska as part of the USArray component of the NSF-funded EarthScope project. With a station spacing of ~70 km, the array will provide unprecedented coverage for producing 3-D images of Earth's interior and new insights into the earthquake process. The array will consist of 400 transportable broadband seismic stations that will advance across the country in a roll-along fashion. The stations will have an average residence time of 18–24 months and occupy nearly 2000 locations over a period of 10–12 years.

Installation of Transportable Array stations approached 300 sites by the end of 2006, exceeding the year-end goal of 272 operating stations. The network is now complete in California, Oregon, and Washington. Construction and installation activities are continuing in Idaho and western Montana and southward into Nevada, Utah and Arizona. By September 2007, the first complete footprint of the 400-station array will be fully installed. Daily updates on the status of the Transportable Array and other EarthScope facilities are provided on the EarthScope home page (www.EarthScope.org) and plots of data from both local and distant earthquakes show the quality and quantity of data already available for each event.

Standardized procedures for the procurement and staging of materials have increased the rate of station construction and installation from 10 new stations per month at the beginning of the year to the current rate of 16 new stations per month. To construct a station, a construction crew digs the holes, pours the concrete, and installs the vault for the seismometer and electronics. After the cement has set, a separate crew arrives on a second day and installs the seismometer, electronics, and communication equipment. Data are telemetered in a variety of ways, including cell phone modem, broadband Internet, and satellite link. The remote sites are all solar powered, though satellite links use power mains where available.



SUPPORT FACILITIES

The construction of the Transportable Array network and the collection and distribution of data from the array depends on the support of staff at a several facilities including the Transportable Array Coordinating Office, the Array Operations Facility, the Array Network Facility, and the IRIS Data Management Center.

The New Mexico Institute of Mining and Technology houses the Array Operations Facility (AOF) and the Transportable Array Coordinating

Transportable Array station C08A in Almira, WA

Office (TACO) in the newly expanded PASSCAL Instrument Center building in Socorro. The AOF supports both the Transportable Array and Flexible Array, fulfilling a role similar to that of the PASSCAL Instrument Center, which consists primarily of testing new equipment and then packing and shipping it to the field. The TACO staff provides administrative and technical support for permitting and landowner activities and plays a vital role in coordinating schedules and materials between the AOF and field crews. The AOF employs 4 FTEs (full-time equivalent staff) for the AOF and 4 FTEs work in the TACO. There are 11 FTEs engaged in field operations.

Data from the Transportable Array stations are transmitted in near realtime to the Array Network Facility at the University of California, San Diego. The 5 FTEs at the ANF check the data for quality and perform online analysis of station and instrument status, environmental monitoring, and state of health. The data are immediately forwarded to the IRIS Data Management Center in Seattle which does further quality control, including routine checking of power spectral density plots to examine noise characteristics of each site. The data are archived and made available to the scientific community and the public primarily via automatic transfers from station to archive with very little delay.

COOPERATIVE SITING AND LOCAL INVOLVEMENT

A key element in the success of the Transportable Array has been the involvement of regional networks and IRIS members in station siting and permitting, tailored to suit the partners in each region. In states with regional networks, the network operators conduct much of the siting or participate by upgrading and making existing stations available to the Transportable Array.

Another goal of EarthScope is to actively engage students who will become the next generation of earth scientists. Building on the success of last year's pilot program to involve students in identifying candidate sites for Transportable Array stations in Oregon, the 2006 program was expanded to include three states, four universities, and 13 students. At the beginning of the summer, a multi-day training workshop was held for students participating from the University of Idaho-Moscow, Boise State University, Montana Tech, and the University of Utah. During the workshop, the students learned to identify sites that meet the requirements of the Transportable Array using a Geographic Information System and their own field investigations. The students then worked in pairs to identify potential sites in Idaho, western Montana, and Utah and make initial contact with landowners. After a site was identified, the student team documented their findings and turned the information over to a professional permitter who verified the site and completed the permitting process. Over a 9-week period, the students identified more than 110 candidate sites.

