Appendix II

IRIS Programs

IRIS Programs

Overview

IRIS is a mature scientific organization that is continuously evolving to meet the changing needs and priorities defined by its primary constituency, seismologists at US universities. The initial challenge for IRIS was to build a modern seismological instrumentation facility, and to make this facility serve the seismological research community effectively. With support from NSF and other funding sources, we have now accomplished this building phase, and seismologists are benefiting from the observational data that IRIS instrumentation provides. In terms of the profit to our science, we are only now beginning to realize the full scientific return on the investments made to build these facilities. Our current challenge is thus to protect the investment made in these facilities, ensure their efficient operation, and improve the quality of IRIS products and services.

The first part of this Appendix describes the broad aspects of IRIS's mission and defines the objectives of the proposed IRIS activities over the next five years. It also addresses some topics that are pertinent to all IRIS facilities, such as program coordination, cross-cutting technological issues, and the relationship between the core IRIS facilities program and other Earth science initiatives. Subsequent parts of this section present the specific plans for each component of the IRIS program.

IRIS - Mission and Objectives

The original goals of the IRIS consortium were (1) the deployment of a permanent global array of modern seismographs (the GSN); (2) the acquisition of a pool of portable seismographs for use by the community in temporary deployments (PASSCAL); and (3) the establishment of a center for the collection, management and open distribution of IRIS data (the DMS). As these core facilities have grown, so has the demand from the seismological community for the services and products that they provide. IRIS facilities, products, and services are now essential for the progress of a large proportion of seismological research funded by the NSF, USGS, DoD, and other US government agencies. IRIS facilities and data are also making new styles of scientific investigation possible. The current proposal reflects the view that the most important goal of the IRIS program for the next five years is the continued and improved operation of the existing core IRIS facilities: the GSN, PASSCAL, and the DMS.

From the beginning, IRIS facilities and products have also been used for educational purposes. Educators use seismograms or earthquake data obtained from the DMS in the classroom, construct public displays of 'live' seismological data from the GSN, and introduce students to field work and research through participation in PASSCAL deployments. Following the advice of reviewers of the 1996 IRIS proposal, and recognizing the opportunity that IRIS has to facilitate the use of many types of seismological data for educators, IRIS in 1998 established the Education and Outreach (E&O) program to address this the need for educational materials and services. With Consortium members throughout the country and access to high quality data and cutting edge research, IRIS is in a unique position to implement an innovative E&O program that meets needs across the educational spectrum and has national reach. In the current proposal, approximately 5% of the budget corresponds to E&O activities. This commitment reflects IRIS's intention to develop over the next five years a distinctive E&O program that is well integrated with IRIS facilities.

The role of the IRIS Consortium in the broader seismological and geophysical research communities in the US has continued to expand during the current cooperative funding agreement with the NSF. IRIS has become an organization that successfully facilitates collaboration and cooperation among seismologists and other earth scientists. As a consortium of universities, IRIS has been able to develop, present and promote initiatives that have broad support in the academic earth science community. The most visible, and largest, of these initiatives is USArray, a component of EarthScope. Funding and possible implementation decisions regarding USArray will be made by Congress and NSF during the fall of 2000. A brief review of USArray and its connection to IRIS is given here to clarify the relationship between the current request for funding from NSF's Instrumentation and Facilities Program and the EarthScope Phase I MRE initiative.

IRIS and USArray

USArray is a proposed scientific facility to be used in a targeted experiment to image the Earth beneath the North American continent. The facility, while primarily seismological, will also involve GPS and magnetotelluric instruments. Funding for the dedicated USArray facility, is currently sought by the NSF in the EarthScope Phase I MRE initiative. If the EarthScope initiative is funded from the NSF MRE account, IRIS is committed to, and prepared for, implementing and managing the USArray component of the initiative.

The USArray seismic instrumentation facility consists of three main parts. The first, and largest, is a set of 400 broadband seismographs that will be deployed systematically in a fixed array geometry across the United States in temporary (12-18 months) deployments over 8-10 years. The second component is a set of broadband and shorter period seismographs to be deployed in conjunction with the fixed array in targeted experiments. The third consists of a number of high-quality broadband seismographs to be deployed permanently in the US in collaboration with the USGS, to provide a fixed reference frame for the mobile deployments and to enhance the National Seismic Network. As the instrumentation for USArray will be dedicated to the USArray experiment, there is minimal overlap with the two instrumentation facilities of IRIS - GSN and PASSCAL. In particular, the PASSCAL program will need to continue serving all individual PI experiments abroad as well as in the US.

The successful implementation and execution of the USArray experiment will be aided greatly by the existence and vitality of the IRIS core programs. The PASSCAL program has a long record of managing and servicing portable instrumentation, and in the current IRIS draft of an implementation plan for USArray the PASSCAL program serves as the key facility for executing the USArray experiment. Equally importantly, the IRIS DMS program has been able to distribute successfully very large amounts of data to the seismological and geophysical community. Implementing data distribution from USArray through the existing IRIS DMS facility will be effective and economical. Similarly, the significant educational opportunities presented by USArray can be efficiently capitalized on through the IRIS Education and Outreach program.

In this proposal, the IRIS Consortium seeks funding to maintain the existing core programs. Funding of USArray will not offset costs described in this proposal, and this proposal does not depend on the funding of USArray. The successful implementation of USArray, as currently planned, will, however, significantly benefit from the existence and health of existing IRIS facilities.

IRIS - COORDINATING PROGRAMS

During the initial building of IRIS facilities, it was effective to focus IRIS efforts on the individual goals of the three original core programs. Many of the issues emerging today, however, cut across program boundaries. Instrumentation and software development, data telemetry and real-time data access are some of the most obvious examples. Many of the activities related to Education and Outreach also require close cooperation with the GSN, PASSCAL, and the DMC. Coordination between programs is necessary for realizing efficiencies and for avoiding duplication of effort. The Executive Committee responded to this need in 1997 when it created the Coordination Committee and charged it with the task of developing yearly coordinated program plans. In the spring of 2000, the Executive Committee also decided to create the position of Director of Operations, who will work with the President to ensure that all IRIS operations are well coordinated.

A continued focus for IRIS facilities is to develop the capability of providing as much data from the field to the individual investigator with as short a delay as possible. This move towards nearly real-time seismology is motivated by several factors:

- With data transmitted in real time from the seismometer in the ground to a Data Collection Center (DCC) or PI's desktop, problems or errors with the data or data acquisition system can be detected early and remedied, improving data quality and data return rates. A two-way communication capability with the station also allows some instrument problems to be repaired remotely. Visits to stations for maintenance or service runs can be minimized reducing overall expense.
- A telemetered real-time data acquisition system has the advantage that data storage at the station on tape or disk can be eliminated or minimized. Since tape subsystems, including the shipping and processing of data tapes, are prone to problems, a telemetered system will lead to increased data recovery, and potentially to reduced maintenance costs. Real-time data access also simplifies the data archiving process, again reducing costs.
- The real-time availability of data makes real-time analysis of the data possible. For example, real-time data from a telemetered subset of GSN stations are already used by the NEIC to detect and locate earthquakes around the world, and GSN data available from the IRIS SPYDER system within hours of large earthquakes are used for detailed source analyses. The quality and completeness of seismicity catalogs will increase when more real-time data are available. Real-time data from local arrays deployed along active fault systems and volcanos will improve our understanding of earthquake and magmatic processes and impact hazards mitigation.
- Real-time seismic data, just as other 'live' environmental data (e.g., the Weather Channel), are able to stimulate the interest of both scientists and the general public. Real-time displays of and access to seismic data are very valuable for a wide range of Education and Outreach programs.

In the plans and budgets for the next five years, IRIS's coordinated efforts toward the development of real-time data collection and distribution are reflected in the individual program budgets, though the efforts are closely linked, as they cut across program boundaries. The GSN and PASSCAL data acquisition systems have a range of different capabilities for transmitting data in real-time to the DCCs, and the program budgets contain the costs for telemetry hardware and software. Customization and development of software to collect and distribute data from the DMC are included in the DMS plans and budget, and the development of software tools and displays of the data are part of the E&O program budget.

IRIS - PROTECTING THE INVESTMENT

A very significant investment has been made by the NSF and other agencies in IRIS facilities, in both hardware and software. Less tangible, but equally important, has been the investment in the human resources that make IRIS an efficient organization. The most significant activity of the mature IRIS organization is the operation of its facilities, and this is directly reflected in the budget in terms of personnel costs and sub-contracts for operations and maintenance. The organizational structure and costs of operation for the individual programs have been internally reviewed within IRIS, and these reviews have led to significant structural changes, such as the consolidation of the PASSCAL Instrument Centers to the new, single facility in New Mexico.

Maintenance of hardware and software is the second largest expense incurred by IRIS. This category includes both the repair and replacement of defective components, and the longer-term amortization of systems. With the rapid pace of development, decrease in cost, and improvement in reliability of the many off-the-shelf elements that make up the recording, transmission, and archiving hardware of the IRIS facilities, it has also been advantageous to adopt a policy of continuous modernization for the maintenance of equipment.

The costs for maintenance and amortization are broken down in the individual program budgets. For the DMS program, the main budget item corresponds to the replacement and expansion of the mass storage device. For the GSN program, amortization corresponds to the gradual replacement of aging parts, primarily data acquisition systems. For the PASSCAL program, the amortization reflects the systematic replacement of old data acquisition systems by new systems, which are currently undergoing tests.

IRIS - ACHIEVING THE ORIGINAL GOALS

With government funding, primarily from the NSF and DoD, IRIS has built a successful facility that in many ways directly realizes the original vision that was articulated 16 years ago in the original IRIS proposal. IRIS, in partnership with the USGS, operates a Global Seismographic Network that in terms of geographical station distribution comes close to the network originally planned. The DMS has evolved into an archiving and data distribution center for IRIS and other seismological and geophysical data with a capacity that far exceeds that originally planned.

The PASSCAL program has also exceeded many of its initial expectations in terms of being able to support a large variety of field experiments. The PASSCAL instrument pool has not yet, however, reached the size that was set as a target more than a decade ago. In terms of capital investment and expansion of the IRIS facility, the acquisition of more field recorders and sensors for the PASSCAL program is the most significant item in the five-year budget. The proposed acquisition will, over five years, bring PASSCAL close to meeting the original instrumentation goal, and will improve the ability of the facility to respond to the large volume of requests for instruments from individual PIs.

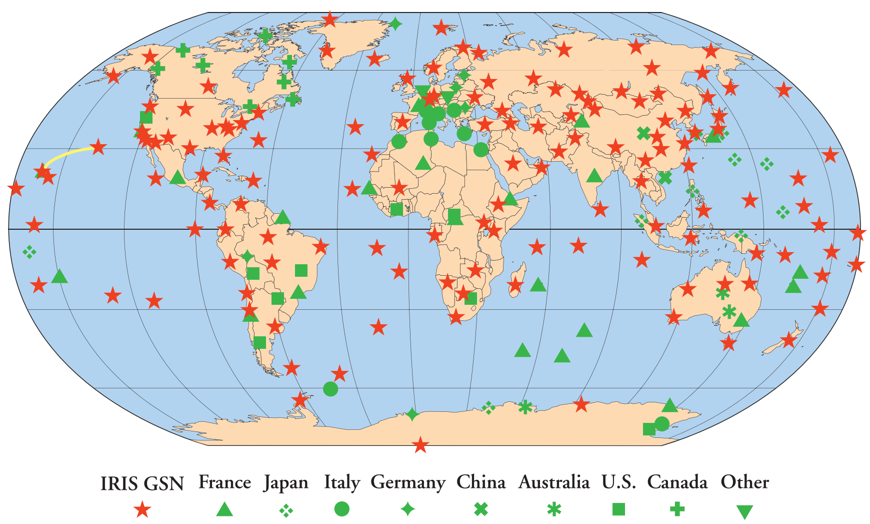
The Global Seismographic Network

What is the GSN?

"The Global Seismographic Network is a blueprint for scientific programs that not only advance our understanding of the physical world, but also address the needs of society."

Neal Lane, Director of NSF and Gordon Eaton, Director of USGS[1]

GSN & FEDERATION OF DIGITAL BROADBAND SEISMIC NETWORKS (FDSN)



The Global Seismographic Network is a cooperative partnership of US universities and government agencies, coordinated with the international community, to install and operate a global multi-use scientific facility as a societal resource for environmental monitoring, research, and education. The GSN is also a state-of-the-art, digital network of scientific instrumentation and inheritor of a century-long tradition in seismology of global cooperation in the study of the Earth. GSN instrumentation is capable of measuring and recording with high fidelity all of Earth's vibrations from high-frequency, strong ground motions near an earthquake to its slowest free oscillations. Sensors are accurately calibrated, and timing is based on satellite clocks. The primary focus in creating the GSN has been seismology, but the infrastructure is inherently multi-use, and can be extended to other disciplines of the Earth science.

The concept of the GSN is founded upon global, uniform, unbiased Earth coverage by a permanent network of over 100 stations with rapid data access. The equipment is modular, enabling it to evolve with technology and the science needs. Equipment standardization and data formats create efficiencies for use and maintenance.

A cornerstone of the GSN is free data exchange with the international community. The stations are open for data access by anyone with a telephone modem or an Internet connection, either directly from the stations or through the Data Management System.

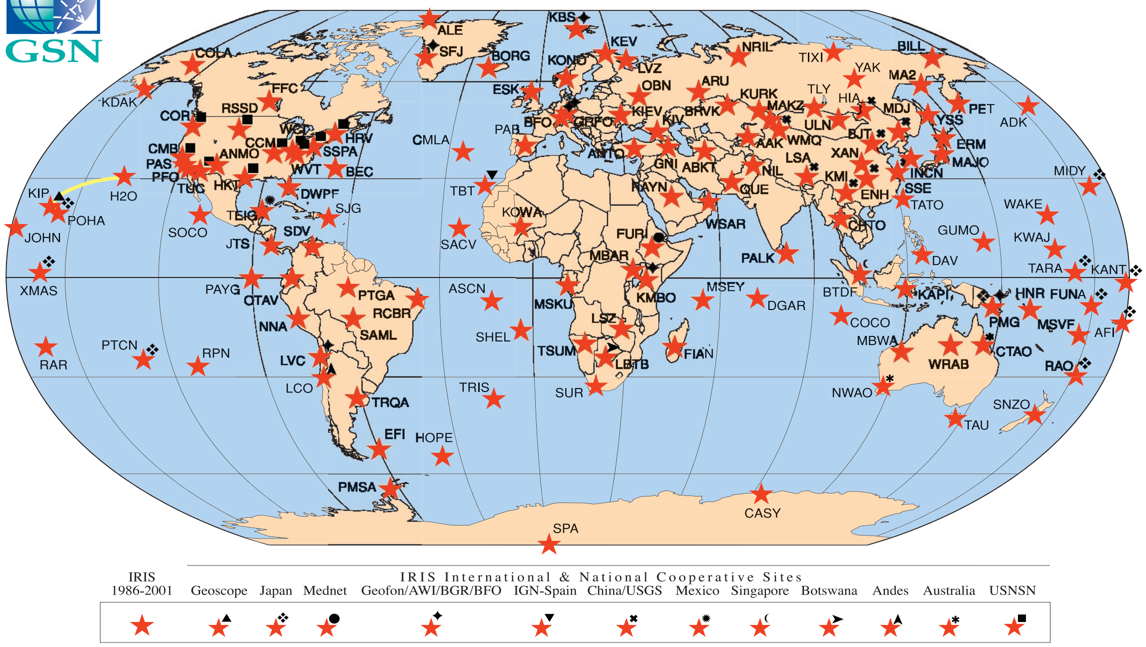
The GSN is both benefactor and beneficiary of government-university cooperation involving the National Science Foundation, US Geological Survey, Department of Defense, National Imaging and Mapping Agency, NASA, and NOAA. As a core US facility, IRIS is a member of the international Federation of Digital Seismographic Networks and data from GSN stations are being used by the International Monitoring System for the Comprehensive Nuclear Test-Ban Treaty. The GSN is primarily operated and maintained through the USGS Albuquerque Seismological Laboratory and the University of California at San Diego.

The GSN is an educational tool for the study of Earth. With the ease of access to data and blossoming computer technology, GSN data are now routinely used in introductory college courses and high school use is rising. The GSN stations themselves are focal points for international training in seismology.

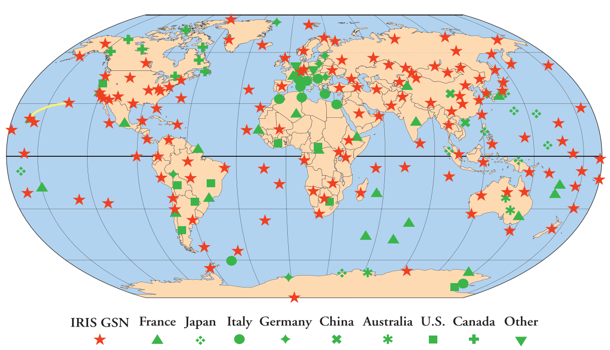
The GSN is a fundamental resource in the compilation of catalogs and bulletins of earthquake locations. Rapid access to GSN data has led to rapid analysis of earthquake mechanisms, bringing public awareness of earthquakes as scientific events, not just news events. GSN data are critical to the public and government agency response to earthquakes, tsunamis, and volcanoes, and as a resource in mitigating earthquake hazards.

GSN

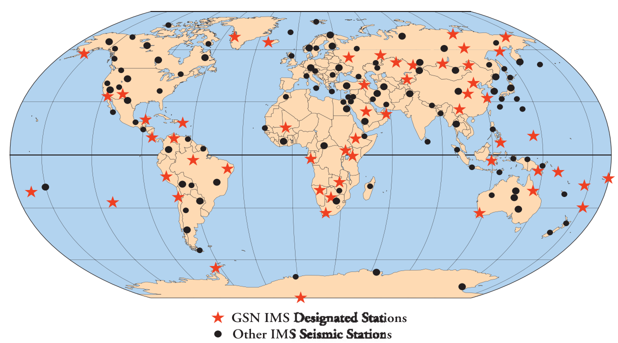
GLOBAL SEISMOGRAPHIC NETWORK



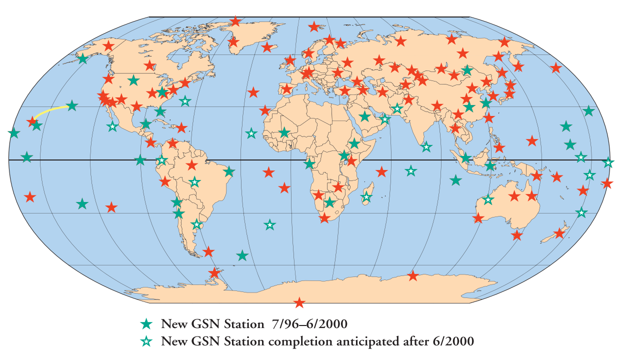
GSN & FEDERATION OF DIGITAL BROADBAND SEISMIC NETWORKS (FDSN)



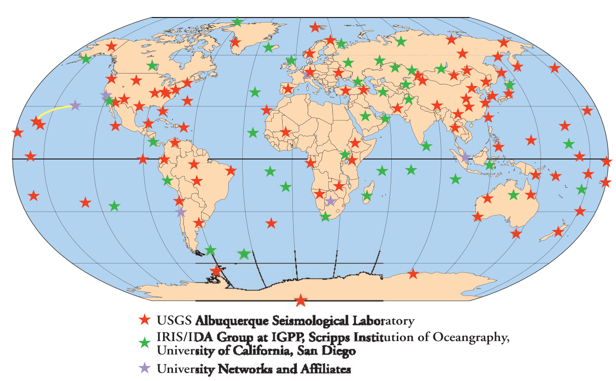
GSN & INTERNATIONAL MONITORING SYSTEM (IMS)



NEW GSN SITES INSTALLED DURING THE LAST FIVE YEARS

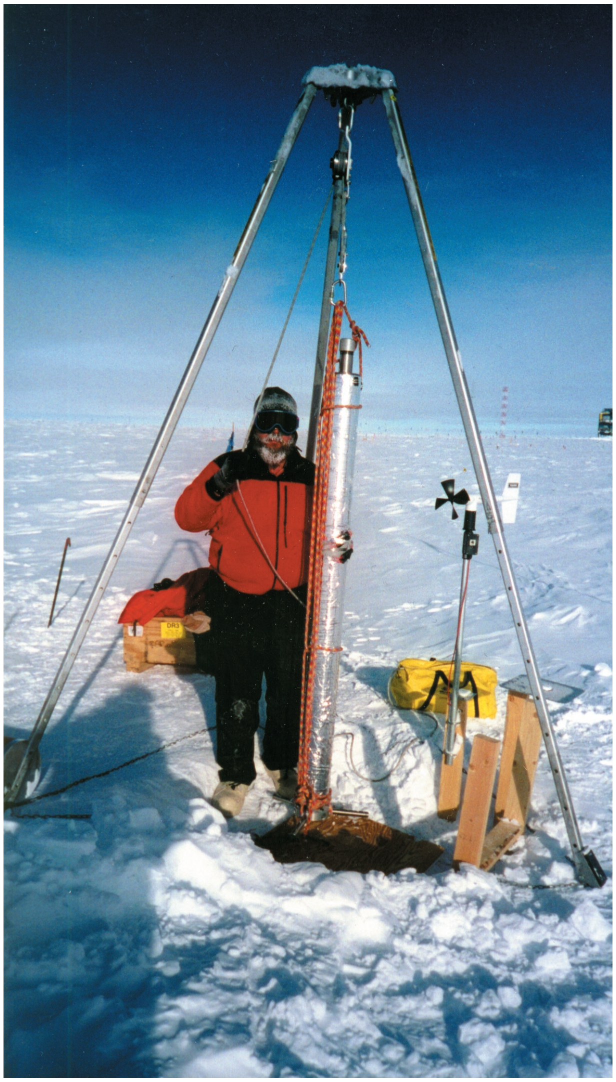


GSN NETWORK OPERATORS



Views of the GSN

The upper figure shows the global distribution of the 136 GSN stations. Stations are shown with their seismic code name. IRIS international and national cooperative sites are noted by the symbol on the ‘shoulder’ of the star. The yellow line to the H2O site in the Pacific indicates the Hawaii-2 undersea cable owned by IRIS. The left central inset shows the distribution of the GSN with its other FDSN Network partners contributing to global coverage. The right central inset shows the GSN stations designated for the International Monitoring System (IMS) of the Comprehensive Test Ban Treaty with other IMS seismic stations. The lower left inset shows the GSN stations that have been installed during the current five-year Cooperative Agreement with NSF. The lower right inset shows the subset of stations operated by the USGS and UCSD, and the seven stations operated by University Networks or Affiliates overseas.



GSN at the South Pole
Kent Anderson of the USGS Albuquerque Seismological Laboratory prepares to test the borehole KS54000-IRIS seismometer at the South Pole in preparation for upgrading the station SPA.

International Cooperation

Seismology is a global science. The GSN is a major facility in support of this global science, and benefits from international cooperation with partners who contribute resources in many ways. Through IRIS, the GSN is a founding member of the Federation of Broadband Digital Seismographic Networks (FDSN), which has served to help coordinate siting of global stations among member networks and to establish an international data exchange format for seismic data (SEED). However, at the most basic level, the GSN cooperates internationally through its individual relationships with the 105 organizations that host GSN stations in 62 nations around the world.

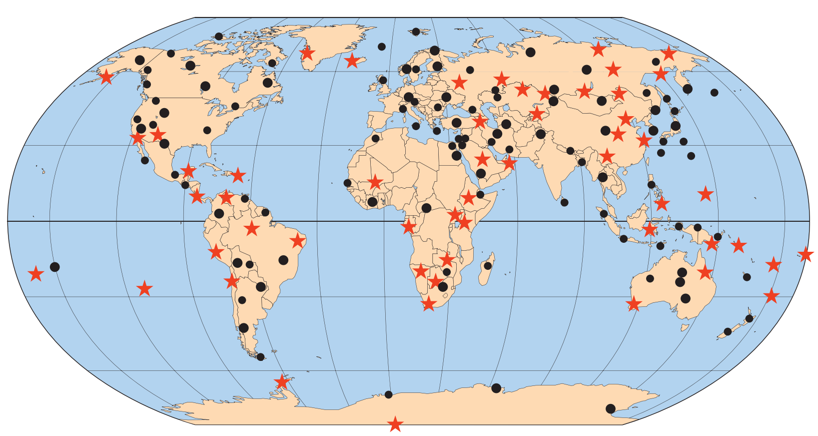
Many GSN stations are cooperatively operated as part of joint international collaboration with other FDSN member networks, or as a part of the national or regional networks within the host nation. These cooperative efforts result in the contribution of seismic equipment, telemetry, and other support in kind that has enhanced GSN stations above and beyond the funding from the United States. These international partners include Network operators in Australia, Botswana, Canada, China, France, Germany, Great Britain, Italy, Japan, Kazakhstan, Kyrghyzstan, Korea, Mexico, New Zealand, Norway, Peru, Russia, Singapore, Spain, and others.

