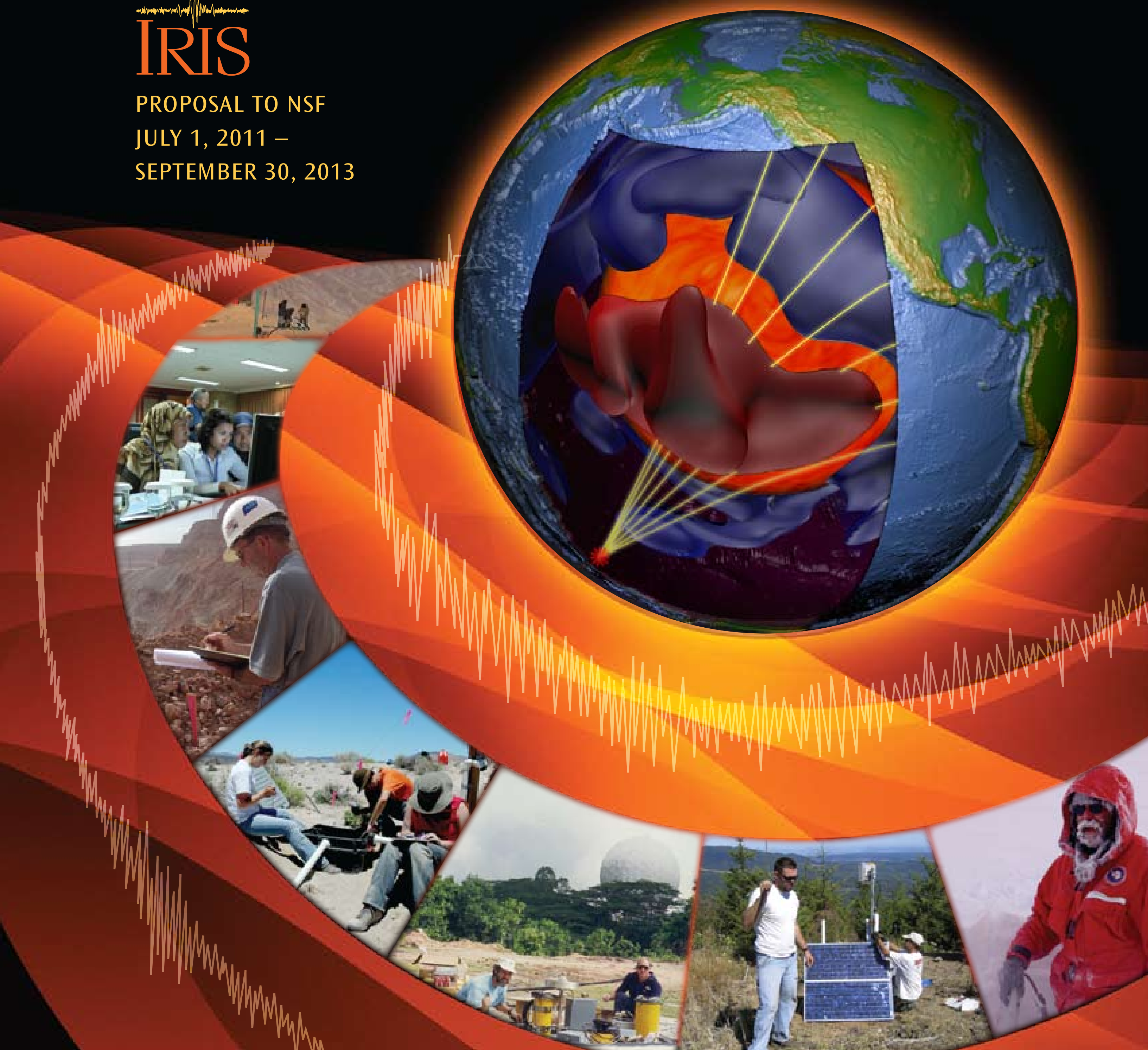
VOLUME I - PROJECT DESCRIPTION

FACILITATING NEW DISCOVERIES IN SEISMOLOGY AND EXPLORING THE EARTH

THE NEXT DECADE

IRIS

PROPOSAL TO NSF
JULY 1, 2011 –
SEPTEMBER 30, 2013



This proposal is submitted by IRIS on behalf of the Board of Directors, which represents the full membership of the Consortium, and thus the collective scientific interests of those 114 U.S. research institutions. The proposal includes contributions from IRIS Program Standing Committees and other governing and advisory bodies of the Consortium, which collectively include more than 60 faculty members who are actively engaged in research projects that are funded by the National Science Foundation.

The proposal and supporting materials are bound in two volumes. Volume I includes the Project Summary, Description, and Budget, as well as descriptions of the individual programs into which IRIS organizes its activities. Volume II is an overview of scientific accomplishments that are based on use of IRIS facilities.

The Project Description begins with an introduction to the IRIS Consortium and facilities, followed by a précis of research facilitated by IRIS. The Project Description also includes a description of activities required to sustain facilities that support state-of-the-art research, a vision for transitioning all IRIS activities into an integrated suite of services, and a brief outline of our funding request.

The Budget is an explication of our estimates of costs to carry out the activities that are summarized in the Project Description and detailed in the Program Descriptions.

The Program Descriptions are synopses of the infrastructure and operation of IRIS core facilities and several related programs. Each synopsis includes an overview of the program's development and its activities under the current Cooperative Agreement, and a detailed description of plans and resources requested to continue meeting the current needs of the research community and support investigators pursuing new opportunities.

The Review of Accomplishments is comprised principally of nearly 250 one-page vignettes, contributed by the research community, and based on research that has been enabled by IRIS, in most cases through use of one or more of the core IRIS facilities or USArray.

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Submitted to
National Science Foundation
Division of Earth Sciences
Instrumentation and Facilities Program

By
Incorporated Research Institutions for Seismology
1200 New York Avenue, NW, Suite 800
Washington, D.C. 20005

On behalf of
Board of Directors
and 114 Member Research Institutions
of the IRIS Consortium

September 2010

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VOLUME I | PROJECT DESCRIPTION

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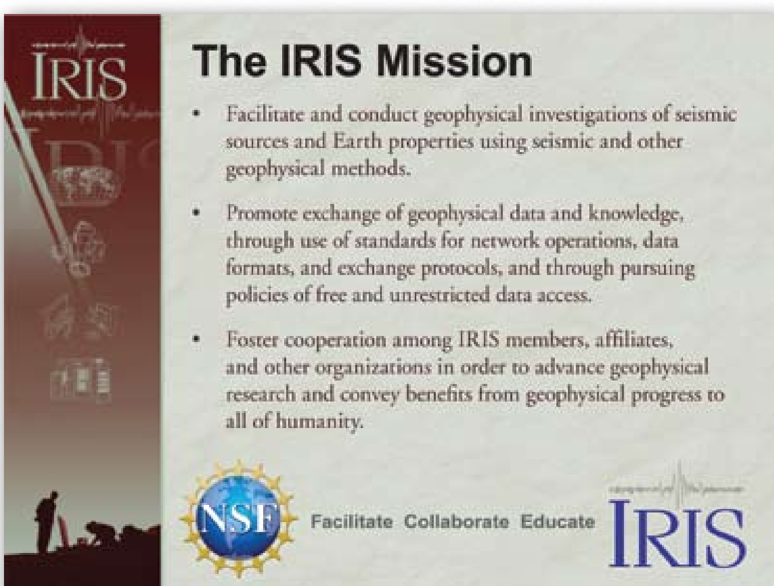
SECTION 1 | CONSORTIUM GOVERNANCE OF IRIS FACILITIES

IRIS OVERVIEW

For 25 years IRIS—the Incorporated Research Institutions for Seismology—has been supported by the National Science Foundation and governed by its Consortium members to manage the key infrastructure resources to support academic research in seismology. IRIS, operating as a not-for-profit consortium of 114 U.S. universities and research institutions across the country, has facilitated and embraced a commitment to high-quality instrumentation, data access and sharing, and data services that now underlie much of the research in seismology and solid Earth sciences in the United States and many parts of the world. IRIS activities comprise distributed core facility programs and projects managed by IRIS staff for the community. IRIS has revolutionized how the technical and organizational aspects of seismology are practiced in the United States and worldwide. The concept of shared resources, and especially data sharing, is gradually being adopted globally in large part due to the IRIS philosophy of open data and data sharing for multiple purposes. Never is the access to data more obvious than after major earthquakes such as the Sichuan, Haiti, or Chile earthquakes. Within minutes after these earthquakes, researchers and others were downloading data from the IRIS archive.



THE 2011–2013 IRIS PROPOSAL

This is the sixth multiyear proposal to NSF to support IRIS facilities since the 1984 founding proposal. While earlier proposals (1991, 1995, 2001, 2006) have each involved a five-year renewal framework, this proposal is distinct in that it is requesting funding for a designated 27-month interval, specified by NSF. This time frame is intended to synchronize the funding cycle for IRIS core programs with the operations and maintenance of the USArray component of project EarthScope with a combined renewal proposal to be developed for 2013–2018 funding.

This shortened funding cycle comes at an auspicious time for IRIS. The Consortium has now completed 25 years of facilities development and construction, largely achieving early goals of the core programs as envisioned in the founding proposal, along with tremendous success under the EarthScope MREFC project. USArray facilities are providing extensive datasets from its Transportable Array, Flexible Array, ANSS Backbone Array, and Magnetotelluric Array activities. IRIS has also initiated a number of activities that had not been envisioned in the founding proposal, including a thriving Education and Outreach program, strong interdisciplinary coordination with other Earth science programs, exploration of linkages between research and hazard mitigation in developing countries, and a strong presence in support of polar research. The current overall IRIS enterprise, as both a set of critical research facilities and as a disciplinary coordinating structure, is mature, vigorous, and highly productive.

Under the current Cooperative Agreement with NSF, the IRIS Board of Directors, its Standing Committees, and management staff have engaged in various planning activities aimed at exploring opportunities to retain the vitality in a mature 25-year organization and to evolve to respond to the changing demands of the research community. In those deliberations, the Board has re-affirmed its commitment to the IRIS Mission Statement (see box) and goals of the Consortium to "facilitate, collaborate, and educate." To remain successful, IRIS must continuously evaluate the relevance of our facilities to current research needs and demonstrate the value of NSF investments through the research accomplishments of our Consortium members and the research community. As in past proposal cycles, we have engaged the research community in demonstrating those accomplishments through the collection of "one-pager" research statements that are included as an separate appendix to this proposal.

Following the very successful review of the 2006–2011 IRIS proposal, NSF requested that the IRIS Board convene a broad community workshop to develop a long-range science plan for seismological research and to explore future facilities requirements to support those research endeavors. This community perspective on research opportunities and facility needs was intended to complement the IRIS internal planning process. The recommendations of the Long-Range Science Plan for Seismology workshop, held in September 2008, are presented in *Seismological Grand Challenges in Understanding Earth's Dynamic Systems*. These recommendations, along with the research accomplishments described elsewhere in this proposal and the advice of the Standing Committees, have informed the IRIS Board in its planning for the continued operation and expansion of the IRIS facilities. The next section of this proposal provides a brief summary of the Grand Challenges and highlights those that link directly to the facility resources supported by IRIS.

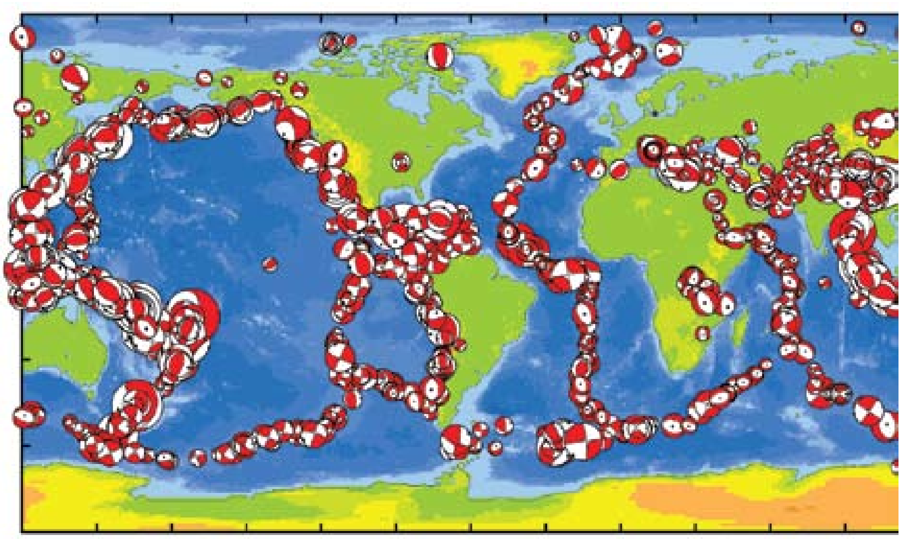
In response to NSF's challenge to develop a plan for merged management of the core programs and USArray in 2013, the IRIS Board has recently approved a number of changes in management structure to help ensure that the core programs and USArray have flexibility and vitality and are well integrated to ensure their future success. In a later section of this proposal, the revised IRIS management structure is described in more detail, to show how it will build on the synergies between our instrumentation programs and encourage integration between field programs, data collection, data distribution and the development of data products.

THE IRIS CONSORTIUM MODEL

As a consortium that from the outset comprised all of the "major players" in U.S. academic seismology, IRIS has engaged a much broader governance community than is typical for the oversight of facilities developed for specific projects of experiments. Rather than focusing on the development of the technical resources for a single experiment or research institution, IRIS facilities are inherently multi-user and multi-use, and directed by a community with a wide range of research interests. This governance model served seismology well in the early days, when it provided a forum for addressing issues such as the mechanisms for integrating pre-existing stations into the GSN, the best mix of instrumentation in the PASSCAL pool, the formats and protocols for exchanging different types of seismological data, and even the overall balance of investment among the GSN, PASSCAL, DMS, and E&O programs. The model has continued to be effective as the incubator for new initiatives such as USArray and EarthScope. Seismology instrumentation is intrinsically distributed and one of the major goals of IRIS is to coordinate data and instrumentation

GSN AND GLOBAL EARTHQUAKE CENTROID MOMENT TENSORS

The NSF-funded Global CMT Project at Columbia University is aimed at monitoring global earthquake activity and determining earthquake source characteristics for all earthquakes greater than magnitude 5.0. The Global CMT catalog (http://www.globalcmt.org), produced primarily from GSN data, contains the most comprehensive collection of global earthquake centroid moment tensors available, and spans the period 1976–2010. The CMT catalog has become recognized as an essential community resource, and is the standard database used in a wide range of seismic, geodetic, and tectonic studies of Earth dynamics and deformation.



Focal mechanisms based on centroid moment tensor solutions determined by the Lamont Global CMT Project for 2725 shallow earthquakes that occurred from January 2008–January 2010.

ENCOURAGING STUDENTS – ENGAGING THE PUBLIC – INFORMING TEACHERS AND FACULTY

The IRIS Education and Outreach Program brings the excitement of seismology and the Earth sciences to the public and the classroom and helps prepare the next generation of practicing Earth scientists. The Active Earth Display (middle) is an interactive kiosk used in museums, parks, and universities to display real-time earthquake activity and waveforms and demonstrate basic Earth science concepts.

The IRIS Summer Intern Program conducts an orientation program at New Mexico Tech (left) and matches undergraduates with university PIs across the country to participate in research. Resources for the public and the classroom teacher (right) include maps, brochures, posters, explanatory notes, and extensive materials available on the web.

with often-complex histories. This inclusive model was and remains important for establishing community ownership of instrumentation resources and data.

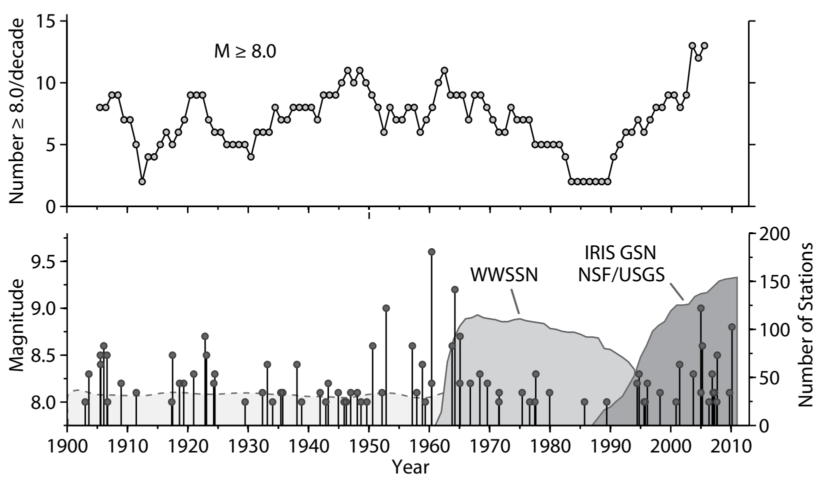
Important changes over time include the progressive increase in sophistication of the facilities and the growth of the Consortium to include virtually every U.S. university with even a modest research program in seismology. IRIS has adapted to these changes by modifying both the staffing and the governance structure of the not-for-profit corporation. The consortium model has served the seismological community well over the years. The community governance model—including the core program Standing Committees reporting to a Board of Directors that is both elected by and comprised of academic members—has provided a framework for the academic seismological community to participate in decision-making and has preserved community oversight of the facilities to ensure that they continue to serve the evolving research needs. In parallel, a combination of contracting and hiring key staff with skills that complement those of seismologists has enabled the facilities to take full advantage of new technologies and make the facilities ever more efficient.

This record of success extends even into integrating facility models that depart significantly from earlier practice—such as the professional installation of Transportable Array stations. The continued broad participation in IRIS governance has ensured that access to portable instruments and services as well as access to data continue to benefit a widening circle of investigators. Alternatives, such as separate governance of each facility by individual institutions or small groups, would put both the integration and the widespread benefits at risk. The benefits of consortium governance and joint management will accrue as long as the underlying technologies of seismic data acquisition and archival continue to evolve.

The consortium governance structure has also had the secondary benefit of providing natural opportunities to integrate early-career investigators into the decision-making

RECORDING GREAT EARTHQUAKES

The IRIS/USGS Global Seismographic Network was initiated in the mid-1980s to replace the aging analog stations of the Worldwide Standardized Seismographic Network (WWSSN). The GSN, with Affiliate stations, has now grown to more than 150 installations, each equipped with very broadband seismometers and providing data to both the monitoring and research communities in real time. GSN's growth has coincided with a substantial increase in the number of large earthquakes over the past two decades, including the M_w 9.2 Sumatra megathrust of 2004 and M_w 8.8 Chile subduction zone event of 2010. The upper graph shows the running average number of events ≥ M 8.0 per 10-year interval (from the PAGER catalog). The lower graph shows individual earthquake magnitudes and the history of stations in the WWSSN and GSN. GSN data have been used to characterize the temporal and spatial details of recent great earthquake ruptures in unprecedented detail and the plethora of large events has provided a rich source of data for investigations of deep Earth structure. (Figure based on C. Ammon et al., Great earthquakes and global seismic networks. *Seismological Research Letters*, accepted, 2010)



structure. Extensive turnover of membership on the standing committees has engaged many universities in IRIS governance at high level, and has brought in younger researchers as first-generation leaders have moved on. Many of those who now make use of IRIS resources and serve in advisory roles on IRIS committees have enjoyed the support of IRIS throughout their entire academic careers. This changing demographic was especially evident during the 25th anniversary celebration at the most recent IRIS biennial workshop. Almost half of the participants were students, postdocs, and early-career scientists, and an award was presented to a Harvard graduate student who *birth date* was three months after the incorporation date for IRIS in 1984.

A final attribute of the consortium model of governance is that, by virtue of its broad representation of the U.S. academic seismological community, IRIS has proven very successful in its interagency collaboration with, for example, the U.S. Geological Survey. IRIS has also fostered successful international collaborations with many countries hosting GSN equipment, and with groups like the International Monitoring System whose data-collection activities help offset many telemetry costs for the GSN. These partnerships are greatly facilitated by the academic stature and multilateral relationships of the IRIS Consortium membership.

SUCCESS OF IRIS IN ACHIEVING PAST GOALS

The 1984 founding proposal for IRIS identified a 10-year program to implement four national facilities for seismology, including a Global Digital Seismic Array with real-time satellite telemetry from 100 observatories, a 1000-unit portable digital seismograph Mobile Array, Central Data Management and Distribution Facilities to provide rapid and convenient access to data for the entire research community, and a Major Computational Facility capable of supporting analyses of the new data. Today, the *Global Seismographic Network* (GSN) is a 153+ station, globally distributed, state-of-the-art digital seismographic network sustained by close partnership between NSF and the U.S. Geological Survey and many international partners. The *Program for Array Seismic Studies of the Continental Lithosphere* (PASSCAL) and the *USArray Flexible Array* includes 875 dataloggers, 2320 three-component sensors (broadband, intermediate period, short-period, high-frequency, and accelerometers), and 6937 single-channel instruments. The *Data Management System* (DMS) is comprised of eight nodes of data collection centers and a Data Management Center (DMC) that provides open and easy access to all IRIS data holdings and data products along with even larger quantities of other seismological data and virtual pathways to international data archives.

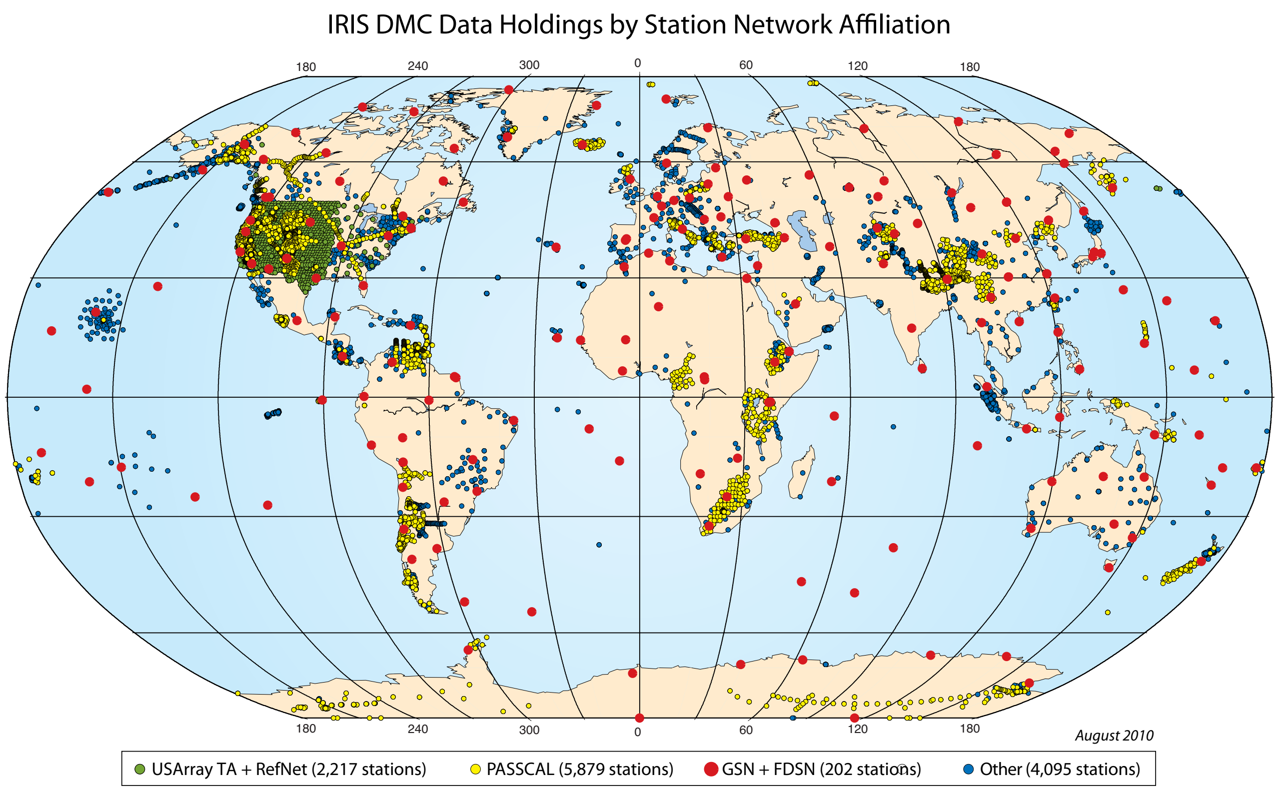
Today, in the wake of a large global earthquake, a few clicks on a web page can provide any seismological researcher anywhere in the world full waveform and metadata information for over 1000 global seismic stations. There are over 103 terabytes of data archived in the DMS (as of Oct. 1, 2009), and 55.1 terabytes have been shipped to researchers by the end of 2009. The primary goals of the 1984 proposal have been realized, and tremendous research facilities for seismology have been achieved. The original IRIS goal of a major computational facility was not realized, but Moore's Law rendered it less of a priority. Technological evolution of workstation and cluster computation elevated computational power in the seismological community to allow fruitful exploitation of the new datasets.

IRIS programs have articulated new goals with each succeeding five-year proposal, many of them in support of training and outreach objectives. The DMS has supported international workshops on data formats and digital network functions. PASSCAL provides extensive training to ensure the adoption of best practices in field experiments and data collection. The *Education and Outreach Program* has become one of the most successful of NSF's solid Earth science outreach efforts, supporting museum displays, teacher training, seismographs in schools, summer internships, distinguished lecture series, and educational poster distributions. These activities have been regularly reviewed and adapted by the Consortium, and are now intrinsic strengths of the core IRIS programs.