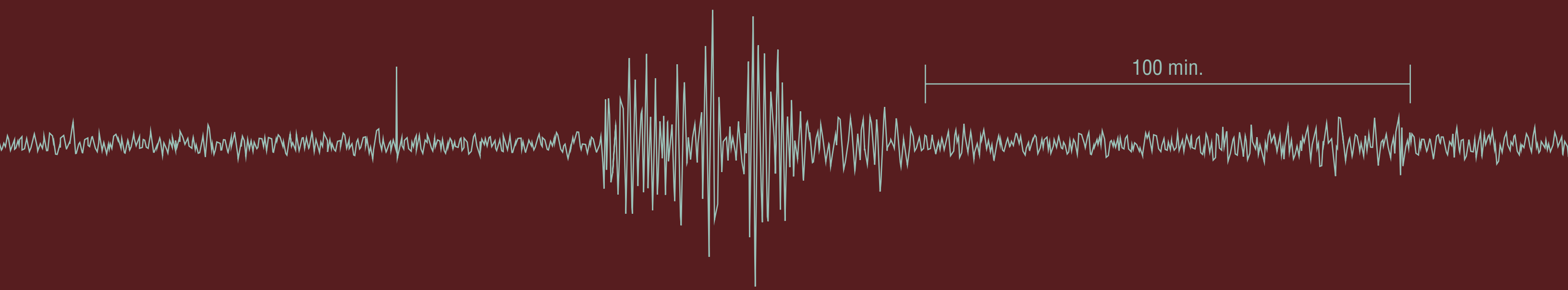
Through a subaward to Arizona State University, the Transportable Array is partnering with IRIS Educational Affiliate Diné College to provide support for reconnaissance activities on Navajo lands, including assistance from a Diné language translator and facilitator, who accompanies the siting teams into the field. Arizona State University has also identified a strong partner both for Transportable Array siting and for education and outreach at San Carlos High School on the San Carlos Apache Nation. The school's principal and faculty have enthusiastically welcomed the siting of Transportable Array station Z17A and a group of the teachers are participating this winter in an experimental place-based, quantitative geoscience course conducted by Steve Semken of Arizona State University.

In early 2006, the Transportable Array, in collaboration with the Plate Boundary Observatory and the EarthScope facilities office, initiated a newsletter, EarthScope onSite. Published quarterly, the newsletter informs station hosts and other interested parties about the status of EarthScope. The first issue, produced this spring, was a general introduction to EarthScope. Following issues have been alternating in focus between the Transportable Array and the Plate Boundary Observatory. More than 400 copies of each issue are mailed to current and potential hosts of Transportable Array stations.

Magnetotellurics Working Group	
Phil Wannamaker (Chair)	University of Utah
Adam Schultz	Oregon State University
Rob Evans	Woods Hole Oceanographic Institute
Dean Livelybrooks	University of Oregon
Kevin Mickus	University of Missouri
Steve Park	University of California, Riverside
Gary Egbert	Oregon State University
Martyn Unsworth	University of Alberta
Shane Ingate	IRIS

MT

Shane Ingate • IRIS Consortium

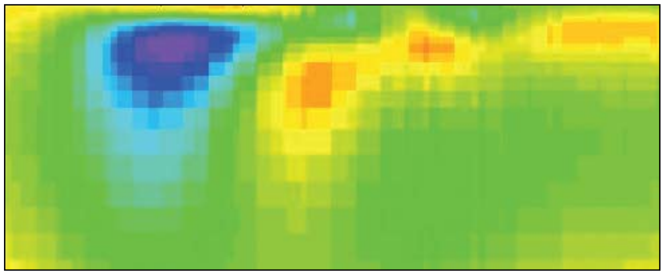


The IRIS consortium, in conjunction with the ElectroMagnetic Studies of the Continents (EMSOC) consortium (*http://emsoc.ucr.edu/emsoc/*) is installing temporary magnetotelluric (MT) stations across the contiguous United States as part of EarthScope/USArray.

MT stations consist of two sets of grounded electrical field measurement lines and a ring-core magnetometer to measure the natural electric and magnetic fields at the Earth's surface caused by electromagnetic waves radiated from the sun and from distant electrical storms. A regional lithospheric/asthenospheric conductivity map of the United States is a high priority product for EarthScope. These mantle conductivity models will complement the seismic tomography images of the structure beneath North America. In some cases, conductivity provides constraints that are difficult to provide from seismic data: for example, conductivity is particularly sensitive to the water content of the mantle. Joint interpretation of conductivity, velocity, and attenuation is beginning to provide better constraints on composition and physicochemical state than can analysis of any one property alone, and the electromagnetic community anticipates that further development in this area will continue.