Particularly noteworthy has been the cooperation between IRIS GSN and Japan's National Research Institute for Earth Science and Disaster Prevention (NIED). NIED has been funding a five-year "Superplume" project to study the Earth's deep interior beneath the Pacific. NIED decided that an excellent way to install seismic stations for these studies was to cooperate with the GSN at sites in the central Pacific. Jointly with the GSN a plan was developed to accelerate the installation of cooperative sites on Midway, Hawaii, Kiritimati, Pitcairn, Tarawa, Funafuti, Samoa, Raoul, and Kanton Islands. Toward this end NIED has provided funding for site preparation on Hawaii and Midway, donated data acquisition equipment at all sites, and is participating in the installation of communication links.

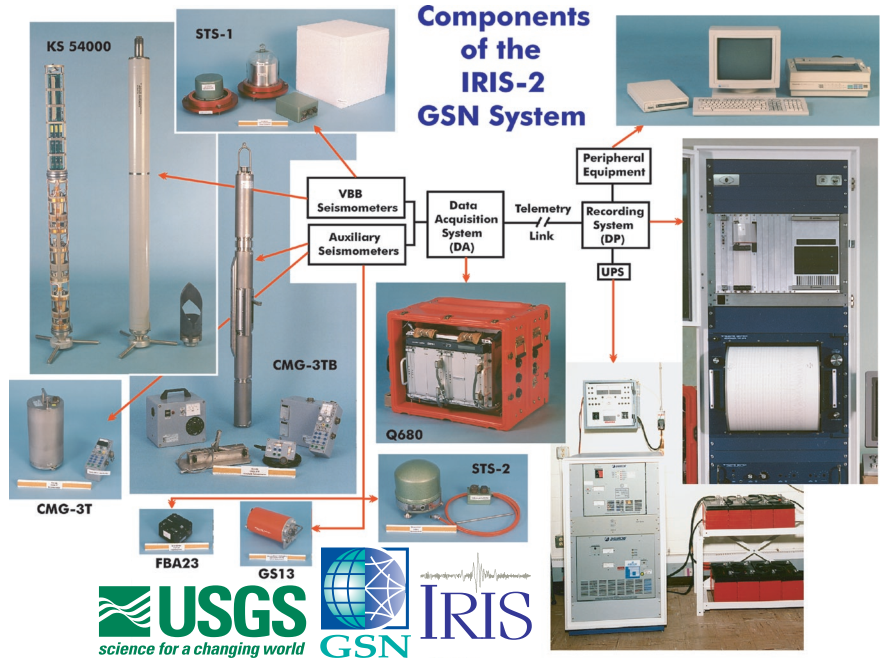
Three stations have joined the GSN as Affiliates—BTDF Singapore, LBTB Bostwana, and BFO Germany. As Affiliate stations, they provide all of the necessary equipment to meet GSN design goals, and fund their own operations and maintenance to GSN standards. GSN provides for data distribution, advice on hardware/software for the station, and consults on operations and maintenance.

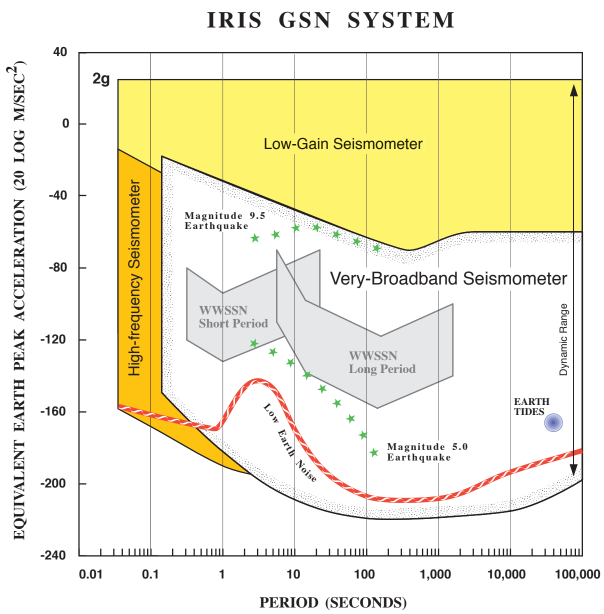
The GSN continues to be a major participant in the activities leading up to and following the signing of the Comprehensive Nuclear Test Ban Treaty. During the

GSN & INTERNATIONAL MONITORING SYSTEM (IMS)



GSN Instrumentation
The GSN instrument family includes the STS-1 and the borehole KS54000-IRIS as the standard very-broadband sensors. Auxiliary seismometers are used to extend the frequency band and dynamic range of the system where appropriate. For installations with high-frequency signals, the GSN uses the STS-2, CMG-3T, and GS-13 seismometers in vault deployments, and the CMG-3TB in a borehole (note 1 foot ruler for scale). The FBA-23 sensor is used for recording local earthquake strong-ground motion, and for recording any great earthquake that might saturate other sensors. The 24-bit data acquisition system shown is used at IRIS/USGS stations, and is separable via a telemetry link from the recording system and other peripheral equipment. A similar data acquisition system is employed at IRIS/IDA stations.





Bandwidth and Dynamic Range
The seismic instrumentation for the IRIS GSN system has tremendous bandwidth and dynamic range compared to its predecessor, the World Wide Standardized Seismographic Network. Using two seismometers, the WWSSN was able to record only a limited period and amplitude range. The stars indicate the approximate acceleration of Magnitude (Mw) 5.0 and 9.5 earthquakes recorded at 30° epicentral distance. The very-broadband seismometer of the GSN system is capable of recording the full range of earthquake motions on scale, and has a long-period response well beyond the Earth tides. To record the strong ground motions low-gain seismometers are used with clipping levels set at 2g's acceleration. High-frequency seismometers extend the bandwidth and noise floor of the GSN system to 40 Hz. The GSN system is capable of resolving the Earth's quietest seismic background noise. (Earthquake amplitudes and instrument ranges provided by Hiroo Kanamori and Bob Hutt, respectively.)

GSETT-3 (Group of Scientific Experts Technical Test-3) verification monitoring experiment conducted under the auspices of the United Nations Conference on Disarmament, 44 GSN stations were nominated and used by host nations for the experiment. Over 50 GSN stations [see map] have been designated by the CTBT as sites for participation in the seismic component of the International Monitoring System (IMS). The GSN is working with the CTBTO toward establishing satellite communications with the IMS-designated GSN stations.

IRIS serves as the US counterpart in joint US-Japanese telephone cable re-use activities and data exchange, and helped the Japanese Marine Science and Technology Agency (JAMSTEC) acquire from AT&T the TPC-2 cable running from Guam to Okinawa. IRIS and the University of Tokyo jointly own the Trans-Pacific Cable-1 (TPC-1) from Guam to Japan, where the Japanese have installed a seafloor station south of Japan. The GSN has installed a seafloor station at the Hawaii-2 Observatory midway between Hawaii and California, reusing the retired Hawaii-2 telephone cable donated to IRIS by AT&T.

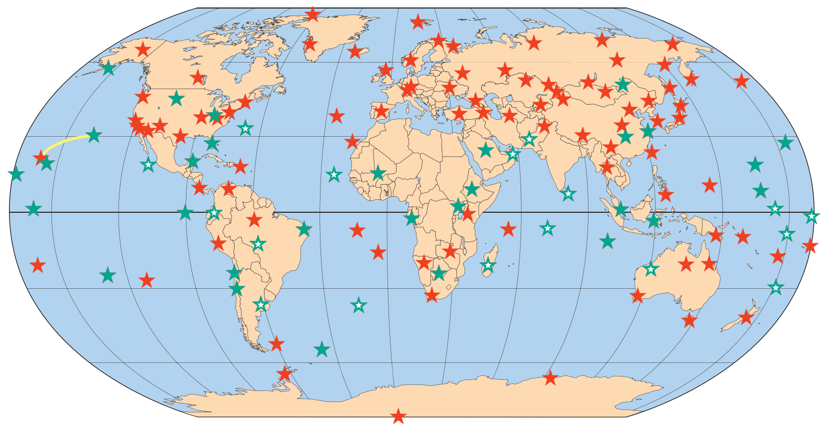
GSN Progress

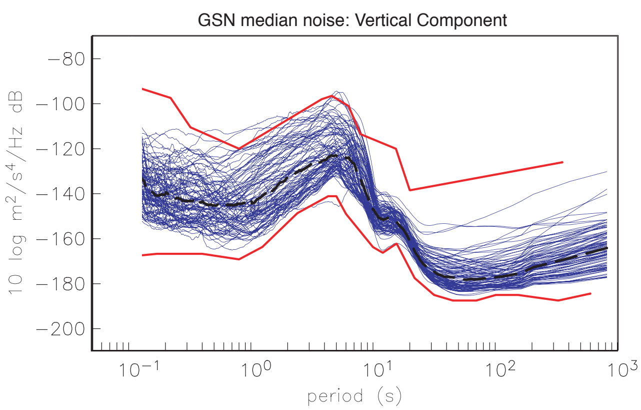
Instrumentation

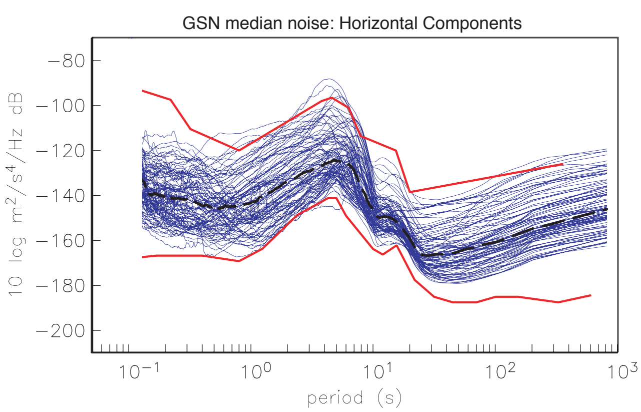
The basic GSN instrumentation design goal is to record with full fidelity all seismic signals above Earth's background noise. This has been accomplished using a combination of high-quality seismometers and data acquisition systems deployed in ways to minimize background noise. The bandwidth of the GSN system meets the diverse requirements of the scientific community, national/regional/local earthquake monitoring, tsunami warning networks, strong-ground-motion engineering community, and the International Monitoring System for the Comprehensive Test Ban Treaty.

To achieve this full coverage, several state-of-the-art seismometers are used in combination. Data acquisition systems are computers with analog-to-digital encoders and accurate clocks. The GSN uses state-of-the-art 24-bit digitizers manufactured by Quanterra and Hewlett-Packard for the very-broadband channels, and 16-bit digitizers selectively on other channels. The computer systems time-stamp the data from a GPS reference standard, provide an interface for operator functions, format data, manage the communications interface, and store all data to a local recording medium. All GSN data are locally recorded for trans-shipment to a Data Collection Center, serving as back-up when a real-time telemetry link exists.

NEW GSN SITES INSTALLED DURING THE LAST FIVE YEARS







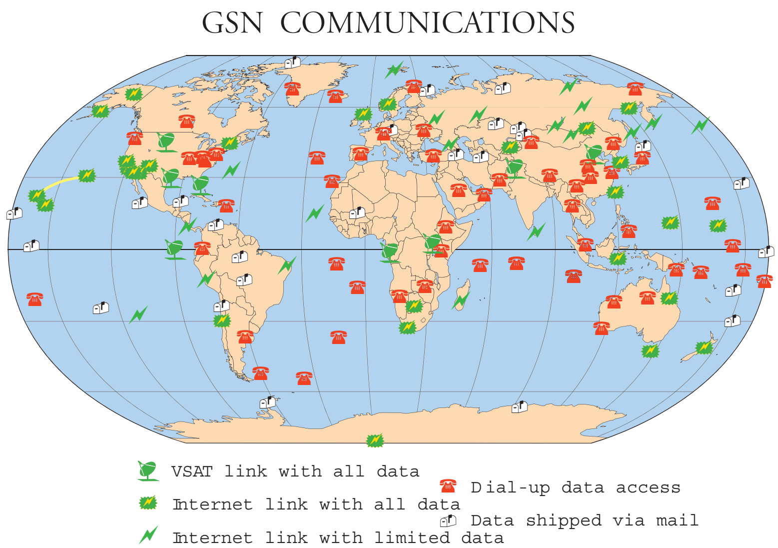
Noise Levels
Vertical and horizontal noise levels calculated from each GSN station show a wide variation of noise characteristics. Each blue line is the median of one week of one station's broadband (20 sps) data calculated from overlapping one hour segments. The red lines are USGS low and high noise models. The dark dashed line is the median of the medians.

GSN stations are deployed to provide uniform Earth coverage. Local noise conditions vary dramatically. Sites are chosen to achieve the best possible quiet noise conditions, while balancing cost and logistical considerations. Many GSN stations are deployed in a split configuration where a local radio link exists between a remote seismometer/digitizer, deployed for low noise conditions, and the computer system located at a local host organization where local personnel are directly involved in the operation and maintenance of the system.

The GSN Network Operators—USGS Albuquerque Seismological Laboratory (ASL) and the UCSD Scripps Institution of Oceanography (IGPP) IRIS/IDA group—have coordinated and conducted a variety of tests in many environments to determine the best siting modes. In general, underground siting is best—getting away from wind-generated and diurnal temperature influence—if one can avoid groundwater and noisy pumps. Hard rock provides for the best coupling of the sensor to the Earth. Sediment sites tend to trap high noise into the layer, and also have spurious local resonances. Boreholes work effectively to reduce long-period (>20 sec) horizontal noise on both the continents and larger islands, and also reduce high-frequency noise (>3 Hz) though not as dramatically. However, ocean-loading effects on very small islands and atolls produces additional long-period noise that is not mitigated by a borehole deployment. Noise level in the "microseism" band from about 2 Hz to 20 sec is generated by the oceans and is not mitigated by installation depth. Here the distance from the sea is the determining factor, with the best sites being within the continental interiors.

Station Deployments

IRIS installed the first GSN station in 1986. The GSN grew rapidly in the mid-1990s, and by June 1996 there were 89 GSN stations. GSN achieved this growth by an infusion of congressional support for nuclear verification in anticipation of the September 1996 signing of the



Data Collection
The current status of communications to all GSN stations is noted by the symbols. Green symbols indicate real-time links. Red telephones indicate dial-up data access. Mail boxes indicate shipment of data by tape.

Comprehensive Test Ban Treaty. NSF and IRIS obtained these funds via the Department of Defense Air Force Office of Scientific Research. Through the exemplary efforts of its Network Operators—USGS Albuquerque Seismological Laboratory (ASL) and the UCSD Scripps Institution of Oceanography (IGPP) IRIS/IDA group—the GSN installed a remarkable 50 stations in three years. Many of these sites provided for a greater station density in parts of Eurasia than would otherwise have been needed for purely scientific, global coverage concerns. Following this rapid-growth phase, the GSN continued its installations at a slower pace, steadily working towards its near-uniform coverage goal. Many of the remaining sites nearing completion have been in the more remote, logistically difficult parts of the planet. The GSN plan, under its current funding cycle has completed or is now finishing the installation of 47 stations, for a total of 136 stations. With complementary coverage by other FDSN networks, GSN is achieving its goal.

In 1998 the GSN installed its first seafloor station, the Hawaii-2 Observatory, located between Hawaii and California. IRIS collaborated with scientists from the Woods Hole Oceanographic Institution (who designed and developed the seafloor junction box) and the University of Hawaii at Manoa (who developed the broadband seismic sensor package and junction box power supply) on this project. A retired telephone cable is used to telemeter data from H2O to the Oahu cable station where it is sent by frame relay to the University of Hawaii at Manoa, and then to the Internet (see photo). AT&T donated the Hawaii-2 cable to IRIS in 1996. H2O collaborators raised funding for the system through peer-reviewed NSF ARI and MRI proposals, outside of the IRIS Cooperative Agreement.

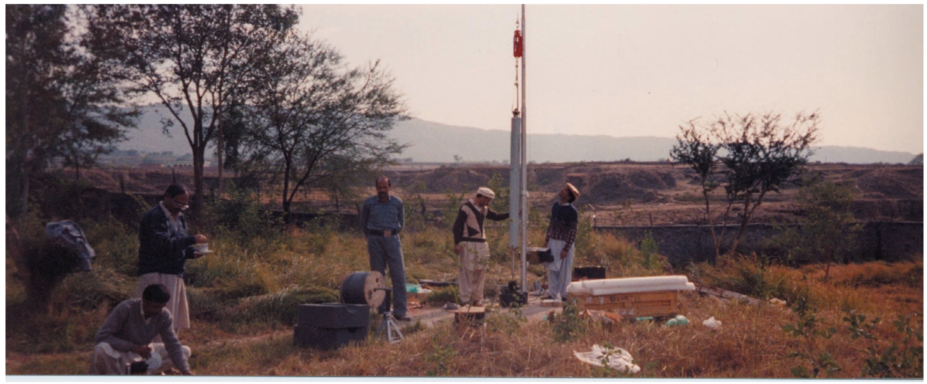
Telemetry

Along with uniform global coverage, real-time telemetry to all GSN stations has been a fundamental network goal from the beginning. It is only now becoming achievable. Telecommunications among computers is becoming ubiquitous, led by commercial needs. From car dealerships to the local 7-11 store, businesses are interlinked to their headquarters, suppliers, and banks via the very-small aperture terminal (VSAT) on their roof. This past year in remote Gabon, Uganda, and the Galapagos Islands, the GSN installed Internet links using off-the-shelf VSAT technology. Even more significantly, the monthly recurring charge to bring back all the data from these sites in real-time is less than long-distance telephone costs to bring back limited segments of selected earthquake data from a remote site.

GSN Internet to Equatorial Africa

In remote equatorial Africa, university students are now enjoying high-speed Internet service as a result of collaboration with the IRIS GSN. Seeking to gain remote access to the seismic data from a newly installed GSN station near Franceville, Gabon, the IRIS/USGS installation team approached Université des Sciences et Techniques de Masuku. For years, the university had been trying to get an Internet link. Now, with funds from the President of Gabon, the university cost-shared a satellite link established for telemetering seismic data. The IRIS/USGS installed a satellite dish as excited students looked on. Soon seismic data were flowing to the US and the first Internet access was opened up to the university and its Medical Research Center.

A big inaugural celebration with dignitaries from Gabon and the US embassy dedicated the new facility on February 11, 2000. Reaction in Gabon to Internet service falls between delighted and ecstatic. In the United States, anyone with an Internet link can now access real-time seismic data directly from equatorial Africa. This is not the first time that IRIS GSN has established Internet to a remote place.



NIL Pakistan
Preparing to lower the broadband seismometer into the borehole at the GSN station NIL, which later achieved fame in recording the recent, nearby Indian nuclear test.

From its beginning, the GSN has been a pioneer in seismic telecommunications. The earliest GSN stations included a modem for dial-up access to data, the first network to provide this as an open service to any user. Soon thereafter, in conjunction with automatic data dial-up following the report of an earthquake, the IRIS Gopher (now SPYDER®) system routinely collected GSN data for the community by telephone. Telephone dial-up access is still a major part of GSN communications. Though telephony is common and available almost everywhere, phone lines to the remote parts of the planet tend to be poor in quality, unreliable and low in bandwidth, and the costs for these calls are as high as $500/month to transmit routine segments of earthquake data.

With the advent of the Internet, the GSN immediately began hooking up its sites. Many remote locations have "free" access, courtesy of the station host, including South Africa, Tasmania, New Zealand, and others. When a link cannot be obtained for free, the GSN site must pay an Internet Service Provider (ISP) for its link. In Mongolia, the GSN established the first Internet link into the country, helping to establish a local ISP. Working with cost-shared GPS funding from the National Imaging and Mapping Agency, the GSN has also established Internet links to five stations in Russian Siberia—Tiksi, Yakutsk, Magadan, Yuzhno-Sakhalinsk, and Petropavlovsk-Kamchatskiy. These links support the foundation of the Internet in these remote locations, and as new users join the ISPs, the link capacities continue to grow and improve without extra GSN effort.

Satellite communications methods—explored and used for over a decade by the GSN—are often the only means to access data from remote locations. In the glasnost days at the end of the Soviet Union era, GSN data from three Russian sites were linked by land lines to Obninsk, where a satellite connection to the United States was established by the GSN. This link has been replaced by an Internet connection. From the South Pole, a geosynchronous satellite in a skewed orbit visible from the Pole for eight hours a day is used to transmit data at T1 rates to the Internet, including data from the GSN station. The GSN is using an INMARSAT B terminal from the remote island of South Georgia in the southernmost Atlantic for high-speed digital telephone service.

VSAT methods were explored in the early GSN days, and have been used for many years in National networks. However, only recently has the international telecommunications tariff structure, the capacity and availability of satellites, and the network of high-capacity optical-fiber linked hubs conjoined to create cost-effective international VSAT systems. In 1999, the GSN established 19.2-kbps VSAT systems in Galapagos, Uganda, and Gabon. Each of these links had significant cost-sharing: with the Darwin Station and with NASA/JPL for GPS in the Galapagos, with NASA/JPL in Uganda, and in Gabon with the University (see sidebar).

Geophysical Observatories

The GSN has pursued a steady course toward expanding the use of its infrastructure for broader scientific observatory measurements. Some additional sensors are specifically

RAYN Saudi Arabia
In the middle of the Saudi desert is the GSN station RAYN. The borehole wellhead is located near the vehicles. The recording building and solar panels are to the left.

useful in a seismological context. The GSN operates LaCoste-Romberg gravimeters at many of its locations. Microbarographs are in the process of being deployed throughout the network to augment seismic data with acoustic wavefield data. Such pressure data are useful for monitoring atmospheric events, such as volcanic explosions, and for understanding pressure-related noise processes at the seismic station.

With funding from the National Imaging and Mapping Agency (NIMA), the GSN has served as a vehicle for establishing GPS sites co-located at eight GSN stations in Russia through the efforts of Dr. Mikhail Kogan and Lamont-Doherty Earth Observatory of Columbia University. GPS data from the GSN sites in Russia provide crucial data as global stations of the International GPS Tracking Network (see http://igscb.jpl.nasa.gov/network/list.html).

The GSN is collaborating with UNAVCO in establishing GPS at GSN stations in Gabon, Uganda, and Argentina. The GSN has provided the GPS receivers for these sites and UNAVCO is providing for the monumentation and installation of the GPS systems. In Uganda and Gabon, the GSN has taken the lead in establishing telemetry for both GSN and GPS data streams, whereas in Argentina, UNAVCO is installing a VSAT link for shared telemetry of data. UNAVCO has also installed GPS equipment co-located with the GSN station in the Seychelles in the Indian Ocean.

Some basic surface meteorological measurements (pressure, temperature, and humidity) greatly increase GPS data's scientific usefulness. Phase delays induced in GPS signals by the ionosphere and neutral atmosphere can be measured with high precision along each of the dozen or so ray paths to the GPS satellites in view, and converted into integrated water vapor and total electron content along each GPS ray path. Toward improving the usefulness of GPS data at GSN stations, the GSN has installed meteorological sensor packages at Russian GPS sites, and will install similar instrumentation in coordination with its UNAVCO installations. These new GPS+Met sites have been registered with SuomiNet, a nascent, national real-time GPS network for atmospheric research in the United States (see http://www.unidata.ucar.edu/SuomiNet/).

VSAT installation at the Darwin Station in the Galapagos has provided our host with an Internet gateway for its own scientific projects. GSN VSAT links have attracted further interest as well in the astrophysical community. The High Energy Transient Explorer (HETE), to be launched in mid-2000, is a small scientific satellite designed to detect and localize gamma-ray bursts (GRBs). GRB coordinates detected by HETE are distributed to Astrophysical Observatories within seconds, thereby allowing detailed observations of their initial phases. GSN sites in Gabon and the Galapagos will offer their VSAT links as part of the equatorial network of ground stations in support of HETE.

