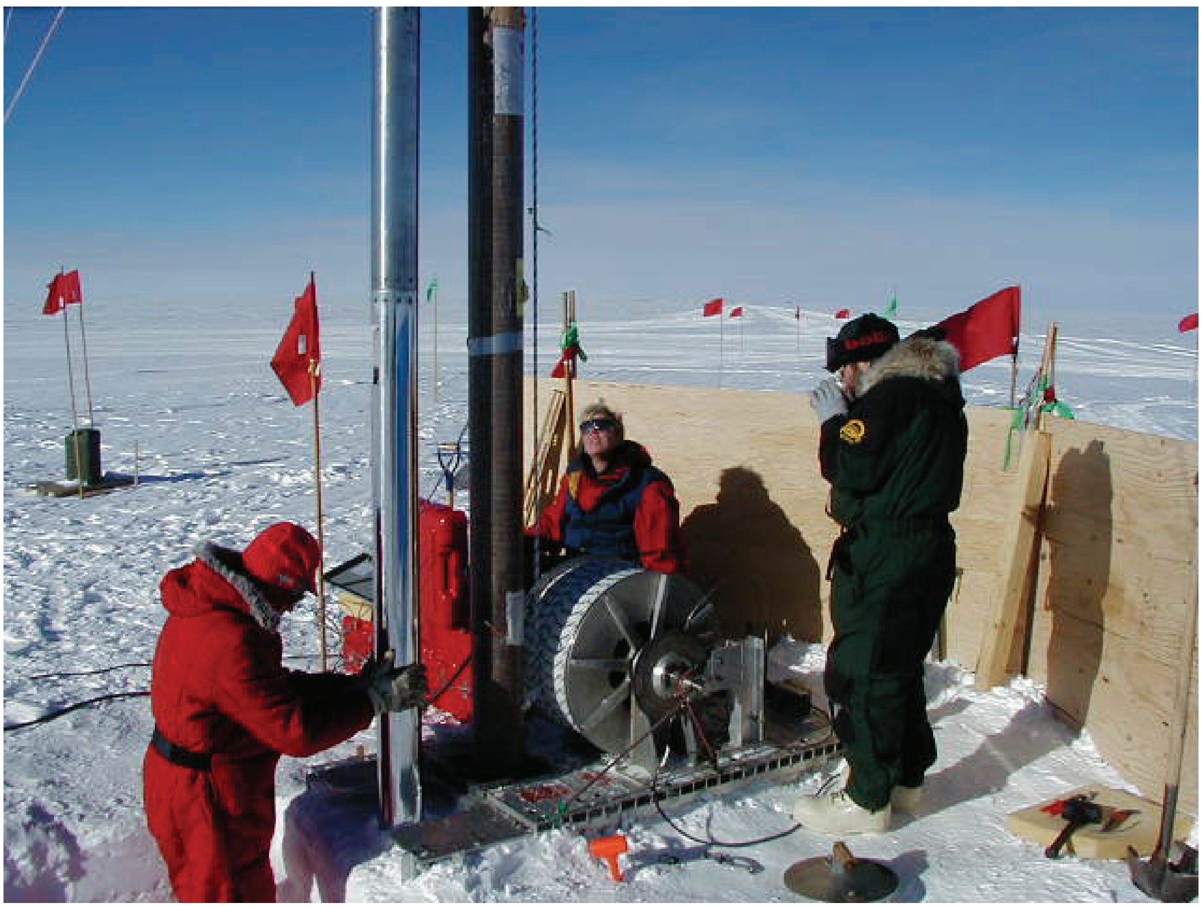
# U.S. Geological Survey Global Seismographic Network—Five-Year Plan 2006–2010

By William S. Leith, Lind S. Gee, and Charles R. Hutt



Open-File Report 2009–1013

**U.S. Department of the Interior**
**U.S. Geological Survey**

**U.S. Department of the Interior**
DIRK KEMPTHORNE, Secretary

**U.S. Geological Survey**
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia 2009

Publishing support provided by:
Denver Publishing Service Center

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Suggested citation:
Leith, W.S., Gee, L.S., and Hutt, C.R., 2009, U.S. Geological Survey Global Seismographic Network—Five-Year Plan 2006–2010: U.S. Geological Survey Open-File Report 2009–1013, 27 p.

Cover photograph courtesy of Kent Anderson, Honeywell Technology Solutions Inc.

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# List of Acronyms

| | |
|---|---|
| AFTAC | Air Force Technical Applications Center |
| ANSS | Advanced National Seismic System |
| ASL | Albuquerque Seismological Laboratory |
| CDSN | China Digital Seismic Network |
| CTBTO | Comprehensive Test Ban Treaty Organization |
| DOI | Department of Interior |
| FDSN | Federation of Digital Seismograph Networks |
| FEMA | Federal Emergency Management Agency |
| HGLP | High Gain Long Period |
| IDA | International Deployment of Accelerometers |
| IRIS | Incorporated Research Institutions for Seismology |
| GEO | Group on Earth Observations |
| GEOSS | Global Earth Observations System of Systems |
| GPS | Global Positioning System |
| GSN | Global Seismographic Network |
| GSNSC | Global Seismographic Network Standing Committee |
| GTSN | Global Telemetered Seismic Network |
| LISS | Live Internet Seismic Server |
| MIDAS | Middle America Seismograph Consortium |
| NEHRP | National Earthquake Hazards Reduction Program |
| NEIC | National Earthquake Information Center |
| NIST | National Institute of Standards and Technology |
| NOAA | National Oceanic and Atmospheric Administration |
| NRTS | Near Real Time System |
| NSF | National Science Foundation |
| O&M | Operations and Maintenance |
| OFDA | Office of Foreign Disaster Assistance |
| PAGER | Prompt Assessment of Global Earthquakes for Response |
| PART | Performance Assessment and Management Tool |
| PRSN | Puerto Rico Seismic Network |
| SPRESSO | South Pole Remote Earth Science and Seismological Observatory |
| SRO | Seismic Research Observatory |
| USGS | United States Geological Survey |
| UCSD | University of California at San Diego |
| VSAT | Very Small Aperture Terminal |
| WWSSN | Worldwide Standardized Seismograph Network |

# U.S. Geological Survey Global Seismographic Network—Five -Year Plan 2006–2010

By William S. Leith[1], Lind S. Gee[2], and Charles R. Hutt[2]

## Executive summary

The Global Seismographic Network is a permanent digital network of state-of-the-art seismological and geophysical sensors connected by a telecommunications network, serving as a multi-use scientific facility and societal resource for monitoring, research, and education. Formed in partnership with the National Science Foundation and the Incorporated Research Institutions for Seismology, the Global Seismographic Network provides nearly uniform, worldwide monitoring of the Earth, through 138 modern seismic stations distributed globally.