During the summer of 2006, IRIS, University of California Riverside, University of Oregon, Oregon State University, and GSY-USA, Inc. deployed 10 MT systems at 30 sites uniformly distributed throughout Oregon east of the Cascades, coincident with the High Lava Plains and Wallowa temporary seismic experiments. This pilot project was conducted to determine the costs and challenges of routinely deploying state-of-the-art MT systems by a professionally managed services contractor with scientific oversight provided by a university group.

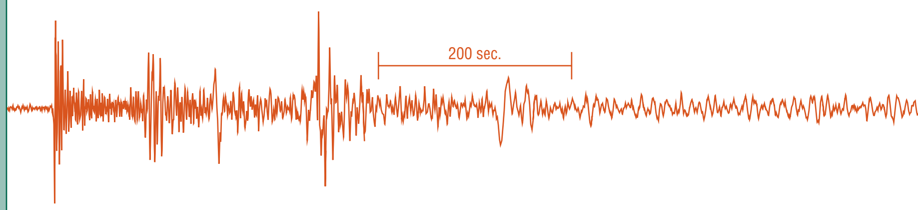
An additional seven systems will be procured for construction of seven permanent MT stations across the United States, which will operate for the duration of EarthScope. Four of these stations were constructed in Parkfield, CA, Soap Creek, OR, Braden, MO, and Hilton Ranch, NM, during 2006.



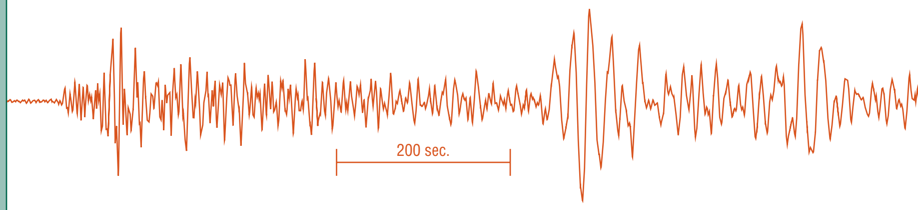
Magnetotelluric cross section at ORPP extending to a depth of 20 km, with no vertical exaggeration.

Datagrams Used In This Annual Report

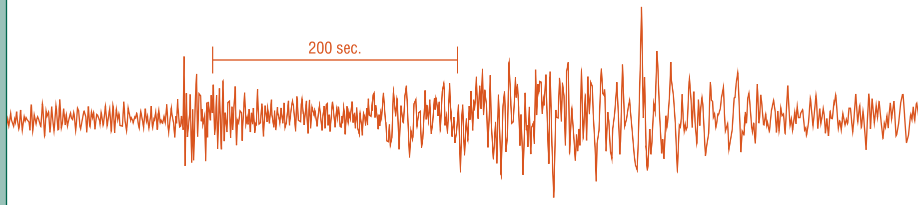
Vertical record of the MW 7.1 Fiji deep focus (h=579 km) earthquake on January 2, 2006 by Global Seismographic Network station on Kwajalein Atoll (KWAJ) at Δ=31.7°. The body wave arrivals P, PP, PcP, S and SS from are obvious even in the unfiltered broadband record. The simplicity of the PcP phase suggests a simple source function; the complexity of the other phases may arise from near surface reverberations at the station and the bounce points.



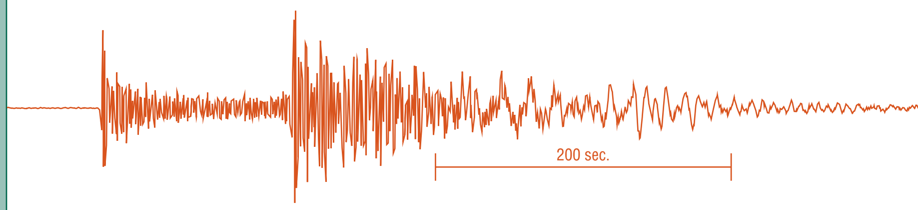
Vertical record of the MW 8.3 Kuril Islands shallow (h=30 km) earthquake on November 15, 2006, by station SMT.YU at Δ=60.5°. The station was deployed as part of a USGS/PASSCAL experiment to study site responses of levees in the in the Sacramento-San Joaquin Delta, California. The P wave train, with dominant periods of 8 to 12 s, shows amplification compared to a local hard rock site that is probably caused by local basin structure rather than the smaller scale levees.