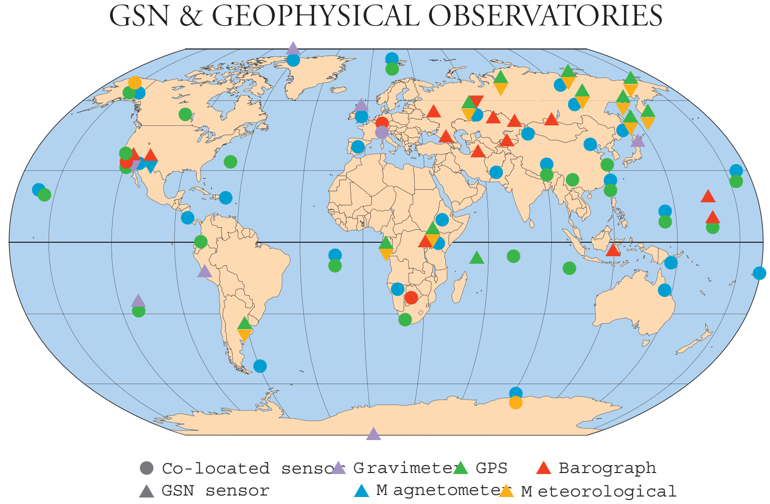
Installation of the new GSN station on Midway Island has been coordinated with an INTERMAGNET geomagnetic observatory on Midway.

GSN Five Year Program Plan

In this proposal we request support over the next five years to operate and maintain a robust, state-of-the art GSN. The Global Seismographic Network is an essential facility for the seismological study of the Earth. Built up over fifteen years, the most important task at hand is to keep this Network robust and vital for the benefit of its many users for decades to come. Robustness requires good operations and maintenance support. Network vitality is equally important for the GSN to continue its state-of-the-art service to the community it serves. In a world of technological revolution, the GSN cannot remain static—it too must evolve. The vitality of the Network is nourished by enhancements to its stations that improve data quality and availability, and diminish maintenance needs. As GSN equipment is amortized, updated, and replaced, the goals will be high reliability and low maintenance. As the global telemetry infrastructure evolves and accelerates, the GSN will eventually transform from a reliance on shipping physical data media to a fully telemetered network. Indeed, one can imagine in the not too distant future a GSN station that is simply a seismometer whose output is digitized, packetized, and input directly into the global telemetered Internet.

In addition to operation and maintenance, support is requested for specific improvements to the GSN such as

GSN & GEOPHYSICAL OBSERVATORIES



Geophysical Observatories
Many GSN stations have other geophysical sensors co-located at or nearby the GSN seismic equipment. Triangles note sensors installed by the GSN program. Circles indicate sensors installed by other groups. Color code indicates sensor type.

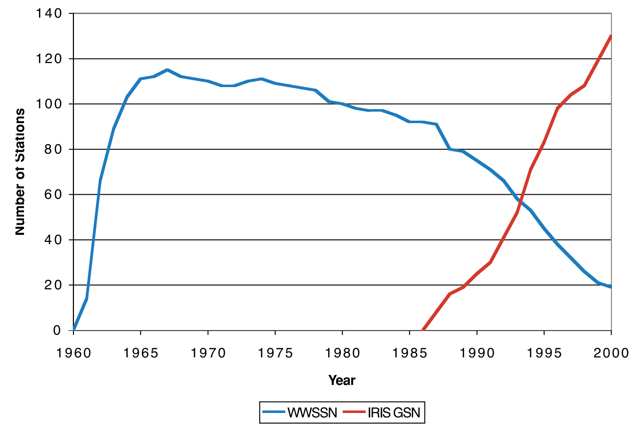
real-time telemetry, which will result in better data quality and data return. GSN data quality will also be improved by enhancing station siting conditions, upgrading equipment with low-maintenance replacements, closing and relocating problem stations, and coordinating better with station hosts and sister sciences in joint operations and maintenance efforts—each of these improving productivity. The GSN will continue its observatory efforts, coordinating with other scientific groups to co-locate geophysical sensors at GSN sites. By itself the land-based GSN, augmented by the existing seafloor Hawaii-2 Observatory (H2O) site, only partially addresses issues of global coverage. Though extending the GSN further into the oceans is not explicitly a part of this five-year proposal, the GSN will continue its coordination with seafloor observatory planning by the ocean sciences community, to eventually achieve truly uniform Earth coverage.

Operations and Maintenance

The GSN's single most important task is network Operations and Maintenance (O&M). O&M is the annual investment that the seismological community must make in order to insure a healthy return of high-quality data from the installed base of state-of-the-art GSN stations. Operations and Maintenance requires people, equipment, supplies, travel, and cooperation with our station hosts. Average station uptime in 1999 was 82% for IRIS/IDA stations and 74% for IRIS/USGS stations. As the GSN moves from its installation phase toward a focus on operations and maintenance, and with emphasis on improvements in data quality and data return, it is expected that Network uptime will improve toward the 90% uptime goal established at the initiation of the GSN.

O&M includes not only activities in support of the network stations, but also the flow and quality assurance of the data from the stations. The GSN has two primary Network Operators. The USGS Albuquerque Seismological Laboratory (ASL) operates 88 IRIS/USGS stations, and the University of California San Diego operates 41 IRIS/IDA stations. Additionally, 7 GSN stations are operated as part of individual University Networks or as foreign affiliates. Under a Memorandum of Understanding with IRIS and NSF, the USGS is to provide for the O&M support for ASL. In this proposal, funding is requested for the O&M support of the IRIS/IDA element of the GSN, for the amortization of all GSN equipment at 5% per year, and for recurring telemetry costs to bring GSN data to the US in real-time. The basic O&M support of the IRIS/IDA element of the GSN includes personnel (9 full-time equivalent), O&M travel, station supplies and stipends, repairs, and overhead.

The funding for routine operations and maintenance support of the IRIS/USGS component of the GSN by ASL is provided separately by the USGS. IRIS, NSF and USGS coordinate and cooperate in their roles and responsibilities for the GSN under two NSF-USGS Interagency Accords



WWSSN and GSN
The growth of the digital Global Seismographic Network (GSN) compared to the analog World Wide Standardized Seismographic Network (WWSSN). The GSN was initiated as the WWSSN instrumentation became obsolete and lost support for operation and maintenance. The GSN is designed as a sustainable network that will meet the data needs for the full range of scientific users for decades to come.

(1984, 1986), the IRIS/USGS Cooperative Agreement (1984), and the GSN Technical Plan (1990).

Enhancing GSN Stations

The GSN has reached its design plateau in terms of station siting. At 136 stations located from the continental interiors, to the margins, ocean islands, and even to the H2O site on the seafloor, the GSN provides unparalleled seismological Earth coverage. With our FDSN partners providing coverage and data from other key areas, there are now few areas with marginal coverage. Among these are central Siberia, northern Africa, India, Iran, the eastern Amazon in South America, Antarctica between the South Pole and coast, and a few remote islands. Further improvements in coverage must be balanced with improving the existing network.

Many GSN stations may require enhancements over the next five years for a variety of reasons. These improvements lead to quieter noise conditions and greater data return. Persistent noise anomalies may require simple adjustments to instrument siting (e.g., better thermal shielding in a vault, or adding sand to the annular space between a borehole sensor and casing to reduce convective noise) or structural enhancement of a vault or pier. Local noise conditions at a surface site may be improved by drilling a borehole. Corrosive atmospheric conditions in a deep mine or lava tube, flooding, urban-encroachment, or resumption of mining activity nearby can require site relocation or extensive site re-conditioning. Some sites installed in marginal locations, that were dictated by logistical necessity at the time of the original installation, may now be upgraded as local infrastructure improves. At other sites, catastrophic conditions whether political or environmental may necessitate closing and relocating a station altogether. Re-locating stations may be used as a means to improve global coverage elsewhere. A wide range of activities, including civil works, personnel and travel costs, and sensor upgrades (in the case of replacing a vault with a borehole), are covered under these enhancement efforts, which include re-locating stations as well.

New Telemetry

Of the 136 GSN stations, about 30% have or will have adequate real-time telecommunications capabilities by the middle of 2001. Most of the remaining stations have some form of dial-up access or low-speed internet connection. The GSN would like to continue to improve its communications infrastructure. As the internet expands and improves, opportunities to link GSN site to local internet service providers will open. The nexus of interest in communications will continue to lead to cost-sharing opportunities with other groups while improving GSN telemetry.

Seafloor observatories

The operations and maintenance of the H2O system are cost-shared between the GSN and NSF Ocean Sciences. Through an arrangement with NSF-OCE, the GSN provides funding comparable to the operations, maintenance, and data collection cost for a GSN station and the remaining costs for H2O are borne through a regular proposal separately submitted to NSF-OCE. These additional costs include operations and maintenance of the seafloor instrumentation, ship and remotely operated vehicles costs, and coordinating installations of new sensors systems on H2O. Funding for new sensor systems are generated by proposals to NSF by independent investigators. Support is requested to fulfill obligations in the operation and maintenance of H2O, and to continue efforts to extend the GSN into the oceans through coordination with seafloor observatory planning efforts in the Ocean Science community.

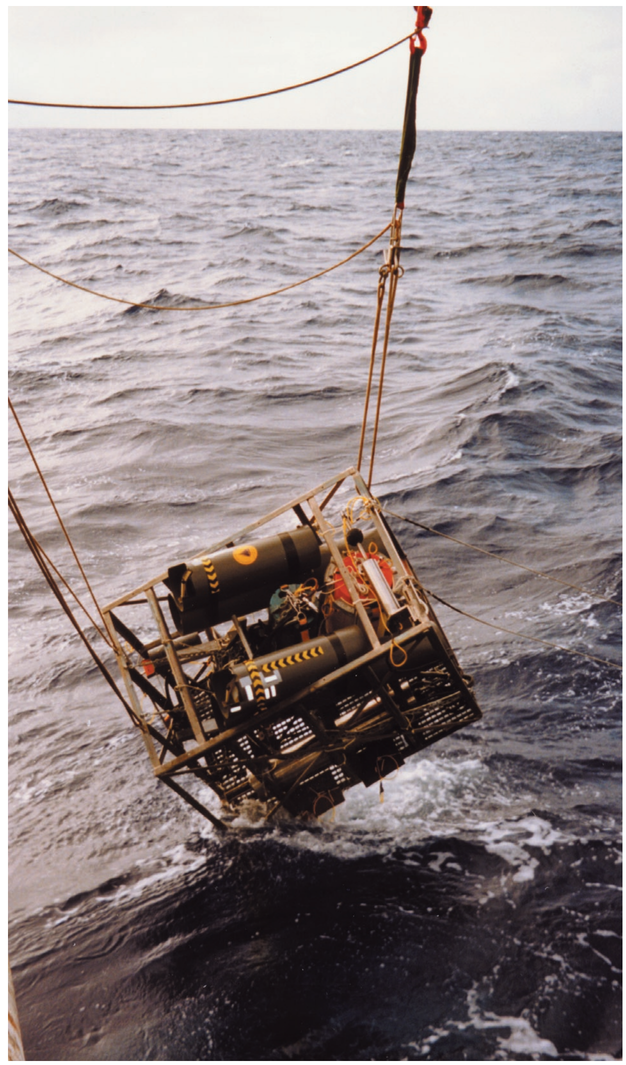
Co-located geophysical observatories

The Global Seismographic Network is an established core infrastructure for broader science around the world, and is receptive to coordination and collaboration with other scientific disciplines. Co-location with GPS instrumentation is expanding. Concomitant installation of meteorological sensors expands the geodetics horizon of GPS into a new areas of atmospheric monitoring. Installation of microbarograph sensors at GSN stations extends seismology up from the solid earth. During the next five years we plan to continue to collaborate with operators of GPS and atmospheric sensors, and would work to expand cooperation in the field of geomagnetism.

University Network collaboration

About 10% of the GSN has been established in partnership with primary funding from IRIS member Universities. These sites contribute not only their data, but also to the educational activities of the Universities. Several University sites are focal sites in large regional networks, and collaboration and coordination with the GSN in the development of Network software has been mutually advantageous..

[1] Neal Lane and Gordon Eaton, Seismographic network provides blueprint for scientific cooperation, EOS Trans. AGU, **78**, 36, pp. 381,385, Sept. 9, 1997.



H2O Ocean Floor Observatory
The University of Hawaii sensor system is being lowered from the R/V Thompson to the Hawaii-2 Observatory (H2O) site 5,000 meters below. The broadband GSN seismometers are in the blue package in the center, next to the burial caisson with orange cover. The seismometers were later set within the caisson, which itself was buried 0.5 m below the sea floor at 15 m distant from the titanium frame by the ROV Jason. System electronics housed within the titanium frame are linked to the H2O junction box (built by WHOI and UH) via an underwater-mateable connector.

Program For Array Seismic Studies Of The Continental Lithosphere (PASSCAL)

Overview

The founding goal of PASSCAL was to make a dramatic improvement in our ability to image Earth structure and earthquake processes. By providing a powerful and flexible array of high-performance instruments, PASSCAL has made it possible for the university community to routinely undertake large broadband and active source experiments that would otherwise be impossible. The PASSCAL resources have significantly expanded the scope of experiments and the number of investigators involved. Outstanding PI's from both large and small universities and colleges can now participate in innovative scientific research and provide unique educational opportunities and training for their students. These facilities, and the experiments conducted as a result of their development, offer the ability to produce three-dimensional images of the Earth with increasing resolution.

PASSCAL operates and maintains a portable pool of instruments for use by the academic community. Funding for individual experiments is provided by NSF, USGS, DoD, and other federal agencies, through a peer review proposal process. PASSCAL currently has a stable of more than 700 portable, digital seismic recording systems, comprised of approximately 330 3-channel recorders, 210 6-channel recorders, 200 single-channel "Texan" instruments and 4 multi-channel reflection/refraction systems. An additional 100 Texans will be delivered in late 2000. In addition to the instruments owned by IRIS, PASSCAL provides maintenance support for the Seismic Group Recorder (SGR) facility at Stanford University and for 440 "Texan" instruments owned by the University of Texas-El Paso. All of the IRIS instruments are supported by a dedicated staff of 12 at a new PASSCAL Instrument Center located at the New Mexico Institute of Mining and Technology in Socorro NM.

While a basic metric used to measure PASSCAL's progress has been the number of instruments available for use in experiments, the scope of the facility extends well beyond hardware alone. Underlying the hardware pool, PASSCAL maintains an extensive support structure for instrument design, maintenance, field support, software development and training. PASSCAL operates as a resource for the research community, in effect serving as a "lending library" for specialized seismological equipment, but also providing technical support and user training. Principal operations supported by PASSCAL include:

- Experiment Mobilization Support
- Logistical Assistance
- Equipment Repair
- Equipment Testing and Design
- User Training
- Software Development and Documentation
- User Software Access
- Administrative Organization
- Shipping and Receiving of Instrumentation
- Public Relations and Local Education and Outreach.

In the original 1984 IRIS proposal, it was estimated that about 1000 instruments with 6000 recording channels would be needed to support the experimental requirement for field programs in seismology. Since this time, PASSCAL has supported over 300 experiments, each leading to new discoveries about the Earth. In many ways, the range of investigations that has been made possible with the PASSCAL facilities has exceeded those envisioned at the start of IRIS. PASSCAL resources are now fully subscribed for use in peer-reviewed research programs – confirmation of the importance and success of the PASSCAL facility to the Earth science community. In each of the five-year reviews of the IRIS programs, the assessment of PASSCAL has been clear and consistent – the founding vision of a pool of portable of seismic recorders as a means of advancing our understanding of Earth processes continues to be validated through the breadth and quality of the research supported by the facility. Experiments to use the PASSCAL instruments continue to be highly ranked in peer review and funded by the NSF. Demand for instruments and technical support continues to exceed capacity. However, while the scientific impact of PASSCAL is far-reaching, it also stands out as one component of the IRIS program that has not yet fully achieved the equipment facility laid out in its founding vision. An important focus of this 2001-2005 IRIS proposal is to bring the PASSCAL facility closer to being able to fully support the experiment needs and scientific goals of the seismological community. Through support for operation and maintenance, replacement of aging instruments, and investment in a new generation of equipment, this proposal requests the funds to advance the PASSCAL facility to a complement of 1000 single-channel and 200 three-channel short period instruments for active-source studies; and 280 multi-channel, broadband instruments that can be used with approximately 300 short-period instruments for passive-source studies.

PASSCAL - A Brief History

The PASSCAL program was launched as part of the original IRIS initiative in the mid-1980's to develop, acquire, and maintain a new generation of portable instruments for seismic studies of the crust and lithosphere. PASSCAL formed the flexible complement to the permanent observatories of the Global Seismographic Network. During the First Cooperative Agreement between IRIS and NSF (1985-1990) the primary emphasis was on the careful specification of design goals and the development and testing of what became the initial 6-channel PASSCAL instruments. The initial set of 35 instruments was delivered in 1989 and maintained through the first PASSCAL Instrument Center at Lamont-Doherty Geological Observatory of Columbia University. During the Second Cooperative Agreement (1990-1995) the Lamont facility, which focused on the use of broadband sensors used primarily in support of passive source experiments, grew to more than 100 instruments. Starting in 1991, a second Instrument Center was established at Stanford University, to concentrate on support of a newer, 3-channel instrument designed for use in active source experiments. By 1995, almost 300 of these instruments were available.

Developments during the 1995-2000 Cooperative Agreement

The PASSCAL facility has continued to evolve through time, not only in the total numbers of instruments, but also in the kinds of instruments available for use and the services provided to users. The facility now encompasses a full spectrum of instruments: telemetered arrays, high-resolution, multi-channel instruments, single-channel reflection/refraction instruments and traditional short-period and broadband instruments for passive-source seismology.

The growth of numbers of instruments and experiments supported is shown in Figure 1. This figure shows a doubling of the broadband pool over the last five years and the acquisition of 300 single-channel "Texans" for active-source experiments in the last two years (by the end of 2000). These single channel "Texans" are operated in conjunction with 440 Texan instruments purchased by the University of Texas,

PASSCAL Instrumentation

Two primary types of experiments, classified by the types of sources being recorded, account for most of the use of PASSCAL instruments.

PASSIVE – These experiments are designed to observe naturally occurring events such earthquakes or volcanic disturbances. The purpose of the experiments may be to study the earthquakes or volcanoes themselves, or to use the elastic waves from these sources to study Earth structure or both. The primary data requirements are for recording of broadband signals (~100 sec to 40 Hz) in long-term, unattended observations, usually for periods of weeks to longer than one year. Instruments need to be low-power, reliable and able to withstand extreme environmental conditions. In addition, they need to have the flexibility to record a wide variety of data channels for various experimental configurations.

The PASSCAL instruments used for passive experiments (Figure 2) are either 6-channel or 3-channel REFTEKS with broadband sensors (Striekheisen STS-2 or various Guralp sensors) with long period response down to below 30 sec.

The PASSCAL Broadband Array is based on the same data acquisition systems used in the 3- and 6-channel recorders. Instead of on-site recording to disk, data are telemetered to a central site and merged in real-time. PASSCAL has the acquisition systems, seismometers comunications, and central recording equipment to implement two 32-station arrays of this type.

ACTIVE – These experiments are designed to observe artificial sources such as explosions, air-guns, vibrators, etc. The primary data requirements are for high sample rates, high frequency, and precise relative timing. The experimental mode is usually to record specific timed segments, synchronized with the timing of the artificial sources. The instruments are moved often in order to occupy many sites. The desired characteristics of the instrument package are simplicity, small size, weight and ease-of-use.

The PASSCAL instruments that have been most widely used for active experiments in the past were the 3-channel REFTEK recorders, similar to those used in broadband experiments . The new single channel Texan (Figure 3) was specifically designed for this purpose. A three-channel Texan is expected in the near future. Sensors are usually 4.5 or 40 hz geophones. The 60-channel recording systems (Geometrics StratView and StrataVisor) are also suited for this purpose, especially for very high resolution studies over small distances.

All passive source instruments are equipped with GPS receivers for timing. The primary recording medium is high density disk. Field experiments are provided with a central field computer for data coordination, quality control and preliminery analysis.

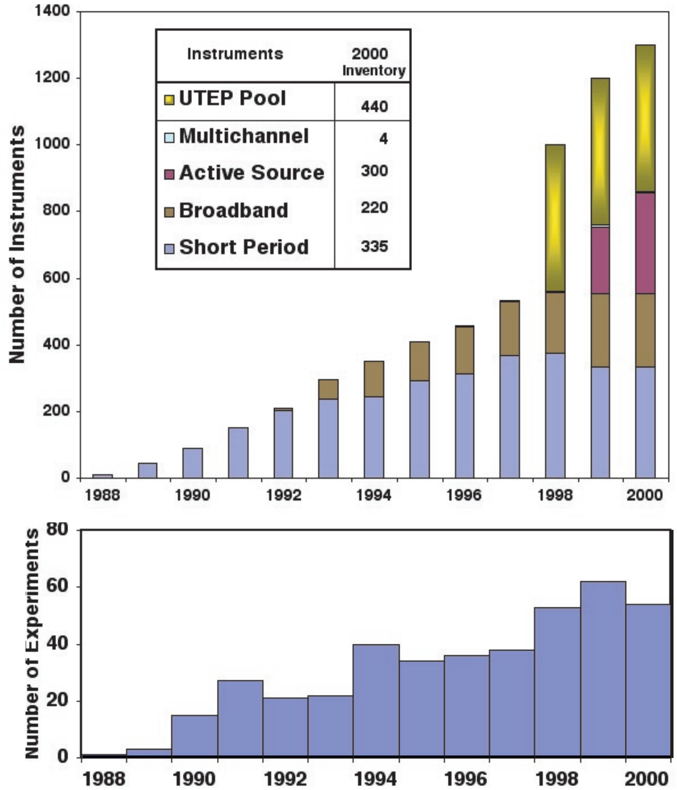


Figure 1. Growth of the PASSCAL Facility
The upper figure shows the growth of the PASSCAL instrument pool, Passive experiments can be supported with either broadband systems (6-channel recorders with broadband sensors) or short period systems (3-channel recorders with short- or intermediate-period sensors). Active source experiments can also make use of the short-period systems, but are now primarily supported with single-channel Texans, either from PASSCAL or in cooperation with the facility at the University of Texas, El Paso. Active source experiments can also make use of the multi-channel systems. The lower figure shows the increase in the number of experiments supported per year. This includes both passive and active experiments. A total of more than 300 experiments have been supported by PASSCAL in the past decade.

El Paso. The number of PASSCAL experiments supported has grown to more than 60 per year.

The previous IRIS proposal made the case for the development and acquisition of new instrumentation, primarily in the area of telemetry/arrays and a simple instrument for support of active-source experiments. While funding constraints over the past five years prohibited direct contracts for development of new instrument design, significant advances have been made in the development and testing of new instrumental capabilities.

Texans

The “Walkman” was envisioned in the last proposal as a small, lightweight, single-channel instrument to provide improved capabilities for the needs of the active-source community. This instrument now exists as the “Texan” data acquisition instrument. The University of Texas-El Paso, Rice University and the University of Texas-Dallas joined efforts with Refraction Technologies Inc. (REFTEK) to raise support from the state of Texas to develop a small, lightweight, easy-to-deploy, single-channel instrument. REFTEK, working with the three Texas universities and IRIS, designed a single-channel instrument (“Texan”) for reflection and refraction surveys. The first prototype instruments were successfully field tested in the summer of 1998. The Texas State funds purchased approximately 200 instruments. UTEP, in cooperation with IRIS, then received a Major Research Instrumentation grant from NSF for the purchase of more than 200 additional instruments. The NSF support was conditioned on the basis that IRIS would help in the maintenance and support of the instruments, and that the instruments would be made available to the entire research community in a manner similar to the conventional PASSCAL instruments. These instruments have proved to be enormously useful. The instruments were used in seven major experiments in 1999 and are expected to be used in major experiments in both the US and Europe in 2000. In addition to the 440 instruments stored at UTEP, PASSCAL received 200 instruments in May, 2000 and expects delivery of another 100 in late 2000.