Data from the Global Seismographic Network are critical to the U.S. Geological Survey National Earthquake Information Center for the detection, location, and characterization of earthquakes around the world. Most Global Seismographic Network stations transmit data in near-real-time, thereby contributing to U.S. Geological Survey rapid earthquake information products such as alerts and email notices, web pages, ShakeMaps, and Prompt Assessment of Global Earthquakes for Response impact estimates. Outside of the U.S. Geological Survey, Global Seismographic Network data play a major role in the operations of the National Oceanic and Atmospheric Administration Tsunami Warning Centers and in the operations of the Comprehensive Test Ban Treaty Organization and the Air Force Technical Applications Center, in their respective nuclear test treaty monitoring missions.

The Global Seismographic Network Program contributes to the Department of Interior Strategic Goal of Serving Communities, the U.S. Geological Survey Hazards Mission Goal to "Provide science... focusing efforts to predict and monitor hazardous events in near-real time and to conduct risk assessments to mitigate loss," and supports the Director's responsibility under the Stafford Act (Public Law 100-707) to issue warnings for earthquake disasters.

The U.S. Geological Survey portion of the Global Seismographic Network has grown from 72 to 85 stations since 1998, soon to be 89 stations. At the same time, the budget for operating and maintaining the network has decreased from $3.4 million in 1998 to just over $3.3 million in 2005. Thus the funds available for operating and maintaining each station have decreased by 18 percent, before adjusting for inflation.

Following the catastrophic loss of life on December 26, 2004, from the Sumatra earthquake and tsunami, the Administration proposed and Congress appropriated funds to the U.S. Geological Survey to upgrade telemetry for the Global Seismographic Network, and to increase the number of seismic stations in the Caribbean region. The current goal is to establish real time telemetry links at more than 96 percent of the stations, to better support the missions of National Earthquake Information Center and the National Oceanic and Atmospheric Administration Tsunami Warning Centers and to enhance capabilities to detect and address maintenance issues.

Seismic sensors at some Global Seismographic Network sites are already operating in combination with meteorological sensors, Global Positioning System receivers, gravimeters and magnetometers. Thus,

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as a platform for a number of additional geophysical observations, the Global Seismographic Network can contribute data to the Global Earth Observation System of Systems, whose goal is to collect and disseminate data and information from a variety of earth observation systems.

Long-term performance goals for the U.S. Geological Survey Global Seismographic Network are:

- Operate at a data availability rate of 95 percent or higher.
- Provide reliable telemetry from 95 percent or more of Global Seismographic Network stations, to support earthquake monitoring, tsunami warning, and other real time missions.
- Perform quality control on 99 percent of data received.

Additional goals include: Incorporate new seismic sensors and data acquisition systems as they become available; expand observation of geophysical parameters in addition to ground motion; increase geographic coverage in under sampled areas (oceanic and polar regions); improve cost efficiency and reliability; and improve noise performance

Specific 5-year goals are:

- Improve station reliability through more timely maintenance, an expanded inventory of spare parts, replacement of obsolete technologies, and standardization of equipment.
- Incorporate the Global Seismographic Network into the Global Earth Observation System of Systems effort and cooperate with Incorporated Research Institutions in Seismology, National Science Foundation, and other agencies in continuing to use the Global Seismographic Network as a platform for general geophysical observations.
- Improve the network's utility for hazard warning (earthquake and tsunami) by expanding and improving real-time communication links and by increasing geographic coverage.
- Enhance network performance through relocating noisy stations to quieter sites and through the use of new seismometer and installation technologies.
- Improve network efficiency by developing and implementing automated quality-control methods.

To achieve these goals, the program maintains a talented staff at the U.S. Geological Survey Albuquerque Seismological Laboratory, consisting of field engineers, software engineers, programmers, system administrators, electronics and computer engineers, machinist, packing and shipping specialist, engineering tech, scientific management, administrative and clerical personnel. Contract personnel make up the majority of the staff, with six U.S. Geological Survey staff filling management and oversight positions plus one programming position.

The principal issues for the current 5 years include: completing the U.S. Geological Survey component of the network (four stations); completing the planned Caribbean expansion (nine stations); completing the planned telemetry expansion; maintaining a high performance level at constant dollars and increased fixed costs; obtaining the resources needed to replace aging equipment; and ensuring the adequate replacement of the STS–1 sensor.

Both Incorporated Research Institutions in Seismology and U.S. Geological Survey management policies require external advisory committees for the Global Seismographic Network program. Both entities recognize that their institutions, and the scientific community as a whole, will not be well served with two such bodies offering possibly conflicting guidance. As a result, U.S. Geological Survey and Incorporated Research Institutions in Seismology have agreed to accept the Incorporated Research Institutions in Seismology Global Seismographic Network Standing Committee as a joint advisory committee for the Global Seismographic Network. Incorporated Research Institutions in Seismology consults with National Science Foundation and U.S. Geological Survey in the appointment of the membership of the Global Seismographic Network Standing Committee, and there is a permanent seat on the Global Seismographic Network Standing Committee for a voting U.S. Geological Survey member, plus a seat for the U.S. Geological Survey Global Seismographic Network operator, filled by a representative of Albuquerque Seismological Laboratory.

# Introduction

## Brief program history and authorizations

The Stafford Act (The Robert T. Stafford Disaster Relief and Emergency Assistance Act, Public Law 100-707, known as the Stafford Act, amended the Disaster Relief Act of 1974, Public Law 93-288) states that, "The President shall insure that all appropriate federal agencies are prepared to issue warnings of disasters to State and Local officials." Specific United States Geological Survey (USGS) responsibilities are detailed in a Federal Register Notice of April 12, 1977, that empowers the Director of the USGS to issue disaster warnings "...for an earthquake, volcanic eruption, landslide, mudslide, or other geologic catastrophe." In addition, the Earthquake Hazards Reduction Act of October 7, 1977, further directs the USGS, along with the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), and the National Science Foundation (NSF), to be part of an interagency *National Earthquake Hazards Reduction Program*, with a balanced effort encompassing hazard assessment research, seismic monitoring, prediction, and information dissemination. USGS responsibilities are spelled out specifically in U.S. Code Title 42, Chapter 86: Sec. 7704, which states that, "The United States Geological Survey shall conduct research necessary to characterize and identify earthquake hazards, assess earthquake risks, monitor seismic activity, and improve earthquake predictions."