The ultimate success of IRIS must be gauged by the scientific impact of the facilities, and Volume II of this proposal on scientific accomplishments provides strong testimony to the importance of IRIS resources in enabling U.S. academic Earth science research. The evolution of the discipline of seismology since 1985 has been extraordinary: over 600 PASSCAL experiments with more than 5000 portable stations have been deployed to study plate boundaries, cratons, orogenic systems, rifts, faults, magmatic systems, glaciers, icebergs, and structural responses in the built environment. Thousands of earthquakes around the world have been studied using GSN data to define tectonic motions, stress distributions, and exotic sources such as impacts, ring faults, and volcanic plumbing. Local, regional and global tomography have leapt

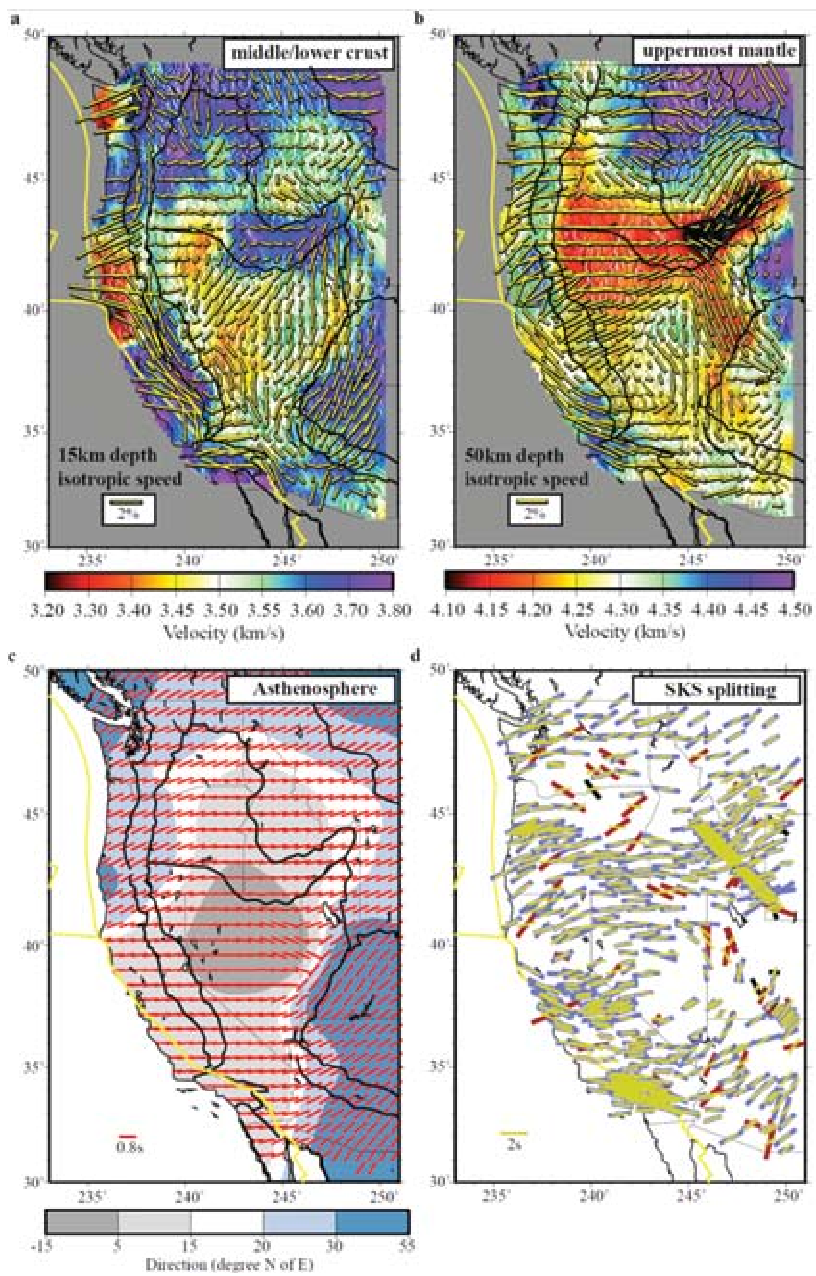
ENCOURAGING FREE AND OPEN EXCHANGE OF DATA

By establishing standard formats, developing exchange protocols, providing archival and distribution resources, and encouraging a culture of open data sharing, IRIS has helped to greatly expand the data available to research scientists worldwide. The IRIS Data Management Center archives and distributes all data from IRIS programs (GSN, PASSCAL, and USArray) and is the archive for continuous data for designated stations from the International Federation of Digital Seismograph Networks (FDSN). Numerous other U.S. and international networks also contribute data for distribution through IRIS. This map shows the locations of more than 12,000 permanent and temporary broadband stations for which data are available at the DMC.



forward capitalizing on improved spatial coverage and resolution using GSN and PASSCAL datasets, imaging previously unknown structures from the inner core to the surface. Synergies with geodynamics, mineral physics, volcanology, and even climatology have emerged that were unprecedented prior to the availability of IRIS datasets. IRIS-recorded ground motions, spanning from Earth's continuous hum, to non-volcanic tremor, to violent shaking from numerous great earthquakes around the world, have been used in thousands of research studies, revealing the fundamental nature of lithospheric deformations and ocean-atmosphere-solid Earth interactions. The large number of U.S. university programs with seismological research programs is largely a response to the open access provided to IRIS data, enfranchising research programs at all levels to pursue innovative research. This open-data policy has had great international impact on seismological data access, and establishing a precedent for sharing all varieties of scientific data between nations.

AMBIENT NOISE IMAGING

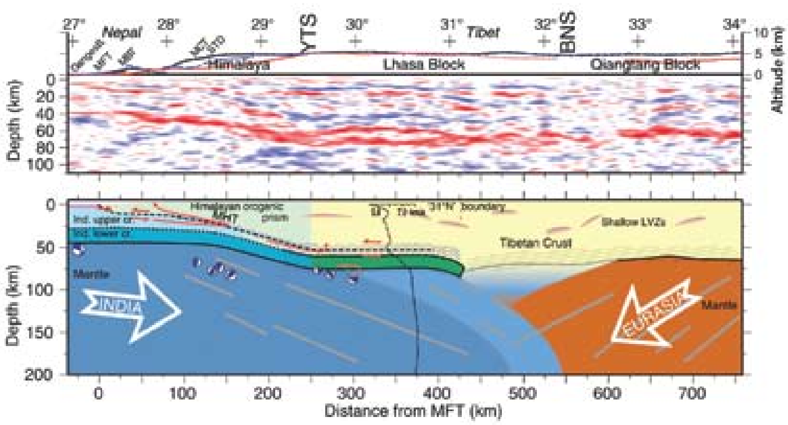


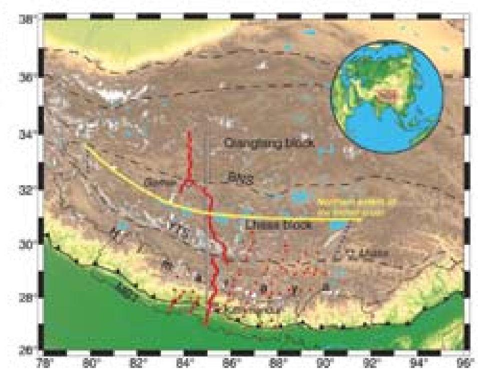
New techniques that use ambient noise as well as earthquake signals have revolutionized investigations of the velocity structure of the crust and upper mantle. These techniques have been applied to USArray data to reveal both isotropic and anisotropic properties of the crust and uppermost mantle. Simultaneous interpretation of these results with SKS splitting measurements generates a 3D model of azimuthal anisotropy in the crust and uppermost mantle. (a)–(c) Anisotropic properties of the crust, uppermost mantle, and asthenosphere are shown, where the fast propagation direction and anisotropic amplitude are represented by the orientation and length of the yellow/red bars on a 0.6° spatial grid. Isotropic shear wave speeds at depths of 15 and 50 km are color coded in the background of (a)–(b), and the fast direction is shown in the background in (c). (d) Comparison of observations of SKS splitting and predictions (yellow) from the 3D anisotropy model shown in (a)–(c). The blue, red, and black colors of the observed measurements identify differences with the model predictions of the fast axis directions: Blue: 0°–30°, Red: 30°–60°, Black: 60°–90°. Anisotropy is stratified vertically, dominated by relatively shallow tectonic processes confined to the crust and uppermost mantle, although the patterns of anisotropy in the crust and mantle are uncorrelated. The more homogeneous deeper asthenospheric anisotropy broadly reflects a mantle flow field controlled by a combination of North American plate motion and the subduction of the Juan de Fuca and Farallon slab systems. These results would not have been possible without USArray, and future work will apply the methods to new USArray stations to the east. (Courtesy of Mike Ritzwoller and Fan-Chi Lin, University of Colorado)

EXPLORING CONTINENTAL LITHOSPHERE WORLDWIDE

As the highest mountain range in the world, the Himalayas and the nearby Tibetan Plateau have fascinated Earth scientists for centuries. The Himalayan-Tibetan Continental Lithosphere during Mountain Building (Hi-CLIMB) project and several earlier PASSCAL-enabled experiments in Tibet, carried out with significant local support and in scientific collaboration with various Chinese institutions, have provided new insights into the regional lithospheric structure and modes of deformation.

These studies, along with geodetic and geologic data, have shown that the mountain-building deformation front has moved southward as Indian crust is transferred to the overriding plate. Underthrusting is now known to continue beneath southern Tibet at least up to the south Lhasa Block, but its northern limit and geometry remain uncertain. Hi-CLIMB included a closely spaced, 800-km-long linear array of broadband PASSCAL seismometers extending northward from the Ganges Basin, across the Himalayas, the Yarlung Tsangpo Suture, and the Banggong-Nujiang Suture to central Tibet. Migrated receiver functions from different subsets of the Hi-CLIMB linear array data show that the lower part of the Indian lithosphere underplates the Himalayas and Tibet up to 31°N and that the Moho beneath Tibet is anisotropic, indicating shearing during its formation. The dipping mantle fabric suggests that the Indian mantle is subducting diffusely along several evolving subparallel structures. (From Nabelek et al., 2009. Underplating in the Himalaya-Tibet collision zone revealed by the Hi-CLIMB experiment. *Science*, doi:0.1126/science.1167719. Reprinted with permission from AAAS.)





SUSTAINING INVESTMENTS AND PREPARING FOR THE FUTURE

The ongoing support of any facility program requires a delicate balance between operating, maintaining, and refurbishing existing facilities, and investing in both technological innovation and new initiatives that advance the science. A central organizational and financial commitment in all IRIS proposals is to continue to support and maintain those core facilities and resources that form the essential underpinning for a broad sector of research support in seismology for the U.S. academic community. At the same time, we seek to provide the infrastructure and facilities to support the research community in new and interdisciplinary lines of research in the Earth sciences.

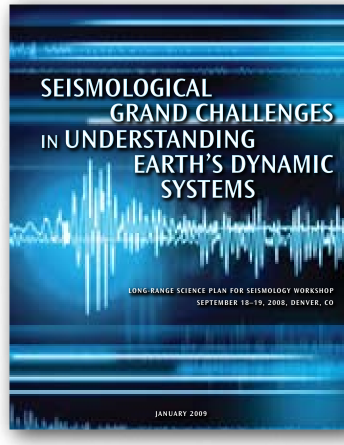
In Section 3 of this proposal we describe the activities and budgets necessary to continue to support the activities of the core IRIS facilities. In Section 4, we outline the recent changes in IRIS management structure and show how these will lead to consolidated management of the core and USArray programs starting in 2013. We also describe how we will use this new structure to initiate the cross-programmatic innovations and developments in technology that will enhance the activities within the existing core programs. The new directions build upon the opportunities articulated in the *Grand Challenges* document and support the research community as it assesses future opportunities.

Achieving the goals defined by prior IRIS proposals has involved diversifying funding bases, collaboratively working with other agencies besides NSF to develop and sustain the facilities, and working with hundreds of international partners to provide the global coverage and communications facilities that underlie the facilities. NSF can legitimately view its investment in IRIS facilities as being heavily leveraged to the benefit of the scientific undertakings of the seismological research community.

SECTION 2 | RESEARCH ENABLED BY IRIS FACILITIES

SEISMOLOGICAL GRAND CHALLENGES

During September 2008, well over 100 seismologists and geophysicists attended the Long-Range Science Plan for Seismology (LRSPS) Workshop where they presented exciting new research successes and highlighted fundamental knowledge gaps. The workshop culminated in a community-driven set of Grand Challenges that span a range of Earth systems, show the wide range of topics in which seismological research plays an integral role, and can help drive future science initiatives, including:



- How do faults slip?
- How does the near-surface environment affect natural hazards and resources?
- What is the relationship between stress and strain in the lithosphere?
- How do processes in the ocean and atmosphere interact with the solid Earth?
- Where are water and hydrocarbons hidden beneath the surface?
- How to magmas ascend and erupt?
- What is the lithosphere-asthenosphere boundary?
- How to plate boundary systems evolve?
- How do temperature and composition variations control mantle and core convection?
- How are Earth's internal boundaries affected by dynamics?

IRIS facilities are organized and operated to meet the requirements of the research community, which evolve as new opportunities and frontiers are identified through several different forums. The scientific context for this proposal is illustrated through the documentation of ongoing research efforts of individuals and collaborative teams as summarized in the one-page project descriptions in the Accomplishments volume of this proposal. These current research summaries include nearly 250 individual contributions, covering broad areas from the nature of faulting to the details of the time-varying nature of the boundaries within the mantle and core.

Forward-looking activities provide the basis and motivation for the refinement and support of IRIS services and the facilities. The Board of Directors, the Program Standing Committees, and other IRIS governing bodies all comprise active researchers who themselves carry out and publish cutting-edge research and participate in dozens of scientific conferences, workshops, and review panels in the United States and around the world. The strength and validity of the Consortium depends on sustaining and adapting facilities to enhance these research opportunities, and relies on the continuous input of this research community.

Figure 2.1. 2010 IRIS Workshop, Snowbird, UT.

The IRIS Workshop and the EarthScope National Meeting in alternating years are important forums for identifying new and innovative science that the Consortium can facilitate. Each plenary session at the 2008 Workshop in Stevenson, WA—integrating seismology and mineral physics, western U.S. mantle dynamics, polar ice dynamics, episodic tremor and slip, and synergy between earthquake monitoring and research—has been an area of tumultuous progress in the ensuing few years. The 2010 Workshop in Snowbird, UT, was special in several ways: an occasion to reflect on how seismology has changed during the 25-year history of IRIS, to discuss the broader impacts from seismology research in light of the 2010 Haiti earthquake disaster and great Chile earthquake, and to review radically new results regarding mantle dynamics and triggered earthquakes that have been possible partly thanks to the existence of USArray. Each of these special topics suggested nascent plans for the future, ranging from long-term facilities needed by individual researchers, to earthquake hazard mitigation in the 21st century, to new facilities that can be built to capitalize on science from USArray.

Other events that IRIS convenes, often in partnership with complementary organizations, may engage more tightly focused groups in more in-depth exploration of a specific set of issues. Examples from the past few years include:

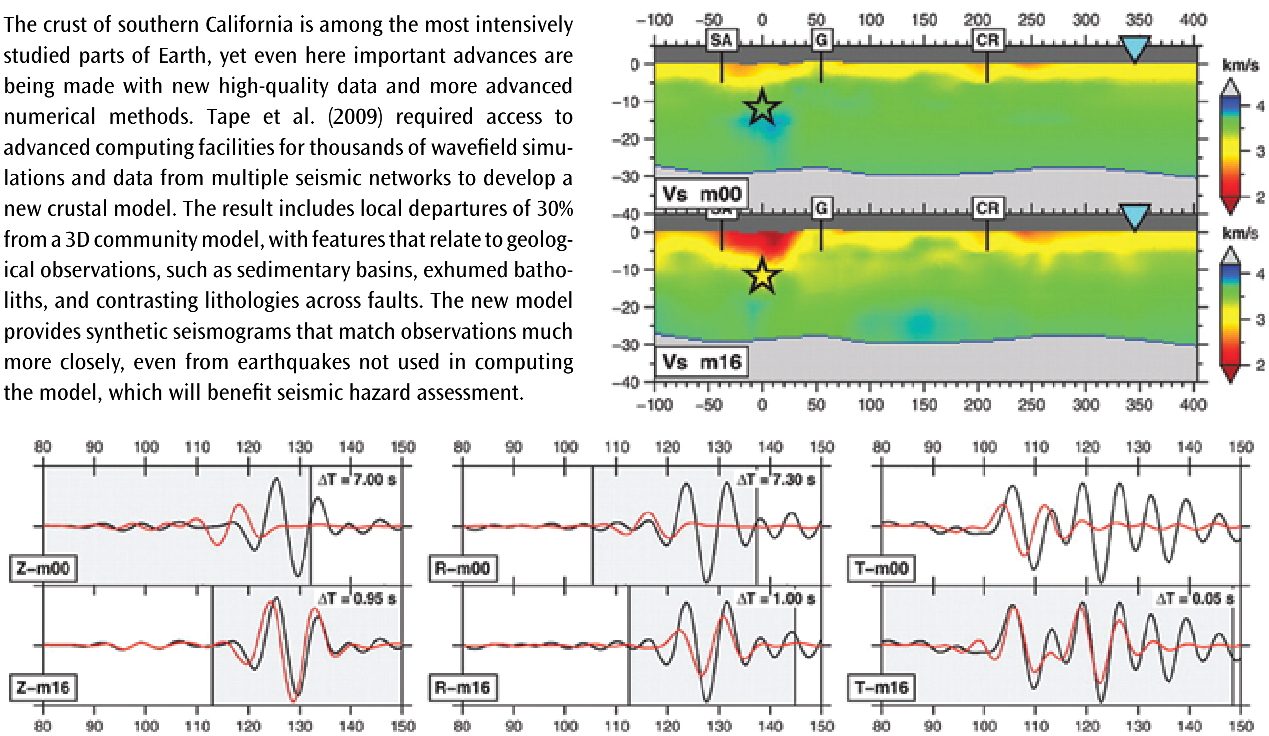
- *Out of Africa, February 2008,* brought together key members of the IRIS community in the United States, throughout the Americas, and in Southeast Asia to build strategies for transitioning networks of earthquake monitoring stations in developing countries into fully sustainable networks of advanced geophysical observatories.
- *Seismic Instrumentation Symposium, November 2009,* addressed the intersection between scientific requirements and technological advances, spanning the entire seismic spectrum from earthquakes, nuclear explosions, and Earth structure studies, to the monitoring of man-made structures. Participants from across different disciplines were drawn from universities and federal agencies as well as private companies.
- *Experiments with Portable Ocean Bottom Seismographs, September 2010,* examines the future of portable OBSs to study problems in Earth structure and dynamics. The objectives include identifying long-term opportunities, requirements for facilities, technologies with potential for significant impact, and strategies to maximize scientific returns.
- *Autonomous Polar Observing Systems, October 2010,* focuses on cooperation among scientific, technical, and logistical communities to maintain and expand stationary autonomous ground-based polar observing systems. The goals include identifying new science opportunities, best practices to improve reliability, technologies that may enable exciting new science, and strategies to maximize scientific returns.

GRAND CHALLENGES IN SEISMOLOGY

The Long-Range Science Plan for Seismology Workshop held in September 2008 brought together a diverse group of university and government research scientists to explore and document the most exciting directions for seismology on a decadal time frame. The participants clearly articulated research directions for the academic community that

CRUSTAL STRUCTURE IN SOUTHERN CALIFORNIA

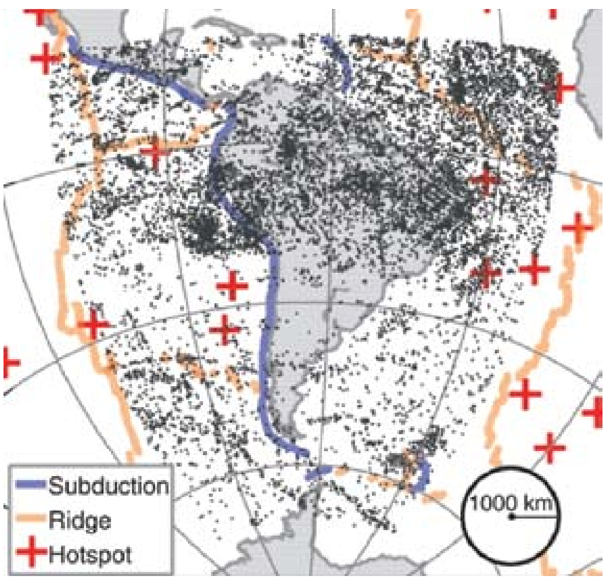
The crust of southern California is among the most intensively studied parts of Earth, yet even here important advances are being made with new high-quality data and more advanced numerical methods. Tape et al. (2009) required access to advanced computing facilities for thousands of wavefield simulations and data from multiple seismic networks to develop a new crustal model. The result includes local departures of 30% from a 3D community model, with features that relate to geological observations, such as sedimentary basins, exhumed batholiths, and contrasting lithologies across faults. The new model provides synthetic seismograms that match observations much more closely, even from earthquakes not used in computing the model, which will benefit seismic hazard assessment.



A cross section of S wave speed (top right) shows that a community 3D model of the southern California crust (m00) includes only modest lateral heterogeneity, while a new model (m16) to generate synthetics (bottom) that better match broadband waveform shape has significant differences both at the surface and to depths of 20 km. (Modified from Tape et al., 2009. Adjoint tomography of the southern California crust. *Science*, doi:10.1126/science.1175298. Reprinted with permission from AAAS.)

MAPPING EARTH'S INTERIOR WORLDWIDE

Broadband seismograms collected from USArray and other networks available from the DMC have been used to map topography of phase boundaries in Earth's upper mantle. The relative timing of reflections from Earth's surface and boundaries within Earth can be measured with high-resolution stacks of precursors to the seismic phase SS, if the data are of sufficiently high quality. The discontinuities usually found near depths of 410 km and 660 km are both deeper in the down-dip direction of subduction zones, which is inconsistent with cold material at 410-km depth. Several mechanisms invoking chemical heterogeneity within the mantle transition zone might explain this feature. In some regions, there are multiple reflections from the discontinuities, consistent with partial melt near 410-km depth and/or additional phase changes near 660-km depth. Thus, the origin of upper mantle heterogeneity has both chemical and thermal contributions, and is associated with deeply rooted tectonic processes.



The "bounce points" of SS phases midway between earthquakes and the stations that record the waves are widely distributed, providing usefully diverse sample points to create a reliable map of upper mantle properties (From Schmerr and Garnero. 2007. Upper mantle discontinuity topography from thermal and chemical heterogeneity. *Science*, doi: 10.1126/science.1145962. Reprinted with permission from AAAS.)

can resonate with a broad audience, which formed the basis for the workshop's report: *Seismological Grand Challenges in Understanding Earth's Dynamic Systems*. The science goals and facility recommendations from this *Grand Challenges* report form the foundation for continuation and expansion of the IRIS resources described in this proposal.

EARTHQUAKES

Understanding earthquakes—and an attendant hope to anticipate and mitigate their effects—is the original motivation for studies in seismology. Recent work in seismology has continued to advance our understanding of the structure of faults and the physics of earthquake rupture. High-quality data from continuously operating seismic networks remain indispensable for computing the locations of numerous earthquakes that define the seismically active faults around the world. More complete and reliable catalogs of earthquakes have facilitated discovery of subtle changes in rates of earthquake occurrence that document phenomena that were only suspected until recently, such as remote triggering. Records that capture the broad band of seismic frequencies with wide dynamic range are the primary source of information for mapping rupture propagation in time and space during a single earthquake. Recent work has shown that dense, large-scale arrays add additional constraints in computing rupture propagation maps that reduces uncertainty and imaging artifacts, leading to unambiguous evidence of previously doubted phenomena such as supershear rupture. Stable sources of data—stations with well-known response functions operated over many years—have led to the discovery of repeating earthquakes with nearly identical waveforms and opened the possibility of using subtle changes in the waveforms over years or decades to monitor changes in the stress state of faults.

Progress in understanding some complex processes has been achieved by using seismic data in conjunction with data from other geoscience disciplines. Mapping episodic tremor and slip requires both seismological and geodetic monitoring at a sufficient density to map the complementary phenomena. High-resolution three-dimensional seismic imaging and deep drilling into active fault zones are essential approaches to understanding complex plate boundary systems. Structure and deformation models are developed from seismic and geodetic data, rock samples and in situ rock properties from drill holes, and signals from small earthquakes.

CRUSTAL STRUCTURE

Receiver function analyses from numerous stations, in some cases using sophisticated migration techniques to more accurately locate features, are revealing structural details in many plate boundary systems, pervasive patterns of spatially complex anisotropy in the lower crust, and spatial variability of crustal hydration in overriding plates of subduction zones. Where temporary stations are sufficiently dense, features in both the upper and lower crust that are diagnostic of tectonic history are being mapped by ambient noise tomography, in some cases with extraordinary resolution by using new spectral techniques that can resolve V_S at offsets less than a wavelength. These new products can be computed from both newly collected and archived data, making it possible now to independently determine both radial and azimuthal anisotropy—even where field projects were completed more than 10 years ago—providing more spatially complete evidence of crystal alignment. With this work, it now appears that crustal thinning is widespread in extensional provinces and that there are jumps in tectonic fabric across many transform plate boundaries.

New instrumentation is facilitating larger-scale active-source experiments to map lower crustal structure. Results from these studies suggest underplating and reveal magmatic structures in some regions that extend far beyond the physiographic expression of volcanic activity. Three-component recording from active sources has made it possible to map V_P/V_S ratios, providing additional evidence of the degree of partial melting and helping to link seismologically observed structures with surface features.

Where geodetic data demonstrate that magma injection is an ongoing process, investigators are using forward modeling of fluid-filled porous media to predict polarization of seismic arrivals, and so explore the degree of melt crystallization and water saturation in the mid crust.

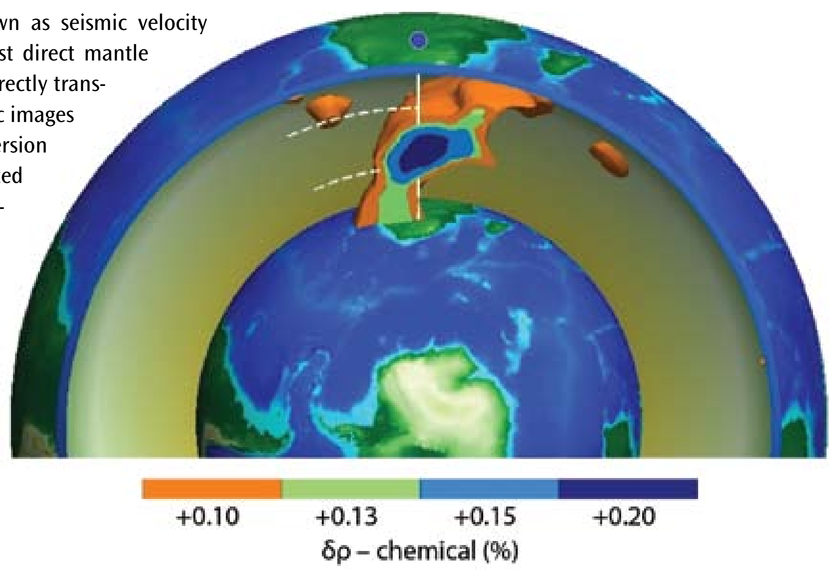
DYNAMICS IN THE LITHOSPHERE AND UPPER MANTLE

Essentially all surface deformation—earthquakes, volcanic activity, slow tectonic deformation—results from forces associated with mantle convection in the asthenosphere. Transmittal of these forces through the nearly rigid lithosphere depends on the nature of the lithosphere-asthenosphere boundary. New studies of the nature of this boundary have been motivated by advances in laboratory observations of deformation mechanisms and the elastic properties of mantle rocks. Advanced imaging techniques based on conversion between S and P phases are providing more robust images of discontinuities within the upper 200 km of the mantle. Regional surface-wave analyses, now using large-aperture arrays, are yielding higher-resolution estimates of absolute velocity and attenuation at these depths that can be directly compared to laboratory-based predictions. Estimates of variations in the layering of seismic anisotropy, from shear wave splitting and azimuthally variable surface wave dispersion, provide an additional means to map layering and deformation history within the uppermost mantle.