Telemetered Arrays

The broadband telemetered array was developed in the early 1990’s under the IRIS Joint Seismic Program (JSP) for deployment in the former Soviet Union for nuclear test-ban verification calibration tests. When the JSP program was completed, the equipment and expertise necessary to operate the array were transferred to PASSCAL. The original PASSCAL broadband array consists of 32 broadband sensors and digitizers that telemeter the data via spread-spectrum radios to a concentrator site located up to 80 km away. At the concentrator, the data are routed to a conventional computer network for transmission back to a central facility. The central computer facility is configured to locate earthquakes in real time, to write the data to permanent archive and to provide the user with data for further analysis. PASSCAL currently has the capability to field 2 broadband arrays. Broadband arrays have been used in Colorado and South Africa with great success, and currently are deployed in California and Montana. While the PASSCAL telemetered broadband arrays are actively being used now, they have also provided a look into the future of real-time seismology. Transmitting data back to a central distribution facility in near real-time will make it possible to create virtual seismic networks, provide real-time analyses, effectively monitor stations and schedule maintenance, and will greatly ease data-handling making it possible to archive the data as soon as they have passed quality-control checks.

Additional telemetry developments

Over the last five years, communications technology began to have a significant impact on the PASSCAL program. While it is still impractical to transmit all of the data from low-power instruments at remote field locations, advances in satellite telemetry and other communication technologies make us optimistic that significant advances, of direct application to PASSCAL, will emerge in this area over the lifetime of the next IRIS Cooperative Agreement.

To provide researchers with critical state-of-health information from instruments in remote locations, PASSCAL has experimented with low-power, low - bandwidth satellite-based systems. Thirty low-power ARGOS satellite-telemetry units are available that can transmit daily state-of-health information from remote stations anywhere on the globe. While these units only allow one-way communication, they provide PI's with daily updates on the health of the linked stations. These units have been used successfully Antarctica, Fiji, Indonesia, South Africa and Chile. PASSCAL now is in the process of deploying updated satellite communications: ORBCOMM stations that provide more versatile systems with limited two-way communications. Using the ORBCOMM system, information can be requested from a station as desired. It is also possible to remotely start and stop data acquisition and reset the instrument. While still short of what ultimately is desired, the present usefulness of such systems make it clear that satellite telemetry will become even more valuable in the future.

Scientific Impact of PASSCAL

Images of the lithosphere, mantle and core provided by both active- and passive-source seismic experiments are of fundamental importance to study of the structure and evolution of the solid Earth and the dynamic processes that shape it. Since the first active- and passive-source PASSCAL experiments in 1986 and 1988 (respectively), the breadth of new information about Earth structure and dynamics developed through PI-driven PASSCAL experiments is astounding. In just the past 10 years, over 300 large- and small-scale PASSCAL arrays have been deployed to image many of the planet's major plate boundaries, cratons, orogenic systems, rifts, faults, and magmatic systems. Experiments use locations worldwide as natural laboratories to study a wide range of structures and processes (e.g., Tibetan Plateau, Rocky Mountain Front, Cascadia subduction zone, Yellowstone hotspot, the Rio Grande, Baikal and East-African Rifts, Basin and Range Province, Canadian Cordillera, Andean subduction zone, Tanzanian Craton, Abitibi Greenstone Belt, Kaapvaal Craton, Himalayas, southern Sierra Nevada, Iceland hotspot, Tien Shan, Antarctic Mountains, Archean-Proterozoic Cheyenne Belt suture, etc.).

The advances made possible by PASSCAL are driven by the creativity of scientists using the PASSCAL facilities, by the technology that PASSCAL makes available, and by the flexibility of the instrument pool to foster innovative research. While we sometimes measure the success of the PASSCAL's program by the number of instruments available and the number of experiments conducted, the real measure of success of the program lies in the diversity of important science that has been accomplished. This is evident in the array of scientific vignettes presented in Appendix I of the proposal, which provide a snapshot of the exciting science supported by the PASSCAL program. In addition to the types of studies typical of PASSCAL-supported experiments over the past decade, new opportunities exist for forging broad partnerships and interdisciplinary research collaborations:

• *Large-Scale Multi-Institutional Deployments* – Over the next five years, PASSCAL will continue to develop the facilities to support large-scale integrated experiments

Figure 2. PASSCAL Equipment for Broadband Experiments
This photo shows a basic REFTEK digital acquisiiton system (3-channel or 6-channel are similar in size), along with various broadband seismometers and a GPS time receiver. The satellite systems shown are the state-of-health systems described in the text.

using many easily deployed data-acquisition systems and sensors for three-dimensional lithospheric and deep-Earth imaging. While these experiments will not replace single-PI experiments, larger, multi-institutional experiments also hold promise for producing exiting new discoveries.

• *International Collaboration* – The next five to ten years will be a period of dynamic international scientific collaborations, and will most likely be accompanied by growing demand for development and expansion of seismological capabilities in regions where earthquake-hazard mitigation and nuclear-test monitoring are national concerns. PASSCAL serves as a model and catalyst for development of international equipment pools and coordinated development on a regional or global basis of resources for support of international seismological programs.

• *Cooperation with Industry* – Opportunities exist to develop large-scale, "high-resolution" experiments with exploration-industry partners to leverage their technical expertise in 3-D acquisition and processing in order to focus on challenging scientific problems from near-surface to lithospheric scales. These experiments would not be duplications of exploration imaging efforts in which industry already excels, but instead would represent added scientific value through innovative integration of wide-angle or 3-component recording on scales appropriate for targets of tectonic interest.

• *Volcano Monitoring and Volcanic System Imaging* – PASSCAL facilities will play an essential role in future efforts to monitor and image volcanic systems. Better equipment will permit detailed, real-time data acquisition and could provide a means for densification of 3-D monitoring arrays during RAMP (Rapid Array Mobilization Program) deployments or for detailed subsurface imaging.

• *Fault-Zone Studies* – Delineating the geometries and physical properties of active and fossil fault zones will provide important new information on earthquake processes and controls. Use of new generations of PASSCAL instrumentation – from real-time arrays of broadband receivers to Texans deployed for 3-D acquisition, to rapid-response earthquake monitoring using RAMP instruments – will enable higher resolution at lower cost. Integrated experiments, made easier by improved PASSCAL facilities, will be better able to span multiple scales of interest for such studies.

• *Broadband Arrays* – Evolution of real-time broadband arrays, and development of virtual seismic networks using Internet-ready, next-generation data-acquisition systems, will make the arrays easier to deploy and operate, facilitating larger or denser experiment designs.

• *Basin Hazards* – Recent experience with Kobe, Northridge, Loma Prieta and other destructive earthquakes points out the need for seismic studies in a number of heavily populated sedimentary basins to calibrate structure and hazard models. Earthquake wave propagation analyses and hazard parameterizations for incorporation into hazard-mitigation plans are natural areas for PI collaborations using PASSCAL instrumentation. In particular, this is an important area for cooperation and interaction with the USGS ANSS initiative.

Figure 3. Equipment for Active Source Experiments
This figure shows a complete Texan data acquisition system (19.6 cm long cylinder at top) and typical high-frequency geophone. A GPS clock and data recovery box are also shown. The compact size means that many units can be installed and retrieved quickly.

• *Hydrologic Studies* – The importance of groundwater and other water supplies to the world's population is paramount. In the next five years, PASSCAL instrumentation will be used in local, to possibly large-scale, seismological studies of the geometries and physical properties of aquifers and impacts on agricultural and municipal water supplies.

• *Environmental Seismology* – Mapping the geometries of subsurface contaminant plumes and reservoirs, and characterizing channel-controlled flow, will increasingly utilize seismic techniques in concert with other tools. For some applications, seismic techniques provide critical data on physical properties of lithologies and pore fluids; other applications may rely on seismically determined properties and geometries to constrain infiltration analyses. As with so many applications relevant to the science of the Earth and to societal concerns, PASSCAL facilities will play an important role in better understanding environmental factors that affect human lives.

Figure 4. PASSCAL Instrument Center at New Mexico Tech, Socorro, New Mexico
This 11,000 sq foot facility was built by New Mexico Tech in 1998, especially to house the PASSCAL Instrument Center. Extensive laboratory, testing, training and storage areas are available. A vault for seismometer testing is available in the hills behind.

PASSCAL Core Facilities

Instrumentation

The size and composition of the PASSCAL inventory has evolved through a continuing reassessment of the balance between technical and scientific pressures. While standardization of equipment, data formats and operational procedures is an essential ingredient in the success of all IRIS programs, PASSCAL must handle special challenges in the trade-offs between standardization, specialization and optimization. The wide variety of experimental configurations supported by PASSCAL, and the need for performance optimization under extreme field conditions, have led to the development of a number of "standardized" field systems. On the technical side, desires to keep the equipment "state-of-the-art" are balanced by issues of reliability, simplicity and cost. In a facility that provides equipment for use by operators with a wide range of technical skills and training, there are advantages in minimizing the number of different types of instruments. Nevertheless, the wide range of field conditions and scientific problems to be addressed requires an appropriate variety of instrument characteristics. On the scientific side, the PASSCAL Standing Committee, with input and oversight from other IRIS committees and staff, continually addresses the balance of resources provided to support the special needs of different sectors of the research community: passive vs. active source; short period vs. broadband; long term vs. short term. A short summary of the basic components of the existing PASSCAL instrument pool is presented earlier and the current inventory is summarized in Figure 1.

Instrument Center

The core facility for support and maintenance of the PASSCAL instruments is the PASSCAL Instrument Center (PIC) located at New Mexico Tech in Socorro, NM. This facility was established in 1998, after proposal solicitations and exhaustive review, to consolidate experiment-support efforts, improve efficiency, and lower the operational costs associated with maintaining the two former instrument centers. The Center (Figure 4) is housed in a new building with 7500 sq. ft. of lab space and 3500 sq. ft. of warehouse space. The building was designed by the PASSCAL technical staff to optimize Center operations. The centralization of the facility has allowed us to provide improved services while maintaining the same number of outstanding employees even as the number of instruments maintained and experiments supported grows.

The staff at the Instrument Center, who are supported under sub-award to New Mexico Tech, consists of:

- 1-Director
- 1- Office Manager
- 3-Seismologists
- 3-Software Engineers
- 4-Hardware Engineers

The IRIS PASSCAL Program Manager is also stationed in Socorro.

User Services, Training and Field Support

For most passive-source experiments, PASSCAL provides researchers with pre-experiment planning, help with special hardware that may be needed for the experiment, customs documentation and personnel training, and also provides one or more field engineers to assist in the initial deployment. PASSCAL personnel in the field do not conduct the experiment, but provide training and assistance so that researchers can. In addition, the instrument center provides repair services and is available by phone and e-mail throughout the experiment.

Active-source experiments are of shorter duration and are much more time-critical. PASSCAL usually provides one or more engineers during large active-source experiments. These field-support personnel provide skills to maintain the equipment, oversee training of field personnel and help with problems associated with handling large numbers of instruments and very large data volumes.

In addition to critical field engineering support, PASSCAL provides users with large amounts of documentation covering all aspects of the equipment and operations. The User Guide and Training Manuals provide information for personnel training and practical suggestions for experiment design and operation. All of the PASSCAL software is documented on line as well as in the equipment manuals. On-line documentation is available through the web (http://www.iris.edu/passcal/passcal.htm) and is resident on all field computers.

Software

PASSCAL software fundamentally provides researchers he tools necessary to extract and format data from PASSCAL recording systems for further processing and interpretation. Typical long-term passive broadband experiments involve the use of 40 to 60 instruments recording continuously, effectively representing arrays that are larger than all but a handful of the permanent seismic networks. Rapid technological advances, and the consequent ability to record ever larger volumes of data, means that, without appropriate software support, researchers could soon become overwhelmed with data. To handle large data volumes in the field, PASSCAL provides PI's with one or more field computers, a database software system, technical support, and coordination with the DMC to insure proper archiving of the data. The PASSCAL software system allows PIs to retrieve data from the acquisition systems, perform quality-control functions such as applying timing corrections on the data, and output the data in SEED format for permanent archival, as well as in any other formats the PI may require for further processing. The success of this system is demonstrated by the fact that data are reaching the DMC for permanent archiving more quickly than was possible a few years ago. Software development is coordinated as appropriate with other software development efforts by GSN, DMC and E&O.

RAMP (Rapid Array Mobilization Program)

PASSCAL reserves ten instruments for the RAMP instrument pool in order to respond very rapidly to aftershock-recording efforts following significant events. PASSCAL instruments were first used in an aftershock study at Loma Prieta, less than one month after the first instruments were delivered in 1989. During the past few years, instruments have been deployed after important domestic events such as Mendocino, Joshua Tree, Landers, Hector Mine and Northridge as well as after major foreign events in Venezuela, Indonesia and Turkey.

The pool continues to be used for aftershock studies, but also for special short-term projects that otherwise could not get access to instruments. In the event of a significant earthquake requiring an aftershock response, all RAMP instruments are available for shipping within 24 hours. In addition to the ten instruments reserved for RAMP, PASSCAL makes instruments available for such studies if they are not immediately required for other experiments. For example, in the case of the Hector Mine deployment, up to 80 instruments were made available for over a month to record aftershock seismicity.

Next Generation Instrumentation

In 1998, a special IRIS Instrumentation Committee was appointed to evaluate the growing need for new instrumentation within IRIS. The committee comprises members from the IRIS community with broad experience and interests in instrumentation issues, and includes USGS personnel to coordinate with the USGS efforts in instrument development. This committee has focused on three principal areas: data loggers, sensors and communications. The acquisition of sufficient numbers of new-generation passive- and active-source systems that are cheaper, smaller, more reliable, and easier to operate will make possible the dense deployments of instruments required for adequate resolution for scientific problems ranging from near surface to deep Earth. For the first time, large-scale academic three-dimensional surveys will be possible.

Data Loggers

Design goals for a new generation of data loggers were developed in coordination with the PASSCAL user community and have evolved to incorporate the deployment modes used by GSN and expected with USArray. By taking advantage of recent advances in computer and communications technology, it should be possible to achieve the following characteristics in new-generation data loggers:

- Power requirement about one-half that of the current instrument,
- Designed to act as a node on the Internet for robust communication,
- Designed to integrate auxiliary data streams more easily than current instrumentation.

The costs of the new data loggers are expected to be approximately one half the current instrument. Based on a call for proposals issued by IRIS to instrument manufacturers in 1999, two companies have been selected to initiate development of new data acquisition systems. Two prototypes are on order for testing and evaluation in the second half of 2000.

Communications

The global communications infrastructure is changing very rapidly and is being driven by market forces external to IRIS. The design of the "next generation" IRIS instruments is based on the assumption that, in the near future, it will be possible to connect to the Internet from almost anywhere in the world. VSAT systems may be a cost-effective solution in many environments. Digital cellular communications technology also is bringing wireless Internet communications to large portions of the US. Low Earth Orbit (LEO) satellite systems offer the hope of a worldwide wireless Internet. Technological improvements and lower cost are inevitable, and we continue to evaluate all of these options as they develop and mature.

Sensors

The seismic community needs a more rugged, easy-to-manufacture (lower cost) broadband sensor if it is to meet the long-term goals of IRIS and the USArray program. Currently, there are two suitable broadband sensors available for this purpose. However, these sensors are expensive and can be manufactured only in limited numbers. While the market is small, IRIS, in partnership with the USGS, will work to promote development of lower cost, portable, broadband sensors over the next few years that may significantly increase our deployment abilities.

Pressures on the Facility

Pressures for increase in the number of the PASSCAL instruments come from two main sources: the need for unaliased, high-resolution images to capture the true complexity of solid-Earth systems, and a growing backlog of requests for equipment that has produced unacceptable wait times for PIs trying to organize and conduct experiments. We have achieved spectacular results to date, but for the most part, we are still recording aliased wave-fields and our images do not reflect the true heterogeneities in the solid Earth. Even though the broadband instrument pool has doubled in size over the last five years, the wait time for instruments for passive-source experiments has increased, thus demonstrating a strong science-based demand from the research community.

The demand for larger numbers of instruments comes at the same time that we find our existing hardware nearing the end of its useful life. Over the last ten years, virtually every working PASSCAL broadband seismometer and data logger has been in constant use in the field. Newly purchased equipment generally is shipped to the field within weeks of arrival (after initial testing and configuration), and turnaround of equipment from one experiment to the next generally is done at a very hurried pace. Exacerbating the problem is the increasing failure rate of the data loggers and broadband sensors due to simple wear and tear from extensive use and frequent shipping around the world.

Long-Term Passive Deployments

Much of PASSCAL's effort centers around the fielding of long-term deployments of arrays of 50-80 broadband sites focused on dense spatial sampling of the teleseismic, regional and local seismic wavefield. These large, densely sampled experiments target lithospheric and upper-mantle structure, lower-mantle and core-mantle-boundary structure, earthquake-aftershock recordings including fault-zone-property studies, and volcano monitoring. The number of simultaneous broadband experiments has grown over the last five years while the average size also has grown to about 22 stations (Figure 6).

This year, PASSCAL is supporting four large passive-source deployments consisting of 65, 60, 50 and 30 broadband recording stations each. In addition, nine other experiments totaling 70 passive-source sites are in operation. The largest PASSCAL passive-source experiment (to date) involved 80 broadband seismometers deployed in South Africa in 1999. As of June 2000, an 81-station broadband array is operating around the Yellowstone hotspot. With more than 200 broadband instruments constantly in the field, many in long term deployments, PASSCAL is supporting a combined array approximately twice the size of the GSN, with the data being archived at the DMC within months of their field collection.

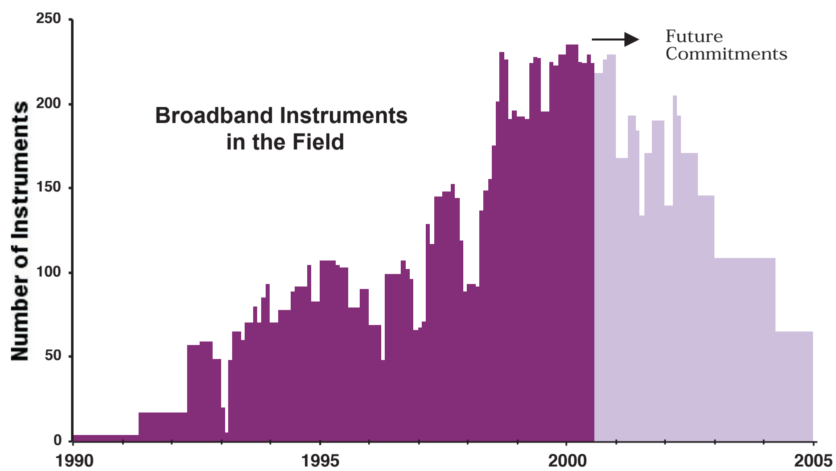
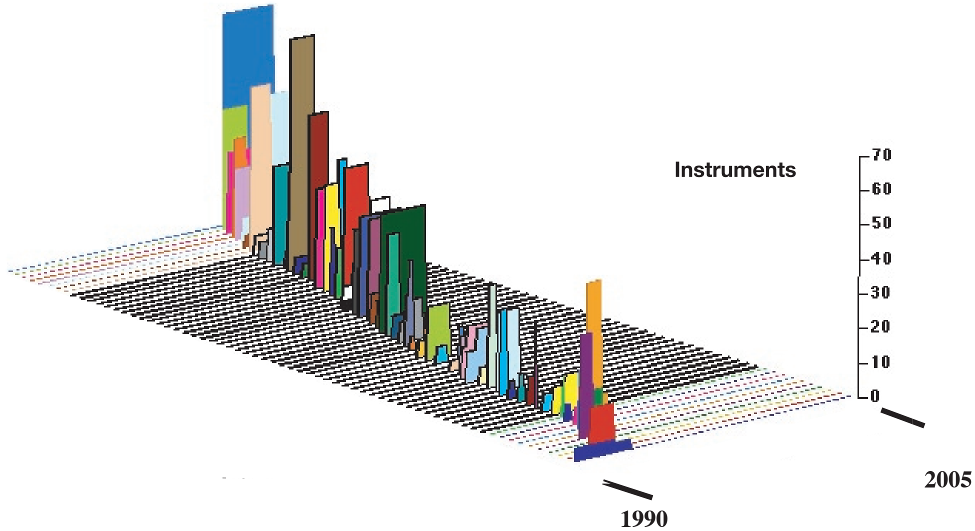


Figure 5. Broadband Instruments in the field
The number of broadband instruments deployed in the field has grown steadily, to more than 200 today. The lighter colors on the right show future commitments - either instruments that are already in the field, or funded NSF projects. Almost half the current pool is already committed to 2004 .

Figure 6. PASSCAL Broadband Experiments
This figure shows the time history of some of the largest of the PASSCAL broadband experiments. Each experiment is one line. Earliest experiments are at the front; recent and future proposed experiments are at the back. The size of the box shows the duration (length on the time axis) and number of instruments for each experiment. The trend to longer deployments (wider boxes) with more instruments (higher boxes) is clearly seen.



The increased demand for equipment has resulted in a two- to three-year wait for significant numbers of broadband sensors and data loggers. We anticipate the improved capabilities of the new generation of instruments will increase the already intense pressure on the facility for broadband instruments; increased experiment efficiency made possible by digital communications capabilities will expand the range of what researchers propose and ultimately accomplish. Nevertheless, we do not expect demand for instrumentation and experiment support to grow in an unbounded fashion. Augmentation of broadband recording capabilities in the next five years will significantly improve the science that can be achieved, and will help us to get closer to a reasonable balance between equipment demand and supply.

To meet the needs of the community, we need to systematically begin replacing the current aging pool of data loggers with simpler, more reliable, data loggers. Although the current data loggers have performed extremely well, their increased failure rate, 15 year-old technology, and complexity of operation make their replacement an priority. Simpler, more reliable, data loggers will enable the largest experiments (of 60-120 broadband sites) to be logistically possible for a small group of researchers to conduct simpler, more reliable, data loggers, in tandem with real-time telemetry, will significantly reduce the cost of maintenance.

In addition, the size of the broadband equipment pool needs to be increased by at least 70 stations to begin to provide adequate resolution as envisioned in the original IRIS proposal 15 years ago and demonstrated repeatedly by experiments in the intervening years. This increase would make it feasible for researchers to conduct broadband experiments with 100 or more instruments. As an example of what could be achieved, 100 instruments in a 10 x 10 array with a 50-km spacing provides a 500-km aperture and resolution on the order of tens of kilometers at the base of the lithosphere. Furthermore, such an array would provide the ability to resolve deeper Earth structures with an unprecedented accuracy. Similarly, closer spacing of these same instruments would dramatically increase 3D resolution in the lithosphere.

Active-Source Experiments

In the past decade, by pooling the PASSCAL instruments with those from the Geological Survey of Canada, the Stanford/IRIS/USGS SGR(Seismic Group Recorder) facility and the US Geological Survey, cooperating groups of researchers have been able to conduct surveys with as many as 600 instruments. While this helps with spatial coverage, use of several different types of instruments with different instrument responses invariably introduces significant data-concatenation and processing difficulties, seriously reducing efficiency and data quality. In addition, the SGRs and cassette recorders now have far exceeded the end of their useful lives, and support for the SGR facility is being discontinued.