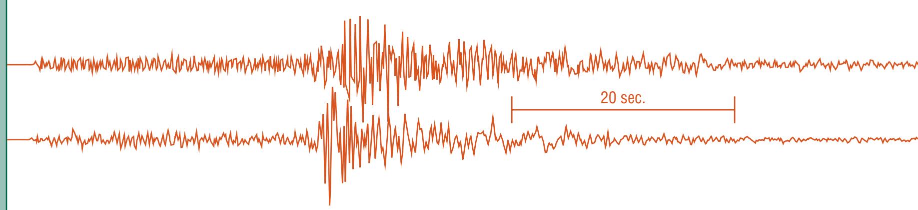
Vertical record of the mb 5.7 Sunda Strait intermediate depth (h=87 km) earthquake on January 23, 2006 by the Malaysian Meteorological Service station at Kulim (KUM.MY), at Δ=12.9°. The unfiltered broadband record shows both the P arrival (complicated by the travel time triplication at this distance) and, despite the focal depth and relatively short epicentral distance, the dispersed Rayleigh wave.



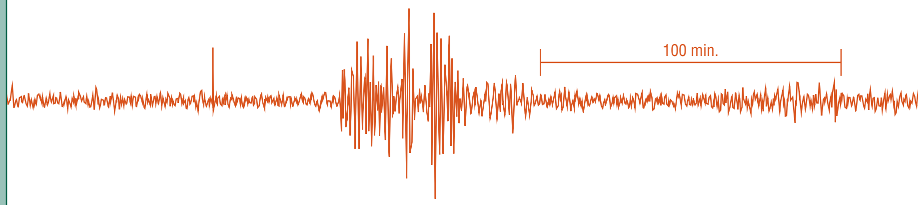
Vertical record of the MW 5.8 Gulf of Mexico shallow (h=14 km) earthquake on September 10, 2006, by the Floyd Central High School station (PPNAF) of the Indiana PEPP network, at Δ=12.0°. The earthquake was featured in many news stories because it is unusually large for the region and because of then-recently announced plans to drill for oil in deeper parts of the Gulf. The S arrival is unusually prominent partly because no significant Lg energy propagated from the oceanic crust in the Gulf into the continental crust of North America.



Vertical records of the *mb* 4.7 Mt. Ranier, Washington, shallow (*h*=3 km) earthquake on October 8, 2006, by Transportable Array stations C08A (Δ=1.97°, *α*=60°, above) and B07A (Δ=1.90°, *α*=31°, below). The unfiltered waveforms differ markedly at these two nearby stations, perhaps due to different site effects at C08A (in flatlands just south of Grand Coulee Dam) and at B07A (within the Cascadia Range).



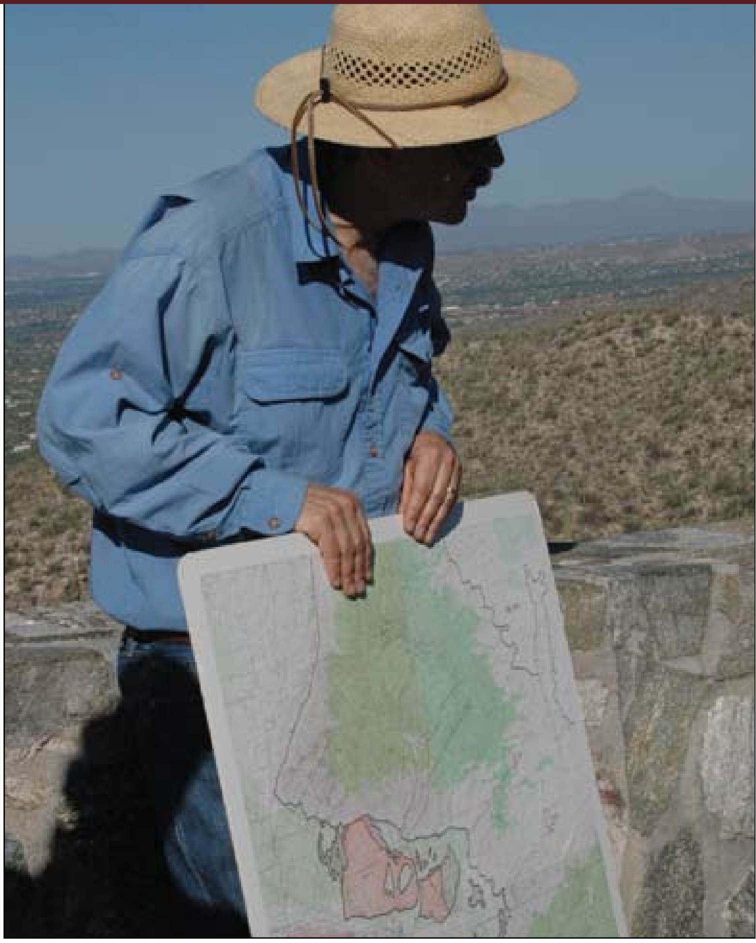
Filtered (200 s – 1 s) telluric north-south record of a transient signal on September 1, 2006, by USArray magnetotelluric station ORJ05 in Oregon. With a dominant period near 100 s and a planar source, the signal is probably from a magnetic pulsation and storm in the upper atmosphere.