EarthScope data offer extraordinarily detailed regional-scale images of seismic velocity, anisotropy, and attenuation beneath the western United States, while ever-larger PASSCAL experiments around the world provide complementary information in other tectonic settings. New insights are being gained about the evolution of plates and plate boundaries,

MANTLE HETEROGENEITY AND FLOW FROM MULTIDISCIPLINARY DATA

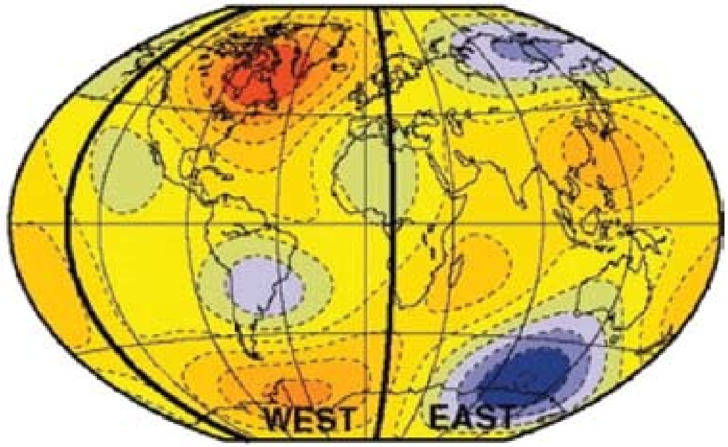
Mantle heterogeneity is most commonly shown as seismic velocity anomalies, because seismic waves are the most direct mantle probe, but these static images are difficult to directly translate to mantle flow. More complete tomographic images of the mantle can be derived through joint inversion of seismic data and a suite of convection-related observations, including surface gravity and topography, core-mantle boundary topography, and tectonic plate divergences, interpreted with viscous-flow response functions and mineral physics constraints. Temperature variations dominate shear-wave and density heterogeneity in the non-cratonic mantle, but notable compositional anomalies are evident, most strongly within the "African Superplume." Time-dependent flow calculations from the jointly derived density models suggest that even minor compositional anomalies play an important dynamic role, not just beneath the African plate, but also in anomalous flow patterns that coincide with the New Madrid Seismic Zone, the Colorado Plateau, and other tectonic features.



A thermal model of the mantle can be derived assuming that heterogeneity is due only to temperature anomalies. The "Africa Superplume" uniquely requires an additional high compositional anomaly to also fit geodynamic data (From Simmons et al., 2007. Thermochemical structure and components of the African superplume. *Geophysical Research Letters*, 34, L02301, doi:10.1029/2006GL028009)

REGIONAL INNER CORE ANISOTROPY FROM SEISMIC NORMAL MODES

Previous seismic body wave studies have suggested hemispherical variation in the isotropic and anisotropic structure of the inner core, but could not constrain their global extent. Theoretical advances to include coupling between normal modes that are close in frequency were motivated partly by the growing number of high-quality records of odd-degree normal modes, including those from the 2004 Sumatra, 2008 Wenchuan, and other recent large earthquakes. The observed odd-degree modes are now seen to suggest more complicated regional variations than a simple east/west hemispherical pattern. Instead, the similarity of the observed seismic pattern with Earth's magnetic field suggests that anisotropy may originate from freezing in of crystal alignment during solidification of the outer core or texturing of the inner core by electromagnetically induced stress.



Cross-coupled splitting function 16S5-17S4 showing antisymmetric splitting, which is characteristic of east versus west hemispherical variation in inner core anisotropy. (From Deuss et al., 2010. Regional variation of inner core anisotropy from seismic normal mode observations. *Science*, doi:10.1126/science.1188596. Reprinted with permission from AAAS.)

as well as the fate of recently subducted lithosphere and its ongoing influence on surface tectonics. As large-scale dense arrays are deployed elsewhere, we learn about the structure and dynamics of putatively "stable" cratons.

MINERAL PHYSICS AND DYNAMICS IN THE LOWER MANTLE

The base of the mantle is one of the most exciting frontiers for exploiting seismological observations to gain insight into deep Earth dynamics. The existence of a seismic discontinuity at the top of the D" layer at the core-mantle boundary has been known for several decades, but its cause remained enigmatic until the discovery of the post-perovskite phase transition provided a natural hypothesis for its origin. Parallel developments in experimental and theoretical mineral physics and observational seismology, enabled particularly by dense broadband array data, have led to rapid strides in our understanding of this discontinuity and its dynamical implications. Detailed imaging of lowermost mantle structure has led to a suggestion of an intermittently observed double discontinuity indicative of regional "lenses" of post-perovskite above the core-mantle boundary. In turn, these observations have been used to estimate temperatures and heat flux at the core's surface, yielding insight into first-order questions about the evolution of Earth's interior. Strong lateral heterogeneity of seismic velocity near the base of the mantle has recently been recognized as evidence of both thermal and chemical structure, while the presence of ultra-low velocity zones—characterized in increasing detail in recent years—may demonstrate the presence of partial melt. The delineation and interpretation of seismic anisotropy at the base of the mantle has the potential to permit characterization of lowermost mantle flow patterns, with important implications for understanding mantle dynamics. In contrast to the bulk of the lower mantle, which is generally isotropic, D" exhibits anisotropy in many regions, with a variety of anisotropic geometries proposed. Much work remains to be done to characterize this anisotropy in enough detail to understand the cause and to relate it reliably to mantle flow patterns, but this represents a promising avenue for understanding the dynamics of the lowermost mantle.

STRUCTURE AND HISTORY OF THE CORE

The structure of the core-mantle boundary and the core have been probed with increasing detail in recent years, enabled by data from both long-running stations and new dense broadband arrays. New theories for the viscosity of metallic melts at core pressures and temperatures, together with observations of translational modes of oscillation of Earth's solid inner core, suggest a rapid increase in the dynamic viscosity near the bottom of the liquid outer core, perhaps in a glassy state characterized by a frequency-dependent shear modulus and increased attenuation. If lateral variations mapped from array recordings of high-frequency body waves correlate with structure of the uppermost inner core, they may be used to map flow in the liquid outer core and lateral variations in core solidification.

The inner core is being explored using a variety of approaches. Records from repeating, moderately large earthquakes continue to be collected and used to map temporal changes of the inner core's surface. The growing number of high-quality stations in polar regions is yielding additional evidence about three-dimensional structure and anisotropy, and their relationship to Earth's rotation axis. With coverage improving thanks to modern records of large earthquakes, splitting of normal modes as high as order 17 has now been measured reliably and suggests complicated spatial variations that may be linked to regional variations in the strength of the magnetic field. Stacking and beam-forming analysis with array data have made it possible to observe elusive phases, including S waves in the solid inner core and underside reflections of P waves at the boundary between the inner core and the outer core. Earlier claims of detected S waves in the inner core were rare and questionable; reliable measurements of them now yield new information on the shear modulus of the inner core. Inner core underside-reflected P waves have never before been observed; they can serve as a "reference phase" for comparison with waves that pass directly through the deepest part of the inner core, allowing more precise and reliable mapping of anisotropy in Earth's centermost region. Multidisciplinary studies can build on this exploration to shed light on the mechanism of inner core growth by progressive freezing, which generates energy to maintain Earth's magnetic field and is critical to the thermal evolution of the core and the cooling history of the planet.

BROADER IMPACTS FROM ADDRESSING GRAND CHALLENGES

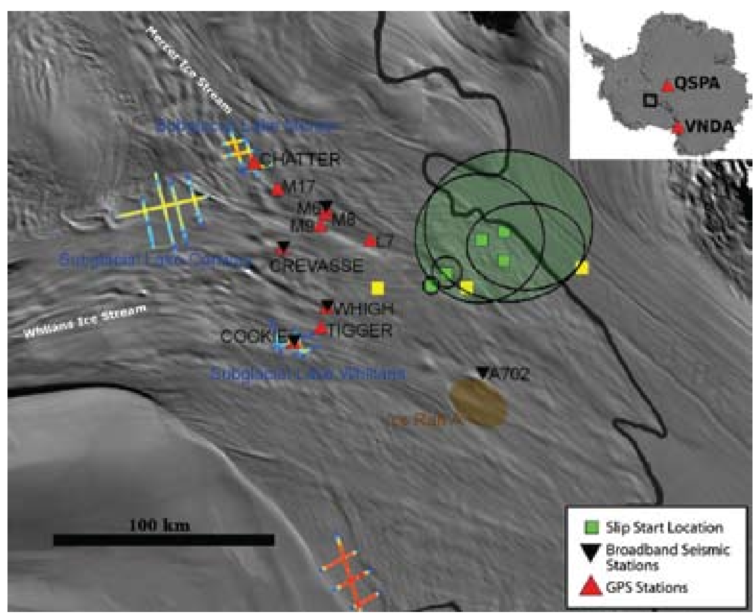
While the need to understand our world remains both a significant motivator of Earth scientists and a source of interesting challenges, broader applications of geophysical knowledge are an important part of why society funds research in seismology and other geoscience disciplines. Addressing the *Seismological Grand Challenges* would have a wide-ranging and profound impact on society. Indeed, monitoring the environment, exploring natural resources, mitigating natural hazards, and improving national security are each societal goals that can be accomplished more effectively with key contributions from seismology.

MONITORING THE ENVIRONMENT

Seismic methods reveal temporal changes in the three-dimensional distribution of oil and gas resources, most dramatically demonstrated during 2010 when repeat seismic surveys were used to monitor subsurface changes after emplacement of a containment dome to cap the *Deepwater Horizon* oil drill hole in the Gulf of Mexico. Subsurface monitoring will be critical as underground carbon sequestration becomes more common, sustainability becomes a more important issue in use of underground aquifers, and hydrofracturing is employed further for exploitation of geothermal and hydrocarbon resources. Seismic reflection is an effective tool for large-scale mapping of gas hydrates frozen in the soil beneath shallow oceans,

SECULAR CHANGES IN GLACIER MOTION

An increase in ice flow over the past decade is suggested on the basis of secular changes in long-period seismic sources associated with glacier motion. The relationship to ice flow is only now being calibrated by direct observation, but surface waves from slip events during a GPS deployment on the Whillans Ice Stream show that the seismic origin time corresponds to slip nucleation on the bed. A region of the bed acts like an "asperity" in traditional fault models. Seismic waves are also generated tens of minutes later when the slip terminates at the ice stream edge and the grounding line. Seismic amplitudes are modest, often equivalent to $M_S < 4$, so some parameters—including the total amount of slip—cannot be determined without improving permanent regional monitoring networks. Nevertheless, because seismic radiation from ice movement is proportional to the rate of slip acceleration, long-period seismic waves are thus useful for detecting and studying sudden ice movements.



Slip-start locations, shown as green and yellow squares, were determined from broadband seismic stations deployed during the 2008 field season. Continuous GPS confirmed that the seismic events corresponded to times of accelerated motion of the ice stream. (From Fricker et al., 2007. An active subglacial water system in West Antarctica mapped from space. *Science*, doi:10.1126/science.1136897. Reprinted with permission from AAAS.)

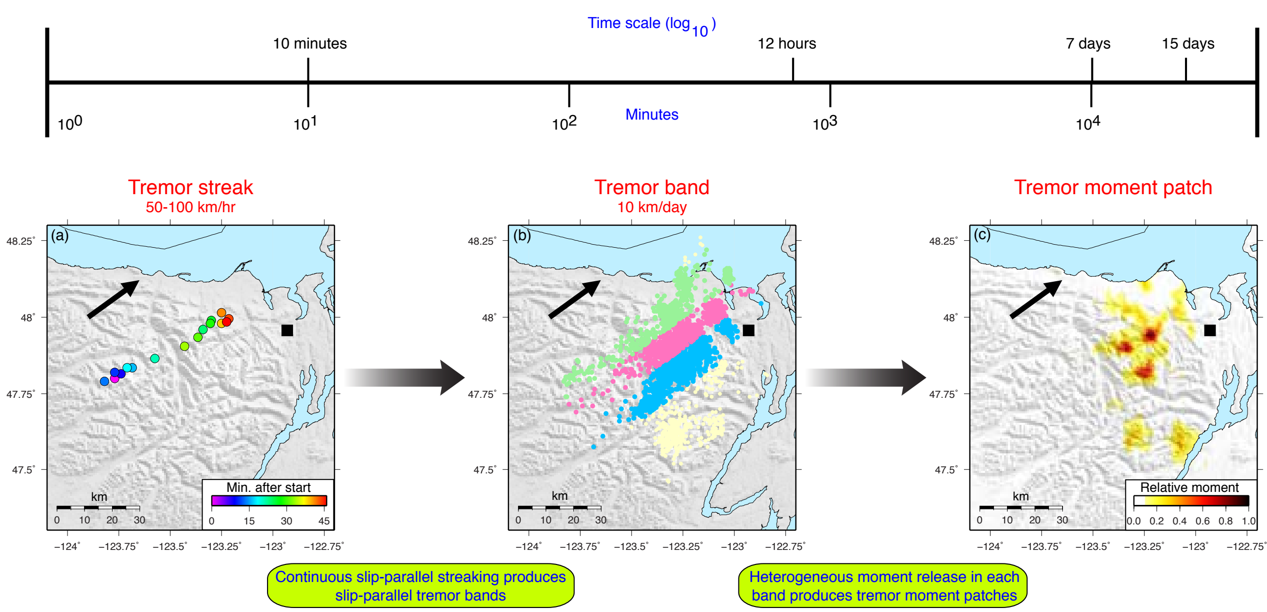
while high-resolution, three-dimensional seismic images show the plumbing system that feeds gas hydrate deposits. Waveform modeling can identify local concentrations, and temporal changes, in gas hydrates when seismic monitoring includes repeated surveys. When CO_2 is injected into deep rock layers to isolate it from the atmosphere, it is critical to assess where the gas goes and how effectively it is contained. High-resolution, three-dimensional seismic imaging offers key information on impermeable rock layers and subsurface geology for identifying viable structures for sequestration, while repeat imaging detects time-dependent changes for monitoring injection and migration.

Seismological techniques are being used to study the tectonic evolution of West Antarctica and the history of ice cap changes, tidally modulated motion of ice streams in West Antarctica, the collisions and break-up of Earth's largest ice shelves and icebergs, glacial calving, and a newly observed class of remotely detectable events from major tidewater outlet glaciers in Greenland. Microseisms recorded on the global networks have been used to explore past climate variations and movement of icebergs and glaciers.

The ocean's fine structure is usually mapped by lowering instruments that measure temperature and salinity, but this slow process limits the volume of ocean that can be sampled and the degree of horizontal resolution. Marine seismic profiles can rapidly map boundaries between water masses, revealing layers as thin as 5 m with unprecedented lateral resolution, while also imaging kilometer-scale eddies that are thought to play a major role in ocean mixing. Seismic imaging has revealed the thermohaline structure of the ocean, as well as oceanic mixing processes, by detecting internal tides.

MAPPING THE DETAILS OF EPISODIC, NON-VOLCANIC TREMOR

Studies of non-volcanic seismic tremor are offering new insights into fault mechanics and are leading to the development of new approaches for deploying seismic and geodetic stations, and data processing. Techniques for computing the tremor source region have evolved from double-difference methods using relative arrival times based on cross correlation of waveform envelopes, to beam back projection from dense, small-aperture seismic arrays. Beam back projection is much more effective at detecting coherent tremor, greatly increases resolution in relative tremor location, and can track migration of a tremor source from minute to minute. The technique was used to discover that tremor sources can migrate continuously for several minutes parallel to the dip direction of the Cascadia interplate thrust at a speed of ~50 km/hr, form bands of sources that sweep along strike at a speed of ~10 km/day for several hours, and develop distinct moment patches that overlap with geodetic slip patches on the interface. These varied and intriguing observations challenge Earth scientists to develop a unified view of tremor.



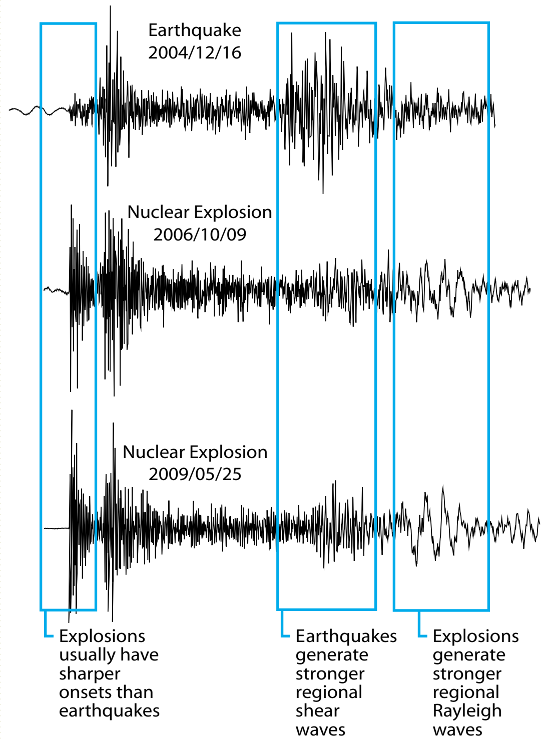
The maps show different elements of spatio-temporal tremor distribution, positioned along the logarithm time scale to illustrate the typical duration of each element. The arrow in each map indicates slip direction of the Cascadia Subduction Zone and the black solid square marks the Big Skidder array. (a) Circles are tremor locations, colored to show rapid migration of slip-parallel tremor streaks. (b) Circles are tremor locations, colored to show the slip-parallel bands that migrate along strike over several hours. (Faint yellow locations fall outside the tremor bands.) (c) Relative band-limited tremor moment patches that release much of the seismic moment during an ETS event. (Figure courtesy of Abhijit Ghosh, University of Washington)

EXPLORING NATURAL RESOURCES

Seismic data and methods have long been a key component in detecting the subsurface hydrocarbons and other resources. The petroleum industry relies on high-resolution, three-dimensional seismic surveying to map oil and gas reservoirs with the detail necessary to image the faults and complex sedimentary features that can trap energy reserves. Time-lapse imaging requires repeat surveys to monitor reservoir mechanical and fluid changes during resource extraction. Surveys are increasingly accompanied by monitoring of production-induced microearthquakes. Three-dimensional seismic reflection imaging has delineated coal-bed methane deposits, and its use is likely to grow as easily accessible deposits are exhausted. Pioneering work adapting seismological techniques to non-layered and steeply dipping targets in crystalline rocks has proven valuable for mapping mineral deposits. New seismic data and techniques—including cross-correlation Greens functions between stations from ambient noise and other sources—have been instrumental in higher-resolution images of the deep curst and upper mantle, as well as the near surface where natural resources are accessible.

MONITORING EXPLOSIONS

Earthquakes generate seismic waves but so do numerous other phenomena, including landslides, mine collapses, underground explosions, ocean storms, and many human activities. Seismic data may be the only or best data to address a societal need to identify a source type, so investment continues in research and supporting infrastructure. Identification is more reliable when high quality broadband data are available from stations near and at different azimuths around the source, and if the properties of the crust and upper mantle are well known. Signals recorded by permanent stations installed at quiet sites and temporary stations deployed in denser arrays provide complementary information to continue improving seismic identification capabilities around the world.



The GSN/CDSN station MDJ near Mudanjiang, China, (red triangle) is about 370 km from the nuclear test site (yellow circle) of the Democratic People's Republic of Korea and is the closest station that provides open data in near-real time. At this distance, it is possible to see several features of regional seismic arrivals that help to discriminate between earthquakes and underground explosions.

MITIGATING NATURAL HAZARDS

Seismology provides indispensable real-world observations of earthquake statistics and rupture kinematics to which laboratory experiments, numerical models, and inferences from paleoseismology must be compared. In the last decade, array processing has been extended to imaging rupture propagation of the largest earthquakes from teleseismic distances, including the 2004 M_w=9.2 Sumatra and 2010 M_w=8.8 Chile megathrusts, the 2008 M_w=7.9 Wenchuan intracontinental earthquake, and the 2010 M_w=7.0 Haiti earthquake. Accessibility of data from networks around the world has improved the cataloging and characterization of earthquakes. Combined use of InSAR, GPS, and other geodetic information with seismic data has improved the resolution of rupture models.

Dense deployments of temporary stations have been and continue to play a key role in documenting newly discovered phenomena, such as non-volcanic episodic tremor and slip and low-frequency earthquakes. New pictures of the Pacific Northwest intraplate fault zone suggests that the probable regions of strong ground motion during future earthquakes at active continental margins extend significantly further inland than had been thought, closer to large population centers. The pervasiveness of these previously unknown fault behaviors has fundamentally altered our view of fault physics.

Recent devastating earthquakes in Haiti and Chile have highlighted the critical role of real-time access to seismic and other geophysical data in improving emergency response and tsunami warnings. Static stress changes computed shortly after the January 12, 2010 Haiti event, based on finite source models and aftershock locations from teleseismic networks, were used to map areas near Port-au-Prince that are likely closer to experiencing another earthquake rupture in the future. Improved models of the near-surface geology, partly from high-resolution urban seismic mapping can be sued to identify variations in ground shaking and damage during earthquakes and to identify fault structures that may produce damaging earthquakes.

Mitigation of volcanic hazards is a multidisciplinary endeavor, incorporating the analysis of seismic, acoustic, geochemical, and other data. Seismological advances related to environmental monitoring—such as the methodology of repeat surveys—and to resources exploration—such as cross-correlation Greens functions—reveal temporal changes in velocity that are likely caused by opening of near-surface cracks in the volcanic edifice as it inflates by increased pressure within the underlying magma chamber, and other precursory activity, that lead up to eruption.

CONCLUSION

The most compelling evidence for a vibrant and exciting research field is the level of publications in the peer-reviewed literature. A database of IRIS-related and IRIS-facilitated scholarly publications includes over 2400 papers in refereed journals. The annual number of prominent, peer-reviewed papers based at least partly on IRIS services continues to grow. A systematic review of *Science*, *Nature*, and 10 frequently cited geophysical and seismological journals shows that the number of IRIS-facilitated publications in those journals has grown to an average of 175 per year since 2006, compared to 131 annually during the previous five years. The most recent compilation from 2009 suggests that the growth is accelerating.

Seismological Grand Challenges highlights that surface and interior processes are not always independent, and suggests that future work will help to better resolve to what extent such processes are coupled spatially and temporally. The solution to these problems requires multidisciplinary approaches where seismology can provide a significant contribution. Indeed, over 75% of IRIS-facilitated papers published during 2009 were in journals that do not specialize specifically in seismology, indicating that the results are already directly applicable to issues of broad interest among geoscientists. While many of the Grand Challenges identified in the 2009 report will continue to inspire seismologists and geoscientists well into the future, new challenges will continue to emerge as additional high-quality data are recorded, analyzed, and interpreted jointly with data from other disciplines.

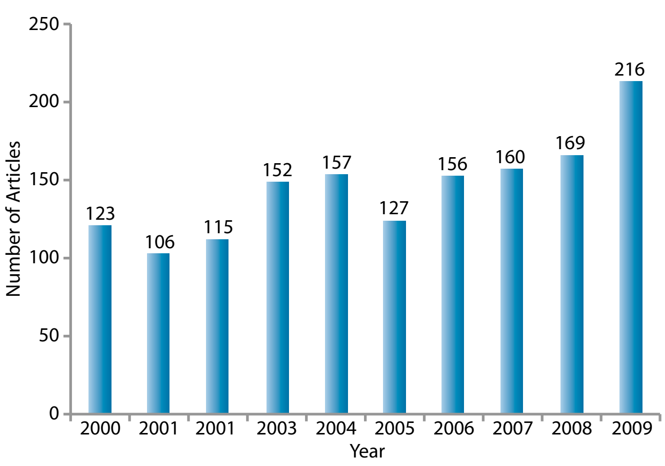


Figure 2.2. For 10 years, IRIS has tracked the number of publications facilitated by IRIS services in *Science*, *Nature*, and 10 widely cited seismological and geophysical peer-reviewed journals. These journals include only a small fraction of all IRIS-facilitated publications, but the stability of the journal selection and completeness of tracking within those journals helps to identify trends over time.

OVERVIEW OF IRIS CORE PROGRAMS

Since its inception 25 years ago, the IRIS programmatic structure has reflected our core mission to facilitate seismological research and education by providing the means to generate and distribute high quality data. Over those 25 years, the scope of these activities has evolved and expanded, such that IRIS now seamlessly integrates the collection, development, and distribution of products that range from raw seismic waveforms to educational PowerPoint presentations. This seamless delivery of a great spectrum of data products and services derives from the underlying structure of IRIS, which is based on the pillars of the four core programs: 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 (E&O) program.

Two of the original three core facilities, *GSN* and *PASSCAL*, were natural extensions of the two principal modes of seismological observation. The GSN, a worldwide network of permanent very broadband seismometers that records and transmits high-fidelity data in near-real time, became the digital successor of the World Wide Standardized Seismic Network (WWSSN) and the basis for research at a global scale. The main purpose of PASSCAL, a pool of well maintained, state-of-the-art portable instruments, has been to enhance and facilitate local- and regional-scale research. The organic growth of these facilities from existing paradigms led to their early and enthusiastic embrace by seismological researchers, but their demonstrable success over the past 25 years is due as much to the forward-looking vision of the IRIS community as it is to adapting lessons from the past. For example, much of GSN's success derives from an ongoing and imaginative exploitation of new and evolving technologies that enable the collection of a suite of geophysical data streams from remote corners of the globe in real time, while PASSCAL revolutionized regional scale, array-based research by creating high-quality, state-of-the-art instrumentation with the versatility and resiliency to be deployed in almost any environment, regardless of an investigator's access to in-house instrumentation facilities.

The third of the original three facilities, the *Data Management System (DMS)*, provides an even more compelling example of how the original community vision has transformed seismological research. The DMS was created as a centralized facility to archive, manage, and distribute data from GSN and PASSCAL, but, because it was not constrained by any narrow restriction on the type or source of "data," the DMS adopted a holistic view that has resulted in a centralized archive of seismological and related data from hundreds of IRIS and non-IRIS observatories worldwide. In the process, the DMS has widely promulgated the IRIS philosophy of open, accessible, high-quality, well-documented data. The DMS has had a broad impact on how other disciplines now manage data, and it has become the standard in data management to which other data centers aspire.