For the last three or four years, the number of 3-channel instruments has remained around 300, of which approximately 250 have been available to active-source experiments. However, passive-source experiments have been placing a strong demand on these facilities, particularly over the last year, creating scheduling difficulties for active-source experiments. When not in use in active-source deployments, these systems have been used increasingly in passive-source experiments to fill the gap between instrumentation supply and demand. Although these older 3-channel REFTEK units still have an important role to play (for instance, in some 3-component studies and very large deployments), they are difficult and expensive to use for most current active-source applications that typically require high-density, mobile deployments during short, high-intensity experiments. As their usage in active source studies decreases, the 3-channel instruments are proving to be very effective in passive operations. For the past decade, there has been growing pressure from the

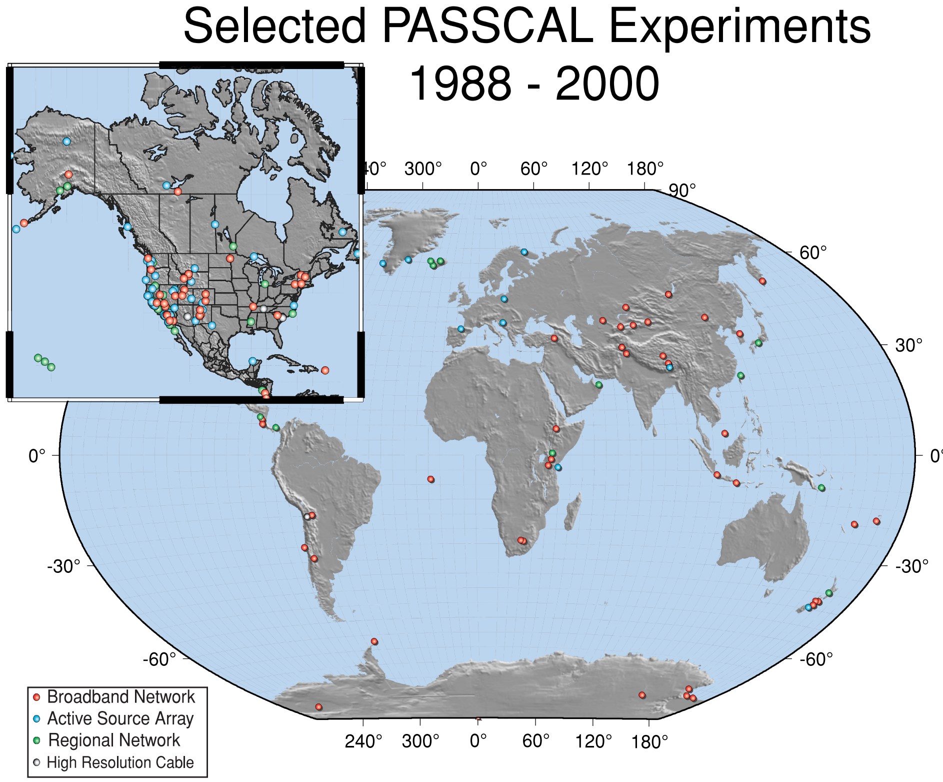


Figure 7. PASSCAL - A National and International Facility
PASSCAL experiments have been carried out on every continent and sampled most of the tectonic environments of North America. Most of the international projects involve close collaboration with researchers in the host country. A map with more detail of experiments in the western US is included in the main part of this proposal .

active-source community for more instruments and especially for instruments that are smaller and easier to deploy. The REFTEK 125 "Texan" instrument was designed specifically to meet this need. This lightweight, compact, single-channel recorder has been used very effectively in the field since early 1999.

For reasonably practical large-scale 2D and modest 3D surveys, researchers need on the order of 2000 such instruments to achieve appropriate structural resolution for crustal and lithospheric imaging, and to be able to link subsurface geophysical images with surface geological mapping. Two thousand instruments would produce adequate 3D-wavefield sampling to enable an array of 45 x 44 stations with an aperture of about 4.4 km to be used to image important geological structures (e.g., fossil sutures, magmatic systems, complex fault zones, etc.) and resolve details on the order of a few hundred meters (to a kilometer) into the mid crust. With closer station spacing, the same array could be used to image near-surface structures in environmental, groundwater or neotectonic studies with resolutions on the order of a few meters. Deployed as a linear array, these instruments would provide sufficient aperture and resolution to significantly improve lithosphere-scale refraction and reflection profiles. Balancing aperture and resolution considerations for different situations permits a great deal of flexibility in experiment design, and provides the versatility needed for creative imaging experiments.

Over the next 5 years, we seek to add 720 single-channel Texan instruments and an additional 200 3-channel Texan instruments. PASSCAL currently has 300 Texan instruments and supports another 440 "Texan" instruments in the PASSCAL instrument center through a cooperative agreement with the University of Texas, El Paso. The UTEP-owned systems are used for PASSCAL experiments effectively in the same fashion as the IRIS instruments. Thus by 2005, PASSCAL would be able to field up to 1660 Texan instruments for field experiments with a total of up to 2060 channels. Direct extrapolation of the largest PASSCAL active-source experiments conducted previously (approximately 1000 channels), and plans under development for upcoming PASSCAL active-source experiments, indicate that the increased efficiency of deployment of the Texan instruments alone will lead to requests for at least 2000 of these instruments in a single experiment as soon as they are available.

The first two PASSCAL multi-channel recording systems were purchased with support from the Basic Energy Sciences program of the Department of Energy. During the last five years, two additional systems were purchased and demand for their use has kept pace. The equipment, each of which recorders 60 channels on a single recorder, has been used very effectively for crustal imaging and a number of shallow studies of fault zones, aquifers and hazardous-waste sites, as well as training and education in undergraduate classrooms and field labs. The number of experiments supported by this pool of instruments is now on the order of 20 per year, with many experiments utilizing multiple systems.

The multichannel equipment is intended to supplement similar systems already in the research community. In most of the major experiments, the PASSCAL equipment will be used along with similar equipment owned by the PI or the USGS. At the present time, we anticipate a growth in the number of these systems to six.

Five Year Program Plan

Core Program Support

The next five years will bring major changes in the operation of the PASSCAL facility, with additions of significant numbers of new-generation instruments.

The request for core program support, which represents the basic day-to-day operation of the PASSCAL facility, includes:

- Instrument Center Operations,
- Experiment support costs,
- Instrument repair and maintenance,
- Broadband Array and Texan support,
- Staff salaries,
- Staff and instrument center personnel travel costs,
- Standing Committee costs,
- Insurance and
- Miscellaneous materials and supplies.

We also expect to coordinate PASSCAL facilities maintenance and development with USArray as it develops over the next five years. Together, these programs will provide unprecedented opportunities for detailed imaging of the Earth's crust, mantle and core. With the PASSCAL instrumentation pool, seismologists can pursue innovative ideas to study relevant problems anywhere in the world. This ability is perhaps the greatest success of the PASSCAL program over the last 15 years. USArray is a natural extension of this success but it is not a replacement for the PASSCAL core program. If funded, USArray will function as a single integrated experiment focused exclusively on the US. Instrumentation in large transportable and flexible arrays that make up the seismic component of USArray will be deployed in a coordinated fashion for a ten-year period. We anticipate that a potential outcome of USArray will be to increase the demand for similar dense deployments elsewhere in the world. Thus, we seek to maintain and slowly expand the PASSCAL pool to meet this demand.

Amortization – Protecting Past Investments

The original REFTEK instruments were designed in 1985, and the first production instruments were delivered to PASSCAL in 1988. By the start of the next five-year agreement in July 2001, the average age of the PASSCAL REFTEK instruments will be almost 8 years. Instrument failures have become more frequent, and maintenance is increasingly more time consuming and expensive. We propose to replace the oldest instruments with new-generation instruments over the course of the new agreement.

As the age of the current instrumentation increases, greater effort is required to maintain the instruments and keep them suitable for field use. The PASSCAL equipment is either in use or in transit continuously and, therefore, the wear and tear is much greater than on other systems that might only go to the field once a year. Both older and newer versions of the current recording units have the same operational capabilities, but do not have the same electronics inside due to design modifications introduced over time. Circuit boards are not universally interchangeable so configuration management has become a significant issue with older units. Furthermore, different-revision repair parts must be kept in stock. So far, this instrument aging process has been manageable, but maintaining experiment success rates has been increasingly costly, and success rates will be adversely affected in the relatively near future if significant equipment purchases are delayed.

The proposed amortization will allow us to replace approximately 196 data recorders and 65 broadband sensors over the next five years. This will allow us to take the oldest and hardest-to-maintain instruments out of field operations. While many of these instruments will be discarded, we anticipate that a few (~10 per year) could be made available to the community for "non-portable" or educational applications.

Advancing the Facility toward Completion

To satisfy requirements for reliable and flexible field instrumentation, even at current levels, additions of three types of new instrumentation are needed in the next five years. These additions include increases in the number of new Texan instruments, acquisition of broadband stations and the purchase of more multichannel units.

The most significant area of growth in the core PASSCAL program will be in the number of single-channel and 3-component ("Texan") recorders. We plan to purchase an additional 720 single channel instruments during the next five years. We also plan to purchase 200 three-channel versions of the Texans. These instruments will be able to provide three-component recording in experiments where shear waves are important and still maintain the small size and weight characteristics of the single channel units.

Proposed PASSCAL Instrument Facility		
	2001	2006
Short-Period Passsive Stations	330	330
Broadband Passive Stations	210	280
Texan Single-Channel Recorders	300	1020
Texan Three-Channel Recorders	0	200
Multichannel Sytems	4	6

We plan to purchase an additional 70 broadband stations. This will help alleviate some of the back log we have currently, and these station, coupled with the replacement instruments we will be purchasing. will provide a significant number of new instruments in the PASSCAL pool.

Finally, the demand for the four multichannel instruments has exceeded our projections. The program proposed here would add an additional two instruments over the next five years.

Integrative Activities

The concept of the Seismic Wide Area Network (SWAN), first introduced in the last IRIS proposal is that all instruments would be interconnected through some type of digital communications infrastructure. In the past five years this technology has advanced dramatically and instruments with this capability have been developed. IRIS has placed orders for prototypes of this instrumentation from two different manufacturers. These new instruments will be capable of operating either in the now-traditional stand-alone mode, or as an element of a network of virtually any scale from meter-scale station separation to global scale like the GSN. The only difference between different networks would be in the communications medium and the software used to control data flow to a central recording and distribution site. Such capabilities also make it possible for researchers and educators to readily implement "virtual seismic networks" by combining data streams from any stations they choose, locally globally or in any combination.

The global Internet communications system is rapidly changing. Although universal internet service does not exist today, this will be much closer to reality in the next five years. The new-generation hardware will allow IRIS to adapt to changes in communications technology as these changes emerge in the next five years. Our recent experience with the new broadband array, and the limited global data currently available, has demonstrated that improved communication capabilities lead to significant increases in data quality and recovery rates, thus improving experiment success. Perhaps more importantly, real-time telemetry drastically reduces the data handling tasks faced by a PI. Real-time data allows the PI to detect events and associate them with catalogues on a systematic and regular basis. This makes it possible to monitor the operation of the array and detect problems as they occur. Real-time delivery of data also relieves the massive sort problem associated with creating network volumes from station tapes and also allows the delivery of data to the DMC in a timely manner.

PASSCAL will continue to acquire moderate numbers of "state-of-health" communication systems to meet critical needs for remote deployments, as well as to expand and improve the broadband-array capabilities during the next few years. As the technology improves and power and transmission costs make it possible to acquire low-power telemetry systems that can transmit all of the data from a remote station, we plan to integrate such new systems as rapidly as possible.

Software development in support of telemetry and field operations will be done in cooperation and coordination with the other IRIS programs. For instance, major problems introduced with telemetry will be related to remote station control and data quality control, problems that are important to PASSCAL, GSN and DMC, and require both coordinated and program-specific software development.

The Data Management System

Introduction

Fifteen years ago, most seismologists were limited to the data they collected themselves or received from colleagues. Today, due in part to the IRIS Consortium and its Data Management System (DMS), researchers can now harvest a rich variety of data from coordinated and linked data systems. Before a comprehensive data management structure existed, a tremendous effort was required, even for researchers at large institutions, to assemble, organize, reformat, and digest data from a multitude of independent data sources. Researchers from smaller institutions were at a significant disadvantage because of their inability to either acquire seismic data in the first place or manipulate large amounts of data.

To deal with the increase in data volume expected from the GSN and PASSCAL programs, the founders of IRIS included the concurrent developments of a centralized data system. The fundamental goals of the initial DMS were to coordinate the routine aspects of data gathering and organization and shift these tasks to a central facility accessible to all researchers. The DMS would enable seismologists to focus on their research instead of the more mundane aspects of collecting and assembling the required data sets prior to beginning research.

The investment made by the National Science Foundation in gathering large quantities of high quality seismic data needs to be protected and preserved for future generations. Like other Geoscience disciplines, such as oceanography and atmospheric sciences, the value of seismological data often increases with time, as it can be used to study slowly changing characteristics of the Earth. In addition to facilitating current research activities, the DMS has responsibility to maintain and preserve the continually increasing archive of seismological data for future studies.

Evolution of the IRIS Data Management System

The original 1984 IRIS proposal stressed the development of a central node called the IRIS Data Management Center (DMC). At that time, a large brick and mortar data center was envisioned. In 1985, the technology capable of storing the volumes of data projected from the GSN and PASSCAL programs was just emerging. The anticipated requirements were to manage about 500 gigabytes of new data per year and service a few hundred data requests per year. Although today this task seems straightforward, one must remember that a large disk drive in 1985 stored less than 500 megabytes and physically occupied the space of a standard washing machine. Scientists were just beginning to hear the term gigabyte. Currently, we are adding four terabytes of waveform data to the archive each year and servicing several thousand requests each year. The original design goals underestimated our science's growth by an order of magnitude.

To manage the data from the GSN and PASSCAL programs, the DMS initially worked with the University of Texas Institute of Geophysics in Austin to develop an interim DMC. We felt that the knowledge gained by developing a small interim system, would allow IRIS to create a more flexible, permanent data system. By the late 1980's, an interim DMC had been established in Austin where data were being stored and requests for data were being processed. Simultaneously, Columbia University began developing software to formulate data requests, and the University of Washington began to develop a real-time system to recover data from stations after significant earthquakes.

The early stages of development focused on procedures for quality control and data management, with particular emphasis on GSN data. IRIS worked with the Albuquerque Seismic Laboratory (ASL), operated by the USGS, and the IDA group at the University of California, San Diego to develop two Data Collection Centers (DCCs). These facilities continue to serve as the primary source of quality control for GSN data and, more importantly, the keepers of the metadata (e.g. instrument response) needed to fully understand the seismic data being generated. As the DMS evolved, other layers of quality control have been incorporated in institutions that use a large amount of GSN data, such as the University of Washington and Harvard University. These centers are charged with examining data quality from a user's perspective, in a manner that complements the procedures carried out by the GSN network operators at the DCC's.

As the DMS procedures for handling GSN data have evolved and stabilized, there has been increasing emphasis over the past five years on mechanisms for the effective handling and archiving of PASSCAL data. Data from long-term, broadband PASSCAL deployments are now treated at the DMC in a manner that is similar to GSN data, allowing scientists to use a common set of request tools to access all data. In cooperation with the PASSCAL program, the DMS

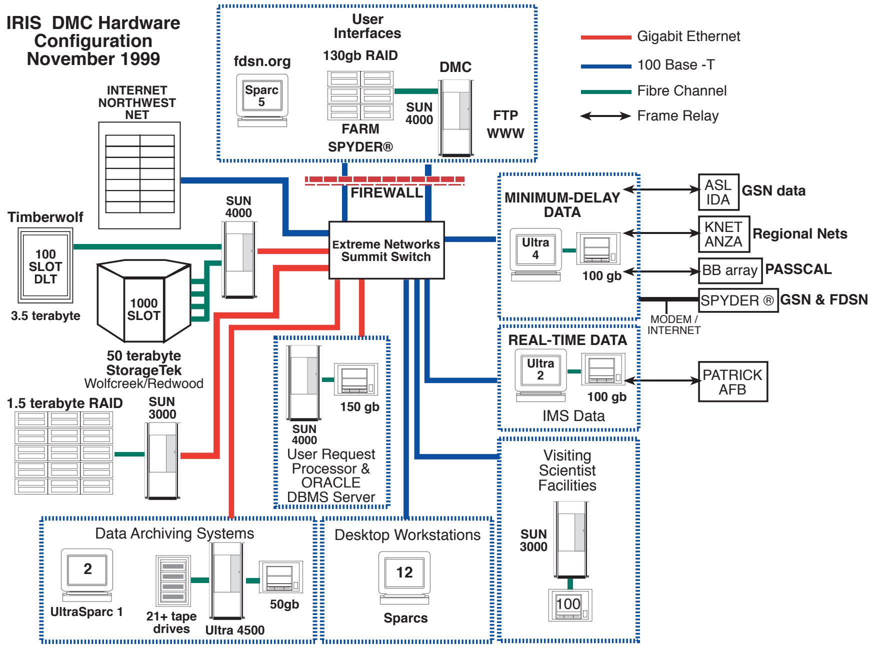


Figure 1. Computing Infrastructure at the IRIS DMC
NSF funding has enabled IRIS to purchase the infrastructure required to archive terabytes of seismic data and service thousands of requests for data. The client-server based architecture relies heavily upon server technology from SUN Microsystems. Tape mass storage systems are those from Storage Technology Corporation Servers are interconnected with either gigabit ethernet (server to server) or 100 base-T technology from workstations to servers. Due to the scalability of this configuration, capacity can be increased by incrementally increasing computer memory and processors rather than introducing additional, and expensive servers. Large disk based RAID systems are used in mission-critical locations in the hardware system.

also provides hardware, personnel and software support to help PIs consolidate data from large experiments and prepare data for archiving at the DMC. In some cases, seismologists choose to have data delivered to the DMC directly from the field, either in near real-time (in the case of the PASSCAL broadband array), or soon after collection and initial quality control, in the case of disk/tape-based retrieval. PI's can then make use of the data management services and extensive hardware resources of the DMC to carry our pre-processing and data selection. The services allow users to reduce the large volumes of raw field data to manageable quantities for use at their home institutions.

IRIS is inherently an international organization due to the geographic distribution of seismic sensors it operates. The IRIS DMS has worked with international operators of a variety of networks to develop standardized data formats, data request methods, data distribution techniques and documentation. IRIS involvement in the Federation of Digital Seismographic Networks (FDSN) has resulted in data exchange with other nations, including Canada, China, France, Germany, Italy, Japan, Netherlands, Switzerland, and Taiwan. In most instances, these data meet the standards set for data from the IRIS GSN. Our international partners consult with IRIS on data management and data distribution methods. Seismological networks around the world are using applications developed by the DMS to archive, distribute and quality control their seismological data. In cooperation with US Geological Survey, the DMS has encouraged the exchange of data between other US-supported networks. Many regional networks now contribute data to the DMC and cooperate with the DMS in the development of new techniques for interactions between data centers.

Where the IRIS DMS is Today

Components of the Core Facility

Underlying the structure of the DMS are:

- the physical infrastructure, the hardware (computers, disks, mass storage systems) and communication devices (modems, Internet and telecommunication links) as shown in Figure 1,
- the core data archive, the permanent archive of all IRIS-produced data and contributed data from cooperating networks,
- the software system, the data base management system, data quality control tools, fast data handling methods, and the user access tools as shown in Figure 2, and
- the staff, the dedicated and highly competent personnel at the DMC and DCC's, who operate the hardware, maintain the archive, develop and maintain software, and interact with the user community in responding to requests.

The physical infrastructure has evolved in response to both increasing demands on the facility and developments within the computer industry. In the DMC, IRIS now has a state-of-the-art facility that is modular in structure and is placed to evolve and grow in step with hardware enhancement and user demands.

The core data archive consists of 14 terabytes of data stored "near-line" in the primary mass-storage device. Because researchers have two fundamentally different types of access patterns — station-oriented and time-oriented — the continuous waveform archive includes all data stored for both methods of retrieval. In addition, a duplicate copy of all data is stored for safety. Special subsets

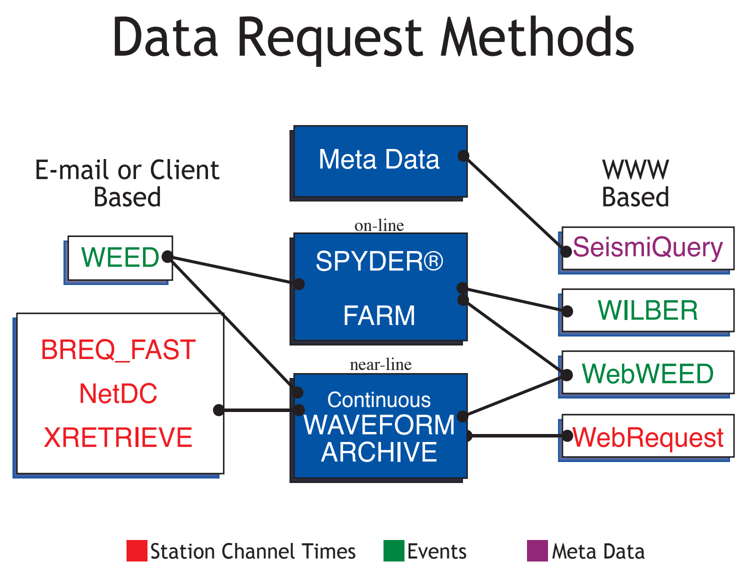


Figure 2. Data Request Tools
Several methods of generating data and information requests have been developed by the DMS. There are a variety of tools, some are e-mail based, others are WWW based. Some tools are tailored for making requests by specifying specific seismic channels and time periods, whereas others are intended to make requests based upon the interrelationship of events and seismic stations. This figure acts as a guide for users to determine which tool best meets their specific data needs.

of the waveform archive are also maintained on-line (Figure 2), in a large RAID (Redundant Array of Inexpensive Disks), to facilitate rapid access by users, and optimize interactions with the mass store. The most important of these subsets are near-real-time data from selected stations (SPYDER®) and quality-controlled data for all large events (FARM). All metadata, containing full descriptions of archived data and data sources, are also available on-line.

The central component of the software is a relational database management system that links the user to the database and provides a set of tools for interrogation of the DMC holdings and selection and extraction of data. The IRIS DMS also develops and maintains other software applications to assist users. These include applications for: generating data requests with complex requirements; converting data in SEED format into a variety of analysis formats; evaluating and removing the complex filter responses for specific seismic recording channels; and a variety of other utilities to assist seismologists in dealing with data received from the DMC.

The staff at the IRIS DMC in Seattle consists of:

- the DMS Program Manager,
- a webmaster,
- an office manager,
- a systems administrator responsible for systems level software and computing infrastructure,
- a director of operations and an operations staff of three technicians for all data archiving and request processing, and
- four software engineers who take care of all internal applications as well as distributed software.

DMS staff also work closely with the field and software engineers at the PASSCAL Instrument Center to ensure proper archiving, and ease of accessibility of data from PASSCAL experiments. In addition to the staff at the DMC,

Figure 3. Data Shipments
This figure shows the number, by type, of data shipments for the past several years. The bottom (red) area, depicts data requests serviced out of the mass storage system, the next 4 areas (yellow through dark green) show those serviced out of the on-line data sets in the FARM and SPYDER® datasets. The violet areas depict shipment of entire FARM products, via either physical (tape) or electronic (ftp) methods. Ten years ago data shipments were in the hundreds per year and now we anticipate servicing more than 55,000 requests in the year 2000.