To fulfill this mission, the USGS has deployed seismic networks within the United States for monitoring and research. Success in the National Earthquake Hazards Reduction Program also requires the USGS to play a significant role in global seismic monitoring. Not only do earthquakes outside the boundaries of the United States endanger United States assets overseas, but such events may create destabilizing impacts abroad. Moreover, earthquakes around the world help us understand and better assess hazards at home. For example, the recent devastating Sumatra-Andaman earthquake in 2004 provided valuable data and lessons for understanding the behavior of the Cascadia subduction zone, while studies of the disastrous earthquakes in Turkey in 1999 have yielded improved understanding of the San Andreas and Denali faults.

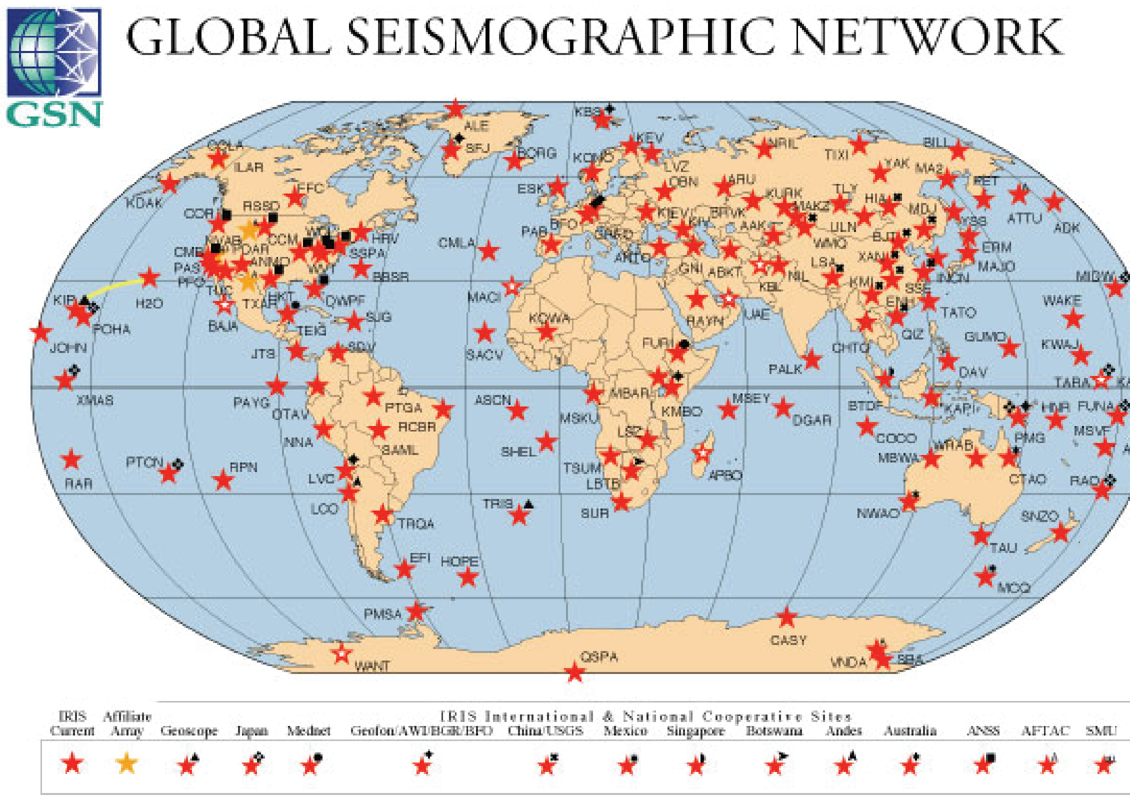



**Figure 1**. Stations of the Global Seismographic Network, including GSN-affiliated sites (figure courtesy of IRIS).

As part of the effort to address global earthquake hazards, the USGS, NSF, and the Incorporated Research Institutions for Seismology (IRIS) Consortium have formed a partnership to install and operate the Global Seismographic Network (GSN). The GSN provides near-uniform, worldwide monitoring of the Earth, through 138 modern seismic stations distributed globally, from the South Pole to Siberia and from the Amazon basin to the seafloor of the Northeast Pacific Ocean (Fig. 1). Established in 1986 to replace the obsolete, analog World Wide Standardized Seismograph Network (WWSSN), the GSN continues a tradition in global seismology that dates back more than a century to the initial deployment of Milne seismographs on all inhabited continents.

Today, the GSN is a permanent digital network of state-of-the-art seismological and geophysical sensors connected by available telecommunications to serve as a multi-use scientific facility and societal resource for monitoring, research, and education (Butler and others, 2004). All GSN data are freely and openly available via the Internet, both in real-time and from archival storage.

GSN data are critical to the USGS National Earthquake Information Center (NEIC) to detect, locate and characterize earthquakes around the world. Most GSN stations transmit data to NEIC in near-real-time (currently 89 per cent), contributing to USGS rapid earthquake information products such as alerts and email notices, web pages, ShakeMaps, Prompt Assessment of Global Earthquakes for Response (PAGER) impact estimates, and so forth. Outside of the USGS, GSN data play a major role in the operations of the National Oceanic and Atmospheric Administration (NOAA) Tsunami Warning Centers in Hawaii and Alaska and in the operations of the Comprehensive Test Ban Treaty Organization (CTBTO) and the Air Force Technical Applications Center (AFTAC) in their respective nuclear test monitoring missions.

Beyond its contribution to earthquake monitoring, the GSN data acquired over the last 20 years have facilitated many advances in the study of global Earth structure and earthquake sources. These data have also improved the plate-tectonic framework for understanding earthquake hazards through better earthquake locations and accurate earthquake source parameters. Seismologists around the world have used the broadband waveforms produced by GSN seismographs to elucidate the details of rupture processes during large earthquakes from a variety of tectonic settings, shedding new light on the geologic and dynamic factors that govern the configuration of seismogenic zones and how earthquakes start and stop.

With each passing year, GSN data adds new information to the understanding of global seismicity by the direct observation of large, rare events and the delineation of low-level seismicity that may mark the eventual occurrence of such events. The evolving patterns of seismicity will also improve mapping of features in the crust and mantle that control seismicity and may be indicative of the forces causing faulting.