In recognition of a need to enhance awareness of seismological research in education and by the general public, the *Education and Outreach (E&O)* program was established in 1997 as a fourth core facility. E&O provides resources for K–16 teachers, for other formal and informal educators, for research scientists contributing to education, and a framework for outreach to public, professional, and other Earth science communities. These resources have become increasingly sophisticated and effective. Excellent example are the creation of the "Teachable Moments" web resource and the "Active Earth" kiosk displays that provide various forms of educational content related to significant seismic events. The content is both timely (much of it is produced within a day of the event) and versatile (the level of the content can be customized for audiences ranging from elementary to university-level students and the general public).

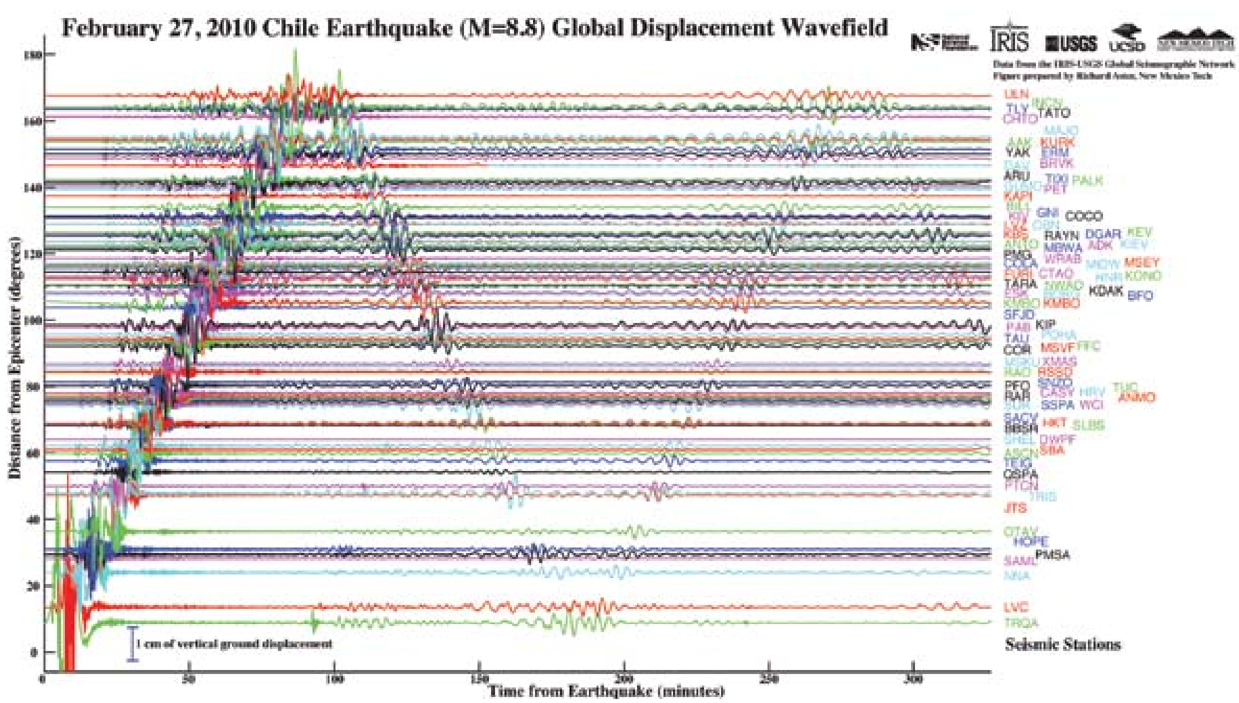
With close links to all four "core" programs, IRIS has played a major role in the creation and operation of *EarthScope* and *USArray* since their inception. In the context of a data-collection enterprise, IRIS's role in this effort is an unqualified success. IRIS has completed the assembly of the Transportable Array (TA), which constitutes the main component of USArray, oversees the operation and maintenance of the array as it rolls across the country, and manages and archives the openly available, real-time data through the DMS. It also provides the means for EarthScope-funded investigators to carry out ancillary projects by maintaining a Flexible Array (FA) pool, which combines the PI-controlled experiment design of PASSCAL, with more complete data collection and archiving services akin to the TA. By including a magnetotelluric (MT) component in USArray, IRIS has helped to establish a complementary observational facility and revitalized U.S. community involvement in this geophysical discipline.

In a very real sense, the standards that IRIS has set in both data collection and management both inspired and made feasible the concept and reality of USArray.

Building directly on the success of these core programs, IRIS has taken a proactive role in cultivating new initiatives of interest to the seismological research community. Two examples of how IRIS has recently taken a lead role in facilitating community efforts are the *International Development Seismology (IDS)* program and the expansion of *Polar Services*. IDS provides a formal mechanism to capitalize on the extensive international experience developed over the years through GSN, PASSCAL, and DMS, to better facilitate various forms of capacity growth in seismology and the development of earthquake hazard assessment and monitoring networks in the developing world. Recent IDS activities include assistance in the coordination of an international response to the long-term rebuilding of Haiti after the January 12, 2010 earthquake, and supporting the Chile RAMP (CHAMP) project involving the installation of 58 broad band stations in the rupture zone of the February 27, 2010 M8.8 Chile earthquake. The Polar Services program is an amalgam of initiatives to expand instrumental capabilities to support research in the extreme environment of the poles. GSN now operates five real-time stations in Antarctica, and PASSCAL has been developing the methodologies that allow instruments to be deployed easily and rapidly, and record data successfully through the polar winter. In addition to supporting basic research in polar environments, the innovations that come from this effort, such as low-power instrumentation and alternative power supplies, will eventually benefit the broader community. A recent and significant addition to IRIS polar activities has been the Greenland Ice Sheet Monitoring Network (GLISN) project, in which IRIS collaborates with a number of international partners in establishing a real-time array of 25 broadband stations in Greenland. A common thread of these recent advances is that they are truly pan-IRIS: they are centered on activities that support, and are supported by, data-collection efforts within GSN and PASSCAL, as well as data distribution and outreach activities associated with DMS and E&O.

THE GREAT CHILE EARTHQUAKE OF FEBRUARY 27, 2010

A record section of vertical ground displacements from 92 GSN stations for the M_w8.8 Chile earthquake of February 28, 2010. Surface waves can be observed making two passes around the globe during the first three hours following the earthquake. The closest station is in Argentina and the most distant one is in Mongolia. The vertical displacements observed are comparable to the 2004 Sumatra-Andaman earthquake (note the scale at the bottom). A M6.9 aftershock is visible for comparative scale, approximately 90 minutes after the mainshock. On-scale, very broadband data from the GSN have provided important new information to characterize the nature and extent of faulting in great earthquakes. (Figure courtesy of Rick Aster, New Mexico Tech).



Grand Challenges Recommendations

The boxes used in this and the following section of the proposal list all of the recommendations from the final chapter of the report on *Seismological Grand Challenges in Understanding Earth's Dynamic Systems*. This proposal does not consider all of the recommendations. Those that do not have a response are shown in blue and a footnote in the box explains why it is not an area where IRIS support is requested in this proposal).

GRAND CHALLENGES RECOMMENDATIONS – 1

Sustaining Global Observatories

- Advance coordination with other environmental monitoring facilities and communities to establish multidisciplinary monitoring stations at global seismographic facilities, as well as to augment global seismic instrumentation.
- Share the sustained support of IRIS/USGS GSN long-term operations and equipment upgrades among all federal agencies that rely upon global seismic data as part of their operations.
- Coordinate between the academic community and international sponsors of hazard assessment and mitigation, especially in poorly studied regions in developing nations to create multi-use programs for monitoring, research, training, and capacity building.
- Set the completion of the ANSS by the USGS as a high priority[1].
- Continue support for the operations of the ISC, which assembles and reprocesses catalogs from many international networks to the benefit all users of seismological bulletins.
- Deploy global ocean bottom borehole installations, guided by the International Ocean Network (ION) plans for establishing uniform global Earth coverage.

[1] Assistance with completion of the ANSS backbone is being implemented as part of USArray

PROPOSAL STRUCTURE

The recent history of the IRIS facilities is impressive both in terms of continuing accomplishments and new initiatives. A key element of this proposal is to continue to maintain these critical resources to support Consortium members' university-based research and contributions to both national and international Earth science. In this section of the proposal we present brief synopses of the activities, tasks, and budget elements involved in maintaining the core programs and existing cross-programmatic efforts. For each program, core operational tasks and budget elements are followed by summaries of enhancements and new initiatives to be undertaken over the next 27 months. Each of these new activities is keyed by page number to the section in the appendix on Program Descriptions, where more detail can be found. More detailed information on the budgets is provided in the budget section and accompanying notes, and in the budgets and work statements for major subawards. The appendix to the proposal on Program Descriptions describes the history of each program, recent accomplishments under the current five-year Cooperative Agreement, and the outlook for the future. In Section 4, "Transitioning for the Future," we describe recent changes in the IRIS management structure that are intended to enhance program coordination, and proposed activities that will build on synergies between programs in the development and implementation of new directions in technology and cross-program activities. Throughout the next two sections, the recommendations found in the chapter on "Sustaining a Healthy Future for Seismology" of the *Seismological Grand Challenges in Understanding Earth's Dynamic Systems* report are listed in text boxes. For completeness, all of the recommendations from that report are included and brief explanations are provided for those that are not identified for implementation under this proposal.

GLOBAL SEISMOGRAPHIC NETWORK

The *Global Seismographic Network (GSN)* is a cooperative partnership of U.S. universities and government agencies, coordinated with the international community, to install and operate a global multi-use scientific facility as a societal resource for Earth observations, monitoring, research, and education. GSN data underlie most fundamental studies of global earthquake dynamics and tomographic analyses of the elastic and anelastic structure of Earth. GSN data are also a critical resource for both national and international agencies in monitoring and characterizing earthquakes, tsunamis, and nuclear explosions. The concept of the GSN is founded upon global, uniform Earth coverage by a permanent broadband network with real-time data access. GSN instrumentation is capable of measuring and recording with high fidelity all seismic vibrations from high-frequency, strong ground motions near an earthquake to the slowest fundamental oscillations of Earth excited by the largest great earthquakes. The instrumentation is modular, enabling it to evolve with technology and the science needs. Standardized equipment and data formats create efficiencies for use and maintenance. GSN telecommunications, using Internet links and dedicated satellite circuits, seamlessly provide a real-time flow of data to the IRIS Data

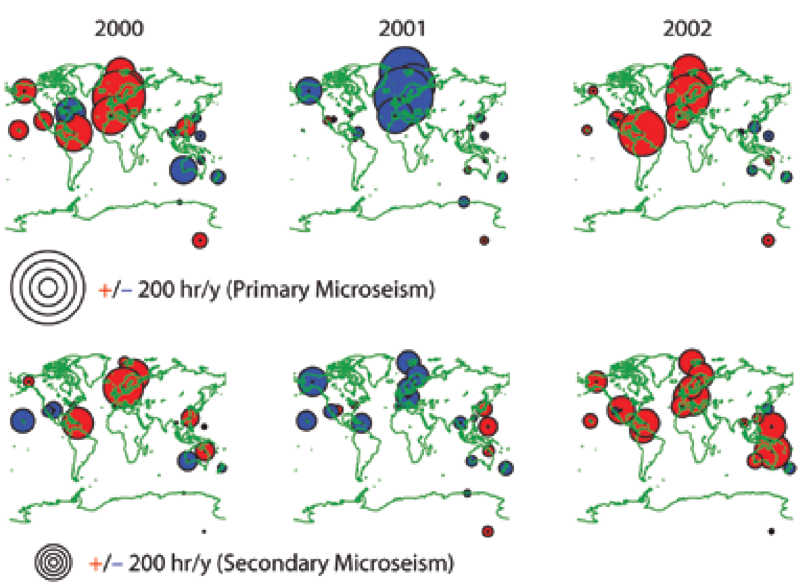
Management Center and mission agencies. As a result, GSN data are openly available to the research community and monitoring networks only seconds after they are recorded.

The GSN is a partnership between IRIS and the U.S. Geological Survey, cooperating under a Memorandum of Understanding, with additional U.S. agency support from the Department of Defense, Department of Energy (DOE), NASA, National Weather Service (NWS), and NOAA. The GSN is a foundation for both the Advanced National Seismic System (ANSS) and the USArray Reference Network in the United States, and provides critical core data for the international Federation of Digital Seismograph Networks (FDSN), Pacific Tsunami Warning Center, and other international tsunami warning systems. GSN stations are installed and operated by the USGS Albuquerque Seismological Laboratory and by the IDA project at the University of California, San Diego. IRIS GSN global siting plans are coordinated with other international networks through the FDSN, of which IRIS is a founding member.

The GSN has seen steady progress toward its long-term goals as defined in the original GSN Science Plan, which was developed as part of the original IRIS proposal in 1984. With the current network of 154 GSN stations and affiliates, the goal of one station per 2000 km on continents, and coverage of as much of the ocean basins as allowed by installation on oceanic islands, has been achieved. More than 96% of GSN stations have real-time telemetry. During the current Cooperative Agreement with NSF, a major advance was made in the adoption of standardized data-collection hardware across the network and installation of these new-generation systems will be completed during the next three years.

OBSERVING EARTH'S OCEAN WAVE CLIMATE WITH MICROSEISMS

Seismic stations worldwide record an incessant excitation of seismic waves stimulated by ocean wave activity, the microseism. This signal has two principal components, a primary near 16 s period resulting from the coastal energy transfer of breaking and shoaling waves, and a (stronger) secondary, near 8 s period, arising from standing wave components of the ocean wave field, such as are created by incoming swell interfering its coastal reflection. Here, the incidence of winter microseism intensity extremes (uppermost fifth percentile microseism events from large, wave-generating storms) at GSN stations is depicted as the number of hours per year exceeding (red) or less than (blue) the long-term averages in these extremes at each station. The quiet year in 2001 is associated with a notable 2000–2002 La Niña-El Niño transition, illustrating a remarkably widespread influence of the El Niño-Southern Oscillation on extremal wave climate. Microseism data are currently available in digital form since the early 1970s, and recent efforts suggest that, by digitizing and processing older analog records, wave climate can be synoptically studied back to the early 20th century, providing important new information in regions lacking buoy or other data. (After Aster et al., 2010. Global trends in extremal microseism intensity. *Geophysical Research Letters,* 37, L14303, doi:10.1029/2010GL043472.)



CORE GSN OPERATIONAL TASKS AND BUDGET ELEMENTS

The primary IRIS/GSN tasks under core operations are to:

- Continue maintenance of the current network
- Enhance quality-control procedures
- Install hardware already acquired to upgrade all stations to of the network to new and standardized data acquisition systems
- Continue collaborations with national and international partners
- Continue community engagement through support of the GSN Standing Committee

Operation and maintenance of the GSN is shared between IRIS and the US Geological Survey. The USGS, through a special GSN line in their Department of the Interior budget, supports the staff to provide operational and data collection for 80% of the network. IRIS, through a subaward to UCSD, supports the staffing for maintenance of the remaining 20%. The largest budget element in this proposal is for the subaward to UCSD for staffing and travel, operational spare parts and supplies, and stipends for station operators. IRIS directly supports part of the telecommunications costs and holds funds in reserve, to be appropriated on an annual basis, for upgrade, repair and re-location of stations requiring attention. Only minor additional new hardware is requested in this proposal, because funds from NSF over the past five years under the current Cooperative Agreement, along with special funding allocations to both IRIS and USGS in 2009–2010 (related to the American Recovery and Reinvestment Act of 2009), have been used to acquire all of the major capital equipment items necessary to upgrade all GSN stations to new and standardized data loggers. This standardization across the network of all data logging equipment is the first major upgrade cycle for the GSN, and will have a significant impact on improving data quality and increasing efficiencies in operations. At the time of writing of this proposal, approximately 45% of the network has been upgraded and the funding requested under this proposal will allow for completion of the upgrades by the end of 2013.

GSN ENHANCEMENTS AND NEW INITIATIVES

QC Enhancement (pgs A-11–A-12) – The quality of data recorded and archived from the GSN has become a significant concern over the past few years. This has been partly related to the deteriorating performance of the STS-1 and borehole sensors, but also involves degradation of aging site infrastructure and deficiencies in reporting and maintaining appropriate metrics to assess waveform quality. In the summer of 2010 the GSN operators established a Quality Assessment Team and the IRIS Board appointed a Waveform Quality Review Panel to review GSN data quality and provide recommendations for implementation of metrics and reporting procedures related to GSN data quality. Funding is requested in the GSN and DMS budgets to share support for an additional staff position to implement the recommendations of this Panel. These efforts will be part of a pan-IRIS approach to data quality control and will be coordinated through the new Instrumentation and Data Services structure s described in Section 4.

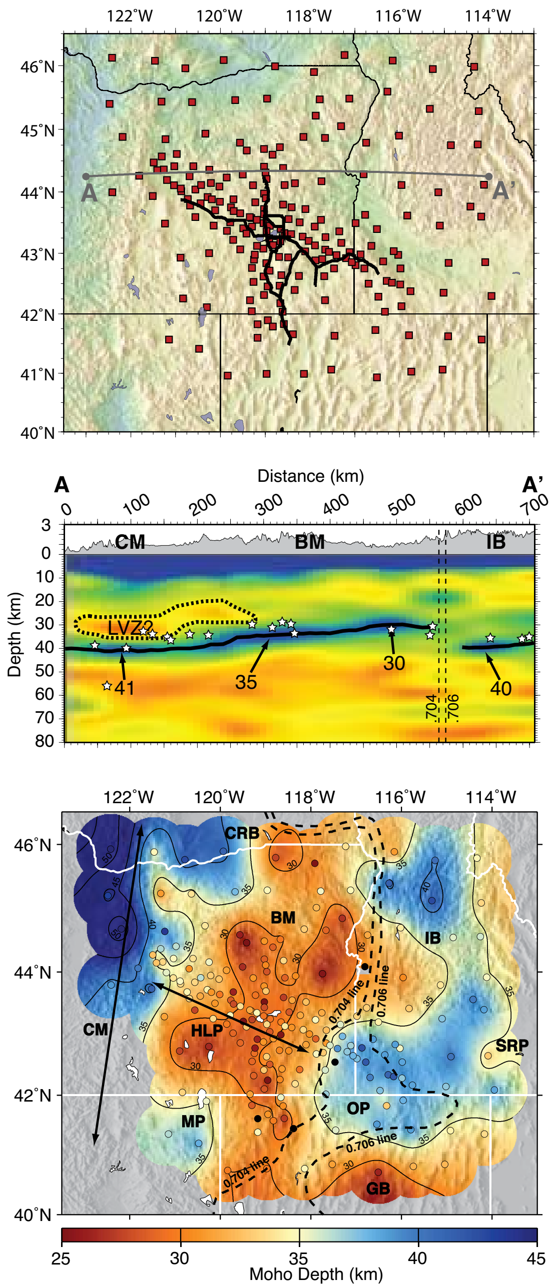
Seismic Arrays (pg A-13) – The *Grand Challenges* report recognizes that dense seismic arrays offer great potential in complementing a sparse network like the GSN in resolving important questions related to deep Earth structure and earthquake dynamics. GSN proposes to hold two workshops. One will explore the application of array technology to deep Earth studies and the other will develop specific scientific objectives and priorities for augmenting the GSN with fixed arrays and production of a technical plan (array geometry, siting, instrumentation, and international coordination) needed to achieve the scientific objectives. Funding is also requested to support a pilot experiment, using data from an existing array (e.g., USArray TA, SIEDCAR experiment (Seismic Investigation of Edge Driven Convection), High Lava Plains (HLP) Project) to demonstrate the capability for resolving research targets. These activities will be coordinated with PASSCAL and USArray under the new Instrumentation Services structure.

Sensor development (pg A-12) – The Streckeisen STS-1, which has been the primary vault sensor for the GSN since inception, is no longer manufactured. Replacement of this important component of the GSN was identified as a major concern in the 2006 IRIS proposal. In recent years it has become obvious that the STS-1's at some stations were starting to show degradation in the stability of their long-period response. The failure rate of the primary borehole sensor (KS-54000) has also become unacceptable. It now appears that the primary source of the STS-1 problem is aging of the seals on the feedback electronics box. A complete redesign of the feedback electronics (partially supported by a grant from EAR/I&F) and its housing appears to rectify the problem at most sites where it has been installed. All STS-1's are being retrofitted as part of the ongoing upgrade of the GSN. At the same time, new instrument designs (partially supported by EAR/I&F) and investments by commercial instrument manufacturers have recently shown promising results in producing sensors that match the demanding response characteristics of the STS-1. Funds are requested in this proposal to purchase and field test prototypes of these new sensor designs.

Enhanced International Data Exchange (pgs A-13–A-14) – Since its inception, IRIS (through both GSN and DMS) has collaborated closely with the international Federation of Digital Seismograph Networks (FDSN) in site selection and encouraging policies for open data exchange. GSN station locations have been chosen to complement those of other FDSN members. The IRIS DMC acts as the FDSN archive for continuous waveform data. FDSN membership now includes 65 institutions in 52 countries. The number of high-quality broadband stations established by these members has increased significantly, but not all of these stations are openly available and there exist networks that are not a part of FDSN. For a volunteer organization, the task of maintaining an inventory of these rapidly expanding broadband stations lies beyond the current abilities of FDSN. IRIS requests funds to work with FDSN and ISC to prepare an expanded inventory encourage open data sharing and document the procedures for accessing data. Other FDSN members have been approached and indicated a willingness to collaborate with IRIS on funding this activity.

COMBINED ACTIVE AND PASSIVE SOURCE EXPERIMENT IN THE HIGH LAVA PLAINS

The High Lava Plains Project in eastern Oregon is a multi-institutional, multi-disciplinary project to understand why the Pacific Northwest is the most volcanically active areas of the continental United States. A four-year deployment of 104 broadband PASSCAL instruments located at 118 sites observed hundreds of global and regional events that are being analyzed using a variety of techniques to study three-dimensional crustal and upper mantle structure, including thermal and compositional heterogeneity, as well as anisotropy to better understand the tectonic evolution of this complex region. An active-source experiment using the entire PASSCAL and USArray inventory of ~3,000 Texan instruments recorded at 15 shot points is providing complementary high-resolution images of the crust. The seismic results are currently being jointly interpreted with the results of geologic, geochemical, and petrological studies to provide the first holistic model of tectonomagmatic evolution of the region. USArray magnetotelluric data are augmenting this effort. Shown are maps of locations of broadband PASSCAL and TA stations (red squares) and active source reflection/refraction lines (black); an E-W cross section; and Moho depth. Details can be found in one-pagers included in the Accomplishments volume. (Figure courtesy Kevin Eagar and Matt Fouch, Arizona State University)



Collaborations with Ocean Observatories Initiative (OOI) (pg A-14) – The Ocean Observatories Initiative (OOI, an NSF MREFC project) will soon begin the construction and installation of a new generation of permanent observatories in the ocean with real-time telemetry that will revolutionize oceanography. The focus of the OOI Global Buoy program on high-latitude sites is of great interest to the GSN, where the proposed sites would fill in significant gaps in GSN global coverage. Unfortunately, the current OOI science plan does not include seismometers at these significant locations. The GSN Standing Committee will initiate a working group to develop a detailed plan for adding broadband seismic instruments to the OOI global buoys. Funds are requested to support proposals, based on the recommendations of the working group, from the NSF-funded Ocean Bottom Seismometer Instrumentation Pool (OBSIP) to test a prototype burial system in a deep-water environment. Through the combined efforts of the working group and the field-testing of a burial system by the OBSIP groups, the GSN will be well positioned to begin filling the current gaps in the oceans as part of the next five-year IRIS proposal to be submitted in 2013.

PASSCAL

The Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL) provides and supports a range of portable seismographic instrumentation and expertise to diverse scientific and educational communities. The PASSCAL Instrument Center (PIC) at the New Mexico Institute of Technology in Socorro, NM is responsible for acquiring, warehousing and maintaining all PASSCAL equipment; training student and PI's and supporting field experiments; implementing improvements in hardware; developing software for efficient data collection and initial processing; and assisting PI's in preparing data for archiving and eventual distribution through the IRIS Data Management Center. The cost for operation of the PIC is shared between the IRIS PASSCAL core program and EarthScope for support of the USArray Flexible Array. The mix of PASSCAL instrumentation, especially when viewed in concert with the USArray resources, enables a wide variety of deployment schemes— mobile arrays for recording of planned explosions; temporary deployments for aftershock studies; longer-term deployments for observations of regional and teleseismic events.

PASSCAL has influenced academic seismology in all parts of the world explored by US seismologists, by providing instrumentation to spur or augment international collaborations, and by introducing modern digital data collection and field techniques to scientists in developing nations. Many of the standards and facilities pioneered by IRIS for instrumentation and data collection, archival, and open exchange have been adopted by other seismological networks and organizations in the US and worldwide. The widespread presence of PASSCAL has spurred the dissemination of the IRIS open-data culture to both seismological and non-seismological data collection groups in the US and abroad. Internationally, similar portable seismograph facilities have patterned their operations on PASSCAL.

Over 60 individual experiments ranging from a few to more than 2500 instruments are supported annually. Since the 1984 start of the program, PASSCAL has supported over 500 experiments, leading to a host of new discoveries about the Earth, some of which are summarized in the one-pagers that accompany this proposal. PASSCAL resources remain fully subscribed for use in peer-reviewed research programs—confirmation of the importance of the PASSCAL facility to the Earth science community. Indeed, despite continued growth in the size of the instrument pool, demand for instruments and technical support continues to exceed capacity. The gap between demand and capacity remains a major concern of the PASSCAL community, where the queue for broadband instruments now exceeds two years.

GRAND CHALLENGES RECOMMENDATIONS – 2

Advancing Portable Instrumentation

- Continue support by federal agencies to sustain seismic data collection and open data distribution facilities with long-term amortization and investments in new technologies.
- Increase the pool of three-component broadband sensors, which are required for improved resolution in next-generation 3D and 4D imaging efforts of crustal, lithospheric, and deep mantle and core structure.
- Support the EarthScope Transportable Array deployment through completion of its traverse across the United States, including Alaska[1].
- Expand the pool of portable OBS's for systematic large-scale deployments in portable arrays[2].
- Significantly increase the number of sensors for active-source experiments, including three-component systems, which are essential for advances to occur in high-resolution crustal imaging.