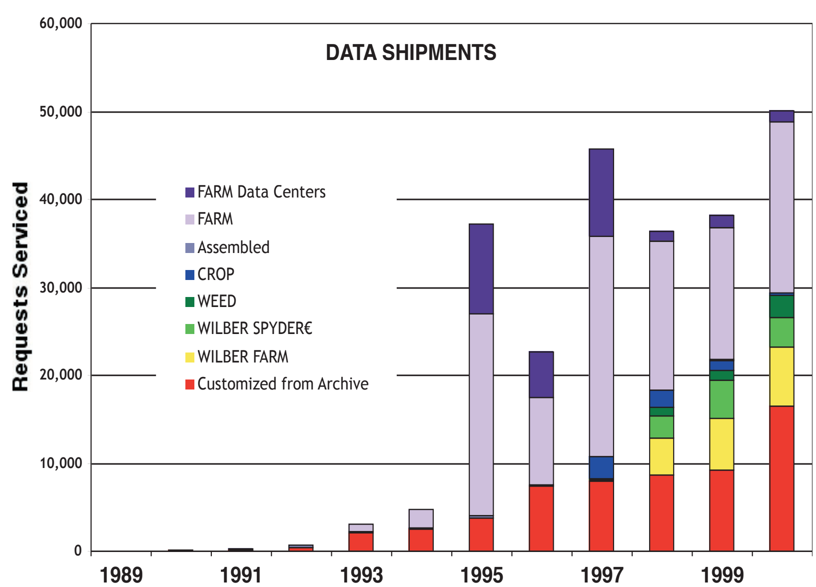
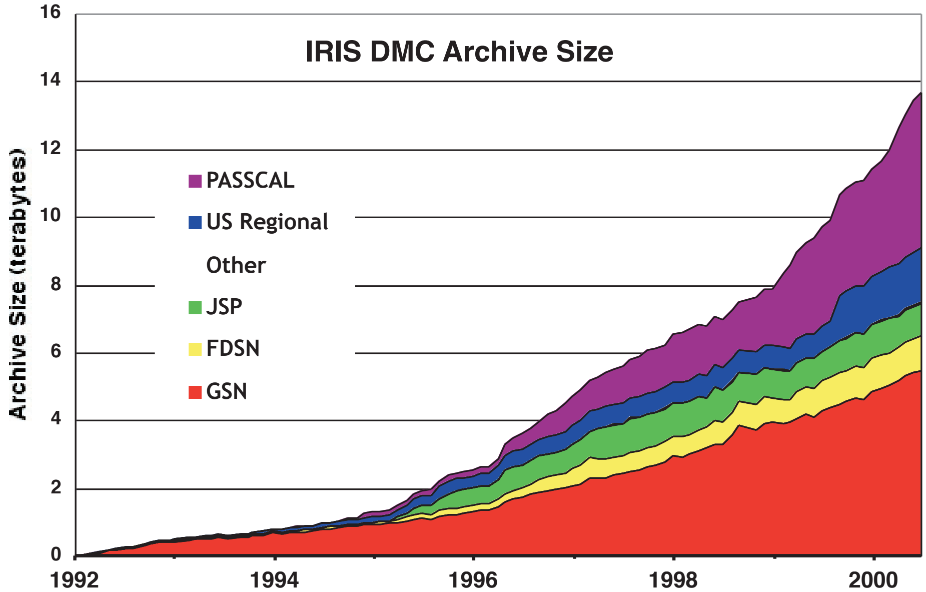


Figure 4. DMC Data Archive
This figure shows the exponential growth in the data holdings at the DMC. The red area shows data from the USGS GDSN network and the IRIS GSN, the yellow area shows data contributed to IRIS by the FDSN, the green area shows data from IRIS arrays in the former Soviet Union, the blue area shows data from US regional networks and the US National Seismic Network, and the purple area shows data from the PASSCAL program. A total of 14 terabytes of waveform data are now stored at the DMC. The archive is growing at the rate of about 4 terabytes per year.



the core operations of the DMS includes approximately 4 FTE's at UCSD and 7 FTE's supported by the USGS at ASL.

Automated Methods for Data Collection and Distribution

For the past dozen years, the IRIS Data Management System has been servicing data requests from the seismological community. The number of requests has grown from approximately 200 requests per year in 1990 to more than 50,000 per year today (Figure 3). At the same time, there has been an exponential increase in the volume of data stored in the archive (Figure 4). The experience with usage patterns has allowed the DMS to develop new methods of providing data. By creating request tools carefully linked to user needs, and by implementing automated procedures, the DMC has been able to respond to the increased demand with only minor increases in staff.

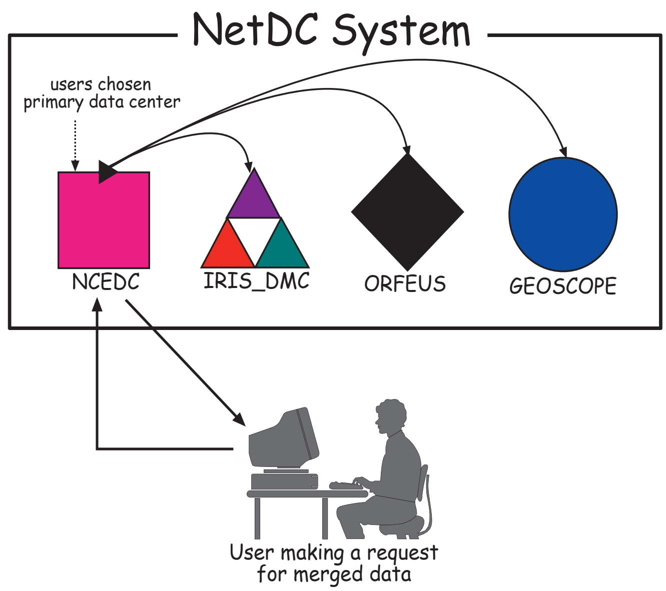
On the data collection side, advances in storage and communications technology have made it possible to keep pace with the rapid increases in data flowing into the archive. We have developed systems that safely store seismic waveforms in mass storage systems of considerable capacity and high reliability. We have moved from physical data transfer on tape, to electronic data transfer, by implementing a high performance, dedicated data network between the DMC in Seattle and the largest data generating nodes. In so doing, data can be archived in a completely automated manner, as they arrive, instead of requiring the interaction of a data technician.

On the data access side, we have developed a variety of user access tools that allow scientists to easily generate requests for data in a variety of ways (Figure 2). The most obvious example of how adaptation to user demand can enhance operations has been in the development of the FARM archive. If the number of customized responses to individual requests had continued to increase at the rate experienced in the early 1990s, it would have been necessary to increase the number of staff significantly. Instead, a different strategy was adopted, in which datasets were proactively assembled from the most significant earthquakes. These secondary sets of data products, which we named the Fast Archive Recovery Method (FARM) products, have been effective in reducing the load on the primary mass storage system. The FARM archive now contains data for all large earthquakes (Mw >5.7) recorded since 1972. The interactive web-based tool, WILBER, allows scientists to view seismograms and extract portions of the FARM products that meet their particular needs, rather than requiring them to transfer the entire dataset. Simultaneously, the more general data request tool, WEED, was modified so that the requests it generated could be automatically directed to the FARM when appropriate, rather than to the large, general-purpose archive.

By implementing such strategies, the growth in user-defined data volumes has been accommodated primarily from the on-line data sets of the FARM and the near-real-time SPYDER® system, rather than from the large mass storage systems. In Figure 3, the lower sections of each column are those data sets that are serviced directly from our mass storage systems and are somewhat resource-intensive to produce. The upper components in this graph all represent automated reuests which require no operator participation. In addition to being more efficient in the use of DMC resources, these request mechanisms are much faster, with users typically receiving data within minutes of their request.

While these enhanced data access procedures greatly improve efficiency, they not restrict the users ability to access any and all data in the archive. As indicted in Figure

Figure 5. Networked Data Centers
NetDC is a software system that includes a format specification for researchers to find out information about the waveform holdings of a data center and receive data in a uniform manner. A NetDC user can send a request to any participating NetDC data center and receive waveform data or information from any of the other centers. The NetDC response can be sent directly from each data center to the researcher, or as depicted above, the responses of each data center can be merged into a single response for the original information requester. The NetDC system is a true distributed data center architecture, with all nodes being peers with one another.



2, most data request methods allow direct interaction with the full archive. Directing a request to the full archive can take longer (althoough the median response time is much less than one day), but users have access to all continuous data and are not limited to segments containing only large events.

The DMC is positioned to accommodate increasing use through strategies that are already in place. We anticipate that the future increases in the number of data requests will be accommodated by automated methods, allowing the DMC to service more requests with little increase in operations staff.

Integrating Data from Many Sources

Historically, extra effort was required to merge data from permanent global observatories, temporary networks, and array deployments such as PASSCAL experiments. An important accomplishment during the past five years has been the integration of nearly all IRIS generated data into one data storage and access model. Today it is possible to request data from IRIS GSN, IRIS PASSCAL, regional networks, and non-US national and/or global networks in a single data request. The IRIS DMC database management system effectively combines data from multiple sources, with all of the nearly 14 terabytes of data in the archive accessible in exactly the same manner – from the tool used to generate the request, to the applications that use the data. The data are returned to the requestor in the self-documented SEED (Standard for Exchange of Earthquake Data) format. Figure 4 shows the volume and sources of seismic data currently residing at the DMC.

IRIS encourages the exchange of data between national and international networks. As a founding member of the Federation of Digital Seismographic Networks, the IRIS DMC acts as the first FDSN archive for continuous data. As such, data from most of the FDSN members are available to the global community in a manner that is identical to IRIS GSN and PASSCAL data. The yellow section in Figure 4 represents the volume of data stored at the DMC from FDSN networks. Although the data volume is small compared to IRIS generated data, the network locations and the high quality of the data make these data a valuable as part of the global seismic record.

Networking the Networks

The merging of IRIS and other network data at the DMC represents a *centralized* data center model. While this model is one way of handling data from several networks, the IRIS DMC has also worked to develop one of the first truly functional *distributed* data systems called NetDC (Networked Data Centers), as depicted in Figure 5**.**

NetDC is now fully functional at four data centers: the GEOSCOPE Data Center in France, the ORFEUS Data Center in the Netherlands, the Northern California Earthquake Data Center (NCEDC) in Berkeley, and the IRIS DMC in Seattle. The system is designed to allow a seismologist to request data from any node in the system and to receive information or data from any of the centers. Although the system was only recently deployed, it is a promising approach to distributing the effort required to meet the scientific community's data requests.

A Portable Data Collection Data Center (PDCC) software application has been developed as a complement to NetDC (Figure 8). This enabling technology allows seismic networks with limited resources to make their data available to the worldwide community. Several networks have adopted the PDCC approach to data management. The PDCC system can be installed with NetDC software, giving a network the ability to participate in the distributed system.

Five Year Program Plan

The IRIS Data Management System has met most of its design goals, and exceeded all original data storage and request estimates. We believe that we are well positioned to maintain the growing archive, handle the evolving data demands of the seismological community, and help foster new methods for responding to user requests.

Core Operations

With our solid foundation, we propose to continue to enhance and improve the services and products provided to the community. Our goal continues to be the delivery of high-quality seismological data in a manner that promotes ease of access with minimal delay. To achieve this goal and to develop new data archival and delivery techniques, we will continue to improve automation of the main processes at the DMC.

Expand the IRIS DMS Dedicated Data Communications Network

The amount of data being handled by the IRIS DMC continues to grow. In the past, data were transferred to the DMC by tape, requiring operators at both the tape production and tape reception points. Reading and writing physical media also introduced a point of mechanical failure in the data flow path. Beginning in 1997, we began installing dedicated data circuits between the major data providers and the IRIS DMC. Currently we use Frame Relay circuits to the US National Data Center for the International Monitoring System (IMS) for the Comprehensive Nuclear Test-Ban Treaty (CTBT) located at Patrick Air Force Base, Florida, the Albuquerque Seismic Laboratory, and the University of California, San Diego. We have found that receiving data electronically allows us to automate the archiving and management of waveforms, greatly reducing the number of data control technicians needed at the DMC and DCC's. We propose to extend the dedicated Frame Relay circuits to additional locations (e.g. the PASSCAL Instrument Center in Socorro and the National Earthquake Information Center (NEIC) in Colorado). Decreasing prices and cost savings through coordination of network links allow this activity to be accomplished with minimal increase in cost.

Development of Comprehensive FARM Products

The growth in data shipments over the past three years has been accomplished by building useful access tools to pre-assembled, event-based data sets. Although currently we only build FARM products for IRIS GSN data, we intend to fully populate the FARM data holdings with data products from all networks at the DMC. This effort is primarily an operational task that can be accommodated with existing staffing resources, time and a modest increase in our on-line disk storage. As more data become available, we anticipate that the DMC can continue to service an increasing number of data requests from our on-line sources automatically. Not only will we be able to improve our responsiveness to user's data requests, but we can also shift even further into the automated environment.

Development of More Comprehensive Request Tools

As IRIS and other data sources have produced more complex data types, the need to make it simple for seismologists to gain access to the data continues to evolve. The DMS, along with a number of other US seismic data centers, has adopted a commercial product (ORACLE) as the relational database system for management of the DMS archive. As more complete data descriptors are linked from the metadata into the ORACLE database, it becomes possible to develop comprehensive request tools integrated with the capabilities of ORACLE. In that manner, requests for data with a complex set of attributes will become possible. Our long-term goal is to develop a single data request tool, with both flexibility and ease of use, which will satisfy most research applications.

Amortization - Protection of Previous Investments

New Mass Store Drive Technology

When the current mass storage system was acquired in 1997, we adopted a state-of-the-art robotic system with helical scan tape drives. With a list price of about $150,000 each we could acquire only four of the costly drives for the tape sub-systems. Our present mass storage system is approximately half full and will need to be replaced or augmented during the course of the next proposal. In addition, initiatives such as EarthScope/USArray and the USGS Advanced National Seismic System (ANSS) will place additional demands on the DMS. We estimate, for example, that EarthScope/USArray alone could double or triple data archival requirements. The ANSS could increase archival requirements by a factor of four or five. New technology, high-capacity, high-performance tape drives will soon surpass the capabilities of our current helical scan devices. At the same time, the cost of these new drives is likely to be much lower, in the neighborhood of $25,000. We propose to augment our existing mass storage systems with newer and less expensive tape drive technology. Due to capacity concerns, we also propose to replace or augment the existing tape library with a 6000-tape library during the second year of the next cooperative agreement. We will increase the number of installed drives, allowing us to process requests for data while simultaneously archiving data at a greater rate. This will significantly increase efficiency, as well as capacity, at the DMC.

Integrative Activities

Data Collection

The use of real-time communication technologies for data collection and distribution has been a goal for IRIS since the beginning and is a theme that runs throughout all of the IRIS core programs. Monitoring the CTBT, responding to earthquake hazards, and providing data access to non-seismologists for educational use and museum exhnbits are all applications that benefit from real-time telemetry. In addition, the automated processing that can accompany real-time data collection and delivery offers efficiencies in operations.

In 1989, as an early IRIS initiative in near-real-time data distribution, the University of Washington developed the SPYDER® system, which enabled people to view seismic data from large events in near-rel-time. The system has become popular, with thousands of users accessing it each year. However some aspects of the SPYDER® system have not kept pace with developments in near-real-time telemetry. In close coordination with the other IRIS program, and with organizations such as the USGS and the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO), we propose to enhance the DMS capabilities with a comprehensive system that will be able to ingest data from a large variety of different data transmission systems, insert the data into a large disk buffer in a unified format, and develop data access tools.

Over the past few years, a variety of data generating organizations have experimented with real-time communication technologies and have developed real-time data collection systems optimized for their particular needs. The CTBTO uses the "CD-1 format", the IRIS/IDA group uses "NRTS ", the IRIS/ASL and USGS/NEIC groups use "LISS ", the PASSCAL Broadband Array and some US regional networks use "Antelope/ORB", and the USNSN and many of the US regional networks use "Earthworm". Many networks allow access to near-real-time data using autoDRM methods (Data Request Manager). To an end user, dealing with the various data systems can be an onerous task. IRIS can play a useful role in dealing with these various protocols and can serve the broad community by collecting and archiving data from the expanding variety of data sources. In cooperation with the parent networks, we will connect to available sources of real- or near-real-time seismic data, and homogenize the data into a single format and data model at the DMC. The real time data will be buffered in disk systems and be stored on-line for about four weeks. The data will then be migrated to the tape based near-line storage systems at the DMC.

Concurrently we will develop data access tools and connection protocols that will allow the scientific research community to gain access to the data in the real time buffers in a single standardized manner. We will work closely with other IRIS programs, other agencies and the community to define the functionality of this data access system. At a minimum, we anticipate that it will include:

- waveform quality control procedures applied to the data in real-time as they are received at the DMC,
- access to data with delays to the end user measured in seconds,
- the ability to configure the stations and channels the user accesses into their own virtual network,
- establishment of data connections between the DMC and end users over which data will flow in nearly real time,
- the ability to access older events and replay them as if they were occurring in real time,
- seamless merging of data from the real time buffers and the IRIS DMC primary mass storage system with the only difference being the time required to service the request.

For the DMC, a primary motivation for developing a real-time system is efficiency. By emphasizing real-time data flow into the DMC archive, we will be able to develop systems to routinely and automatically ingest data from most data sources. Automation will allow us to increase the amount of data we manage while maintaining the current level of service without a significant increase in staff.

The need for real-time and automated data collection is highlighted when one considers the possible demands that could be placed upon the IRIS DMS when the following new data sources come on-line:

- The International Monitoring System (IMS) of the CTBT Organization (10 terabytes/year)
- The USArray project of the NSF (9.4 terabytes/year)
- The ANSS System of the USGS (16 terabytes/year)
- Projects in the oceans such as DEOS and Neptune (5 terabytes/year)

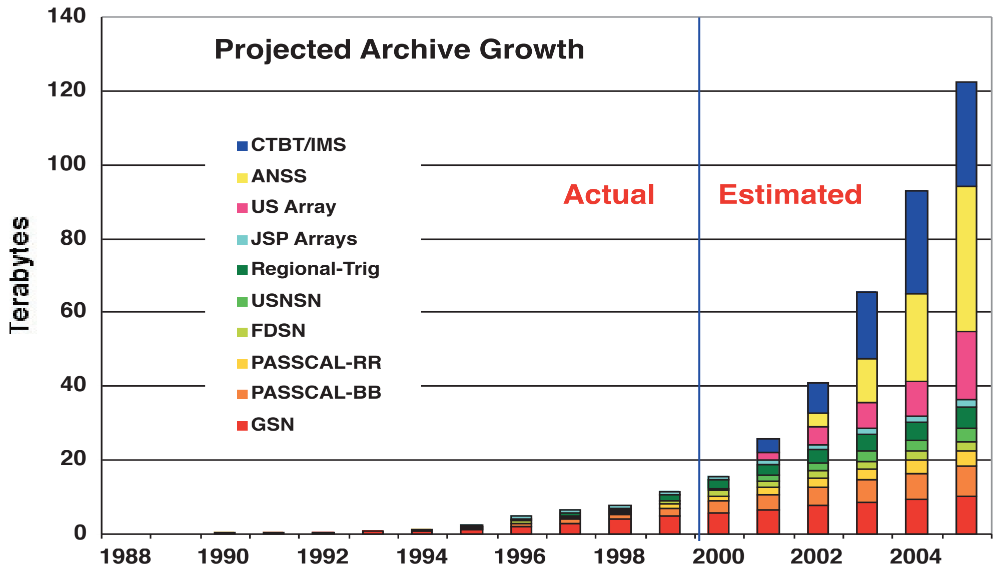
Additionally, other initiatives are already funded and have arranged with IRIS for data archival including: Ocean Bottom Seismograph Instrument Pool (OBSIP; >1 Tbyte/year) and the Electromagnetic Sounding of the Continents (EMSOC, < 1 Tbyte/year).

Given these projects, it is possible that the DMS could be archiving more than an order of magnitude more data by 2005 (Figure 6).

The budget elements requested to support these improvement to data collection activities include:

- enhancements to the dedicated data communications network by adding new circuits to the PASSCAL Instrument Center in Socorro and the USGS National Earthquake Information Center in Golden, Colorado
- high performance, high availability computer and 1 terabyte RAID for real-time data
- software development, primarily in the first two years, through university subaward and/or consultants
- One additional data technician at the DMC to monitor incoming data flow and system performance.

Figure 6. Projected Archive Growth
From the present 14 terabytes, we project that the IRIS archive will continue to grow to more than 120 terabytes by the end of this five-year proposal period. Much of the growth will come through new seismic networks such as the USArray and the Advanced National Seismic System (ANSS). We anticipate that data from the International Monitoring System (IMS) of the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO) will begin flowing to IRIS soon. In addition to the data sources shown in this figure, it is likely that IRIS will also archive data from some programs within the ocean sciences community.



Data Distribution

For the foreseeable future, data collection from remote seismic stations will continue to rely on a myriad of communication technologies and associated protocols, optimized for the operating requirements of each particular network. For data distribution, however, the Internet, or more specifically the World Wide Web, is likely to become universal as the vehicle of choice for the research community and the public. Within the programmatic structure of IRIS, the DMC is the natural node for coordination of data distribution technologies, software and resources. With the rapid evolution of Internet-based systems for data distribution, it is essential that IRIS experiment and apply appropriate technologies. During the next five years, we request support under this proposal to develop a coordinated approach to transmit real time data to end users. The distribution will be done in coordination with developments already undertaken by IRIS programs and other groups in the US, such as LISS2, being developed by the USGS/ASL and Earthworm, being developed by the USGS and university networks. We may also incorporate developments being made outside the seismology community, including services available within the Object Management Group (OMG's) standard Object Request Broker (ORB) architecture.

Development of Data Handling Software

As the amount of data available increases, the average scientist's ability to handle the increasing data volumes and associated metadata using normal Unix or other file system management tools is becoming inadequate. We propose to develop software systems that the user can configure to initiate data requests (continuous or event oriented), initiate data transfer, and provide a local relational database for event and metadata. The data handling system will be configurable so that the data requested are automatically reformatted into a user pre-selected format when it is received, and metadata related to the received waveforms will be updatedand maintained in the user's local relational database.

IRIS is not proposing to develop analysis software for the end users of our data. Instead we propose to developthe infrastructure necessary to manage and manipulate large data volumes at the end user's institution. The software will be platform independent. Rather than developing analysis software, a task more properly done by the research community, we will develop the infrastructure that will manage the data, in an analysis format that will be readily used by the researcher. The data handling software will be written so that analysis software will have simple access to event and metadata through straightforward protocols.

Multi-disciplinary Data Sources

We propose to continue to augment and enhance the IRIS Data Management System to archive and manage data from a variety of non-IRIS data sources, such as relevant data from ocean sciences, and other geophysical data. When possible, we will try to manage the non-seismic data using the same model we use for seismic data. We anticipate, however, cases where our management scheme will have to be modified or enhanced to manage other data efficiently. We will extend the applicability of the PDCC/NetDC system to manage other types of related time-series observations.

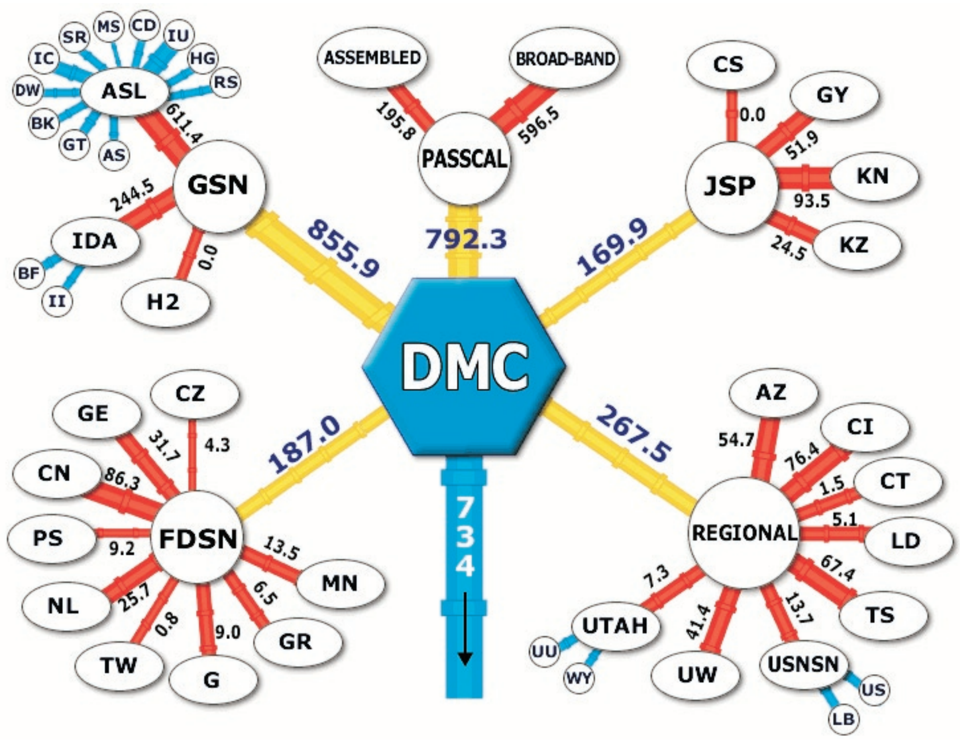


Figure 7. Data In and Out

This figure shows the amounts of data flowing into and out of the DMC archive. Inputs are clustered by the primary data sources (GSN/IDA GSN/ASL, FDSN, JSP arrays in Central Asia, and US Regional Networks). Two letter codes are for individual networks and can be identified using the SeismiQuery tool on the DMC website. Input data volumes are in gigabytes and refer to the dual-sorted increase in the archive size per year. The output from the DMC (734 gigabytes per year) is the volume of data delivered to users. All data volumes are averaged over the past five years; the current rates are significantly higher (see Figures 3 and 4).