## Program history

Throughout the first half of the 20th century seismograph stations were installed at various places around the globe without any overall coordination. This unplanned development and deployment of seismological observatories resulted simply from a growing research interest in earthquakes. However, in the second half of the century, the notion of a structured global network of seismograph stations with common instrumentation became both attractive and fundable. Such entities as the WWSSN (Oliver and Murphy, 1971), the Seismic Research Observatories (SRO) (Peterson and others, 1976), and the Global Telemetered Seismograph Network (GTSN) (Peterson and Orsini, 1982) came into existence and functioned effectively for several decades.

While the first global networks were based on band-pass instrumentation (short or long period) and used analog recording, in the late 1970s very-broad-band high- dynamic-range instrumentation became available (Wielandt and Streckeisen, 1982). At that time the concept of a global network of digital broadband stations, capable of recording large local earthquakes as well as faint free oscillations, became viable. The first projects to embrace the new digital technology were the USGS's Global Digital Seismograph Network (GDSN) (Engdahl and others, 1982), University of California San Diego (UCSD)'s Project International Deployment of Accelerometers (IDA) (Agnew and others, 1976), and the French GEOSCOPE (Romanowicz and others, 1984).

In 1984 IRIS, a consortium of universities with seismological research programs, was established for the purpose of creating and managing new research facilities in seismology (Smith, 1986; IRIS, 2004). From the outset, the GSN was one of the principal components of IRIS, created by joining the two United States–led global networks, the GDSN and Project IDA, operated respectively by the USGS and UCSD. Today, the USGS Albuquerque Seismological Laboratory (USGS/ASL) operates about 2/3 of the network and the UCSD/IDA operates about 1/3 of the network. The GSN has also allied with other global operators and national and regional networks to enable wide distribution of high-quality stations around the world through the Federation of Digital Seismographic Networks (FDSN).

This 5-year plan concentrates on the USGS-operated GSN stations.

## Funding history

The GSN was begun in 1986 with funding to IRIS from the National Science Foundation and the cooperation of the USGS. Between 1988 and 1996, NSF funding for GSN was supplemented by the Department of Defense. The first appropriated funding to the USGS for GSN was in fiscal year 1998 (funding in prior years was provided by NSF and DOD). GSN funding to USGS is authorized under the National Earthquake Hazards Reduction Program (Public Law 106-503).

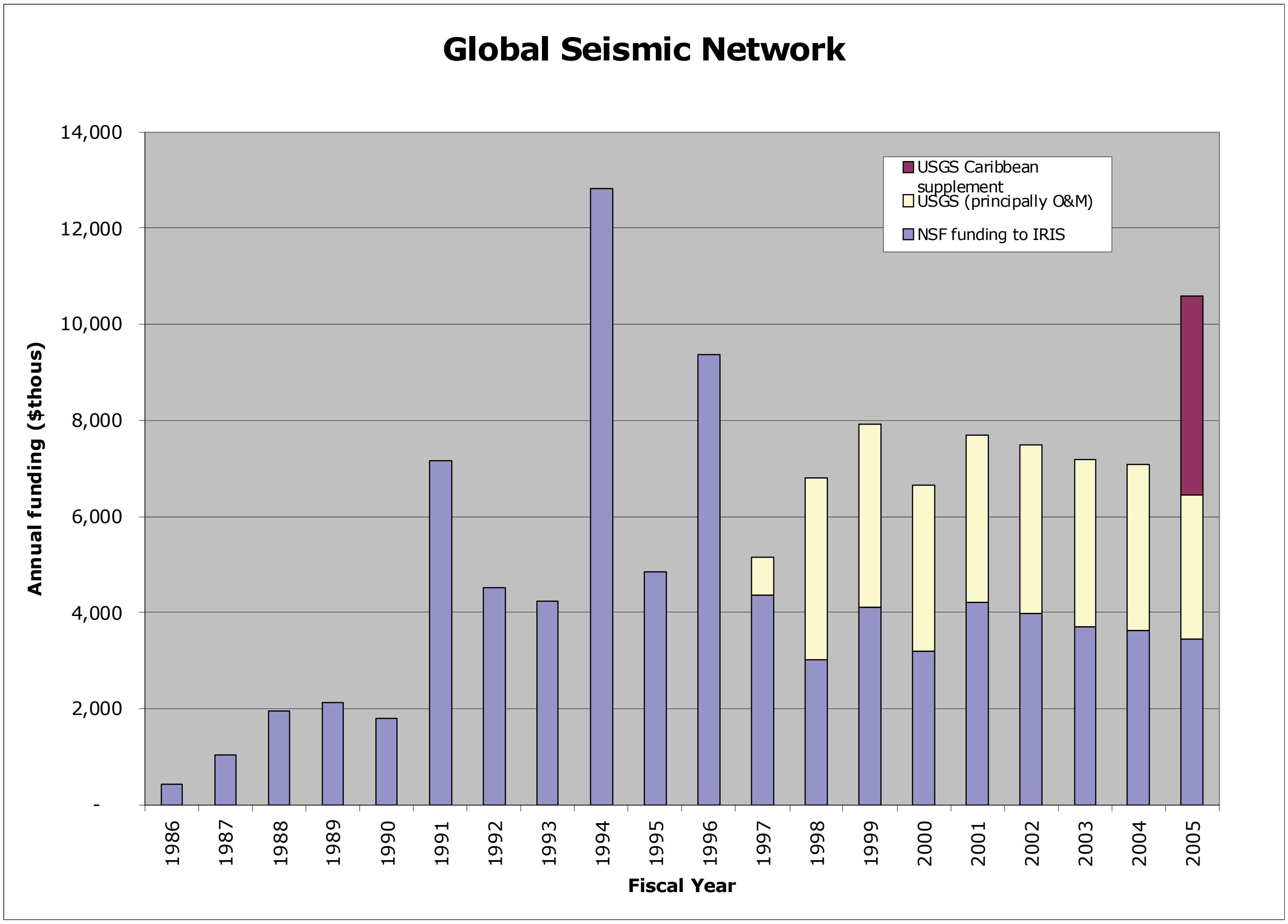



**Figure 2**. GSN funding, in thousands, from 1986-2005. Purple indicates NSF and DOD funding to IRIS, yellow indicates USGS funding, and red indicates funding from the fiscal year 2005 'Tsunami Supplemental', associated with the GSN telemetry upgrade and the Caribbean network.

The total capital cost of the GSN through fiscal year 2004 was approximately $20 million, and thus the capitalization of the USGS portion is approximately $13 million. Gross USGS funding for operations and maintenance (O&M) and Data Collection Center (DCC) operations since FY1996 total approximately $30 million.