[1] *Completion of the TA through Alaska is anticipated as part of EarthScope funding*

[2] *IRIS is convening a workshop in September 2010 with joint EAR/OCE funding to explore the scientific targets for portable broadband OBS*

IMAGING OF SHALLOW EARTH STRUCTURE

PASSCAL instrumentation can be used in studies of the near surface in investigations of fault structure, shallow basins, aquifer geometry, and waste sites. This photos shows 600 single-component "Texans" deployed in a dense array at the Hill Air Force Base to image a toxic waste site.

CORE PASSCAL OPERATIONAL TASKS AND BUDGET ELEMENTS

The primary PASSCAL tasks under core operations are to:

- Provide user services to support NSF-funded PIs in carrying out portable field experiments
- Continue to maintain the existing pool of high-frequency, short-period and broadband instruments
- Acquire limited new hardware to maintain the existing pool
- Provide services to PIs to assist in data collection and preparation of data for delivery to the IRIS Data Management Center
- Expand resources for near surface imaging
- Continue community engagement through support of the PASSCAL Standing Committee

Most of the PASSCAL support activities are implemented through a major subaward to New Mexico Tech to staff and operate the PASSCAL Instrument Center (PIC) in Socorro, NM, and a minor subaward to University of Texas, El Paso to support a UTEP-owned pool of active source recorders (Texans). Both of these awards are primarily for personnel support – all major equipment items and most supplies for expendable materials used during experiments are purchased directly by IRIS. In addition, costs for insurance, shipping, maintenance contracts and travel (for management, PIC staff and committees) are also budgeted as IRIS expenses. In this proposal, we request new hardware to enhance the PASSCAL capability to support near surface investigations (high-resolution seismic, ground penetrating radar and electromagnetic) but only minor equipment and parts to repair and refurbish the existing pool of broadband and short-period recorders and sensors. As described below and in the next section, a major new task under this proposal will be to define and develop a new generation of PASSCAL equipment. Acquisition of these new systems will be proposed under the next five-year Cooperative Agreement.

GRAND CHALLENGES RECOMMENDATIONS – 3

Controlled Seismic Source Support

- Establish a facility or collection of facilities for sources used in active-source seismology so that research programs and education in this area can be sustained. This facility could possibly be developed through access to the vibrator trucks of NEES, reinvigorated participation of the USGS in active source seismology, and in partnership with industry.
- Improve interactions among academic, governmental, and industrial efforts in active-source seismology to sustain the discipline.
- Expand the ability to conduct 3D active-source imaging at sea.[1]

[1]*Active source marine seismic studies are supported through NSF/OCE*

PASSCAL ENHANCEMENTS AND NEW INITIATIVES

Next generation equipment (pgs A-23–A-24) – One of the most important new initiatives during the next 27 months will be to develop the specifications for a new generation of portable instruments and begin prototype testing. A recurring and compelling facility needs identified in the *Grand Challenges* report is for a new generation of portable instruments that can respond to the research communities needs for higher-density deployments for high-resolution studies of both structure and earthquake sources. Part of PASSCAL's success has been rooted in strict adherence to standardized instrument configurations, but the core design of the current sensors and data acquisition systems is now based on decades-old technologies. Incremental changes, especially in storage capacity and telemetry, have been incorporated in recent years, but with exciting new advances in low-power devices, telemetry, and MEMS (micro-electro-mechanical systems) sensor technology, there are now opportunities to engage with instrument manufacturers to develop a completely new generation of instruments to complement and eventually replace the existing PASSCAL pool. Coordinating a pan-IRIS approach to this development effort will be one of the first activities undertaken by the Instrument Services structure described in the next section.

Flexi-RAMP (pg A-24) – Included in the *Grand Challenges* report are a suite of recommendations related to earthquake source science and fault zone properties. Many of these studies would benefit from near-source, high-frequency observations using temporary deployments of large numbers of instruments. Typical applications could include recoding of aftershock sequences or high-resolution imaging of faults. From the early 1990s, PASSCAL has committed a set of RAMP (Rapid Array Mobilization Plan) instruments for use in aftershock recording. A core set of ten PASSCAL instruments has been specifically allocated to this pool and this has often been supplemented with other instruments when available. While these instruments have provided critical data in a variety of aftershock studies, the number of instruments is limited and the standard PASSCAL configuration is not optimal for rapid deployment. As a first trial implementation of new technologies, funds are requested to begin acquisition of a new set of low-cost instruments, optimized for rapid deployment in large numbers. The FlexiRAMP concept envisions a flexible-use strategy, with at least some of the instruments deployed in easily retrievable temporary arrays when not in use for aftershock studies.

Sources (pg A-25) – The *Grand Challenges* report includes a specific set of recommendations on controlled sources for reflection studies of the near surface and crust, and this topic has been reviewed recently by a special PASSCAL working group on active sources. Based on the recommendations of that working group, PASSCAL will be purchasing a small weight-drop source for shallow imaging under the current Cooperative Agreement. In this proposal, partial FTE support is requested to develop in-house expertise within PASSCAL to provide researchers with advice on both sources and permitting for active-source studies. There remains a critical need for high-energy sources, and IRIS strongly supports the creation of an Explosives Sources Center such as that proposed to NSF by the University of Texas and New Mexico Tech.

DATA MANAGEMENT SYSTEM

The *Data Management System (DMS)* is the primary conduit for data flow within IRIS and to the scientific community. The IRIS Data Management Center, the central element of the DMS, has become one of the most actively used scientific data centers in the world. The DMS ingests an exponentially increasing volume of observational time series data every year, from an expanding number of seismic networks and stations. Currently, more than 20 terabytes of new primary observational data are being added to the archive holdings each year, and an increasing amount of data is being delivered to the research community (estimated to be 80 terabytes in 2010) through batch requests to the archive, streaming data in near-real time, and through advanced remote clients that directly access both metadata and time-series data.

Originally, the DMS was designed to receive, provide quality assurance, archive, and distribute data from the other core IRIS programs, as well as U.S. regional networks supported by the USGS. The DMS quickly developed close ties with the international seismological community, who were provided innovative, easy-to-use tools to access the openly available data in the archive. As a result, the DMC evolved to become a primary archive for continuous data for the FDSN and many non-FDSN networks around the globe. All broadband data from the GSN, PASSCAL, USArray, and international contributors are available in a seamless fashion from the DMC in SEED format. Active-source data are available in SEG-Y format. As of mid-2010, more than 118 terabytes of waveform data were archived online in more than 8.4 million files. Fully redundant copies of waveform data, database tables, and operating software are available at an active backup location at UNAVCO in Boulder, Colorado.

In addition to its role of archiving and distributing data, the IRIS DMS is responsible for quality control of IRIS-generated data and has a well-established mechanism in place to monitor and correct data problems as they are discovered. The IRIS DMS has developed novel means of accessing data in near-real time and supports a variety of real-time data communication protocols. The BUD system operated by the DMC receives nearly 12 terabytes of data per year in near-real time. Systems such as WILBER provide a convenient way for scientists to access data for significant events shortly after they occur. A complete database management system and associated user tools allow researchers to make complex requests for customized subsets of data stored in the IRIS archive. The IRIS DMS, with supplemental support from USArray, is now generating many data products defined by the research community, drawing from the primary observational data managed at the DMC.

By actively developing, supporting, and promoting the open exchange of data based on well-established interchange standards, the DMS has played a key role in ensuring that properly documented data are made available to scientists worldwide, with a minimum of barriers, for use in a wide range of research topics and applied applications.

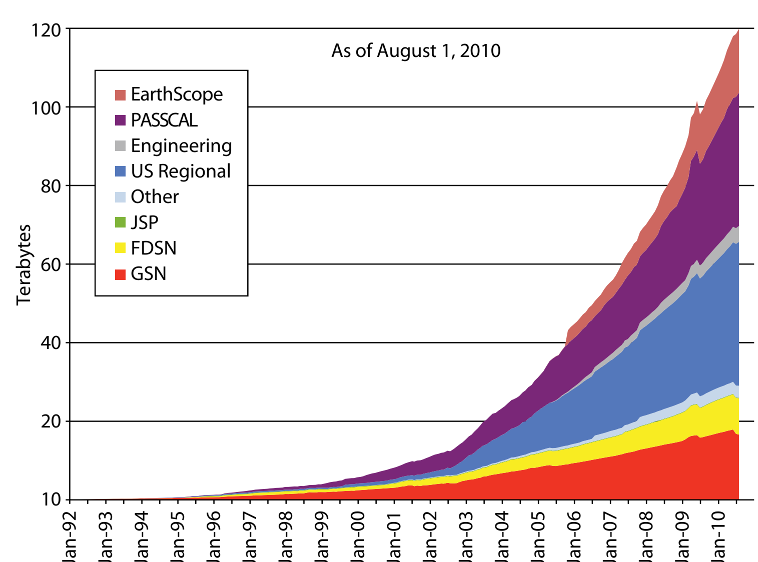
CORE DMS OPERATIONAL TASKS AND BUDGET ELEMENTS

The primary DMS tasks under core operations are to:

- Operate and maintain the primary IRIS data archive and databases at the Data Management Center in Seattle
- Support the GSN IDA Data Collection Center at UCSD and collaborate with the USGS/ASL Data Collection Center in Albuquerque
- Provide user services and training to support researchers in gaining access to data
- Support the development of data products (in collaboration with USArray)
- Encourage international involvement through training workshops and limited support of regional data centers in developing countries

ARCHIVE GROWTH AT THE DATA MANAGEMENT CENTER

The quantity of data archived at the IRIS Data Management Center continues its exponential growth. More than 120 terabytes of data are now in the archive, compared to approximately 35 terabytes when the previous proposal was submitted in 2005, or approximately 8 terabytes at the time of the 2000 proposal. More than half of the data are from IRIS programs (GSN, PASSCAL, and EarthScope USArray) but significant contributions are made the Federation of Digital Seismograph Networks (FDSN), U.S. regional networks, other EarthScope components (SAFOD and PBO) and other national and international partners.



GRAND CHALLENGES RECOMMENDATIONS – 4

Enhancing Free and Open Access to Data

- Continue to have federal programs and seismology organizations strongly advocate for open access to seismic data on a global basis, with real-time access to the greatest extent possible.
- Communicate and foster seismological capabilities for addressing hazards and environmental monitoring concerns and data exchange with developing nations through coordinated international efforts.

Enhancing Access to High-Performance Computing Capabilities

- Make available to the broad research community carefully vetted seismological software and processing tools, along with integrative data products. There is also a special need in developing countries with significant earthquake hazards to provide simple, standardized and open software tools for processing and analysis of seismic network data.
- Ensure data storage and online open access to all seismic datasets in perpetuity.
- Establish readily accessible pathways to facilitate the use of massive computer resources through academic, industry, federal (e.g., national laboratory) and other collaborations.
- Sustain instrumentation programs that provide intermediate-size university computer capabilities involving workstations and clusters.[1]

[1] *Institutional requests for computational systems are usually funded through separate proposals to NSF*

- Continue community engagement through support of the DMS Standing Committee

In contrast to the GSN and PASSCAL (where the primary operational tasks are carried out under subawards), the IRIS Data Management Center is operated and staffed as an IRIS facility. All of the facility operating costs (staff salaries, travel, operational costs, computer equipment replacement and maintenance, software licensing, and printing) are thus budgeted as direct IRIS costs, and these, along with the linked costs of subawards to UCSD and the University of Washington, represent the major components of the core DMS budget. Additional support is requested to encourage the engagement of foreign networks through continuation of a very successful series of metadata workshops that provide training and resources to develop network data protocols for local use and international data exchange. Special support is provided to regional networks in Kazakhstan and Kyrgyzstan, to continue data delivery from networks installed with IRIS and other U.S. support in the 1990s, and encourage data exchange with other networks in Central Asia. Participant support costs are also requested for training courses, usually held in conjunction with AGU meetings and biennial IRIS workshops, for researchers and students at IRIS member institutions.

DMS ENHANCEMENTS AND NEW INITIATIVES

Data Brokering Service (pg A-32) – To encourage data exchange with other national and international centers and to provide user access to the holdings of other archives, the DMS will retain a consultant to develop and implement an FDSN-sanctioned data brokering service. This service, applicable to archived data, will allow users to submit a request to the DMS, where the "broker" will translate the request into a format appropriate for the archive where the data reside, submit the request, retrieve the data, and send them to the user.

Enhanced Data Access (pg A-32) – With the increasing variety of data types in the archive and the increased use by non-seismologists, a need has been identified to provide access tools that are aimed at the novice or occasional user, rather than optimized for frequent use by research scientists. Support for a new FTE at the DMC is requested to develop and implement new access methods and tools, many of which will be web-based or capable of being linked to common time-series tools like MATLAB.

Cloudlike Computing (pg A-34) – A condominium model for data processing, in which processing and storage services are purchased rather than hardware, is becoming very cost-effective. The University of Washington is developing a high-level condominium cluster, HYAK, and the DMS proposes to begin experimentation with this system by acquiring five nodes on this system in the first year and five more in year three. The long-term savings could be substantial.

FDSN Turnkey System (pg A-33) – Interactions with foreign network operators, especially in developing countries, have repeatedly identified a strong need for a low-cost (free), simple, open-source software package for the basic tasks involved in network operation, data collection, event location, catalog generation, and archiving. This need was highlighted in the *Grand Challenges* report and is a key element in developing "sustainable networks" under IRIS's efforts in International Development Seismology. Funds are requested to cost share in the development of such as system under the FDSN framework.

QC enhancement (pg A-11) – As discussed in the GSN section above, a GSN Waveform Quality Review Panel will report back to the IRIS Board in the fall of 2010 with recommendations for implementation of new quality assessment metrics and reporting procedures for GSN waveform data.

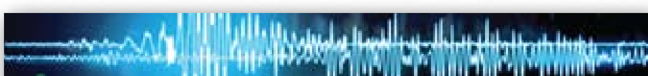
The costs for implementation of these activities will be shared by GSN and DMS. These efforts will be part of a pan-IRIS approach to data quality control and will be coordinated through the new established Instrumentation Services and Data Services structure.

EDUCATION AND OUTREACH

The seismological community recognizes the potential for coordinated *Education and Outreach (E&O)* activities in seismology to contribute significantly to the advancement of national awareness, interest, and understanding of science and mathematics. The IRIS E&O program was established in 1997 to communicate the results of scientific research to the public more effectively, advance science literacy for greater understanding of our rapidly changing and increasingly technological world, and attract more students to study Earth science. IRIS E&O Program activities are targeted at audiences ranging from K–16 students to the general public, and are focused on areas where IRIS is well positioned to make substantive contributions stemming from our strong data resources and links to the research activities at our member universities. E&O efforts emphasize seismology and the use of seismic data and maintain high levels of scientific accuracy while employing best educational practices.

The E&O staff works in close collaboration with diverse allies, including IRIS members, K–12 teachers, undergraduate institutions, science museums, and other national and regional Earth science organizations. Programs range from those that impact large numbers of people for brief time periods (e.g., museum displays, lecturers, teacher training, posters) to those that impact smaller numbers of people through extended interactions (e.g., internships, Educational Affiliates). The E&O program also looks inward to develop talent within the ranks of IRIS member institutions so that all may fully participate in building an education program of national scope and prominence. Current E&O efforts include an IRIS summer Internship program (funded primarily under a separate NSF REU award) where undergraduates receive training and conduct research with seismologists throughout the United States, a range of K–16 educator workshops, widely distributed teaching modules and associated tools, and an Educational Affiliate membership for undergraduate institutions desiring to improve their seismology instruction. The Seismographs in Schools program provides seismographs and software for viewing and interpreting seismograms as well as an online community where schools throughout the world share data and resources. Outreach to the general public is enhanced through a very successful Distinguished Lecture Program (in collaboration with the Seismological Society of America), permanent exhibits at major museums, and Active Earth Displays designed for installation at visitor centers, parks, and universities. Improved access to and use of seismic data are facilitated via the IRIS web site, along with other informational materials, including Teachable Moment slide sets released shortly after major earthquakes, and educational animations and videos.

Over the past decade, the E&O program has matured, had a successful external evaluation and panel review, and developed a new strategic plan based on those reviews. E&O is in a prime position to greatly enhance the impact of the program, expanding beyond its prior focus on K–12 and informal education to put more emphasis on undergraduate instruction, and workshops and training for the IRIS community. This change in emphasis will also help to serve the needs of early career seismologists who will be training the next generation of scientists.



GRAND CHALLENGES RECOMMENDATIONS – 5

Building and Sustaining the Professional Pipeline

- Further engage seismology community organizations with industry to increase awareness of opportunities in seismology among undergraduates and high school students.[1]
- Expand E&O efforts of these organizations to promulgate public awareness of the discipline and its societal contributions, and support undergraduate and graduate training materials and enhanced educational opportunities.

[1] *IRIS E&O has worked primarily through linkages with its member universities, but plans to develop industry contacts.*

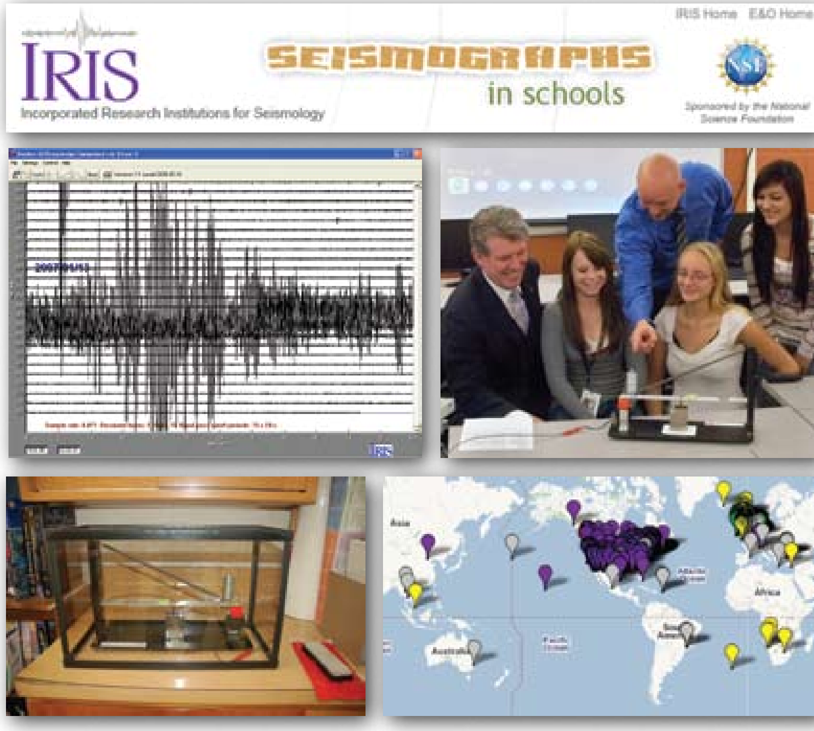
CORE E&O OPERATIONAL TASKS AND BUDGET ELEMENTS

The primary Education and Outreach tasks under core operations are to:

- Provide professional development for teachers and college faculty
- Develop and install public displays for museums and other venues
- Continue and expand the Seismographs in Schools program
- Continue formal education activities through the development of printed materials, web resources and animations
- Select speakers and venues for the IRIS/SSA Lectureship program
- Support the undergraduate summer internship program (student costs funded by NSF/REU)

HIGH SCHOOLS COLLECTING AND EXCHANGING EARTHQUAKE DATA

The IRIS Seismographs in Schools (SIS) program provides middle, high school and IRIS Affiliates with an AS-1 seismograph (shown) that can be used to demonstrate the basic principles of recording ground motions and record regional and teleseismic earthquakes. Software is provided to collect, display and exchange earthquake records. Although the AS-1 is extremely simple and has relatively low gain and limited frequency response, in reasonably quiet locations it is capable of recording magnitude 6 or larger earthquakes anywhere in the world. Many school installations record up to ten events or more a month. More than 170 middle and high school seismographs are operating in the US, and partnerships with similar groups in Europe and other parts of the world have led to an informal network of more than 375 stations. IRIS has developed a web site and forum for discussion that is actively used to exchange data, observations and ideas between schools.



- Collaborate on Siting Outreach for USArray Transportable Array stations (funded by EarthScope/USArray)
- Continue community engagement through support of the E&O Standing Committee

The E&O program is implemented by a core professional staff at IRIS (with strengths in formal and informal education, graphics, and software development), leveraged with resources provided through a number of small subawards and consultants. Participant support is requested to cover stipends for professional development workshops (often held in conjunction with the National Science Teachers Association meeting or state equivalent), speaker expenses and stipends for Distinguished Lecturers, and workshops on the use of the AS-1 seismometer in the Seismographs in Schools program. As described in more detail in the E&O section in the program appendix, the new E&O strategic plan places increased emphasis on links to undergraduate education and funding is also requested to support links with the IRIS community on development of undergraduate curriculum materials.

E&O ENHANCEMENTS AND NEW INITIATIVES

During the 27 months covered by this proposal, E&O will capitalize on current programs and products by greatly expanding their impact while retaining the narrow content focus. These efforts will include significant new services for IRIS members, exciting new products for undergraduate education, modifications to existing products that allow them to target multiple audiences, and improvements to existing programs and products that allow them to impact much larger audiences with little or no increase in cost or IRIS staff time. All of these efforts will leverage core funding through collaborations and external funding.

E&O will enhance the impact and efficiency of its efforts in middle and high school curricula by improving teacher access to and use of existing materials. Materials from E&O's face-to-face workshops, activities on the web and DVD, and visualizations and animations will be repackaged into a structured online sequence, enabling teachers to teach themselves and use these materials without attending our workshops. E&O will repurpose the face-to-face workshops to focus on "training the trainer," enabling IRIS member institutions to deliver workshops to teacher groups in their areas (pg A-48).

Undergraduate and International Resources (pgs A-43–A-45, A-48)

A major effort will be an expansion of E&O products for undergraduate education. Using the *Seismological Grand Challenges* as a hook and access to IRIS data as a tool, E&O will facilitate the use of cutting-edge research seismological in the undergraduate classroom by:

- Developing a set of labs, exercises, and lecture materials based on the 10 Grand Challenges
- Adding new content to our Teachable Moment resources specifically aimed at an undergraduate audience
- Collaborating with DMS and their web services initiatives to develop software tools that enable the use of IRIS data in the classroom
- Creating a repository of undergraduate seismology teaching resources with a focus on a limited set of quality-controlled and peer-reviewed materials developed by the IRIS E&O program and by IRIS member institutions
- Developing a clearinghouse for IRIS community members to recruit undergraduate field assistants, which will also provide opportunities for students not currently part of the IRIS community
- Collaborating with International Development Seismology on the creation of workshop and teaching materials suitable for use in training courses in developing countries

Seismic Analysis Tools and Mobile Devices (pgs A-45-48)

A "pyramid" approach will be used to significantly expand the use of seismic data in classrooms.

- At the base of the pyramid, E&O will impact thousands of classrooms by developing and improving "education friendly" software for accessing IRIS data via the web. This effort will be in collaboration with the DMS plans for web services.
- At the middle level of the pyramid, E&O will enable the use of thousands of USB and other MEMS accelerometers (iPhone, Wii) in classrooms. Existing materials will be adapted and new materials created to support the educational use of these sensors. This effort aligns with the *Grand Challenges* recommendation to explore MEMS technology. E&O will leverage this effort through collaboration with the Quake Catcher Network at Stanford and UC Riverside and with external funding.
- At the tip of the pyramid, E&O will expand the impact of the already successful "Seismographs in Schools" program. Improvements in the software (already under development) will allow multiple classrooms in a school, or multiple schools in a district, to share real-time output from AS1-style instruments. The data streaming capabilities, improved user interface, and new help resources in the software will allow a major expansion in the number of classrooms and students impacted without significant increase in IRIS staff support requirements.

The Active Earth Display (AED), originally developed as a real-time kiosk display for use in visitor centers, universities, and small museums, will be enhanced to extend the impact of the system into K–16 classrooms and a broader informal audience. E&O will:

- Adapt the system for widescreen displays that will allow easy deployment on flat-screen TV systems and all-in-one touchscreen computers
- Develop templates and tools that allow end users to create and share AED content and continue to develop new regional content, including the New Madrid region and the Eastern United States to coincide with the arrival of the USArray TA east of the Mississippi
- Generate a page that will be updated each time a new Teachable Moments presentation is created, which will allow subscribers to automatically display timely information about major earthquakes
- Prototype a version of the system for use on mobile computing devices, opening a conduit for near-real-time content on platforms that are rapidly supplanting traditional PCs as the information source of choice for many users

COMMUNITY ACTIVITIES

Community activities are an integral aspect of IRIS that complement the more technical activities carried under the core facility programs. As a Consortium, IRIS has a responsibility to keep its membership informed of the facilities being developed and supported by NSF and engage the community in planning and development of new initiatives and resources. The IRIS governance structure provides direct community advice and oversight to the core programs. Community activities include support of the committee structure that ensures shared governance and broad community input to IRIS actions; convening of biennial workshops, ad hoc working groups and committees formed to digest critical issues in a timely manner; and communicating with the membership and the public through the IRIS web site, bulk emails, newsletters, annual reports, and outreach materials. Equally important are the activities the Consortium undertakes on behalf of the community in high-level interactions with other national and international organizations, in exploring initiatives and programs advantageous to the community, in interactions with other scientific and instrumentation consortia, and in the general advocacy for seismology and Earth science within government and international organizations.

CORE COMMUNITY ACTIVITIES AND BUDGET ELEMENTS

The primary tasks for Community Activities under this proposal are to:

- Support the activities of the Board of Directors and coordinate activities of other governance committees and working groups

- Develop and publish printed (brochures, newsletters, annual reports), and web-based materials on the overall activities of IRIS
- Provide support for the biennial IRIS Workshop in 2012 and other workshops and meeting as approved by the Board
- Support the Consortium in engagement with national and international agencies and partners
- Nurture the development of pan-IRIS initiatives such as International Development Seismology

Community activities are implemented and coordinated by staff at the IRIS Headquarters in Washington DC. Expenses for publications and meeting support include staffing, participant support and printing costs. Funds to support travel and meeting expenses for the IRIS governance structure are included in individual program budgets and as part of the General and Administrative (G&A) expenses for pan-IRIS activities (Board of Directors and special Board-level committees and working groups). For simplicity in budget presentation, the costs for International Development Seismology (primarily FTE support; see below) are included under Community Activities.

INTERNATIONAL DEVELOPMENT SEISMOLOGY

An exploratory program in International Development Seismology (IDS) was established by the IRIS Board of Directors in 2008 and funded as part of Community Activities during the last two years of the current core Cooperative Agreement. IDS is intended to provide an enhanced interface between the NSF-sponsored scientific mission of IRIS and the imperative to ensure that scientific progress enables socially important outcomes. While IRIS has been international since its inception, the specific focus of this effort responds to the recognized importance of developing the partnerships, technical infrastructure, and human capacity required for effective international cooperation. This acts not only as an instrument to accelerate scientific progress through collaboration with technologically equal partners, but also as an essential element of various other modes of current U.S. foreign engagement, including foreign assistance and science diplomacy.