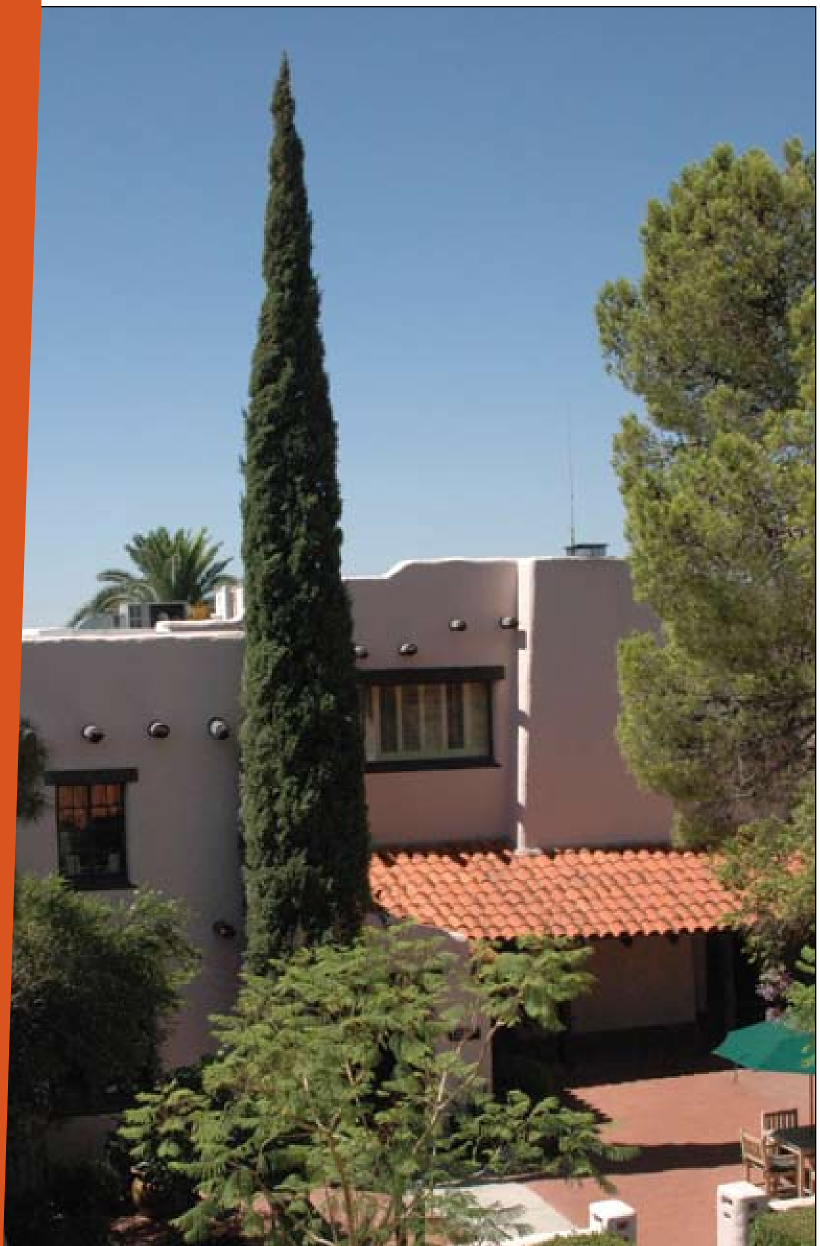


Activities and Publications

Raymond Willemann • IRIS Consortium

In addition to program oversight and administration, the Consortium also serves the role of an ongoing forum for exchanging ideas, setting community priorities, and fostering cooperation. To enhance this role, IRIS engages the broader community through the use of publications and workshops. Our publications, which are widely distributed without charge, are organized around topical issues that highlight emerging opportunities for seismology. The IRIS Workshop and the EarthScope National Meeting are used to assess the state of the science, introduce programs, and provide training. Through a student grant program, young scientists attend the IRIS Workshop at little or no cost, and are introduced to the programs and services of the Consortium. As a Consortium, IRIS also serves as a representative for the geoscience community. IRIS staff and committee members serve on White House committees, State Department advisory boards, USGS panels, and testify before Congress.