The USGS portion of the GSN has grown from 72 to 85 stations since 1998, soon to be 89 stations. At the same time, the budget for operating and maintaining the network has decreased from $3.4 million in 1998 to just over $3.3 million in 2005. Thus the funds available for operating and maintaining each station have decreased by 18 per cent, without adjusting for inflation. If inflation is taken into account (salary and travel cost increases, etc), the reduction is on the order of 50 per cent.

## Program evolution

With 138 stations as of the end of 2005, the GSN is nearing completion (85 operational plus 4 planned USGS/ASL stations, 39 operational plus 2 planned UCSD/IDA stations, and 14 GSN Affiliates/University stations). The four USGS stations planned for FY2006 (Tarawa and Kanton, Kiribati; Tenerife, Canary Islands; and Baja California, Mexico) are still pending and depend on the finalization of memoranda of understanding with the host countries.

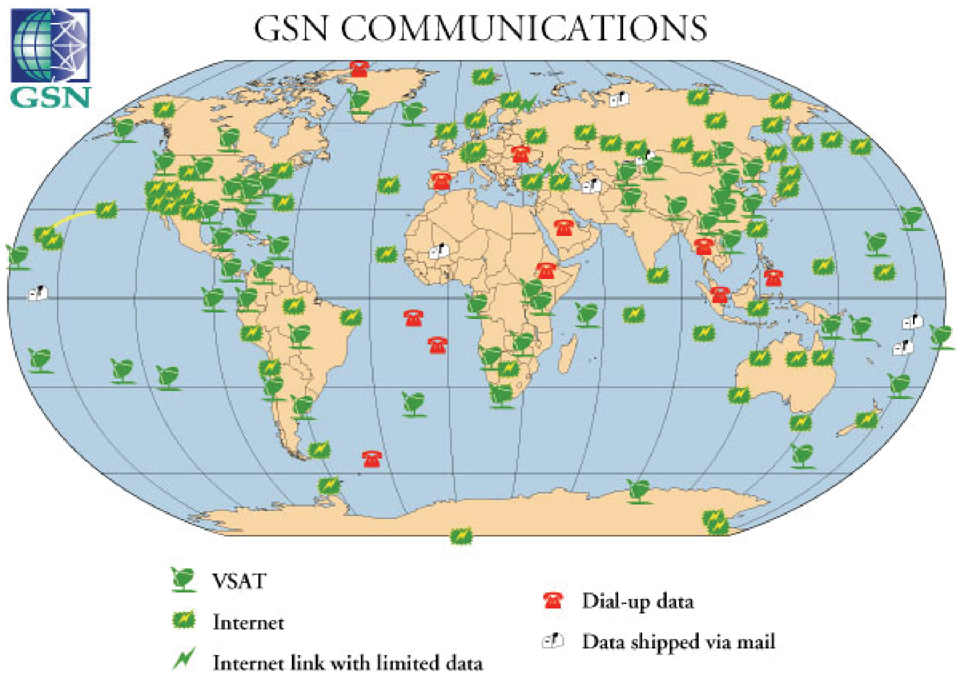
The GSN has been moving into an O&M phase for several years. Some equipment at GSN sites is nearly 20 years old and maintenance logs indicate an accelerating rate of failures in sensors and dataloggers. More ominously, the performance of some STS–1 seismometers appears to be degrading over time as reported by authors such as Ekstrom and others (2004), prompting efforts to identify and repair these unique sensors, as well as to develop the next generation of a very broadband seismometer.

The GSN was originally conceived as a seismological research network, as stated in the scientific objectives in the 1984 Science Plan (IRIS, 1984). In addition to monitoring seismic activity, the GSN has become a platform for the measurement of other geophysical parameters. For example, atmospheric pressure is currently being continuously monitored and recorded at most GSN stations, as a result of requirements to understand the effect of pressure changes on the seismic noise field. A few stations also record wind velocity and magnetic field variations, and Global Positioning System (GPS) receivers have been installed at a small number of stations.

Following the catastrophic loss of life on December 26, 2004 from the Sumatra tsunami, the Administration proposed (Kintisch, 2005) and Congress appropriated funds to enhance U.S. capabilities for tsunami detection and warning. As part of this effort, $4.15 million was appropriated in fiscal year 2005 supplemental funding to the U.S. Geological Survey to improve the detection response time by making data from all GSN stations available in real time, to improve station uptime, and to improve coverage in the Caribbean region through the addition of stations. These upgrades were funded through the one-time Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Tsunami Relief, 2005 (H.R. 1268). In addition, a smaller level of on-going support ($0.6 million per year) is included in the President's budget for FY2006 to support operations and maintenance of these upgrades and operating costs for new stations added in the Caribbean region.

Currently, about 89 per cent of GSN stations are equipped with real-time telemetry links. Many of these existing telemetry links are not robust or have insufficient bandwidth to adequately support the monitoring and notification missions. The goal of this GSN telemetry upgrade program is to establish real-time links at a minimum of 96 per cent of GSN stations and to improve telemetry at GSN stations where telemetry links are not adequate to better support the real-time missions of NEIC and the NOAA Tsunami Warning Centers as well as to enhance capabilities to detect and address maintenance issues.

The Caribbean component of the tsunami initiative consists of nine new seismic stations to support U.S. efforts to improve tsunami warnings in the Atlantic and Caribbean region. Destructive earthquakes and tsunamis are known to be a threat in the Caribbean that cause damage, not only from inundation and strong ground shaking, but also from liquefaction and extensive land sliding. Installation of the new seismic stations, planned for fiscal year 2006, will be a collaborative effort involving member institutions of the Middle America Seismograph Consortium (MIDAS) including: the USGS, the Puerto Rico Seismic Network (PRSN), the Seismic Research Unit of the University of the West Indies, and other institutions in the region. Data from the new Caribbean stations will be shared with the NOAA Tsunami Warning Centers.