Although IDS activities are not directly discovery-oriented, they are designed to support engagement of IRIS members and Foreign Affiliate institutions in low and middle income countries and to serve as seeding efforts or pilot projects driven by the need to support the scientific inquiry, and targeted toward two complementary and synergistic goals. The first of these IDS goals, closely linked to IRIS facilities, is to promote strategies that support fundamental research and exploration of earthquake hazards in developing countries through the advancement of basic seismological observations and data exchange. These efforts are focused on leveraging U.S. investment in advancing scientific understanding of some of the most complex tectonic systems on Earth by encouraging the sustained and active participation of low and middle income countries located in these territories in regional technological investment and capacity building. The second IDS goal, closely linked to IRIS educational efforts and those of our member institutions, is to address the social responsibility of the IRIS community to facilitate the translation of new knowledge into societal benefits by contributing to training, research exchange and sustainable development of low and middle-income countries.

CORE IDS OPERATIONAL TASKS AND BUDGET ELEMENTS

The primary tasks for International Development Seismology under this proposal (as specified in the charge to the IDS committee) are to:

- Promote collaborative partnerships and relationships with government agencies, development banks, academic institutions, industry, and private foundations
- Facilitate establishment of sustainable permanent or semi-permanent seismic networks
- Promote the open exchange of seismic data
- Promote growth in workforces by running workshops, organizing exchanges, and developing education and training resources

GRAND CHALLENGES RECOMMENDATIONS – 6

Recommendations Related to Developing Countries

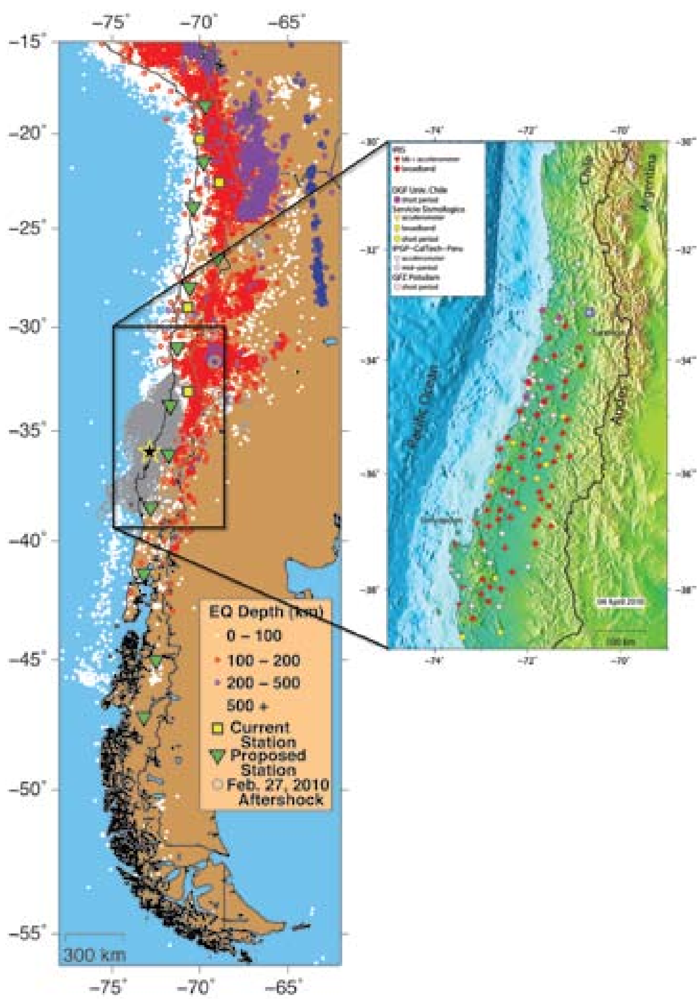
- Coordinate between the academic community and international sponsors of hazard assessment and mitigation, especially in poorly studied regions in developing nations to create multi-use programs for monitoring, research, training, and capacity building.
- Communicate and foster seismological capabilities for addressing hazards and environmental monitoring concerns and data exchange with developing nations through coordinated international efforts.
- There is also a special need in developing countries with significant earthquake hazards to provide simple, standardized and open software tools for processing and analysis of seismic network data.
- Expand infrastructure for learning from disasters and mounting scientific response, along with improved outreach with information for the public.

- Serve as a link between IRIS Foreign Affiliates, Core Programs, Voting Members, and Educational Affiliates
- Develop funding models and identify resources to support activities

As a new and evolving activity for IRIS, IDS support is budgeted as part of Community Activities. Program activities are expected to be supported through additional awards from federal and international agencies outside of the core EAR/IF program budget. This mechanism has already seen significant success in obtaining funds for workshops and initiatives in Latin America, as described in the IDS section of the IRIS Programs appendix. The core IDS support consists of salary, travel, and miscellaneous expenses for the IDS Director. Funding is also requested for publication of a "Guide to Sustainable Networks," and limited seed funding to leverage external support for workshops.

INTERNATIONAL COLLABORATIONS ON THE 2010 CHILE EARTHQUAKE

Following the Chile earthquake of February 27, 2010, funding was provided by the NSF RAPID response mechanism to install 58 portable PASSCAL/USArray stations for five month's observations of aftershocks. Arrangements have been made to share data from similar stations installed by Chilean, French, German, and British investigators (map on right). An NSF/MRI proposal from IRIS has recently been funded to work with the University of Chile to install 10 global reporting geophysical observatories (map on left), with seismic, infrasound and meteorological instruments, as a backbone network within the planned Chilean National Seismic Network. These collaborations in data exchange and network development can form a model for future efforts in International Development Seismology.



POLAR SERVICES

Over the past two decades, there has been increased use of PASSCAL instruments in Antarctica for a broad range of crustal, lithospheric, and glaciological studies. Because of the unique demands of the polar environment, these projects require specialized equipment and significantly more engineering and field support than typical field programs in temperate latitudes. One of the stated goals in the 2005 IRIS proposal that led to the current five-year Cooperative Agreement was to seek funding outside the core programs to expand PASSCAL and GSN efforts in support research in polar regions. Over the past five years, we have been successful in obtaining increased support from the NSF Office of Polar Programs (OPP) for dedicated polar instrumentation and the creation of a special engineering and support team within PASSCAL to focus on polar efforts. In addition, two awards from the NSF Major Research Instrumentation (MRI) program have supported the development and acquisition of specialized cold-hardened instrumentation, power, and communications systems to respond to the extreme climatic environment and unique logistic conditions imposed by polar research. With these enhanced support services and equipment, the PASSCAL Polar Services group can now support a variety of experiments, from short-term active-source projects to long-term passive monitoring. The designs and developments are in direct response to the needs of the scientific community, and the facility leverages the resources of core PASSCAL and GSN programs and staff at the PIC.

GSN has had long-term and stable operations on the Antarctica continent, with a major installation at the South Pole and collaborative efforts (with AFTAC and Australia) at an additional four sites. These stations continue to be

GRAND CHALLENGES RECOMMENDATIONS – 7

Recommendations Related to Polar Investigations

- Install greater numbers of permanent broadband seismic networks in polar regions for long-term observations.
- Acquire large numbers of low-temperature-capable portable broadband seismic and geodetic instruments for temporary deployments in polar regions for experiments around ice-shelves, glacial streams, near glacier outlets, and in other cryo-spheric systems.
- Expand global coverage of boundary structures with new sites in the ocean and at high latitudes to better constrain the structure of Earth's mantle and core.

operated as part of the core GSN program, and there has been increasing benefit from sharing of polar experience between PASCAL and GSN. Starting in 2009, a significant addition to Arctic polar observations has been the Greenland Ice Sheet Monitoring Network (GLISN) project, which will establish a real-time array of 25 stations for detecting, locating, and characterizing glacial earthquakes and other cryoseismic phenomena, mostly related to climate change in Greenland. This project is also supported by the NSF/MRI program and builds on both GSN and PASSCAL resources.

Although there is not a section in the *Grand Challenges* summary recommendations that deals specifically with polar studies, the proposed Polar Services activities are responsive to a number of polar-related recommendations from that report.

POLAR SERVICES TASKS AND BUDGET STRUCTURE

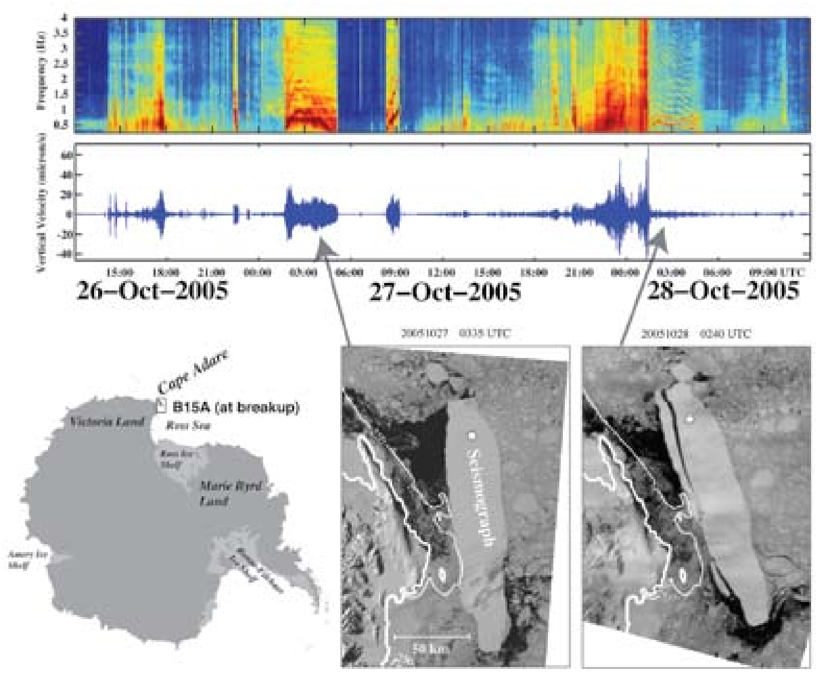
The structure for presentation of the Polar Services activities and budget is different than the other elements of this proposal. The request for support of Polar Services is directed to the Office of Polar Programs and is intended to be a supplement to the funding requested for core program support from the EAR Instrumentation and Facilities program.

The primary tasks for Polar Services as described in this proposal are:

- Provide lab- and field-based support for funded experiments in polar regions through the Polar Services team at the PASSCAL Instrument Center
- Acquire specialized cold-hardened instrumentation for use in polar regions based on the needs of funded experiments

SEISMIC SIGNALS FROM EARTH'S LARGEST FLOATING ICE BODIES

Recent deployments of IRIS PASSCAL instruments have revealed a range of new seismic signals associated with dynamical processes affecting Earth's changing cryosphere. Shown here is a multiday seismogram and spectrogram of chaotic and harmonic iceberg tremor (MacAyeal et al., 2008. Seismic and hydroacoustic tremor generated by colliding icebergs, *Journal of Geophysical Research*, 113, F03011, doi:10.1029/2008JF001005) recorded on a floating seismograph deployed atop the B15A major fragment of giant Antarctic iceberg B15, which calved from the Ross Ice Shelf in 2000. The seismogram reveals dynamic phenomenology of tidally-induced forcing aground, and eventual breakup, of the iceberg against prominent bathymetric features (250-m contour indicated on the accompanying MODIS satellite images) near Cape Adare, Victoria Land. (After Martin et al., 2010. Kinematic and seismic analysis of giant tabular iceberg breakup at Cape Adare, Antarctica. *Journal of Geophysical Research*, 115, B06311, doi:10.1029/2009JB006700.



- Continue development of specialized equipment for polar regions, especially for use in wet and cold environments encountered in glacial projects
- Provide operation and maintenance support, at the end of the MRI-funded phase in 2012, for the GLISN network and coordination with the international GLISN partners
- Continue community engagement through support of the Polar Networks Science Advisory Committee and interactions with the GLISN Science Advisory Committee

Following the practice of recent years, it is anticipated that funds for approved activities will be internally transferred from OPP to EAR and added as a supplement under the same Cooperative Agreement. Polar activities and tasks are described in this proposal, along with a full budget request, to allow joint review and coordination in funding decisions between OPP and EAR.

USARRAY/EARTHSCOPE

The EarthScope project brings a new suite of facilities for research on the structure and dynamics of the North American continent. The seismological resources of *EarthScope/USArray* are supported under a separate Cooperative Agreement through the NSF/EAR/EarthScope Program, but many components of USArray share facilities and resources with the other facilities of the IRIS Consortium. As described in the next section of this proposal, one of the primary activities during the time period covered by this proposal will be to strengthen ties between the core IRIS programs and USArray, leading to merged management of all programs under one Cooperative Agreement in 2013.

USArray consist of three major elements: (1) a Transportable Array of 400 portable, unmanned, three-component broadband seismometers deployed on a uniform grid that will systematically cover the United States; (2) a Flexible Array of 446 portable, three-component, short-period and broadband seismographs and 1700 single-channel high-frequency recorders for active- and passive-source studies that will augment the Transportable Array, permitting a range of specific targets to be addressed in a focused manner; and (3) contributions to a Permanent Array, coordinated as part of the USGS's Advanced National Seismic System (ANSS), to provide a reference array spanning the contiguous United States and Alaska. Additional components of the USArray facility include an array of 27 magnetotelluric sensors embedded within the Transportable and Permanent arrays that will provide constraints on temperature and fluid content within the lithosphere. The goal of this layered design is to achieve imaging capabilities that flexibly span the continuous range of scales from whole Earth, through lithospheric and crustal, to local.

USARRAY TASKS AND BUDGET STRUCTURE

All USArray activities are supported by the NSF EarthScope Program under a separate Cooperative Agreement with IRIS. Brief descriptions of USArray activities are presented in this proposal to identify those areas where there is close interaction between EarthScope and the core IRIS programs. As described in the next section, NSF intends to continue to fund USArray in this manner until 2013, when a new proposal will be requested to manage both the core programs and USArray under one Cooperative Agreement starting in October 2013.

SECTION 4 | TRANSITIONING FOR THE FUTURE

INTEGRATED MANAGEMENT OF THE CORE PROGRAMS AND USARRAY

IRIS is taking steps to address the scientific aspirations of the next generation of Earth scientists. Beginning in 2009, the IRIS Board of Directors, Standing Committees, and management have carried out a series of strategic planning activities that reviewed the long-term goals for IRIS and the organizational structures required to implement them. These planning activities were informed by the report on *Seismological Grand Challenges in Understanding the Earth's Dynamic Systems* and anticipated this proposal for a new Cooperative Agreement with NSF. The goal of these planning activities was to identify opportunities for developing a new level of facilities and services, while simultaneously sustaining the strengths of the core program activities. These reviews confirmed that substantial gains in observational seismology can be realized by building on the capabilities of the core IRIS programs, as demonstrated by development and initial operation of EarthScope and USArray and the significant successes in the nascent efforts in Polar Support Services and International Development Seismology.

The strategic planning efforts have identified benefits to all IRIS operations that will be realized through enhanced coordination and integration among the existing observational programs (GSN, PASSCAL, and USArray) and tighter links between the observational programs and the Data Management System and E&O. For example, the widespread use of data from the IRIS archive (irrespective of the source of the data), and the development of integrated data products derived from those data, point to the substantial benefits to be gained from a cross-programmatic and interdisciplinary approach to data management and product development. Rapidly evolving communications and data acquisition technologies are finding increasingly common application across all programs. Intriguing developments in sensor technologies suggest that new efforts in seismometer design will benefit all of the observational programs.

The move to integrated management of the USArray and core programs also addresses NSF's intent to "integrate the management and operations of the current IRIS core seismic facility with those of the USArray component of the EarthScope Facility under a single award" in 2013. In January 2010, NSF issued a "Dear Colleague" letter in which it outlined a phased plan to integrate management and operation of major seismic and geodetic facilities supported by the Earth Sciences Division. To integrate the IRIS core program and USArray Cooperative Agreements requires changing the duration of the Cooperative Agreement covered by this proposal from the traditional five-year duration to 27 months (October 1, 2011–September 30, 2013). In preparing this proposal, the IRIS Board and management have undertaken a number of steps that not only set the stage for the 2013 integration requested in NSF's plan, but incorporate fundamental changes in management across all programs. These steps will be gradually implemented during the remaining months of the current Cooperative Agreement and under the 27 months covered by this proposal. In the remainder of this section of the proposal, we describe the management changes and point to key areas where we will undertake new activities that will benefit from the new structure.

CHANGES IN IRIS MANAGEMENT STRUCTURE

Changes are being made in IRIS management structure to ensure that the core programs and USArray have flexibility and vitality and are well integrated to ensure their future success. These changes will improve IRIS services by encouraging more interaction between the current programs and opening up new initiatives, especially in instrumentation, enhanced data services, international engagement, and polar programs.

The most significant high-level change integrates the key technical activities of IRIS under three primary elements: *Instrumentation Services*, *Data Services*, and *Education and Public Outreach*. The IRIS governance structure will remain the same, with the Board of Directors and Standing Committees for each of the core programs, and with the Standing Committees continuing to provide community input directly to the Board. The three primary IRIS service areas illustrated by the new organizational chart are:

- *Instrumentation Services:* Enhances coordination of technical activities (involving GSN, PASSCAL, and the instrumentation components of USArray) in sensor development, field practices, communication systems, and the exploration of new technologies.
- *Data Services:* Focuses existing Data Management System activities and enhances user-centric, data-related services, quality control, and products.
- *Education and Public Outreach:* takes an expanded role in bringing the activities of IRIS and the seismology community to the public as well as continuing the traditional E&O activities in formal and informal education.

National Science Foundation
4201 Wilson Boulevard
Arlington, Virginia 22230

Dear Colleague:

This letter is to inform you of plans to integrate and recompete the management and operation of the three major seismic and geodetic facilities supported by the Division of Earth Sciences (EAR) in the Directorate for Geosciences (GEO) at the National Science Foundation (NSF). Those facilities are the core seismic Facility managed by the Incorporated Research Institutions for Seismology (IRIS), the core geodetic Facility managed by UNAVCO, and the EarthScope Facility managed jointly by IRIS and UNAVCO.

The core facilities operated by IRIS and UNAVCO share virtually identical technical and logistical support needs and business systems with the EarthScope Facility, and provide very similar support to the community. In addition, all four awards governing these facilities will expire in the next four years. NSF believes this is a good opportunity to undertake a phased integration and recompetition process involving these three facilities.

NSF considered several different options for recompetition of the management and operation of these facilities, and plans a two-step process. In 2012-13, NSF intends to integrate the management and operations of the current IRIS core seismic Facility with those of the USArray component of the EarthScope Facility under a single award. At the same time, NSF will integrate the management and operations of the current UNAVCO core geodetic Facility with those of the Plate Boundary Observatory (PBO) and San Andreas Fault Observatory at Depth (SAFOD) components of the EarthScope Facility under a second award. Near the end of the first five years of integrated operations, NSF plans to issue a new solicitation to recompete the management and operations of both of these integrated seismic and geodetic facilities.

This plan will: (1) address existing National Science Board policy requiring periodic recompetition of the management of major NSF facilities (NSB-08-16); (2) be consistent with prior National Science Board approval of IRIS and UNAVCO as managers and operators of the EarthScope Facility through FY2018 (NSB-03-62 and NSB-07-116); (3) simplify NSF oversight of these facilities; (4) streamline the management of these facilities leading to more cost-effective operation; (5) allow sufficient time for community input to facility integration before recompetition; (6) minimize disruption to EarthScope Facility operations, especially during the planned deployment of USArray to Alaska in 2014; and (7) further existing partnerships with other U.S. and international agencies in support of these solid Earth deformation facilities.

NSF welcomes community feedback on the integration of the management of these facilities and this plan overall. Please contact any of the following NSF program officers with questions or comments:

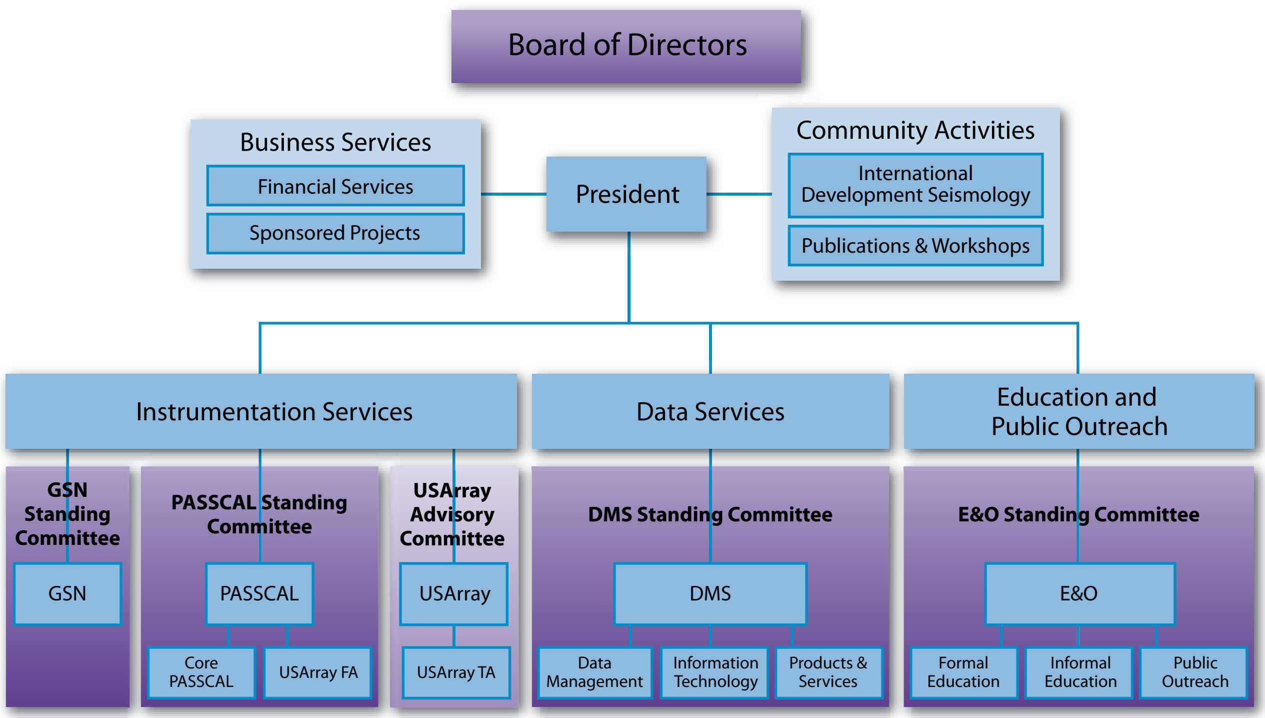
Gregory Anderson	EarthScope	703 292 4693	greander@nsf.gov
David Lambert	Instrumentation and Facilities (IRIS)	703 292 8558	dlambert@nsf.gov
Russell Kelz	Instrumentation and Facilities (UNAVCO)	703 292 4747	rkelz@nsf.gov

Sincerely,

Robert Detrick
Director, Division of Earth Sciences

IRIS MANAGEMENT STRUCTURE

In the new IRIS management structure adopted by the Board of Directors in June 2010, the primary IRIS activities are grouped under Instrumentation Services, Data Services, and Education and Public Outreach. The underlying program structure (GSN, PASSCAL, E&O, and USArray) remains, and the governance structure (purple elements in this diagram) is preserved with the Program Standing Committees continuing to report directly to the Board of Directors. The Business Services are divided into Financial Services (responsible for financial controls, accounting and purchasing) and Sponsored Projects (responsible for award management, reporting, and procurement). The new and evolving program in International Development Seismology is contained within Community Activities along with other Consortium services such as meeting and publications. In addition to providing mechanisms to encourage increased coordination between programs, this structure facilitates the evolution toward integrated management of the core programs and USArray, anticipated to be under a single Cooperative Agreement starting in 2013.



In parallel with review and reformulation of program plans and structure, IRIS management has also undergone a series of very positive reviews that have led to improvements and restructuring of the business side of IRIS as well. NSF carried out an in-depth review of IRIS management and leadership in 2009. In 2010, NSF's Large Facilities Office undertook a detailed review of IRIS business systems focused on EarthScope and USArray, but covering all IRIS management and business systems. As a result of recommendations emerging from both of these reviews, IRIS has implemented a number of changes in its management and business practices. Business services are the primarily internal-facing component of IRIS, and the changes here are important and have significantly strengthened our internal procedures, financial and administrative practices, and responsiveness to NSF-mandated reporting requirements. The previous single IRIS Business Office has been restructured as a Sponsored Projects Office and Financial Services group that have distinctly different activities and responsibilities. The new structure recognizes this specialization and is essentially modeled on the organizational structure used by academic institutions. The specialization provides clear responsibilities, and improves the interfaces within IRIS.

The shortened Cooperative Agreement provides the ideal vehicle for a focused effort over the next 27 months to coordinate and consolidate activities within and between IRIS programs to implement the structure described above. These changes will prepare IRIS for the opportunities presented by the joint management with USArray and beyond, with the following benefits:

- Optimize execution of existing activities
- Prioritize and focus inter- and intra-program interactions
- Enable integrated cross-programmatic approach to new developments
- Streamline management

INSTRUMENTATION SERVICES

The most significant change being implemented in the new IRIS management structure is to bring the primary instrumentation activities together under one umbrella. This will include PASSCAL and GSN activities, and the instrumentation elements of USArray. The core activities of GSN and PASSCAL, as described in the last section, will continue to support the specific needs of the diverse scientific communities that they represent. Different technical and scientific drivers justified the original creation of separate GSN, PASSCAL, and USArray Transportable Array programs, and there are many elements that are still unique to each of these programs; however, advances in sensor and data technologies have led to increasing overlap between the technical solutions being incorporated across these programs. The same sensors and data loggers now service GSN, PASSCAL, and USArray, and many of the timing, communications, and power systems are common as well. Thus, increased coordination among these programs in terms of priority setting, execution of existing activities, and implementation and exploration of new technologies will better leverage our collective expertise and resources.