Portable Data Collection Systems

Many national and regional organizations are now installing and operating networks with characteristics that similar to the IRIS GSN and PASSCAL programs, making their data of potentially great value if they can be readily accessed. By making it easy to exchange seismic data from stations operated and funded by other organizations and countries, IRIS and the NSF can greatly increase the value of individual datasets, and encourage cooperation and interaction between scientists. IRIS and other networks of the FDSN are demonstrating that data should be a shared commodity. The IRIS DMS has gone one step further by developing a system whereby organizations can easily make their quality controlled data available to the global community through NetDC**.**

Several years ago, the IRIS DMS began developing a system called the Portable Data Collection Center (PDCC). The system provides tools allowing seismic data to be reformatted from the recording format to SEED, the international data exchange standard. Additionally the PDCC provides a suite of tools for monitoring data quality. Figure 7 shows the crucial role that the PDCC can play in the operation of a data center. Together PDCC and NetDC provide all of the primary software tools that a network requires to make seismic data available as part of the global archive. We propose to distribute this software widely, and take a proactive role by providing assistance in installing it at foreign networks, where this is appropriate and useful.

Interaction with National and International Partners

The IRIS DMS works directly with the seismological research community to enhance the services and products it offers. As an example, we have had long-term relationships with the University of Washington, as the host of the IRIS DMC in Seattle. We have also supported waveform quality control at Harvard University to augment the quality control efforts of the GSN Data Collection Centers. Periodically we have supported other universities such as Columbia University and UC San Diego to make data from special seismic networks available to the general community. We propose to continue involvement with the research community by supporting activities at a variety of centers that directly contribute to the data quality or data availability through the DMS. We anticipate continuing support for the University of Washington as the DMC host. Their activities will be to continue to develop the near real time data recovery system, SPYDER® as well as to act as alpha testers for new access tools, or software applications developed within the IRIS DMS. We anticipate significant developments in the area of real-time quality control of

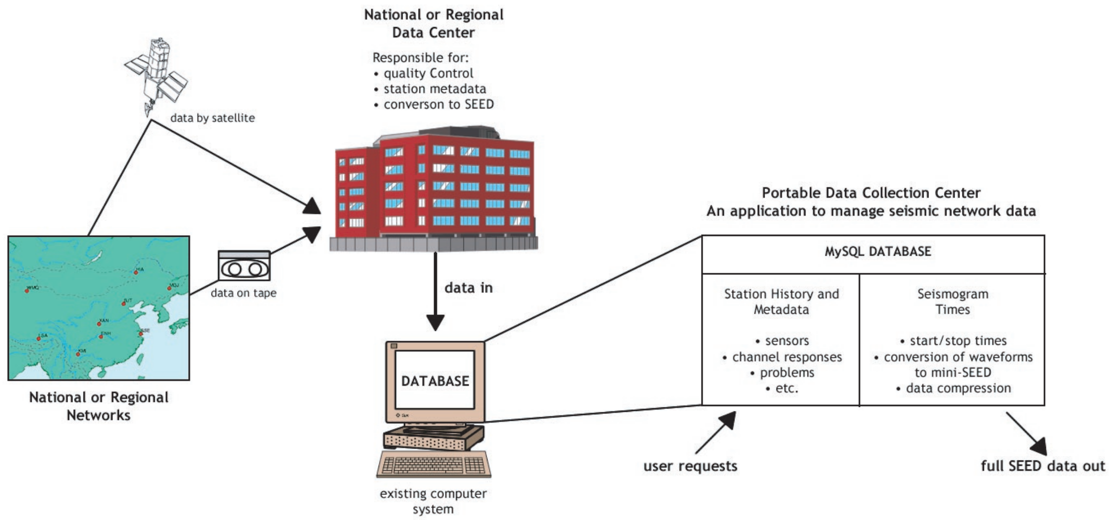


Figure 8. Portable Data Collection Center
The Portable Data Collection Center is an application, written primarily in Java, that can be installed at any existing data center. It is built around the MySQL Relational Database for storage of the metadata needed to describe the station installation and to convert digital counts in the waveforms to actual ground motion. It also has all of the tools to reformat data from its native format into the SEED format. Data request mechanisms are built into the PDCC application. When installed, this software package enables a data center to maintain all of the information required to distribute data in SEED format as well as performing first order quality control of the data.

data flowing into the DMC. For most data sources, the only quality checks that will be made will be by automated algorithmic procedures.

In addition to continuing the host institution arrangement with the University of Washington, we are requesting that an amount equivalent to approximately 10% of the DMS core budget be allocated to develop new interactions between the DMS and national or international centers. These interactions may be with universities or government organizations. Plans for the specific activities to be supported will be developed in coordination the DMS Standing Committee and Executive Committee, and presented to NSF for approval on an annual basis.

As the management and structure for the ANSS and USArray evolve over the next few years, the responsibilities of IRIS for data archiving and distribution may increase substantially. Both programs are in the early planning stages and therefore the exact nature of IRIS responsibilities are still evolving. The IRIS DMC, however, may serve as the archive for both projects. If so, we anticipate that some incremental funding for data management will be provided as part of ANSS and USArray. The basic costs for the core archival infrastructure are included in this proposal. IRIS will be working closely with the USGS, and specifically the NEIC to coordinate our activities related to data distribution systems. We also plan to coordinate activities with the International Seismological Centre in the United Kingdom related to linking their event oriented data center with the waveform oriented data center at the IRIS DMC.

The Education and Outreach Program

Introduction

In addition to the traditional programs associated with data collection and archiving, IRIS now includes a fourth program: Education and Outreach (E&O). As this is the first IRIS proposal to the NSF to include a request for specific funding of E&O activities, we provide below the rationale, background and history of the Education and Outreach program. We detail accomplishments during the first two and a half years of the program and the philosophy behind proposed activities for 2001-2006.

Rationale

As we enter the 21st century, we encounter an increasing number of public policy issues related to land use, resources, environmental challenges, national security, and hazards. Decision-making on such issues requires not only a broad understanding of Earth science data and research, but also an appreciation of their societal implications. It is critical that all citizens are sophisticated consumers of Earth science information, so that they can make informed decisions. This concept of understanding not only scientific data and methods, but their role in society is embodied in the concept of science literacy as defined in the statement "A Cooperative Era of Reform in Science Education" (Science Education News, 1996), issued by the National Academy of Sciences (NAS), the American Association for the Advancement of Science (AAAS), and the National Science Teachers Association (NSTA).

> *"Science literacy consists of knowledge of certain important scientific facts, concepts, and theories, the exercise of scientific habits of mind, and an understanding of the nature of science, its connections to mathematics and technology, its impact on individuals, and its role in society."*

Seismology is an attractive and engaging tool for Earth science education at all levels. Major earthquakes and associated societal implications stimulate a natural public interest in seismology and related Earth science. The study of earthquakes is critical to earthquake hazard preparedness and mitigation. Seismology provides a vehicle for teaching content and skills that directly support the National Science Education Standards (NAS, 1996). Using seismology it is possible to teach:

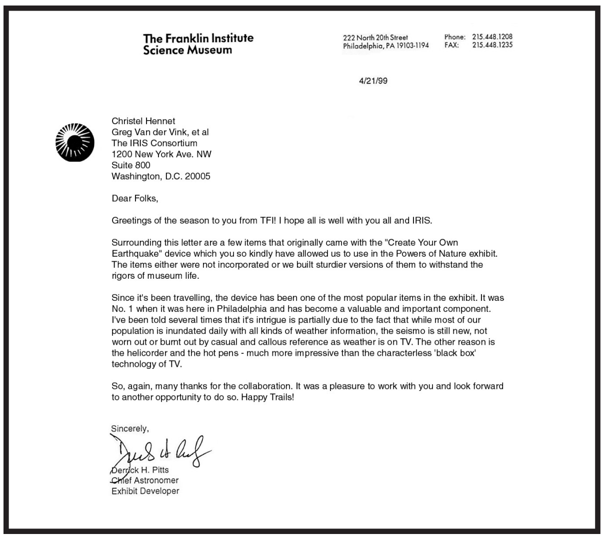
- fundamental Earth science concepts including understanding of the structure of the Earth and plate tectonics,
- critical thinking, problem solving, formulating and testing hypotheses, making inferences,
- the role of technology in accessing, processing and using information,
- occurrences of, preparation for, and the impact of natural disasters,
- fundamental concepts in physics such as wave phenomena, energy,
- basic to advanced mathematical skills,
- data analysis skills including statistical methods, mapping and map analysis, graphing, uncertainty,
- fundamental engineering and related hazard mitigation concepts.

Seismology can be used to involve students of all ages in the processes of observation, analysis and inference -that is in doing science, instead of just reading about or hearing about science. Thus seismology is an excellent topic for integrating education and research, and communicating the essence and excitement of science to students and to the public.

Communicating discoveries in science is not only a societal obligation of the scientific community, it is also a pragmatic necessity. The health and survival of strong scientific research in the United States is predicated upon the public support of scientific endeavors. The Earth sciences, especially seismology, have a unique blend of basic and applied research. Their discoveries are fundamental to understanding the planet we inhabit and have the potential to both catalyze and renew interest in science. This can only be achieved by pursuing strong efforts in education and outreach at all educational levels and for the general public. These efforts must positively impact everyone, not only the small percentage of the population that will go on to pursue careers in science and technology. While there will be few producers of new discoveries, there will be a vast number of diverse consumers of scientific information.

Because of its data, computer resources, organizational structure, membership institutions, and facilitation of basic research, IRIS can make unique contributions to science education at all levels (K-12, post-secondary,

Participating Museum	**Annual Attendance**
American Museum of Natural History *New York, NY*	5,000,000
Carnegie Museum of Natural History *Pittsburgh, PA*	3,000,000
Franklin Institute Science Museum *Powers of Nature Exhibit*	> 450,000
New Mexico Museum of Natural History *Albuquerque, NM*	300,000
Total Audience	**> 8,750,000**


The Franklin Institute
Science Museum

222 North 20th Street
Philadelphia, PA 19103-1194

Phone: 215.448.1208
FAX: 215.448.1235

4/21/99

Christel Hennet
Greg Van der Vink, et al
The IRIS Consortium
1200 New York Ave. NW
Suite 800
Washington, D.C. 20005

Dear Folks,

Greetings of the season to you from TFI! I hope all is well with you all and IRIS.

Surrounding this letter are a few items that originally came with the "Create Your Own Earthquake" device which you so kindly have allowed us to use in the Powers of Nature exhibit. The items either were not incorporated or we built sturdier versions of them to withstand the rigors of museum life.

Since it's been travelling, the device has been one of the most popular items in the exhibit. It was No. 1 when it was here in Philadelphia and has become a valuable and important component. I've been told several times that it's intrigue is partially due to the fact that while most of our population is inundated daily with all kinds of weather information, the seismo is still new, not worn out or burnt out by casual and callous reference as weather is on TV. The other reason is the helicorder and the hot pens - much more impressive than the characterless 'black box' technology of TV.

So, again, many thanks for the collaboration. It was a pleasure to work with you and look forward to another opportunity to do so. Happy Trails!

Sincerely,

Derrick H. Pitts
Chief Astronomer
Exhibit Developer

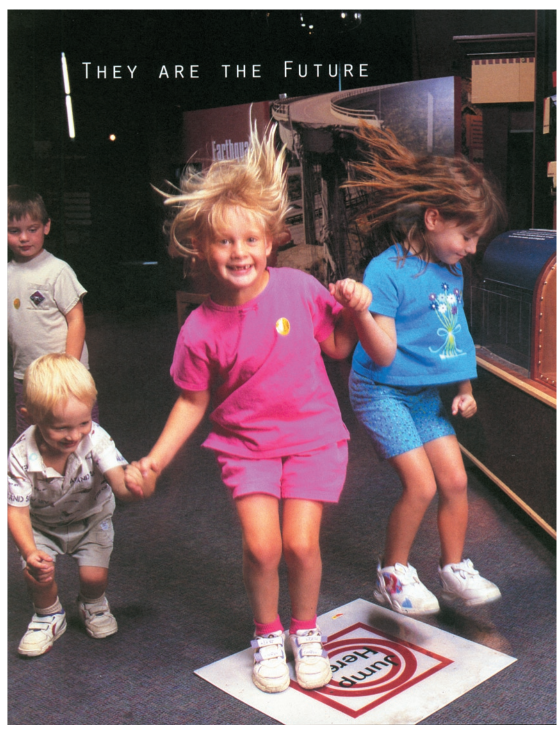
Letter of acknowledgement from the Franklin Institute Science Museum, 4/21/99

Opening of the Hall of Planet Earth at the American Museum of Natural History, New York, NY, 1999

Figure 1. IRIS Museum Program

Powers of Nature Exhibit Participating Museums (April 1998 - October 2001)

Date	**Museum**	**Attendance**
April 1998 *Philadelphia, PA*	Franklin Institute Science Museum	450,000
October 1998 *Los Angeles, CA*	California Museum of Science and Industry	1,000,000
April 1999 *Columbus, OH*	Center of Science and Industry	350,000
October 1999 *Ft. Worth, TX*	Ft. Worth Museum of Science and History	600,000
April 2000 *St. Paul, MN*	St. Paul Science Museum of Minnesota	375,000
October 2000 *Boston, MA*	Boston Museum of Science	550,000
April 2001 *Chicago, IL*	Museum of Science and Industry	1,250,000
October 2001 *Philadelphia, PA*	Franklin Institute Science Museum	450,000
	Total Audience	**5,025,000**



Children experiencing the "Make Your Own Earthquake" part of the exhibit.

undergraduate, graduate, continuing education and public), through the integration of research and education in seismology. This philosophy is consistent with the National Science Education Standards (NAS, 1996) that emphasize providing quality science education (including Earth science) for *all* students at *all* levels of the curriculum. Quoting again from the statement "*A Cooperative Era of Reform in Science Education"*:

> *"The first priority of science education is basic science literacy for all students, including those in groups that have traditionally been served poorly by science education, so that as adults they can participate fully in a world that is increasingly being shaped by science and technology."*

IRIS can contribute to education at all levels through programs that specifically draw on IRIS' strengths. This is important because few organizations are in a position to contribute to education at all levels, yet the full range of students and educators (K-graduate) as well as the general public can benefit from efforts in science education. At the K-12 level, earthquakes, seismology and related Earth science are effective for teaching fundamental science skills in ways that are relevant and consistent with the National Science Education Standards (NAS, 1996). At the undergraduate level, earthquakes and seismology are typically part of introductory Earth science courses. Effective teaching at this level promotes development of scientific skills and an appreciation for the Earth sciences among students who will pursue a wide range of careers. Also, efforts in undergraduate education are critical to encouraging some of the best and the brightest students to become future scientists and engineers. At the graduate level, Education and Outreach activities provide opportunities for broadening the background of students to include experience in non-traditional educational endeavors. Improved communications among research scientists, K-12 educators and the public will benefit all groups. For the public, educational efforts in seismology and related Earth science will help contribute to a more scientifically literate society and build public support for local and national scientific research.

IRIS E&O has actively chosen (both through an internal decision-making process and through the guidance of the education and research communities) to provide products and programs for a variety of audiences. These products and programs retain focus in their content (restricted to seismology, and related Earth science, social and environmental issues). In particular, the IRIS E&O program can stimulate integration of research and education by providing non-specialists with easy access to seismic data and to seismology and Earth science materials, and by providing opportunities to participate in ongoing research projects. Inquiry-based instruction can be supported through the incorporation of real data into Earth science curricula. The nationwide distribution of member institutions allows both national and local programs. IRIS can encourage and support the involvement of its members and other institutions in a wide variety of education and outreach efforts, thus enabling many individuals to participate, commensurate with their interest and expertise. Individual scientists have already started programs in education and outreach that leverage their own research (e.g., the MichSeis seismograph network, teacher-training workshops run by several seismologists, involvement in local museum programs). IRIS E&O is in a position not only to help strengthen the efforts of individual members through IRIS' publications, materials and resources, but to coordinate those efforts nationwide and to engage in partnerships with other organizations involved in Earth science education.

Over the past few years there has been a growing recognition of the need to communicate the results of scientific research to the public. IRIS has significant resources – data, technology, personnel – that can be used to stimulate excitement and support for the Earth sciences. As a result, the seismological and education communities, along with NSF, have worked to establish an Education and Outreach Program within IRIS. In 1997 an E&O committee was formed and the first E&O program manager was hired in January 1998.

Education and Outreach activities over the past two and half years have been funded primarily through core IRIS funding. Additional support was made available in 1998 through an educational supplement provided by the NSF Geoscience Education Program. Since its inception the E&O program has sought additional support for activities beyond those enabled through core funding. Accomplishments over the last two years provide a solid and well-tested foundation for the activities proposed for the next five years, and provide the flexibility to take advantage of new technology and educational initiatives.

Development and Evolution of the IRIS Education and Outreach Program: The first two years

The mission of the Education and Outreach program is to link research and education through seismology and the resources of the IRIS Consortium as described above. Programs focus on seismology and related Earth science, span all educational levels (from public outreach to K-12 and college education), and fall into two broad categories: those that impact large numbers of people, albeit briefly; and those that impact smaller numbers of people through extended interactions. During the past two years, core programs have been established that are expected to

EARTHQUAKES - A ONE - DAY WORKSHOP FOR TEACHERS

Participant Evaluation of Workshop (23 Participants)

5 = Strongly Agree (SA); 4 = Agree (A); 3 = Undecided (U); 2 = Disagree (D); 1 = Strongly Disagree (SD).

	5-SA	4-A	3-U	2-D	1-SD
1. The instructors displayed a clear understanding of workshop topics.	**23**	**0**	**0**	**0**	**0**
2. The workshop was well-organized.	**22**	**1**	**0**	**0**	**0**
3. I can apply information/skills learned in this workshop.	**21**	**2**	**0**	**0**	**0**
4. I found the relative time devoted to the various workshop activities (lecture/discussion; lab exercises; computer exercises; construction/ experimentation with equipment) to be appropriate.	**18**	**5**	**0**	**0**	**0**
5. The learning activities that were included in the workshop will be useful to me.	**21**	**2**	**0**	**0**	**0**
6. The teaching materials that were provided to me at the workshop will be useful to me.	**21**	**2**	**0**	**0**	**0**
7. I am interested in the follow-up activities and am willing to contribute time to the follow-up efforts.	**19**	**3**	**0**	**0**	**0**
8. As a result of this workshop, I will definitely implement some additional seismology and/or Earth science topics in my teaching.	**22**	**1**	**0**	**0**	**0**
9. Overall, the workshop instructors were among the best teachers I have known.	**19**	**4**	**0**	**0**	**0**
10. Overall, this workshop was one of the best that I have ever attended.	**21**	**2**	**0**	**0**	**0**

11. What were the most significant parts of the workshop to you?

- The materials are relevant & useful. The hands on activities are fun and educational.
- Exchanging ideas with other participants in addition to the activities I learned at the workshop.
- I have very limited materials available in my class. Now I have a low cost earthquake activity that I will use this during the spring term this year.
- Using the software to find data about earthquakes.
- Enjoyed explanation & presentation of mantle lithosphere, P, S & surface waves as well as way of demonstrating these to students.
- The tongue-depressor building test. Been looking for a good way to start an earthquake building project for several years.

12. What lessons, materials, skills, or equipment do you anticipate will be the most useful to you?

- The information provided cleared up some misconceptions I had; it will enable me to more accurately inform my students.
- The lesson plans and handouts that I can copy for my classes. I will use the posters, silly putty, and slinky for demonstrations.
- The building design unit
- The computer usage-plotting/graphing and seeing the software.
- All materials will be extremely useful. Some for reference & general knowledge. Others for explanation, demonstration (maps), activities.
- All of it! The part that the materials are affordable and easily affordable is very important.

13. What aspects of the workshop did you like best?

- Everything! Materials! Knowledge & enthusiasm of instructors. Variety of activities.
- Working with other professionals.
- The organization and amount of materials I'll be taking home is wonderful! I know these will be used next year in my classroom.
- I like building the models and testing them.
- I found the P wave-S wave Walk/run a good activity for my students.
- Hands on activities with sound factual background.
- Maps, books, lesson plans. I plan on building a lot of the demonstration pieces. I am very excited about using this info with my students.

14. What suggestions for improvement do you have for the workshop?

- I would have preferred half the time on building structures be spent on other types of activities. One building experience was enough.
- More days, so that more of the activities could be completed. THANKS!
- I really can't think of anything – this workshop was well-thought out and presented beautifully. The only thing we needed was more time.
- Projects should/could be used for computer displays.

Figure 2. Workshop Evaluations. Summary for 1999 NSTA Boston Workshop

Meeting	Time	Location	Attendees (Number & type)
Teach for America (TFA) East Coast Conference	March, 1998	Washington, DC	15 TFA teachers (K-12)
National Science Teachers Association Meeting	April, 1998	Las Vegas, NV	28 K-12 teachers
IRIS Annual Workshop "Software workshop"	July, 1998	Santa Cruz, CA	20 College/university researchers
National Science Teachers Association Meeting	March, 1999	Boston, MA	23 K-12 teachers
IRIS Annual Workshop "Seismologists learning to teach the teachers"	June, 1999	Yosemite, CA	15 research seismologists
Geological Society of America	October, 1999	Denver, CO	20 college/university faculty
National Science Teachers Association Meeting	April, 2000	Orlando, FL	20 K-12 teachers
California Science Teachers Association	October, 2000	Sacramento, CA	~25 K-12 teachers
Geological Society of America	November, 2000	Reno, NV	~25 college/university faculty

Table 1. Education and Outreach Workshops

grow and continue, along with the expansion of other opportunities initiated through coordination with other programs within and beyond IRIS.

Core Programs and Activities

Museums

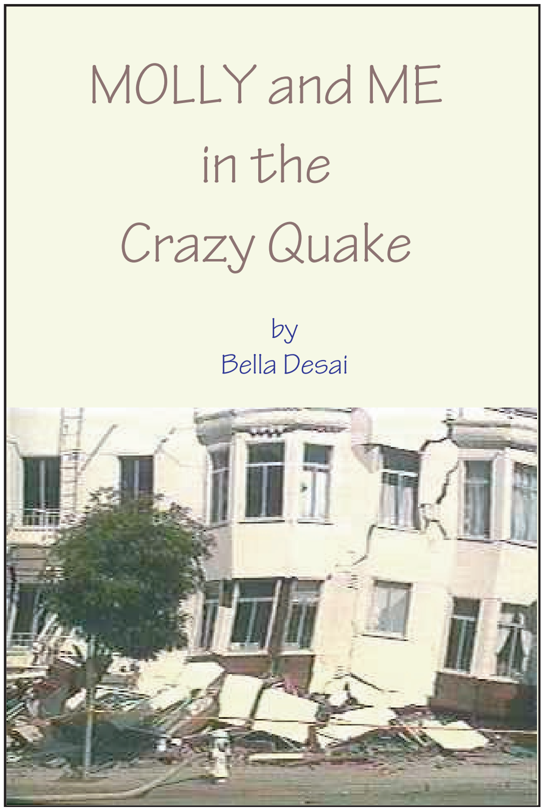
For the last fifteen years, the National Science Foundation and the US Geological Survey along with private foundations and universities have made significant investments in development of the Global Seismographic Network (GSN) and its associated data collection facilities. The GSN has resulted in a bonanza of new discoveries for the scientific research community. The E&O program, in collaboration with the USGS, has begun to exploit this scientific resource for educational purposes, by making data from the GSN accessible to the general public through museum exhibits.

By bringing live research-quality seismic data over the Internet and broadcasting it in museums, we provide visitors with evidence that the Earth's surface is in motion. The displays use earthquakes to capture the visitor's attention and as an introduction to a broad range of geoscience concepts. For example, our displays show why earthquakes occur, how seismometers record earthquakes, how earthquakes relate to plate tectonics, and how we can use seismology to explore the Earth's interior. Accompanying handouts and classroom exercises provide the visitor with follow-up educational materials.

Currently the IRIS E&O program has museum exhibits at the American Museum of Natural History (NY) – Hall of Planet Earth, the Carnegie Museum of Natural History (PA), the New Mexico Museum of Natural History and Science (NM), and an exhibit on tour with the Franklin Institute as part of their *"Powers of Nature"* exhibit (Figure 1). These exhibits together reach approximately 9 million visitors per year. Feedback from the museums has been extremely positive. Visitors spend significantly longer at our exhibits than is average for a museum exhibit, and we have received several personal letters of thanks from museum staff and visitors – an example is shown in Figure 1. An additional prototype exhibit at IRIS headquarters in Washington DC is used for development purposes, has been exhibited in the AAAS foyer during the first Earth Science Week (1998), has been taken to events on Capitol Hill (White, 1999) and has been visited by local K-12 classes.