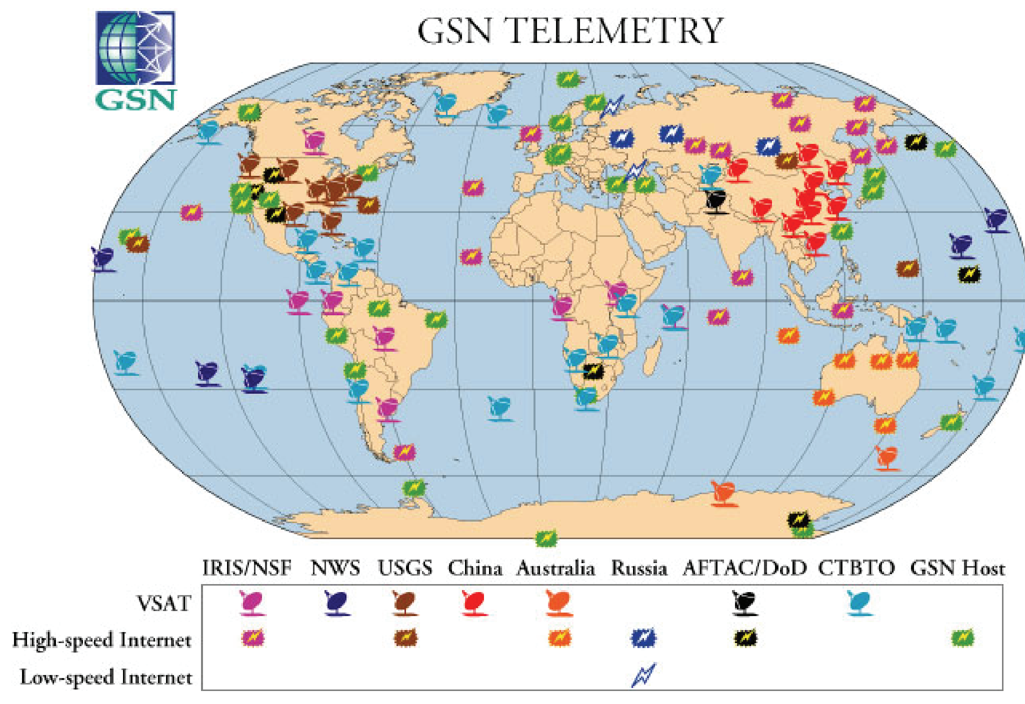




**Figure 3.** Maps of GSN Communications and Telemetry, by type (figure courtesy of IRIS).

The Caribbean and telemetry upgrades will improve the regional earthquake detection capabilities of the USGS NEIC and the NOAA Tsunami Warning Centers, decreasing the time to locate and report on earthquakes and thereby increasing the warning time for a potential tsunami.

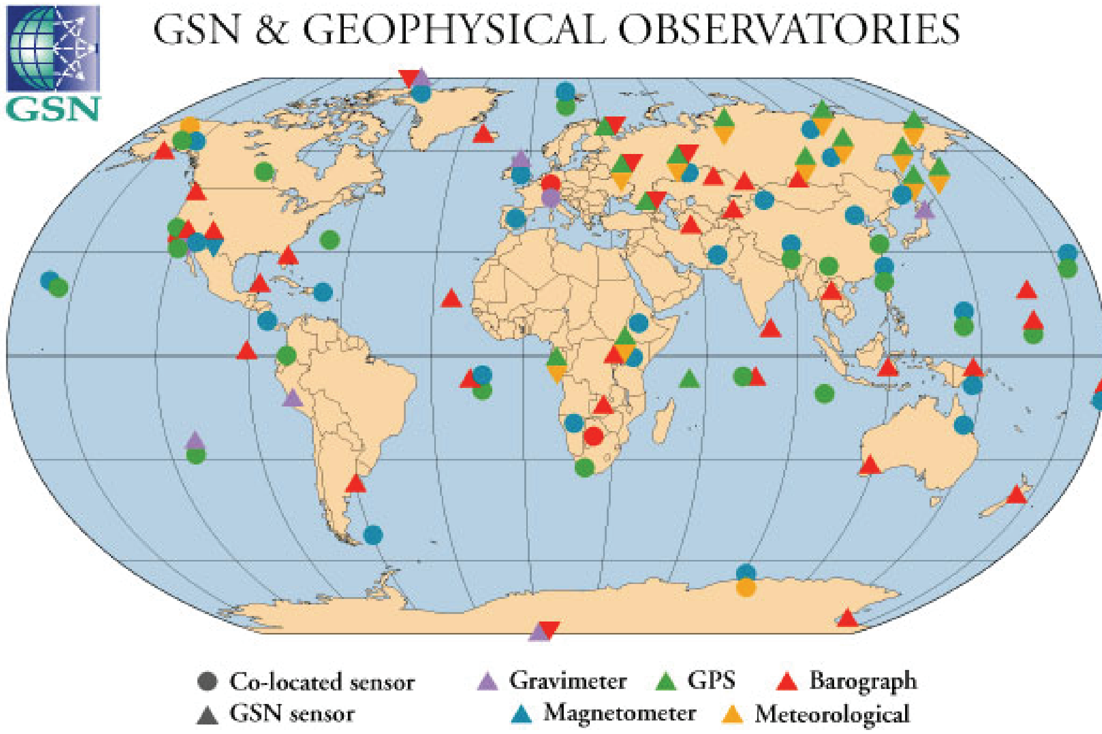



**Figure 4**. Map of GSN Stations that are geophysical observatories, hosting sensors making multiple Earth observations. Symbols indicate sensor types (figure courtesy of IRIS).

## Description of future initiatives and scientific directions

Seismographic networks are generally meeting the need for timely, high-quality information on earthquake occurrence and effects. As noted above, seismic monitors at some GSN sites are already operating in combination with meteorological sensors, GPS receivers, gravimeters, and magnetometers. These multiparameter sites enhance the capabilities of the GSN, as data from the additional sensors contributes to expanded monitoring capabilities and integrated studies of the Earth, as well as extending the GSN user community.

As a demonstrated platform for additional geophysical observations, the GSN can contribute data to the Global Earth Observation System of Systems[3] (GEOSS), whose goal is to collect and disseminate data and information from a variety of earth observation systems. GEOSS is designed to be "a global and flexible network of content providers …. This 'system of systems' will proactively link together existing and planned observing systems around the world and support the development of new systems where gaps currently exist" (GEO, 2008).

Finally, global seismological monitoring could be further enhanced by increasing the spatial resolution on land with permanent and temporary deployments of seismometers,

[3] The ad hoc inter-governmental Group on Earth Observations (GEO) has resolved that understanding the Earth system—its weather, climate, ocean, atmosphere, water, land, geodynamics, natural resources, ecosystems, and natural and human-induced hazards—is crucial to enhancing human health, safety and welfare and to reducing disaster losses (http://earthobservations.org/). Through a series of international meetings beginning in July 2003, GEO has defined the concept of a Global Earth Observation System of Systems (GEOSS) to provide the critical Earth observations and coordinated delivery of information from which decisions and actions for the benefit of humankind can be made.

expanding the coverage of global networks to the ocean floor, and upgrading the present networks as new technologies become available.