During the next 27-months, we will pursue new technical activities already started or planned within PASSCAL, GSN, and USArray. These activities will be structured in a pan-IRIS engineering portfolio. A standard systems engineering approach, tailored to IRIS's unique needs, will enhance the cross-programmatic yield of these new efforts. Further, casting all these efforts as elements in a portfolio allows the costs and benefits across programs to be better evaluated (by the managers, Standing Committees, and the IRIS Board), and ensures that we pursue those elements of the portfolio that are high yield and most aligned with the strategic objectives of the organization. In this approach, the needs and requirements across all of Instrumentation Services will be identified at the beginning of new engineering efforts. Relevant timelines, products, documentation, and costs will be identified at project inception to facilitate evaluation and to ensure that results meet relevant needs. This approach recognizes that PASSCAL, GSN, and USArray have many intersecting needs, but will not necessarily insist that they march in lock-step. Individual programs and the Board will continue to set programmatic priorities, modulated by the benefits of a coordinated approach. Some key new thrusts that will be efficiently tackled with this approach include:

Exploration of refined sensor designs. Existing broadband sensor designs are being refined by the manufacturers to reduce size, weight, and power. These packages can reduce the logistical footprint of deployments, which is equally important across all Instrument Services activities. Sensors are being installed in a number of environments, including on piers in large vaults, and in boreholes, small vaults, and augured holes, and directly buried. These different installation methods present a variety of challenges. Sensor packaging can, and does, have trade-offs with performance. Thus, requirements for new sensors and sensor packaging must be carefully specified and presented to the manufacturers to ensure the resultant sensors will meet the needs of the IRIS community and, where possible, minimize the total number of system configurations that must be supported. At present, there is a critical need for a replacement sensors for use at GSN sites. The existing GSN very-broadband sensors are no longer supported, and the current instruments are nearing the end of their serviceable life, particularly the borehole instruments. The new instruments must be capable of meeting the GSN performance objectives and work with the existing GSN station infrastructure. Obtaining new instruments for the GSN and for other IRIS applications will require communication with vendors regarding actual or desired performance requirements, and careful testing and evaluation of prototypes. The Instrumentation Services structure will ensure

GRAND CHALLENGES RECOMMENDATIONS – 8

Advances in Instrumentation

- Encourage collaborations across federal agencies that utilize very broadband seismic data for monitoring purposes to support development of next-generation very broadband seismometers to replace current instruments.
- Explore MEMS technologies to develop low-cost seismic sensors that can be deployed in great numbers and can supplement or replace current seismometers.
- Increase the number of strong-motion instruments near faults and in urban areas to improve constraints on rupture processes and to better understand the relationship between ground motion and building damage.[1]
- Continue to develop next-generation telemetered seismic instrumentation in hostile environments (e.g., volcanoes, glaciers, seafloor).
- Develop partnerships among industry, national laboratories, academia, and federal agencies to advance and sustain seismic instrumentation innovation and capabilities.
- Sustain existing permanent networks, such as the GSN and ANSS, as long-term observational systems for both research and monitoring, through stable funding from multi-agency partners and continued upgrades to improve reliability and efficiency.

[1] *IRIS participates in the archiving of data from strong motion instruments, but the installation of instruments in urban environments is carried out by USGS and state agencies.*

these activities are carried out in a manner that is cognizant of the wide range of unique and overlapping IRIS instrumentation needs.

New sensor technologies. The experience from PASSCAL and USArray is very clear—PIs are designing and fielding both natural- and artificial-source experiments that demand ever increasing numbers of sensors, which in turn requires simpler and faster deployments. The expanding performance envelopes of new and old sensor technologies, such as MEMS and geophones, are delivering lower noise and greater bandwidth, making them potentially much more interesting for our applications. Under Instrumentation Services, we will organize a systematic exploration of these new technologies to better understand current and future performance capabilities and integration constraints. More actively exploring the commercially available products will put us in a better position to communicate our needs, especially as commercial MEMS vendors start to explore specialty and niche markets that will result in sensors more relevant to our needs.

Power systems. Power can be the Achilles heel of seismic stations. Under Instrumentation Services we will explore opportunities for cross-program leveraging of new charge controller designs emerging from PASSCAL and new power control and distribution designs developed by USArray. Methanol fuel cells are a new technology that we will evaluate for applicability to different environments and situations. Battery technology continues to evolve and we are rapidly collecting and assembling a body of knowledge relevant to our specific demands and applications. For example, Polar Services has systematically evaluated the latest lithium battery designs to build systems suitable for long-endurance deployments in extreme cold. Instrumentation Services will coordinate the pan-IRIS evaluation and testing of new power systems to ensure that we stay abreast of the latest developments in this important area.

Communications and networking. This is another area where the adoption of rapidly evolving new technologies may provide innovative and high-leveraged solutions for the collection of seismological data. Communications technologies such as cell modems, Iridium modems, Inmarsat's Broadband Global Area Network (BGAN) are technologies we are using, evaluating, or will explore. These technologies have very different capabilities and applicability, but are all relevant to the diverse global seismic infrastructure that IRIS supports. Networking technology is also changing quickly, with self-healing, ad hoc mesh networking technology providing a realistic means for simple radio frequency data telemetry from dense deployments of large numbers of sensors.

Field Practices. Interactions among GSN, PASSCAL, and USArray have already led to significant interprogram "technology transfer" in hardware technologies and field practices. For example, all programs have explored different modes of sensor emplacement. The noise performance characteristics of these different emplacement strategies have been carefully analyzed, using the automated quality-control analysis results produced by the IRIS DMC. Quick-deploy boxes developed by Polar Services for use in harsh environmental conditions have been adopted by the USArray Flexible Array and PASSCAL, and have greatly reduced deployment times, and streamlined handling and physical configuration of station hardware. Common interests in other field practices, such as remote station state-of-health monitoring and on-site station waveform review, have led to shared software development efforts.

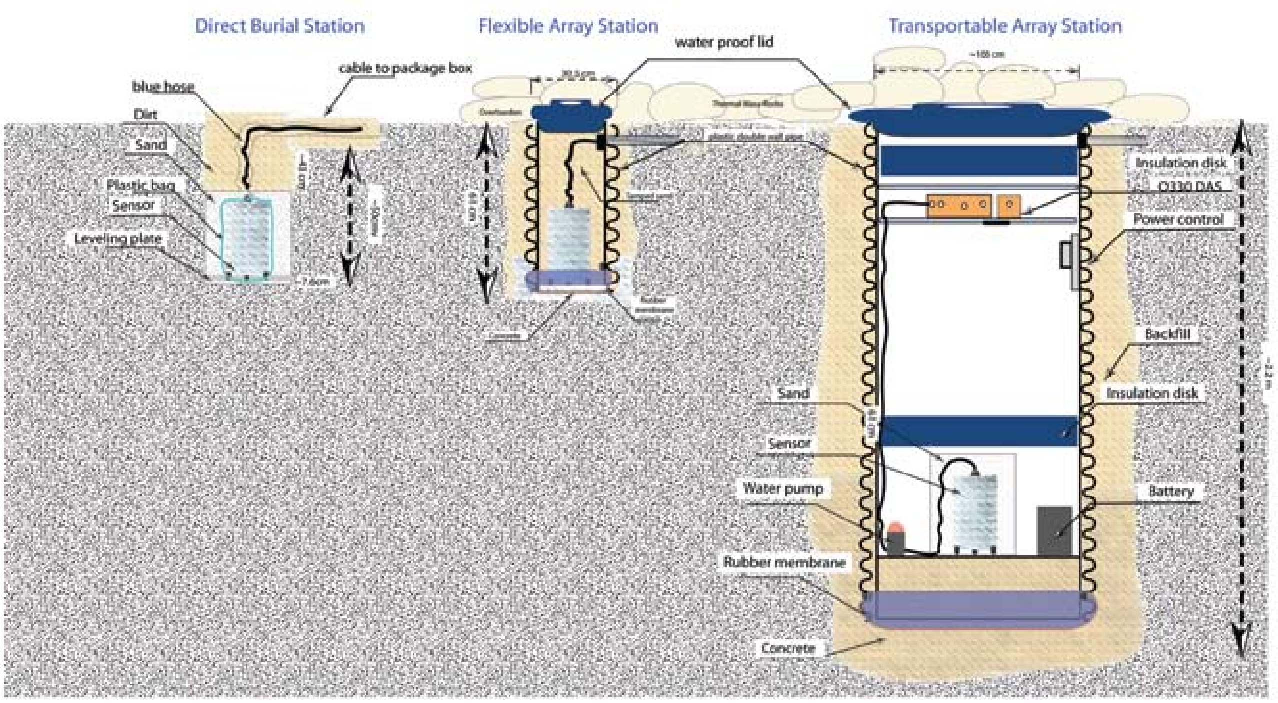
Instrumentation Technology Symposium. In 2009, IRIS collaborated with the USGS and the Network for Earthquake Engineering Simulation (NEES) to sponsor a Seismic Instrumentation Symposium to bring together instrumentalists and scientists from academe, government, and industry to explore new developments in seismic sensor technology. Instrumentation Services will continue to use this very productive forum as a means of ensuring that our community's needs are identified for industry and to highlight emerging technologies that are relevant to our community. These forums stimulate developmental efforts and collaborations that will push the technology forwards and better meet the IRIS community's scientific goals.

Multiparameter Observatories. GSN has traditionally equipped many stations with barometers, meteorological sensors, and GPS. USArray has embarked on a project to equip all stations with barographs and infrasound elements. A recently funded IRIS project will collaborate with the University of Chile to establish a backbone network of 10 "global reporting geophysical observatories" equipped with broadband seismic, meteorological, infrasound and (eventually) GPS. This effort will use station designs developed by USArray, and benefits from the temporary network of PASSCAL and USArray Flexible Array instruments that were already deployed in Chile. The temporary deployments in Chile implemented (on a limited basis) USArray-style cell phone telemetry—providing some much-needed on-the-ground information regarding cellular data transmission in that region. In collaboration with IRIS International Development Seismology, the collaboration in Chile may become a model for future interactions with international partners in expanding not just seismology but other geophysical observations.

SENSOR EMPLACEMENT STRATEGIES

Broadband seismic sensors are typically installed in vaults that are emplaced using a wide range of techniques that vary greatly in the materials and tools they require. IRIS is currently exploring the direct burial of broadband sensors as a means of providing a high-quality installation while minimizing the tools and materials required. The technique of directly burying broadband sensors could have a dramatic impact on the logistical footprint of large experiments, enabling more sensors to be installed more quickly.

The goal of all sensor emplacement techniques is to yield a low-noise environment that is well coupled to the surrounding material. Mechanical and thermal stability are both critically important. Installation materials and tools, as well as local site restrictions, further constrain installation techniques. USArray TA station vaults provide a well-coupled, seismically quiet environment. Basic excavation and vault installation is accomplished with a backhoe and the vault is anchored with ~3,000 pounds of cement. A typical PASSCAL or USArray FA installation uses a small vault that can be excavated with hand tools and that is still anchored with cement. In the direct-burial technique, the seismometer is placed directly in a hand-excavated or augured hole, which is then backfilled directly against the sensor. IRIS is studying the noise characteristics of these installations, examining how this technique performs in different soil conditions. We are also testing the multiple strategies available for making a sensor watertight.



Applications. As the first venture of Instrumentation Services into implementation of new technologies, this proposal requests support for FlexiRAMP. These developments respond to the instrumentation needs expressed by the PASSCAL community: a dense network of easily transported and deployed sensors with an easy-to-configure data telemetry. While FlexiRAMP is aimed at aftershock studies, many of the desired logistical and hardware characteristics apply equally well across all IRIS instrumentation programs. To this end, Instrumentation Services will provide a pan-IRIS environment to ensure that, where possible and appropriate, the broader IRIS technology goals are addressed and will ensure success by bringing the technical experience of all programs to bear.

Polar Services. The recent highly successful development and deployments in polar regions demonstrate the value of IRIS integrating technical approaches across programs. These efforts leveraged shared experiences and technologies between PASSCAL and GSN to develop special cold-hardened systems for use in the polar regions (see Polar Support Services section in the appendix). Deployments in extreme environments typically put a premium on system size, weight, and power budgets, and the need for extended unattended station operation requires that careful attention be paid to potential failure modes. Such considerations are all relevant, in varying degrees, to deployments in less-extreme environments. Thus, the effort put into engineering for polar environments both benefits from, and pays dividends to, the other

Instrumentation Systems programs. The above-mentioned quick-deploy boxes are one example of technology transfer from Polar Services back to PASSCAL and USArray.

DATA SERVICES

Data Services incorporates Data Management, Information Technology, and Products and Services. This new formal structuring of the Data Management System emphasizes an integrated approach to managing the complete data lifecycle: managing all data in a well-structured and maintained archive; providing the IT resources necessary to manage and process data; and delivering the data products and services necessary for data users to exploit the data. The new structure provides the mechanism for fully organizing all data service activities around the core functions—bringing a sharper focus to the existing activities, allowing clearer identification of priorities, and providing clearer interface points for external data users as well as the other IRIS structures. The Data Management group within Data Services will be fully focused on the collection, quality control, archive, and distribution of data, taking a holistic approach to all these efforts. Maximizing data quality and preserving data and metadata integrity will be the number one priority for this group. The Products and Services group will focus on products derived from data (Level 2, 3, and 4 products), as well as the services necessary for users to customize the production of data products. The Information Technology group will focus on providing and supporting the IT resources necessary for all parts of Data Services to function smoothly.

The new Data Services structure will be poised to tackle key new developments that will enhance data access for users:

Data brokering services. This effort will allows a user to submit data requests in a single format to the DMC, while shielding the user from the heterogeneous set of protocols supported by external data centers. This both simplifies data access and expands the range of data centers from which data can be obtained. IRIS is already a leader in developing distributed and federated models of data center interaction. For example, the NetDC concept has been used successfully by several global data centers for more than a decade, and the Data Handing Interface (DHI) also introduced a distributed model of accessing federated information. Both of these systems required the customization and deployment of specific hardware at the distributed centers. This model met with limited success. Data Services will develop a Brokering Service that will allow a data requester to submit a request in a format supported by the DMC and the brokering service will forward the request on to the appropriate data center that holds the requested data requested, but using a method supported by the remote data center. While similar to NetDC, the primary difference is that this approach will translate the user's request into a format understood and supported by the external data center, thus providing a capability that is transparent to both the user and the external data center. This eliminates the need to install software applications or to do anything intrusive at the external data center; it simply requires the data center to support request mechanism of their choice.

HYAK cloudlike computing. The Information Technology group within Data Services will spearhead the effort of moving Data Services toward a condominium model of computer resources to support its processing needs. During the course of 27-month cooperative agreement, IT will acquire a small number of nodes in the University of Washington's HYAK condominium-style computing cluster. This computing model provides organizations with a "private supercomputer" style computing capability, but with one-time buy-in costs and nodes configured to the organization's needs. The University of Washington-sponsored HYAK facility provides a low-cost means of testing and evaluating whether the concept of cloud computing is a means for IRIS Data Services to meet the ever-expanding computational requirements resulting from the extraordinary data volumes and massive user base that IRIS supports.

GRAND CHALLENGES RECOMMENDATIONS – 9

Producing Advanced Seismological Data Products

- Integrate regional and global seismic bulletins into an openly available, definitive international seismic source catalog.[1]
- Commit to improving earthquake location accuracies on large scales by using advanced processing methods and strive to complete catalogs down to levels of magnitude 3 in continents and 4 in oceanic regions.[1]
- Develop a 3D Earth model as the next-generation community model beyond PREM, describing the anelastic, anisotropic, aspherical Earth structure by standardized parameterization that can be used by multiple disciplines.[2]
- Provide ready access to products of seismological research in forms that are useful to fellow Earth scientists to facilitate dissemination of seismological knowledge.
- Expand infrastructure for learning from disasters and mounting scientific response, along with improved outreach with information for the public.

[1] *IRIS has some activities that contribute to development of earthquake catalogs, but this has traditionally been the operational responsibility of USGS/NEIC and ISC*

[2] *IRIS will develop products and tools for the display of Earth models, but production of the models themselves is a community research activity.*

DATA PRODUCTS

IRIS archives the most extensive collection of digital seismological data in the world, reaching back four decades. To help categorize the data and derived data products that IRIS distributes, the DMS has adopted a system of "IRIS data product levels" based on the NASA Committee on Data Management, Archiving, and Computing (CODMAC) definitions of five data levels, and similar to the definitions of product levels discussed in the report of the Workshop on Data Products for Education and Research from the USArray held in Portland in October, 2004. The bulk of the 120 TB in the DMC archive are Level 0 and Level 1 observational measurements, the building blocks from which scientific results are derived. IRIS has developed a highly evolved system for managing and distributing these primary observational measurements. Managing the heterogeneous information contained in the more advanced product levels 2–4 is a fundamentally new paradigm for the DMC. New infrastructure is being developed, made operational, and maintained. These derived products can be collections of anything and everything, but generally fall in levels 2–4. There is not a tight definition of what these products are, but ultimately they are the result of a scientist using primary data products (level 0–2) to create new knowledge. The results of this scientific process fuel further research – but they first need to be captured, managed, and distributed in order to yield the greatest benefit.

Level 0	Unprocessed raw measurements at full resolution
Level 1	Quality-controlled annotated measurements at full resolution
Level 2	Products derived from level 0 or level 1 measurements using non-controversial techniques
Level 3	Scientific products derived using single data types but advanced scientific processes
Level 4	Integrated products drawing from multiple types of measurements and using advanced scientific processes

Waveform quality-control enhancement. Distinct data quality management protocols have been implemented by USArray, PASSCAL, and GSN. Data Services will work with Instrumentation Services to take a pan-IRIS approach to reviewing and, where required, updating quality-control processes and procedures. Quality-control procedures must be tailored to the way in which stations are managed, how the data and metadata are collected, and how the data and information are transmitted to the data archive. In recent years, the Data Management Center and USArray, working together, have developed innovative quality-control strategies that will serve as a model for the larger pan-IRIS QC review effort. The current GSN Waveform Quality Review effort is already establishing the model for this pan-IRIS collaboration on waveform quality.

EDUCATION AND PUBLIC OUTREACH

The Education and Public Outreach structure will continue the traditional IRIS E&O activities, with an enhanced effort in undergraduate education, but will take a greater role in bringing the activities of IRIS and the seismology community to the public. The new structure is organized around the three functions of Formal Education, Informal Education, and Public Outreach. This provides clearer functions and interfaces both within and external to IRIS. As part of its support for USArray activities, the IRIS Education and Outreach team engaged in a number of effective public outreach activities that built on and extended IRIS core program E&O activities. This type of synergy will be increased through the new structure. Further, new efforts will be targeted at:

Developing International resources. The Education and Public Outreach team will work closely with the International Development Seismology effort to adapt educational and outreach resources for international use. These efforts will also be linked with Data Services and Instrumentation Services, which also have significant international activities and interactions.

Seismic analysis tool / mobile devices. The Education and Public Outreach team will leverage the existing pan-IRIS knowledge base for creating seismic analysis tools that provide the essential functions for acquiring and interacting with seismic data for different classes of users. Within IRIS there is a vast experience base in implementing such tools, while the Education and Public Outreach team brings the pedagogical expertise to tailor these efforts to the education and outreach efforts. The mobile devices effort will bring seismology to life, matching up the ever-changing seismological data and information with mobile devices that exist for the purpose of staying in-touch and up-to-date. Again, this is a natural pan-IRIS effort, given the wide range of real-time data and information IRIS manages, and the expertise the Education and Public Outreach team has in distilling this information for different audiences.

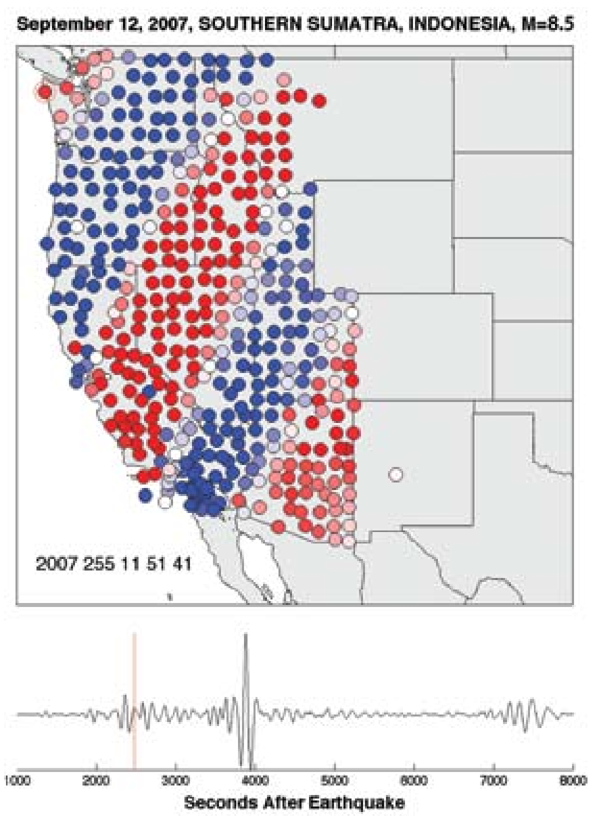
PAN-IRIS SYNERGIES AND INTERACTIONS

In addition to facilitating activities *within* Instrumentation Services, Data Services and Education and Public Outreach, the new organizational structure also provides a management level that is specifically charged with effectively coordinating and planning activities *between* these service areas.

Links between Instrumentation Services and Data Services will improve cross-programmatic interactions on key issues such as quality control, user services, software and product development. Links to Education and Public Outreach will ensure that, where appropriate, data products, software and services meet education and outreach needs. The recently

VISUALIZING THE SEISMIC WAVEFIELD

Wavefield visualizations provide unprecedented illustrations of seismic waves propagating across the continental United States and have become a very popular IRIS data product that is used in a wide variety of settings. The visualizations are presented as movies, and are created by plotting data from the USArray Transportable Array stations (and other nearby stations) as a function of time. Symbols are plotted at the station locations, and change color depending on the intensity of up or down vertical motion recorded at the station at a given instant in time. Combining many sequential time steps into a movie provides a direct visualization of seismic data in time and space. The original visualization concept (developed by Chuck Ammon at Penn State University) has been developed into a standard product at the DMC. The visualizations are heavily used as teaching tools, as they easily convey the characteristics of long-period seismic wave propagation. The visualizations have been used in classrooms ranging from grade school to graduate level as they contain features and subtleties that reward careful observation by all levels of viewers.



established International Development Seismology will benefit from enhanced links to all of the IRIS Services as it continues to explore ways in which IRIS and the academic community can contribute to geophysical capacity development and enhancements to resources for observational seismology.

Quality practices. A major undertaking for the GSN (as described in the GSN Program Description) will be the completion of the upgrade of all GSN stations to a new generation of standardized data loggers. The new hardware will have a dramatic impact on data quality. This hardware provides enhanced calibration and state-of-health monitoring capabilities; USArray already has a significant body of experience in using these capabilities. USArray and GSN will coordinate activities to share relevant quality monitoring tools and techniques. A more closely coordinated approach to waveform quality will benefit all programs by identifying best practices that will be applied, where possible, across all station operation activities. Further, sharing of software development efforts will be more closely coordinated, to ensure efficiency.

Enhanced data services. The PASSCAL program will implement enhanced data services for PASSCAL PIs that will be balanced with and modeled on those provided to USArray FA PIs (as described in the PASSCAL Program section in the appendix). FA data services have been very popular with both PIs and USArray staff, as it saves time and effort for all parties, and results in higher quality datasets. Instrument loan and data policies are already being normalized between the core program and FA. These activities will provide PIs with a more uniform set of services and policies, and will make the differences between PASSCAL and FA experiments more transparent.

Products. While Data Services has the primary responsibility for identifying and developing products to serve the scientific community, useful data products can also evolve out of interactions between Instrumentation Services and Data services—an example is power spectral density (PSD) analysis of waveforms. PSD analysis was originally intended as a QC tool for noise analysis of stations, but has extended into a widely used product for science as well. Further, many data products are used for education and outreach activities, but this requires closer coordination to be most effective. For example, some products require simpler delivery options to facilitate use by non-seismologist users, or require careful attention to annotation and labeling to improve understanding and interpretation by non-experts.

Management, processing, and display of high-volume array data. The explosion of data from USArray and other sources, all available through common request mechanisms from the DMC, has already stimulated a close collaboration with Data Services to accelerate the development of new tools and IT services for managing, processing, delivering, and displaying these data. For example, with large numbers of stations, even a classic data display, such as a record section, becomes challenging to interpret due to the sheer quantity of data displayed. This has led Data Services to extend existing plotting tools, develop new animated presentations of data, and upgrade existing data-delivery tools. The large volume of data is also stressing computational resources, and IT services is responding to the expanding needs with new servers and strategies for using extensible high-performance computing resources. At a more fundamental level, it is necessary to train and inspire the next generation of seismologists to develop the tools and techniques that will take maximum advantage of huge datasets. USArray and Education and Public Outreach are already collaborating with community members to present short courses on high-volume data processing and analysis to advanced graduate students. Data Services is collaborating with USArray to facilitate the collection of increased data volumes. Within Data Services, the Data Collection, IT, and Data Products efforts work closely together to manage and process the large volumes of data—and the number of data channels being collected will only increase in the future. Closely coordinated pan-IRIS interactions will be essential for facilitating and managing this explosion of data and for working with the community of users to maximize the scientific gain.