Teacher Workshops

Over its first two years, the IRIS E&O program has actively engaged in K-12 education, running one-day workshops designed to provide both pre-service and in-service training for K-12 teachers. We use a two-pronged approach to reach the K-12 teacher population through workshops: the first is direct, via workshops held at national professional scientific and education meetings, the second involves training seismologists in our own community to run teacher workshops and then providing these seismologists with the resources to run a workshop locally. This philosophy exemplifies IRIS' ability to impact education nationally, but also locally through leveraging and engaging our own membership in broader educational endeavors. It facilitates contact and communication among



Cover for short story used in lesson 1
to introduce earthquakes

Lesson 3: Meet the Waves

Objectives: Students will be able to:
1. Recognize that energy travels from an earthquake as waves.
2. Describe the motion of P, S, and Surface waves.
3. Describe and differentiate the characteristics of P, S, and Surface waves.

Summary:

In Lesson 3, students use their bodies and slinkies to dramatize and describe the characteristics of Primary, Secondary, and Surface waves.

Name ________________________ Date ____________________

Teacher ________________________ School ____________________

Wave Match!

Directions: Draw a line to match the wave with what it does.

	moves the slowest
P-wave	has the biggest wiggles on the seismogram
	is the first wave you see on the seismogram
S-wave	looks like this:
	only likes to travel near the top of the earth
Surface-wave	moves the fastest
	follows right after the P-wave
	looks like this:
	is one of the last waves you see on the seismogram

Worksheet from Lesson 3

State of California Earth Science Content Standards, Grades K-12

Grades K-4:
- The Earth is composed of land, air and water.
- Earth is made of materials that have distinct properties and provide resources for human activities.
- Some changes in the Earth are due to slow processes, such as erosion, and some changes are due to rapid processes, such as landslides, volcanic eruptions, and earthquakes.

Grade 6: Focus on Earth Science
Plate Tectonics and Earth's Structure

Plate tectonics explains important features of the Earth's surface and major geologic events. As the basis for understanding this concept, students know:

- the fit of the continents, location of earthquakes, volcanoes, and mid-ocean ridges, and the distribution of fossils, rock types, and ancient climatic zones provide evidence for plate tectonics.
- the solid Earth is layered with cold, brittle lithosphere; hot, convecting mantle; and dense, metallic core.
- lithospheric plates that are the size of continents and oceans move at rates of centimeters per year in response to movements in the mantle.
- earthquakes are sudden motions along breaks in the crust called faults, and volcanoes/fissures are locations where magma reaches the surface.
- major geologic events, such as earthquakes, volcanic eruptions, and mountain building result from plate motions.
- how to explain major features of California geology in terms of plate tectonics (including mountains, faults, volcanoes).
- how to determine the epicenter of an earthquake and that the effects of an earthquake vary with its size, distance from the epicenter, local geology, and the type of construction involved.

Curriculum meets part or all of the above California standards, as well as the corresponding national standards (NSES, 1996).

Figure 3. Elementary School 4-lesson Curriculum. Selected pieces from curriculum developed by Bella Desai, Teach for America

member institutions, practicing research seismologists and the local K-12 education community.

Workshops are advertised ahead of time and approximately 15 to 25 participants are selected from a pool of applicants. Topics covered typically include: causes of earthquakes, earthquakes and plate tectonics, propagation of seismic waves, seismographs, earthquake locations, statistics and seismology data, Earth's interior structure, earthquake hazards. Lessons and activities, which are associated with these topics and which are demonstrated and practiced during the workshop, emphasize hands-on and inquiry-based learning. Materials worth about $100 (notebook with lessons and activities, maps, curriculum materials, earthquake book, posters, software and other teaching aids) are provided to each participant.

Workshops run to date, and those planned for the remainder of the year 2000 are summarized in Table 1. Several local workshops run by IRIS researchers (not included in Table 1) have been sponsored by the E&O program. We have also initiated workshops for undergraduate faculty. Undergraduate faculty typically teach outside their specialty area and can benefit greatly from content-based workshops that incorporate good teaching practices. Our workshops are reaching over 100 teachers and their classes annually and this program is growing rapidly.

As with our other programs, we have engaged in self-assessment of our workshops to assist in future planning and to build upon successful approaches. Workshop participants are required to complete evaluations of the workshop in which they have participated. Excerpts from evaluations of a recent workshop are shown in Figure 2. We also collect data on the teachers and their classrooms to assess the broader student audience that our workshops are reaching.

Summer Undergraduate Internship Program

IRIS E&O has initiated a summer undergraduate research internship program. We tailor the internship program to best draw on the strengths of IRIS and to provide different opportunities from other similar programs.

The objectives of the program are to provide the opportunity for students to experience seismological research and to enable student participants to present a student-led paper at a professional scientific meeting during the following academic year. Funding is provided both for the summer research experience, and for travel to the subsequent professional meeting. We target students at non-research institutions and those students with little or no exposure to seismology. Students are hosted by seismologists from IRIS member institutions. Internship projects to date have covered a wide variety of field and laboratory-based investigations. At the end of an internship a report and photographs are due from the student along with confidential evaluations from both the student and the host.

The internship program was initiated in 1998, with two host-intern matches. The program was expanded in 1999 and nine presentations, most of them student-led, have been submitted to professional meetings during the 1999-2000 academic year (see reference list).

The undergraduate internship program has several benefits, both to IRIS and to the participating individuals (hosts and students). The program increases the exposure of seismology to a cadre of students that will go on to wide variety of careers. The research experience it provides is of course an invaluable experience for those students contemplating graduate school. The opportunity for students to attend a professional meeting encourages hosts to develop focussed internship projects and provides students with a sense of accomplishment. Attending a professional scientific meeting enables former interns to network with each other and with other geoscientists, share their experiences, and to investigate graduate school and other career opportunities in the geosciences.

Educational Materials

From its inception the IRIS E&O program has placed high priority on development of educational materials that can be used at all levels of education. One-page handouts and posters (see the main proposal) have been distributed to a wide audience worldwide that includes research scientists, college and K-12 educators and their students and the public at large. Over the past two years, more than 15,000 one-page handouts and posters have been distributed nationally and internationally upon request, with a similar number distributed at national and regional scientific and educational meetings. Requests for publications come from scientists and educators. These include requests for copies for informal and formal education purposes, such as teacher workshops or dissemination through public information centers. The one-page handouts can also be downloaded and printed from our web site (http://www.iris.washington.edu/EandO/onepager.html). In addition, IRIS E&O is developing Teachers' Guides – an example is the guide illustrated in the one-pager in Appendix I of this proposal "*Seismic Waves and the Slinky: A Guide for Teachers*". In our workshops we use educational modules developed by Professor Larry Braile and elementary school teacher, Sheryl Braile. We update and are expanding educational modules and lesson plans through a variety of ways. For example, during summer 1999, a Teach For America summer intern at IRIS headquarters developed a four-lesson elementary school curriculum on earthquakes and seismic waves (Figure 3). The curriculum is introduced through a short story that extends and builds upon a second grade reading assignment within a standard language arts curriculum commonly used in under-resourced schools in California. This curriculum was tested in a second grade class at Belle Haven Elementary School in Palo Alto, CA and the curriculum, assessment and feedback presented at the 1999 Fall AGU meeting (Desai & Johnson, 1999).

New Initiatives & Collaborations

In addition to the core activities that have been successfully initiated over the past two years, the E&O program has pursued new initiatives available to the geoscience education community and has taken a leadership role in the coordination of education and outreach efforts in seismology. For example, IRIS E&O organized and held a 2-day workshop in May 1999 in Harbourtowne, MD to bring together individuals involved in Education and Outreach programs related to seismology and earthquakes. The intent was to facilitate communication by sharing information on the scope of current activities, target audiences and the strengths and weaknesses of our current programs.

Geoscience Digital Library

A major new initiative within IRIS E&O was realized in 1999, following a successful proposal to the Digital Libraries element of the Awards to Facilitate Geoscience Education (AFGE). IRIS E&O is collaborating with UCAR (University Consortium for Atmospheric Research), the Keck Geology Consortium, the University of Colorado at Boulder, the Alexandria Project (University of California, Santa Barbara) and NASA's Universities Space Research Association, Earth Systems Science Education program to develop a prototype for a Digital Library for Earth System Education (DLESE, www.dlese.org). The digital library is envisaged to provide both access to large data sets and a centralized location for resources for teaching geoscience. The prototype development (the Geoscience Digital Library), funded through AFGE, will focus on products aimed at the undergraduate level. IRIS E&O will contribute (1) access to seismological data archives, (2) seismology-based educational resources, and (3) participation in long-range planning for DLESE. The geoscience education community has moved quickly to plan for long-term development of a Digital Library for Earth System Education and NSF is strongly supportive of this effort (Leinen, 2000).

IRIS E&O over the Next Five Years

General Philosophy

The Education and Outreach program proposes to solidify and expand its core activities both in magnitude and scope by leveraging the IRIS facility (people, equipment and data) proposed here. New initiatives will include enabling a broader audience to access real-time data for educational purposes and to access results from IRIS-facilitated research. The E&O program will engage in comprehensive assessment of the educational impact of its programs and activities. As with the digital libraries project additional sources of funding will be sought for major program expansion. A small percentage of core funds will be used for pilot or experimental activities. Successful pilot projects will facilitate external funding of larger initiatives.

Below we provide an overview of how the goals and proposed programs for IRIS E&O match current priorities of the National Science Foundation: integration of research and education, digital library initiatives, 21st century workforce and diversity. The aim of the E&O program to address all audiences ties with the Geoscience Directorate's vision for education for the 21st century as outlined in "NSF Geosciences Beyond 2000".

Linking Resources, Research and Education

Integration of Research and Education

A primary goal of the IRIS E&O program is the integration of research and education. For example, data, software tools and seismographs provided to K-12 teachers and college faculty enable the use of inquiry and discovery methods in teaching and the potential for students of all levels to engage in independent investigations. While there is increasing emphasis on teaching Earth science at the K-12 level, many teachers have little or no background in the Earth sciences. Through the current and proposed core activities, IRIS can make significant contributions to the professional development of pre-service and in-service teachers. The NSF also highlights the need for integration of research and education at the undergraduate level: our faculty workshops and our student internships directly expose undergraduate faculty and students to current seismological research.

Digital Libraries

The development of digital libraries is a major goal of both the National Science Foundation (Leinen, 2000) and NASA (Digital Earth Initiative) for the next decade. IRIS E&O is at the forefront of such efforts within the Geoscience community through its participation in the development of the Geoscience Digital Library (GDL), a prototype for the Digital Library for Earth System Education (DLESE). The very nature of a digital library (access to educational materials and research-quality data sets) promotes the integration of research and education at all levels.

21st Century Workforce and Diversity

Activities that fall under the umbrella of the E&O program directly address the current NSF emphasis on preparation of a scientifically literate 21st century workforce. Because IRIS E&O targets all educational levels and the public at large, we are inherently involved in science education for the 21st century workforce as a whole. Along with other national organizations, the NSF recognizes the need to increase diversity within scientific and engineering fields. In 1999, a workshop on diversity issues within the geosciences was held at NSF. The workshop highlighted the need to provide high quality science education to all students at all levels. This will ensure not only a population of geoscientists that reflects the diversity of the national population, but will also advance scientific literacy of the populace as a whole.

Because of the current homogeneity of the geoscience research community, establishing an education program that effectively targets all segments of the population is a challenge. The IRIS E&O program will impact a diverse audience through a variety of approaches. Through our teacher workshops we can indirectly reach a wide student audience. For example, in our most recent workshop for teachers at the April, 2000 NSTA convention, there were twenty K-12 teachers in attendance. Sixteen of them were women. On average, participants reported that 17% of their students were African-American and 11% were Hispanic, and they estimated that 18% were "at risk." Thus, although it is often difficult to conduct programs that directly address the science education needs of under-represented groups, our teacher workshops are reaching a diverse audience of teachers and students. We have also worked (through workshops and summer interns) with Teach For America (TFA), a national organization that places exceptionally talented recent graduates as teachers for two years in under-resourced rural and urban schools across the United States. TFA provides an excellent link to under-served school districts. We hope to increase the diversity of applicants to our undergraduate internship program through advertising to HBCUs (Historically Black Colleges and Universities) and other minority institutions. Our museum displays reach a broad cross-spectrum of the population. Also over the next funding cycle, we propose to increase our efforts to bring seismology and related Earth science to the general public through the media, thus reaching a variety of audiences (see Core Programs section below).

Proposed E&O Programs

Core Programs and Activities

Over the next 5 years we propose to continue existing E&O programs described earlier (museum displays, educational materials, professional development, and research experiences), in addition to making research pursued by the IRIS community accessible to a broader audience through a variety of media – print, electronic, television and radio. Core E&O activities will also include the Educational Affiliates and Seismographs in Schools programs described below. Substantial groundwork for these two new programs has already been done. To date, we have concentrated on self-assessment of individual E&O programs. Over the next funding cycle we will engage in more formal formative and summative evaluations both of the distinct E&O efforts, and of the program as a whole.

Expansion of the museum program will include new exhibits along with updates and enhancements of existing exhibits. Costs associated with our museum displays include software development, staff time and shipping of hardware from remote sites to the Albuquerque Seismological Laboratory for refurbishment for use in existing or new displays. Over the next funding cycle we intend to also focus on the development of educational materials and programs associated with our exhibits. Materials and educational programs will be designed, developed, tested and evaluated in conjunction with the education departments of participating museums. We have already initiated such a collaboration with the American Museum of Natural History's education department.

We anticipate an increase in the number of professional development workshops. In particular we expect expansion of workshops run through IRIS institutions, as more seismologists become involved. More rigorous assessment of this program will be pursued.

We propose to continue our internship program at a level of 8-10 interns per year. As it grows, the program will benefit from increased ties between interns from successive years. As part of the our goal to reach a diverse audience, we will make particular efforts to advertise the internship program to minority colleges and institutions.

Development of both web-based and hard copy educational materials (1-page handouts, posters, teachers guides, software, summaries for the non-specialist on current seismological research) will be continued over the next five years. Three new posters are currently under development. We also intend to increase the exposure of seismology through print media and television. For example, we are already engaged in discussions with the American Institute for Physics to partner in their Science TV News Syndication program, "Discoveries and Breakthroughs Inside Science". This will provide opportunities to contribute seismologically-based news segments that would be aired over participating local TV networks (currently over 40 networks around the country).

Educational Affiliates

Over the past 2 years IRIS E&O has initiated several programs aimed at serving undergraduate faculty and students including a summer undergraduate internship program and faculty workshops. Our educational materials are also widely used in the undergraduate geoscience classroom. We propose to provide a broader context for our undergraduate educational programs through the formation of an Educational Affiliates membership category within IRIS.

Educational Affiliate institutions must be colleges or universities with undergraduate programs and with a commitment to teaching geoscience. The membership category is designed for institutions whose primary interest in seismology is for educational rather than research purposes. The goals of this program are to increase and enhance the teaching of seismology and related Earth science at the undergraduate level and to improve communications and collaborations between the research and undergraduate education communities. To effect these goals, affiliate members will:

- receive a cost-share from the IRIS E&O program toward a seismometer to be used for educational/ research purposes at the Affiliate's institution,
- have the opportunity for a faculty representative from their institution to compete for travel grants to be awarded annually to attend the IRIS annual workshop,
- receive regular mailings that will include educational materials, the IRIS newsletter, and information on activities such as the undergraduate summer internship program and IRIS E&O workshops at geoscience/ educational meetings,
- have access to special workshops for affiliate members which will provide information on IRIS and training on how to access seismological data and incorporate these data into teaching activities,

The Educational Affiliates program has already been approved by the IRIS Executive Committee and will proceed given approval from the IRIS Board of Directors for the necessary by-law changes.

Seismographs in schools

Over the next five years, IRIS E&O will develop a program to place educational seismographs in schools. This "Seismographs in Schools" program differs from those already in existence (such as the Princeton Earth Physics Program, PEPP, MichSeis) in that it does not involve the establishment of a "network" in the seismological sense. The seismometer that we will use - the AS-1 seismometer - is inexpensive ($500) and effective for educational purposes because of its simple design (basic principles of seismometry are visible) and ease of management. Thus the seismometer is useful for teaching about seismographs and for lab-based experiments/activities as well as for monitoring of seismicity. IRIS E&O has developed improved software for operating the AS-1 and analyzing the data collected, and is also developing a set of lesson plans to go with the seismometers. Three teachers are being supported to develop such educational materials during summer 2000. With the new software, data management is easy and teachers and students can view and analyze their own data as well as exchange or share these data. In concert with the new E&O software tools to be developed under integrative activities described below, teachers and students will be able to compare data recorded in their classroom using the AS-1 with data from permanent research-quality (*e.g.*, GSN or PEPP) stations.

The program is being initiated during the final year of the current IRIS cooperative agreement. It involves requesting proposals from teachers to use the AS1 seismometer in their classroom. We have purchased about 40 such units and plans to have most of these distributed by fall of 2000. Teachers involved in the pilot phase of the program will provide feedback on and assessment of both the software and accompanying educational materials. IRIS will provide these teachers with partial travel support to the National Science Teachers Association meeting in 2001 to facilitate feedback and sharing of experiences and educational materials between participants and the E&O program.

This program will be significantly expanded over the next five year funding period. IRIS E&O will encourage the sharing of educational materials among teachers and we will revise our own materials as well as develop new activities, based on formative assessment of the program.

New Initiatives and Integrative Activities

A major E&O initiative is proposed that directly builds on the broad themes emphasized in this proposal for the whole of IRIS, and that is integrative across IRIS programs. This initiative will also build on our contributions to the Geoscience Digital Library and will provide excellent preparation for US Array. The initiative involves development of a Virtual Seismic Network Explorer – an educational interface to real-time and archived seismic data sets for the non-specialist. The Virtual Seismic Network Explorer will provide the educational front-end to proposed IRIS developments in the acquisition of real-time earthquake data.

The Virtual Seismic Network Explorer

The increasing availability of real-time seismic (and other geoscience) data provides unprecedented opportunities for integrating research and education. We propose to produce a user-friendly, versatile interface to real-time and archived seismic data sets - a Virtual Seismic Network Explorer (VSN Explorer), that can be accessed on any computer running an Internet browser. The VSN Explorer will bring the excitement of scientific inquiry and discovery to audiences far beyond the seismological research community through an interactive display of real-time seismic data in a variety of formats including maps, seismograms, and standard catalogues. Figure 4 shows an example of the type of display envisioned for the VSN Explorer. We propose to develop the VSN Explorer, along with accompanying educational materials for museums and the K-12 classroom. The development and effective implementation of the VSN Explorer will comprise three critical components: (1) software development to produce the VSN Explorer interface, (2) development of accompanying educational resources, including hardcopy and electronic materials and software, (3) "proof of concept" testing and evaluation of the system in museums and K-12 classrooms.

The VSN Explorer will require a PC (Windows or Macintosh machine) with a WWW browser and internet access. The VSN Explorer is envisioned to comprise

- a versatile, web-based interface that provides real-time displays of seismic data from all over the world,

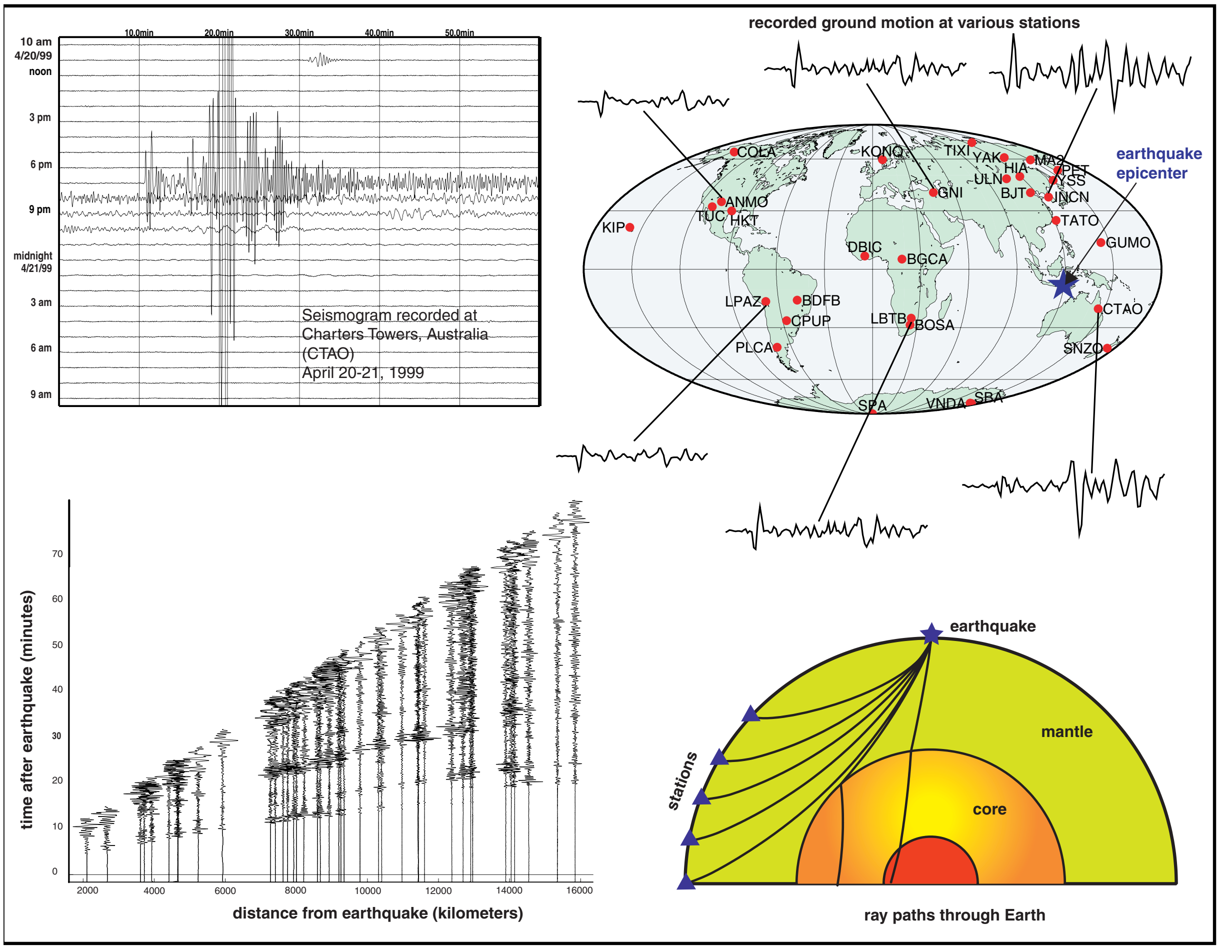


Figure 4. Sample VSN Explorer interface elements.

- standard products – catalogs, maps, seismogram displays – showing near real time status of earthquake activity and data, plate tectonics etc.,
- locally-resident software – downloaded software for display, analysis, inquiry,
- related educational materials and teachers' guides.

There will be substantial user control and interactivity so that the user (teacher, student, museum leader or visitor, interested person on the internet) can explore and investigate earthquakes, seismology, plate tectonics, and related Earth science topics.

To ensure museum and K-12 products which meet the needs of the target audiences, an advisory group will be constituted comprising K-12 educators, science education specialists, museum exhibit experts and museum education experts, in addition to seismologists and members of the IRIS E&O program. We will use our existing museum and teacher contacts to establish a strong advisory group that will provide input and feedback at all stages of development, testing and evaluation of the VSN Explorer and associated educational materials.

The VSN Explorer clearly will complement the AS-1 Seismographs in Schools program proposed above, in that students and educators will not only be able to collect data using a simple seismograph and data acquisition system, but will be able to access research-quality data via well-designed educational interfaces. Development of the VSN Explorer will build on and greatly extend the educational aspects of current products including the IRIS Seismic Monitor (a near-real-time map display and listing of global seismicity), existing underlying architecture that enables access to IRIS data sets (IRIS Data Management System), and the set of educational tools to be produced for the Geoscience Digital Library (the prototype for the Digital Library for Earth System Education, DLESE). The VSN Explorer will be designed to be easily integrated into or accessed from DLESE.

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