Such broad interactions raise the profile of geosciences and provide a direct societal return from the federal investment in IRIS.

IRIS Workshop

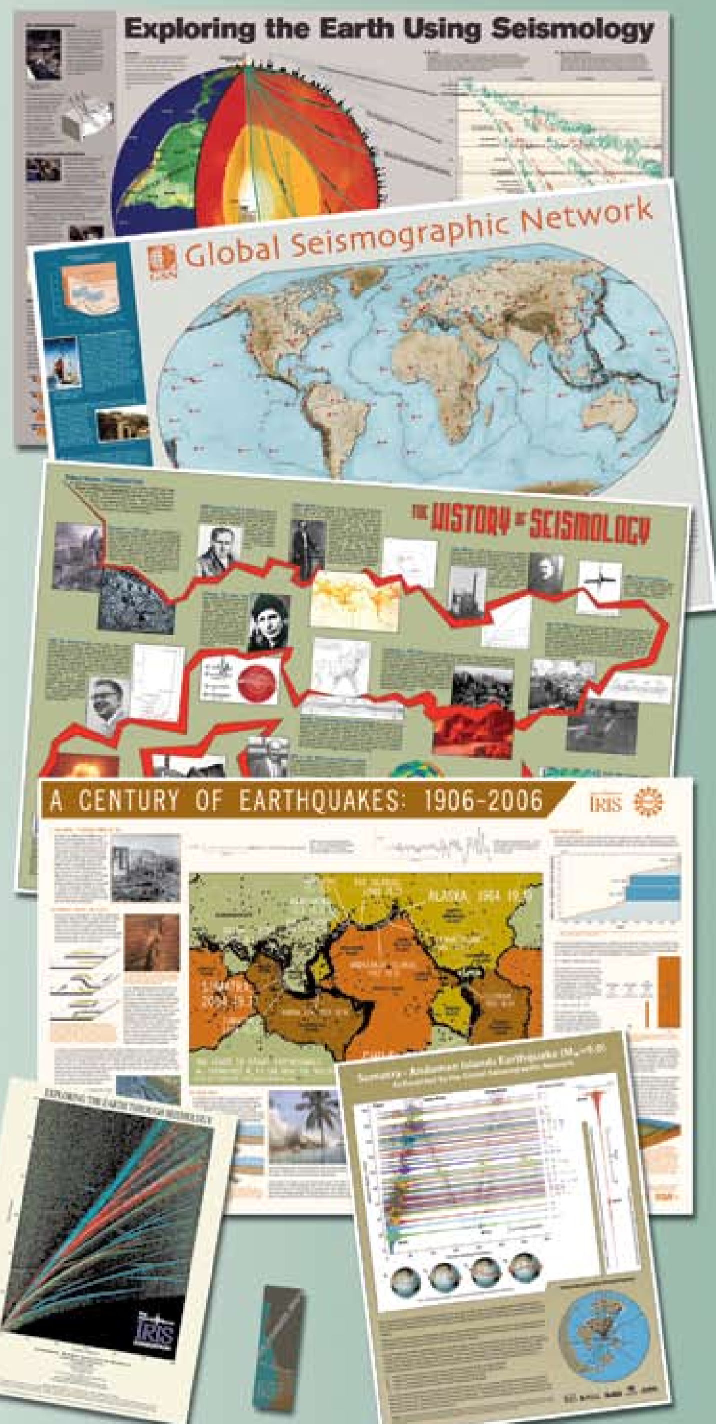
The 18th IRIS Workshop was held on June 8–10 at Westward Look Resort outside of Tucson, Arizona. Once again, the workshop attracted more than 300 participants. Presentations at this workshop showcased rapid advances in understanding physical processes underlying seismological observations and the continued close links between seismology and society at large.