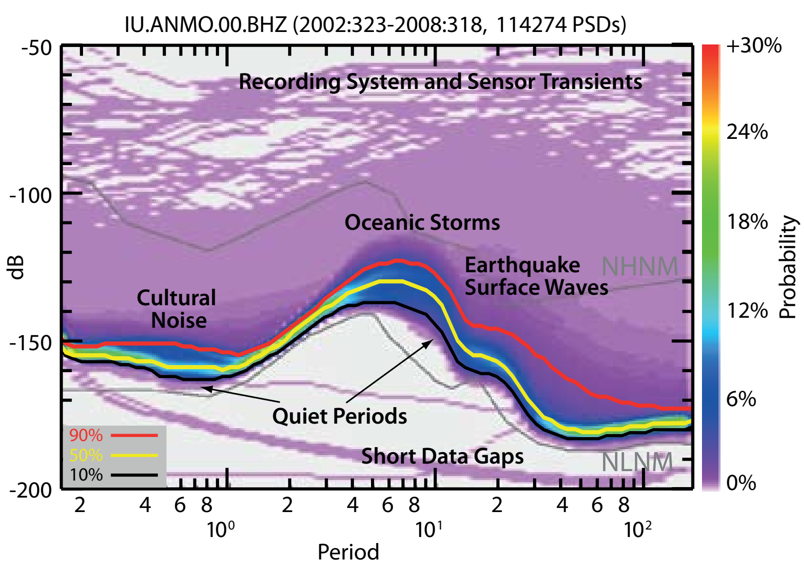
FUTURE DIRECTIONS

The revised IRIS management structure positions IRIS for the future. The research community has laid out a number of Grand Challenges for seismology. IRIS will work with the community to meet these challenges. An important step in this direction is the implementation of the changes described above. As we look ahead, we can identify a number of examples of future activities that will benefit from the changes we are making now:

- Taking the USArray Transportable Array to Alaska will benefit from enhanced technical coordination on topics such as sensor emplacement, sensor packaging, power systems, and communications. Numerous PASSCAL and GSN stations have already been deployed in Alaska, and the connections to Polar Services are obvious.
- IRIS's international activities will be better positioned to draw on the collective capabilities and knowledge of IRIS. The streamlined IRIS management structure means that the growing activities in International Development Seismology can efficiently draw on a wide range of services, whether these are data and data products educational resources, or the collective knowledge base of best practices for station operations.
- Routinely supporting experiments with much greater numbers of channels will be possible as a result of the proposed development efforts, combined with the new management structure. IRIS will be well positioned with the expertise and capacity for these efforts, whether these are permanent international arrays, PI-led temporary

EXPLORING SEISMIC DATA WITH PROBABILITY DENSITY FUNCTIONS

Standardized power spectral density (PSD) computations performed for the large volumes of data flowing into the IRIS DMC have supported a wide range of applications. PSD computations have been used for many years in seismology as a standard tool. By computing the seismic PSD for many segments in time for a single data stream, the results can be combined into probability density functions (PDFs) that are a rich source of information about the seismic energy recorded at a given station location. McNamara and Buland (2004, Ambient noise levels in the continental United States, *BSSA*, doi:10.1785/012003001) demonstrated the utility of the PDF approach for evaluating noise characteristics at seismic stations. The DMC implemented a version of the McNamara and Buland software to compute PSDs for every hour of every day for every station that transmits its data to the DMC in real time. A web-based interface enables users to customize the display of the resultant PDFs for different periods of time. The PDF results, while originally intended as a station quality control tool, have been used for many different purposes, such as detecting annual and seasonal shifts in seismic energy, evaluating different station installation techniques, and to detect very subtle changes in station behavior that might signal the onset or resolution of operational problems or the time evolution of sensor vault conditions.

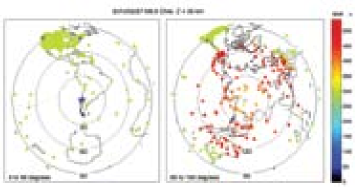


GRAPHICAL DISPLAY OF LARGE VOLUMES OF SEISMIC DATA

Stimulated by the large volume of data flowing in from USArray and other sources, the Data Management System is exploring new strategies for the graphical presentation of event-based data and data summaries. After large events (the M8.8 Chile earthquake of 02/27/2010 is illustrated here) typical data displays, such as record sections, might contain data from over 1000 stations and be completely illegible if presented in traditional ways. This collage illustrates some of the new strategies that are being explored to display large volumes of data in meaningful ways while maintaining clarity when the plots are rendered at usable sizes. Display tools and strategies have been developed by individual data users as well as by the Data Products team working within the DMS. Regardless of the source, the various data visualization strategies are first prototyped, then evaluated by a working group that represents a diverse cross-section of data users. Displays are tuned to the needs of different audiences and analyses. Selected display techniques are then automated and put into routine production. In some cases, interfaces are developed to let users customize the display.

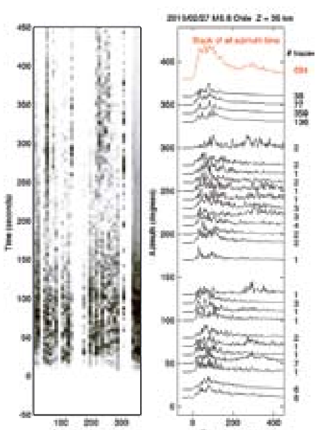
RECORD SECTIONS, STF, SNR MAPS, VESPAGRAMS

M8.8 Chile 2010/02/27 z=35 km

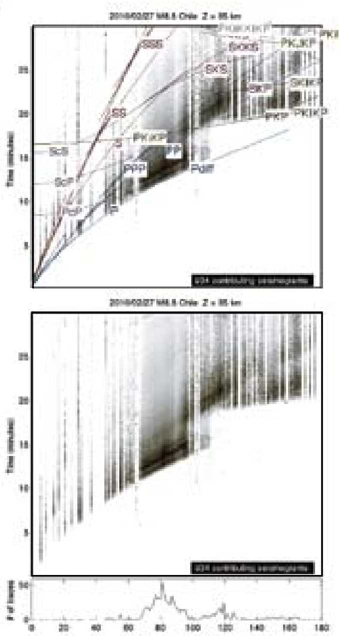


P-wave signal to noise ratio station map

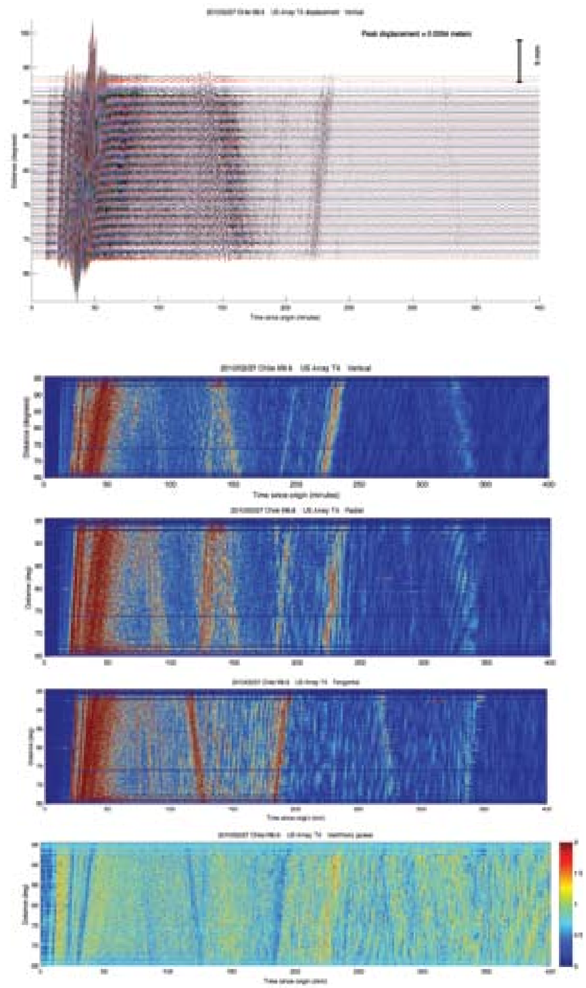
Short period Time-Distance & Time-Azimuth envelope stacks



(Can see southern rupture direction & duration of ~100 sec)

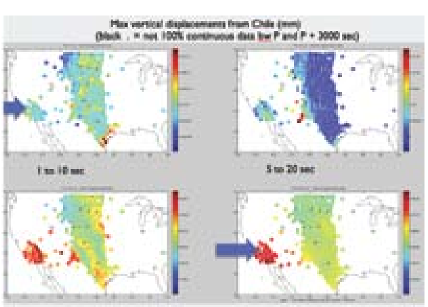


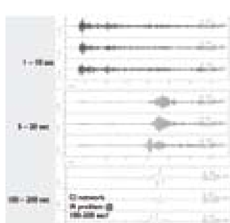
US Array TA record sections



6+ hours!

Visual Instrument Response QC (in consideration)





experiments, or large-scale temporary deployments like the Transportable Array.

- The experience with USArray and increasingly dense PASSCAL deployments has rejuvenated interest in array processing to exploit the signal/noise improvements and frequency/wavenumber filtering that are possible when working with large numbers of regularly spaced sensors. Collaborations between programs under the new management structure, informed by the array workshops proposed over the next two years, will aid in planning and implementing the enhancements in field systems, communications, data management, and software that will be required to fully exploit these powerful analytical techniques.
- IRIS will ensure that the research community can realize the full value of multiparameter geophysical observatories by providing the technical capacity for operating the stations and collecting the data, the data services necessary to manage the data and distribute them to a diverse user community, and the outreach activities necessary to ensure that the various educational and science communities are fully aware of, and able to utilize, these new resources.

The coordination and alignment of IRIS services that will evolve from the recent management changes will enable IRIS to respond more effectively to the current and future needs of the Consortium. Over the next 27 months, activities proposed by each of the core programs will strengthen and consolidate existing activities. The new management structure will improve internal communication, coordination, and technical execution—strengthening the core activities and preparing for integrated management of the core programs and USArray. With continued encouragement and intellectual stimulation from members of the research community, and the advice and oversight from the Board of Directors and Standing Committees, IRIS will be in an even stronger position to support the Consortium's activities to "Facilitate, Collaborate, and Educate" in advancing research and education in the Earth sciences.

SECTION 5 | BUDGET PLAN

The plan presented in this proposal covers the 27-month period July 1, 2011 to September 30, 2013. The request for funding for operation of the core IRIS programs (total of $37, 164,563) is directed to the Instrumentation and Facilities (I&F) Program of the Earth Sciences Division (EAR). The request for support of Polar Services (total of $3,377,277) is directed to the Office of Polar Programs (OPP). This section presents an overview of the funding request to EAR/I&F to support the core program activities, a discussion of the primary budget elements, and a brief review of funding under the current five-year Cooperative Agreement. A summary of the funding request for Polar Services is also presented. It is anticipated that funding provided by OPP to support Polar Services will be transferred internally within NSF and added as a supplement to the new I&F Cooperative Agreement.

BUDGET REQUEST BY CORE PROGRAM

Table 1 and Figures 1 and 2 show how the total core program budget request of $37,164,563 for the 27-month period 2011–2013 is partitioned by time and by program. As shown in the pie chart in Figure 3, approximately 74% of the budget is for support of the three largest programs, GSN, DMS, and PASSCAL. The relative size of the core programs has evolved over the history of IRIS. Prior to the mid-1990s, when the GSN and PASSCAL facilities for instrumentation and data generation were being established, these programs constituted a larger part of the total budget. As the role of the DMS in distribution of data has expanded, the percentage of the budget applied to data management has increased. Education and Outreach accounts for approximately 6% of the budget and Community Activities for 3%. The aggregate allocation for indirect expenses and management fees is 13% of the total budget.

	YR1	YR2	YR3	TOTAL	%
Instrumentation Services (Mgmt)	605,015	620,438	157,230	1,382,683	3.72%
GSN Operations	3,861,805	4,043,459	946,656	8,851,920	23.82%
PASSCAL Operations	4,313,587	4,802,397	1,055,778	10,171,762	27.37%
Data Services	3,810,337	3,789,006	984,640	8,583,983	23.10%
Education & Outreach	918,575	949,799	254,508	2,122,882	5.71%
Community Activities	561,430	431,062	96,672	1,089,164	2.93%
Indirect Expenses	2,172,827	2,184,433	604,909	4,962,169	13.35%
Total	***16,243,576***	***16,820,594***	***4,100,393***	***37,164,563***	***100.00%***

Table 5.1. Budget profile, 2011-2013 by IRIS core program

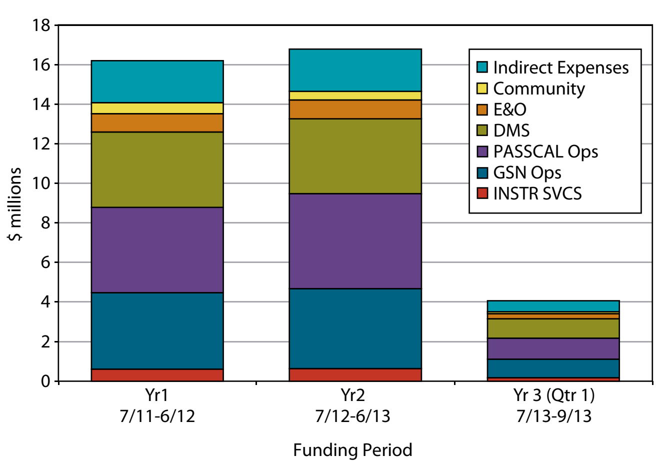


Figure 5.1. Core program budget profile for 2011–2013 by year and program.

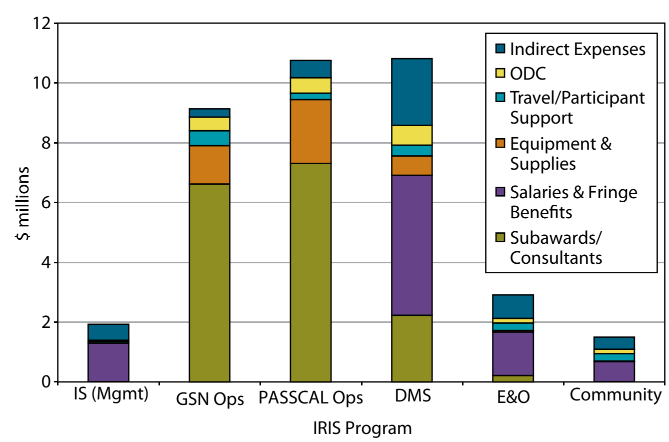


Figure 5.2. Core program budget profile for 2011–2013 by budget category and program.

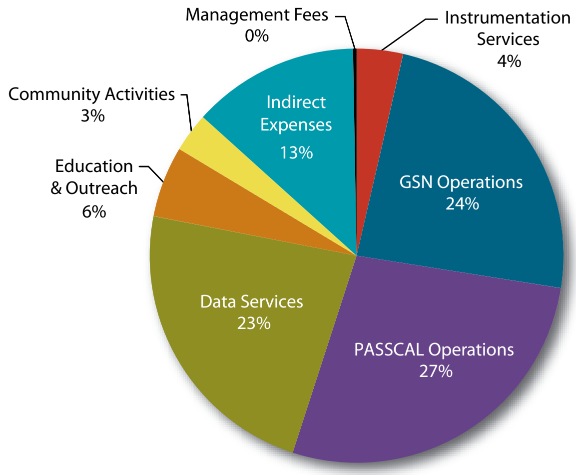


Figure 5.3. Core budget profile for 2011–2013 by percentage for each program

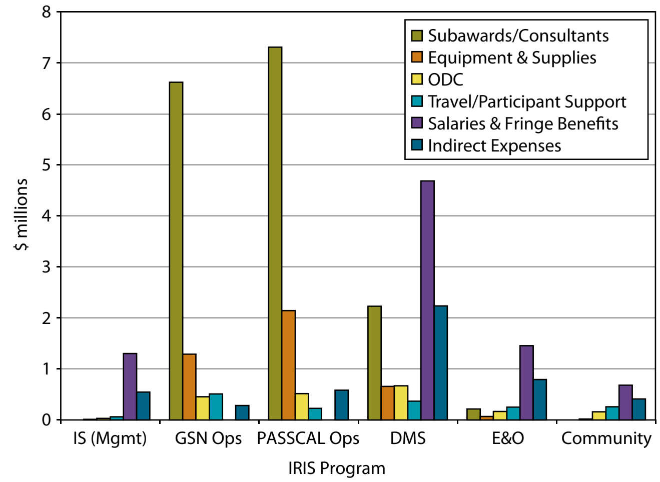


Figure 5.4. Budget profile for 2011–2013 for core programs, showing total amounts in each of the primary NSF budget categories

PROGRAM BUDGETS BY EXPENSE CATEGORY

Figure 4 and Table 2 show the five-year funding request by different budget categories for each of the core programs. In addition to highlighting the main cost elements, this presentation also indicates the different organizational styles of the core programs, with GSN and PASSCAL budgets dominated by subawards and the DMS and E&O budgets primarily for IRIS staff.

Instrumentation Services. Under the revised IRIS management structure, PASSCAL and GSN management has been integrated into a combined Instrumentation Services. An Instrumentation Services management budget is presented in this proposal as a transition to a more integrated GSN/PASSCAL/USArray structure to be implemented in 2013, and includes the Director of Instrumentation Services (0.3 FTE) and the relevant portions of the management personnel for the PASSCAL and GSN programs. The Director of Instrumentation Services will work with the PASSCAL and GSN Program Managers to develop the core PASSCAL and GSN budgets and will oversee the Instrumentation Services management budget, which includes funding for the management staff and other general coordination expenses. The PASSCAL and GSN Program Managers will retain spending authority for their core program operational budgets.

GSN. The subaward to UC San Diego for personnel (total of 13 FTEs, of which 8.8 are funded through GSN and 3.2 are funded through DMS) and operation of the IDA component of the GSN is the primary external subaward for IRIS support of GSN operations. The major component of the equipment budget for GSN is for infrastructure replacement and upgrade of GSN stations (eight per year). All of the capital equipment required for upgrade to new generation data loggers has already been acquired. Funds are also requested to acquire and test recently developed broadband seismom-

	INSTRUMENTATION SERVICES (MGMT)	GSN OPERATIONS	PASSCAL OPERATIONS	DMS	E&O	COMMUNITY ACTIVITIES	TOTAL	%
Subawards/Consultants		6,614,677	7,302,912	2,226,701	210,500		16,354,790	44.01%
Equipment		1,168,500	700,000	282,750			2,151,250	5.79%
Materials & Supplies	6,825	115,777	1,437,300	365,685	59,350	13,000	1,997,937	5.38%
Other Direct Costs	26,523	449,559	512,550	665,564	158,430	151,000	1,963,626	5.28%
Travel/Participant Support	54,218	503,407	219,000	363,250	246,750	252,000	1,638,625	4.41%
Salaries & Fringe Benefits	1,295,117			4,680,033	1,447,852	673,164	8,096,166	21.78%
G&A/Office Overhead	538,970	277,331	580,524	2,227,780	783,503	404,061	4,812,169	12.95%
Management Fees							150,000	0.40%
Total Budget	***1,921,653***	***9,129,251***	***10,752,286***	***10,811,763***	***2,906,385***	***1,493,225***	***37,164,563***	***100.00%***

Table 5.2. Budget profile for 2011–2013 for the core IRIS programs, showing amounts in each of the primary NSF budget categories.

eters to replace the aging STS-1 as the primary GSN sensor. Telemetry costs and site enhancements are also significant components of the GSN operational budget.

The operation of the Global Seismographic Network is carried out in partnership with the USGS. A Memorandum of Understanding between the NSF and USGS establishes the general framework for interagency collaboration in research in the Earth sciences, and an Annex on the Global Seismographic Network between NSF, USGS, and IRIS describes the arrangements for GSN support and operation. Until recently, all permanent equipment for both IDA and USGS stations was provided through IRIS/NSF. Recent augmentation of the USGS GSN budget and a special augmentation with ARRA funds appropriated to USGS in 2009 have allowed USGS to assume a larger role for the acquisition of equipment for their stations. Full funding for the GSN thus includes an additional approximately $4.3M per year spent by the USGS to operate their component of the GSN.

PASSCAL. The core of the PASSCAL operations is the subaward to New Mexico Tech for operation of the PASSCAL Instrument Center (PIC), primarily for staff support. The FTE level for core program support at the PIC has grown from 13 to 17 FTEs over the past five years and is expected to grow to 19 FTEs with the addition of personnel for the enhancements and new initiatives in data services, technical documentation, new technologies, and near-surface instrumentation. Support for field experiments includes training, materials and supplies, and assistance with shipping and permitting. A smaller subaward provides support of the shared Texan instrument facility at UTEP (1.5 FTE). All permanent equipment for PASSCAL and most field supplies are charged directly to IRIS, rather than through the New Mexico Tech subaward. Only minor repairs and spare parts are budgeted for maintenance of the existing pool of broadband instruments, while emphasis is placed on the development of a new generation of sensors and portable recording systems. The primary equipment requests in the PASSCAL budget are for the acquisition of 650 channels of Geode recorders for conducting 2D shallow seismic surveys and near-surface electrical system equipment.

DMS. In contrast to GSN and PASSCAL, the Data Management Center is staffed by IRIS personnel and thus the largest component of the DMS budget is for IRIS staff salaries and benefits. The staff at the DMC supported under this proposal will grow from 17 to 18 over the next 27 months. Equipment included in the DMS budget includes on-going upgrade and replacement of servers, and additions to the primary Isilon storage system at the DMC. Participant support costs cover workshops and courses provided by the DMS for both domestic researchers and international partners in data collection. Subawards are used to provide support to other DMS nodes including the DMC host at University of Washington, IDA Data Collection Center at UCSD, and central Asian networks. Additional expenses include licenses for the commercial database and mass store control software.

E&O. The primary budget element for E&O is salary support for the Program Manager and staff, a total of 5.5 FTE, including one new FTE to support the new initiatives. Staff include specialists in formal and informal education, and software and web development. Proposed new hires include partial support for an E&O software developer and a specialist in undergraduate curriculum and international support. Funds are requested to continue public outreach through the successful museum programs and Distinguished Lecture series. Students and teachers are impacted through professional development workshops, internships, and the provision of classroom materials, including posters, educational seismometers, animations, and teaching supplements. Subawards are planned to support development of undergraduate educational materials, activities and software.

Community Activities. In addition to the core facility programs, IRIS carries out activities through the Headquarters Office to engage and inform the members of the Consortium and coordinate with other national and international programs. The Public Outreach Manager is responsible for production of the Newsletter, Annual Report and special reports, and for partial support of the IRIS web site. Participant support costs offset expenses for Consortium members to attend a biennial IRIS workshop in 2012 and a Seismology Instrumentation Technology Symposium in 2013. The budget requests funding for continuing the new initiative to coordinate IRIS international activities. A Director of International Development Seismology was hired in September 2009 to work with the Director of Planning, Program Managers and Foreign Affiliate Members to coordinate and provide continuity for existing efforts and develop a focused and sustainable program to build upon IRIS's significant international activities. The IDS activities have already had significant success in obtaining external support for scientific and development workshops in Latin America.

Common to each of the programs are travel support for program staff and Standing Committees, and the program's share of IRIS administrative expenses through Indirect Cost Recovery (ICR). The IRIS ICR structure has two components:

- *General and Administrative (G&A)* includes IRIS-wide administrative and business office expenses, including senior management staff. All programs are currently assessed G&A at a rate of 24% on modified total costs (total costs less equipment, participant support costs, and subaward costs exceeding $25,000 per year).
- *Office Overhead* covers the shared rent, telephone, office equipment and administrative support salaries at the IRIS Headquarters office in Washington DC and the DMC office in Seattle, Washington. An Office Overhead rate of 32% for DC and 19% for Seattle is assessed on salaries of all staff working at these locations.

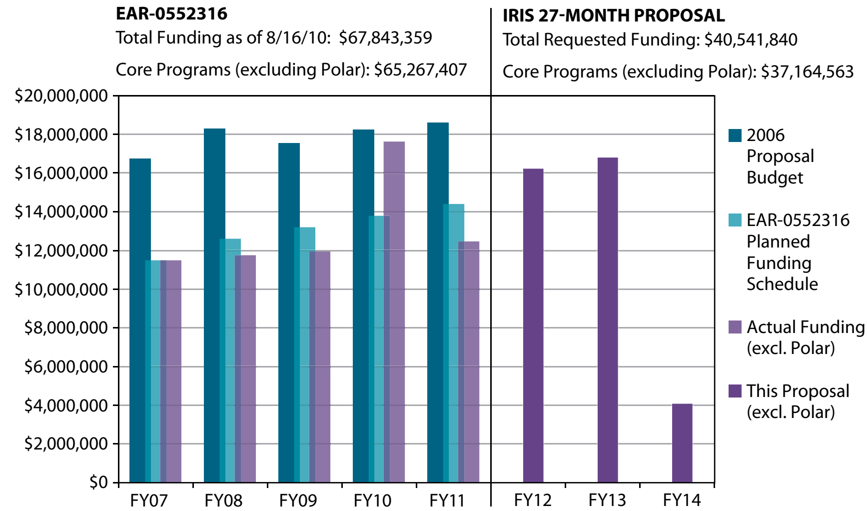


Figure 5.5. Comparison with the current IRIS Cooperative Agreement EAR-0552316 funding. This does not include the prior or current funding from Polar Programs. The FY10 actual core funding included a special supplement of $5.5M for upgrades to GSN and PASSCAL equipment.

COMPARISON WITH THE CURRENT IRIS-NSF COOPERATIVE AGREEMENT

Funding under the current Cooperative Agreement with NSF (CAGR 0552316) is summarized in Table 3. The IRIS proposal submitted to NSF in 2005 requested a total of $89.46M over five years ("As Proposed" in Table 3). Following review by NSF and approval by the National Science Board, the funding schedule included in the Cooperative Agreement anticipated a five-year total award of $65.5M ("Funding Schedule" in Table 3). The actual total funding under the current Cooperative Agreement is $67.8M ("Actual Total" in Table 3). This total ($67.8M) includes supplements of $2.58M from OPP for polar activities and a special supplement of $5.5M in 2009 (made possible by the availability of stimulus funds) for upgrades of GSN and PASSCAL equipment. Figure 5 compares the requested, approved, and actual funding under the current Cooperative Agreement for core program support, to the annual budget requests in this proposal.

POLAR SERVICES

Included in this proposal is a request to manage Polar Services and utilize the staff and facilities of the Polar Support Services group at the PASSCAL Instrument Center and provide specialized cold-hardened instrumentation to support projects in both polar regions. Approximately half of the budget request is for permanent equipment to acquire instrumentation as required to support OPP funded research projects. A subaward to New Mexico Tech will support 4.5 FTEs at the Instrument Center for instrument preparation, training, and field support for an anticipated 20 PI projects related to Earth structure and glaciology in the Antarctic and Arctic. In Years 2 and 3, the FTE level will increase to 5.5 to provide operational support for the GLISN project in Greenland, following the end of the MRI-funded phase of that project. Partial FTE support is requested for IRIS staff to provide management of both activities. The total funding request to OPP is $3.3M and it is anticipated that these funds will be transferred internally within NSF to supplement the new Cooperative Agreement developed as a result of this proposal.

2006–2011 COOPERATIVE AGREEMENT – EAR-0552316				
	AS PROPOSED	FUNDING SCHEDULE	ACTUAL CORE	ACTUAL TOTAL
2006–2007	16,759,321	11,488,519	11,488,519	11,539,082
2007–2008	18,285,871	12,600,000	11,750,000	12,274,686
2008–2009	17,553,722	13,200,000	11,750,000	12,517,377
2009–2010	18,259,484	13,800,000	12,000,000	18,672,052
2010–2011	18,600,679	14,400,000	12,360,000	12,840,162
Multiyear Total	***89,459,077***	***65,488,519***	***59,348,519***	***67,843,359***

2011–2013 PROPOSAL			
	CORE BUDGETS	POLAR	TOTAL PROPOSED
2011–2012	16,243,577	1,343,049	17,586,626
2012–2013	16,820,594	1,622,466	18,443,060
2013 (Qtr1)	4,100,392	411,762	4,512,154
	37,164,563	***3,377,277***	***40,541,840***

Table 5.3. Comparison of funding under the current 2006–2011 Cooperative Agreement (EAR-0552316) between IRIS and NSF, and the 2011–2013 proposal budget