## Program mission and long-term goals

The Global Seismographic Network is a worldwide monitoring network providing high-quality seismic data to address problems related to disaster management, hazards assessment, national security, loss reduction, earthquake physics, and the structure and dynamics of the Earth. The GSN is a collaborative program among the USGS, the University of California at San Diego, and IRIS, which is a consortium of universities supported by the NSF. Initiated in 1986, with funding to IRIS from the National Science Foundation and the cooperation of the USGS, the GSN currently consists of 138 globally-distributed stations (including affiliates), with a design goal of about 150 sites.

### Operation

As part of the GSN collaboration, the USGS/ASL and UCSD/IDA install new stations on behalf of IRIS. Funds for the purchase and installation of new sites are provided to IRIS by NSF. The USGS is responsible for maintenance, data collection, and quality control of two-thirds of the GSN stations and NSF supports the University of California to operate and maintain the other third. Maintenance is accomplished in cooperation with many international partners who, in most cases, provide facilities to shelter the instruments and personnel to oversee the security and operation of each station. USGS tasks include: training station operators, troubleshooting problems, providing major repairs, conducting routine service visits to network stations, providing direct financial aid in support of station operations at those sites lacking a host organization (many of these stations reside within the former Soviet Union), and ensuring data quality and completeness.

As part of GSN activities, the USGS and IRIS also evaluate, develop, and advance new technologies in sensors, instrument installation, data acquisition and management. To improve performance, stations with unusually high background noise are relocated to quieter sites or configurations (for example, placing sensors in boreholes) so that smaller events like earthquakes or explosions or signals of interest may be detected. Siting, permitting, and installation of GSN stations will continue through FY2006 because of extended negotiations with host countries.

> "The Global Seismic Network … is furnishing unprecedented data on the source processes during major earthquakes in remote areas …. The GSN data acquired over the last 15 years have facilitated many advances in the study of global Earth structure and earthquake sources … [and] have also improved the plate-tectonic framework for understanding earthquake hazards …. Discoveries based on data now being collected by the GSN will undoubtedly continue into the indefinite future …. With each passing year, GSN [will] add new information to the evolving pattern of global seismicity by the direct observation of large, rare events and the delineation of low-level seismicity that may mark the eventual occurrence of such events.
>
> "Stable support of the GSN from a federal agency that embraces the mission of global seismic monitoring is essential to the long-term health of earthquake science."
>
> *Living on an Active Earth: Perspectives on Earthquake Science*, National Academy of Sciences, Board on Earth Sciences and Resources, 2003.

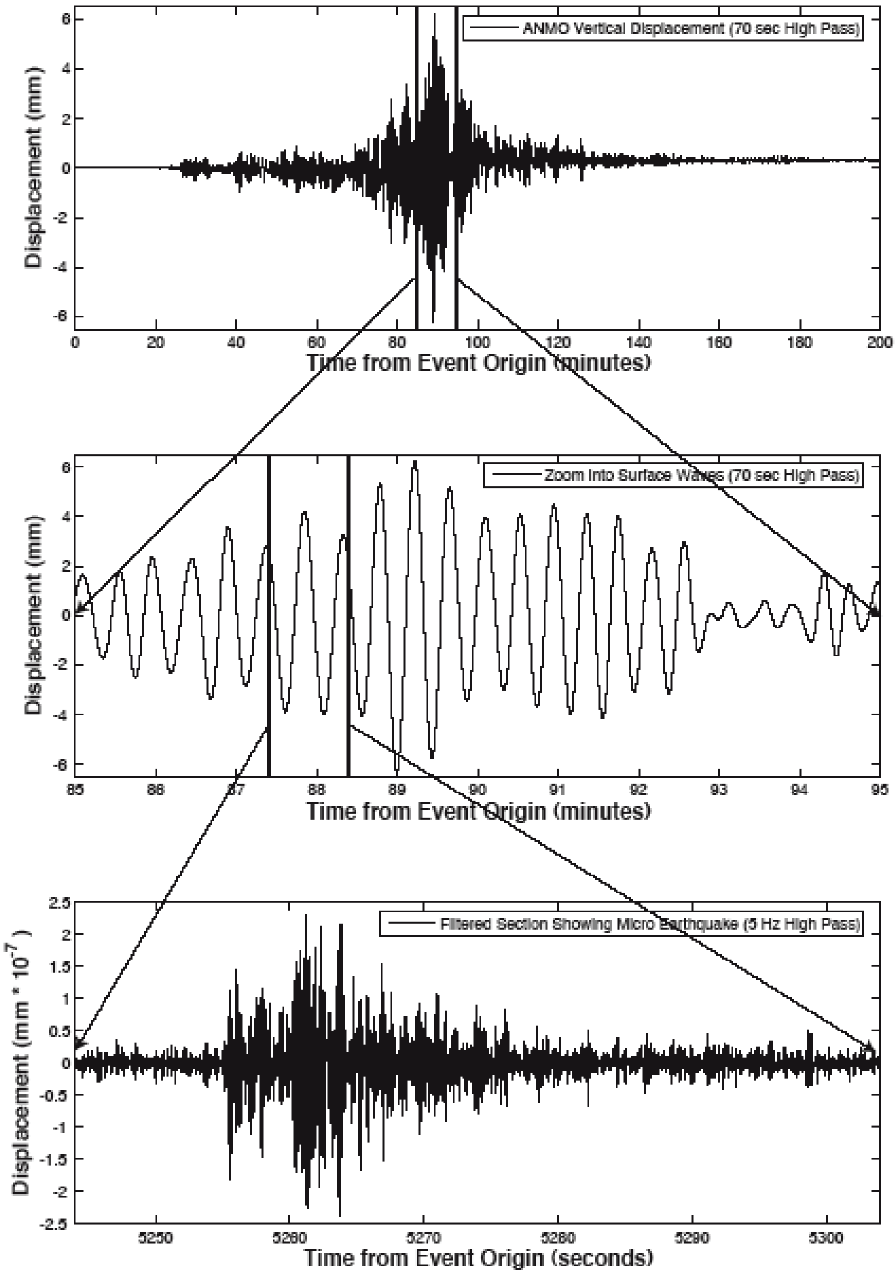



**Figure 5.** The remarkable high fidelity of GSN records is illustrated in this figure. Embedded in the record of the magnitude 9.0 Sumatra-Andaman earthquake of December 26, 2004 (upper panel), the trace of a small local earthquake in New Mexico, recorded faithfully at the same time (lower panel) (figure courtesy of Kent Anderson, IRIS, 2005).