The plenary sessions and posters on USArray science showed that the first few data are already starting to reveal new details about the North American crust and lithosphere, the mid-mantle, and the deep interior of the Earth. The sessions on interpretation reminded everybody that genuine knowledge about Earth arises from collaborating with researchers from other disciplines – including experimental and theoretical rock physics, as well as geodetic, electrical and other observational methods. The sessions devoted to international activities explored the connections of seismological research with the interests of economic development agencies and other non-academic organizations.

The workshop also provides an opportunity for groups with overlapping interests to hold complementary gatherings. On the days before and after this year's main event there were symposia on geophysical data management, magnetotellurics, and EarthScope Educational Affiliates.

Publications

Publication of the IRIS Newsletter was restarted during 2006. Three issues were published, catching up on news about IRIS's Cooperative Agreement with NSF, IRIS workshops, and a variety of other topics. The 2006 issues also included collections of articles on several themes, including developments spurred by the December 2004 tsunami in the Indian Ocean, experiments using PASSCAL's "Texan" high-frequency seismic systems, and science projects funded by the EarthScope program in NSF's Earth Sciences Division to use USArray data. E&O publications included the poster "A Century of Earthquakes," commemorating the 1906 San Francisco earthquake and tying into Seth Stein's IRIS/SSA distinguished lectureship on giant earthquakes. A description of how to use the new Rapid Earthquake Viewer was distributed via AGI's Earth Science Week packets. In a collaborative effort, IRIS and UNAVCO started publishing onSite, a quarterly newsletter for EarthScope station hosts and the general public that provides a brief update of the EarthScope facilities and features articles on how the station they are hosting contributes to expanding our knowledge of the North American continent.



Financial Overview

Candy Shin • IRIS Consortium

Budget and Finance Subcommittee

Brian Stump (Chair)	Southern Methodist University
Anne Sheehan	University of Colorado
David Okaya	University of Southern California
Candy Shin	IRIS

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

IRIS' revenues and expenses have been growing the past few years with the EarthScope awards. Funding for USArray has exceeded the core program budgets (approximately $12M annually) for the past two years with the significant procurement activities associated with the Reference Network, Transportable Array, and Flexible Array in the initial years of the Major Research Equipment and Facilities Construction (MREFC) award. Although the annual budgets for EarthScope/USArray will decline slightly from this peak, the estimated annual costs of EarthScope/USArray-related activities are expected to continue to exceed the core program funding over the next five years, if the operations & maintenance budgets to continue USArray within its original scope are approved by the National Science Foundation, and core program funding remains flat.

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, Albuquerque Seismological Laboratory, Synapse Science Center, Moscow, University of Utah, and Metrozet, LLC.

PASSCAL

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

IRIS Budgets

Core program budgets* (July 1, 2005-June 30, 2006)		EarthScope awards** (Oct. 1, 2005-Sept. 30, 2006)	
	FY2006	**Year 3 funding**	**Subtotal (05/06)**
GSN	3,277,547	Permanent backbone	1,239,349
PASSCAL	3,501,906	Transportable Array	10,756,558
DMS	3,308,762	Flexible Array	3,660,271
E&O	717,210	Data management	645,480
Other	279,945	Siting outreach	104,288
		Other	289,027
		Earthscope Office	1,325,633
Indirect Costs	1,217,561	Indirect Costs	1,891,737
Total	**12,302,931**	**Total**	**19,912,343**

*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 Ocean Sciences, DOE, CTBTO, SCEC, and JPL.

**Includes budgets for the USArray MRE & O&M, and the EarthScope Office Cooperative Agreements and Awards.

instruments in the field. Subawards include the New Mexico Institute of Mining and Technology, the University of California, San Diego, 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, Harvard University, the University of California, San Diego, University of South Carolina, and 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 hard-copy, 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, summer internship support and support of educational seismology networks.

EarthScope

EarthScope awards include funding for USArray, EarthScope Office, and EarthScope E&O activities. Funding for the EarthScope Office was terminated as of December 31, 2006. Subawards include the University of California, San Diego, New Mexico Tech, the USGS, the University of California, Berkeley, the California Institute of Technology, Arizona State University, Oregon State University, Montana Tech, University of Idaho, University of Utah, Boise State University, University of Nevada, Reno, University of California, Riverside. Contracts for USArray TA and MT station construction and installation are to Honeywell, GSY-USA, and Christman Enterprises.

Indirect Expenses

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

Other Activities

Other activities include IRIS workshops, publications and special projects such as the Kyrghyz Seismic Network.

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

Staff

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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.

IRIS

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