The planned lifetime of the completed network is 30 years. However, with proper maintenance and upgrades of data system platform, the GSN can produce data indefinitely with expanded capabilities.

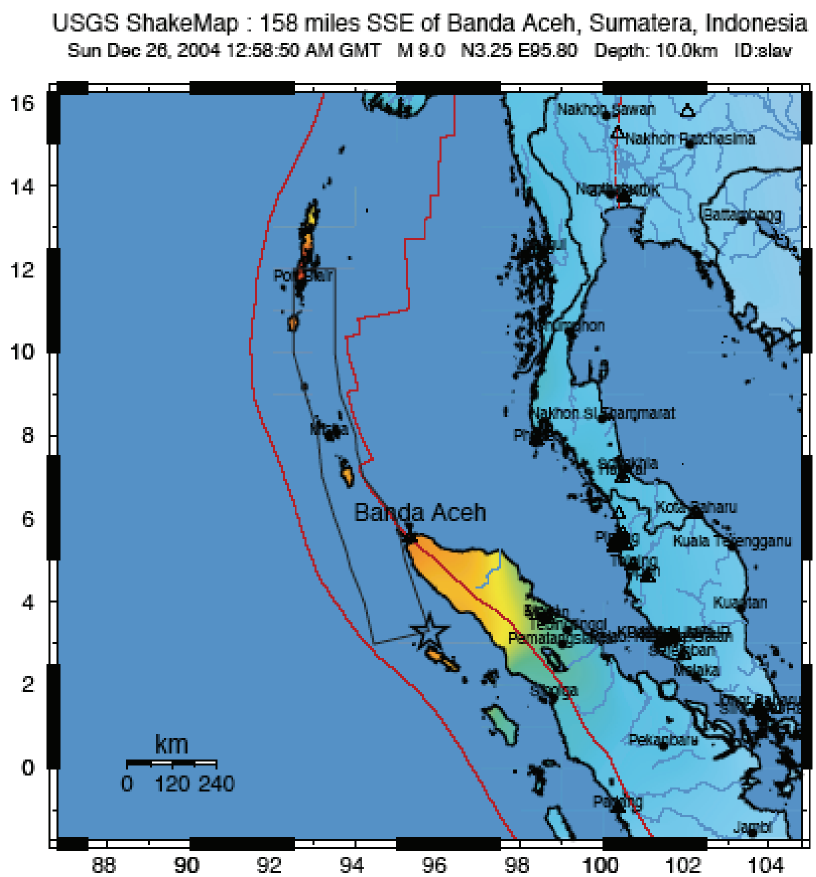
**Figure 6.** Challenges faced by the GSN field teams in deploying equipment in remote locations, illustrated in this case, by a pulley system being used to haul equipment from the shoreline to the cliff top at Raoul, Kermedec Islands, New Zealand (station code RAO). The dinghy was used to offload equipment from a larger vessel that provided island access (photograph courtesy of Ted Kromer, Honeywell Technology Solutions Inc., 2004).

## Data and products

Data and products derived from this program have multiple and diverse uses. The program supports the Department of the Interior's Serving Communities strategic goal to protect lives, resources, and property by making information available to communities for use in developing hazard mitigation, preparedness, and avoidance plans. The information provided to end users supports the intermediate outcome goal of providing information to assist communities in managing risks from natural hazards.

Principal end-users of GSN data include the USGS NEIC in Golden, Colorado, and a broad range of government agencies and academic researchers both domestic and international. These include the CTBTO and the AFTAC, in their respective treaty monitoring missions, as well as the NOAA Tsunami Warning Centers, which supporting tsunami monitoring in the Pacific Rim and disaster alerting in Alaska, Hawaii, Washington, Oregon, California, and U.S. territories in the western Pacific. Data from GSN stations in the region of the December 26, 2004, great earthquake off northern Sumatra were used by the Pacific Tsunami Warning Center to generate tsunami alerts within minutes of the earthquake (Park and others, 2005).

GSN data are used daily in the routine operations of the NEIC to determine the locations, depths, magnitudes, and other parameters of earthquakes worldwide. The high quality of GSN data allow them to be used for the rapid determination of the geometric orientation of the fault that caused the earthquake, and provide an estimate of the length of the fault that ruptured during the earthquake.




| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Moderate/Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | <.17 | .17-1.4 | 1.4-3.9 | 3.9-9.2 | 9.2-18 | 18-34 | 34-65 | 65-124 | >124 |
| PEAK VEL.(cm/s) | <0.1 | 0.1-1.1 | 1.1-3.4 | 3.4-8.1 | 8.1-16 | 16-31 | 31-60 | 60-116 | >116 |
| INSTRUMENTAL INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

**Figure 7**. PAGER estimate of strong ground shaking during the December 26, 2004, Sumatra great earthquake, based on GSN data and model calculations (figure courtesy of Paul Earle and David Wald, USGS, 2004).

The rapid availability of earthquake information is critical for first responders and government officials responsible for assessing an earthquake disaster. In the case of significant domestic earthquakes, the USGS and its partners provide information to Federal and State emergency management and public safety agencies, operators of transportation facilities and public utilities, and national news media. In the case of potentially damaging events outside of the United States, information from the NEIC is immediately sent to following: the Department of State, embassies and consulates in the affected region, the Office of Foreign Disaster Assistance, the Red Cross, and the United Nations, as well as national and international news media.

A new USGS product that relies on GSN data is the Prompt Assessment of Global Earthquakes for Response (PAGER) system. PAGER rapidly estimates the impact on humans from significant earthquakes worldwide by combining maps of shaking intensity with population density and infrastructure fragility. Fig. 7 displays an example of PAGER map output for the December 26, 2004, Sumatra-Andaman Islands magnitude 9.0 earthquake. This map shows which regions suffered the most intense shaking, and when combined with a global population map, indicates that 1.3 million people were exposed to "severe" shaking during the earthquake. The PAGER results were generated within hours of the event and transmitted to the State Department's Office of Foreign Disaster Assistance (OFDA) and other government agencies. PAGER is in development, with supporting funding from OFDA and other government agencies.

Copies of all the data from USGS GSN stations are sent to the IRIS Data Management Center in Seattle, Washington. The IRIS Data Management Center is the distribution point for GSN data to all other users (such as scientists, engineers, and government agencies) throughout the world. Every year it responds to over ten thousand requests for GSN data. In addition, data from over 115 GSN stations are currently available within hours of large earthquakes to the worldwide user community via the USGS Live Internet Seismic Server (LISS), the IDA Near Real Time System (NRTS), and telephone dial-up and (or) Internet connections/satellite links to the stations.

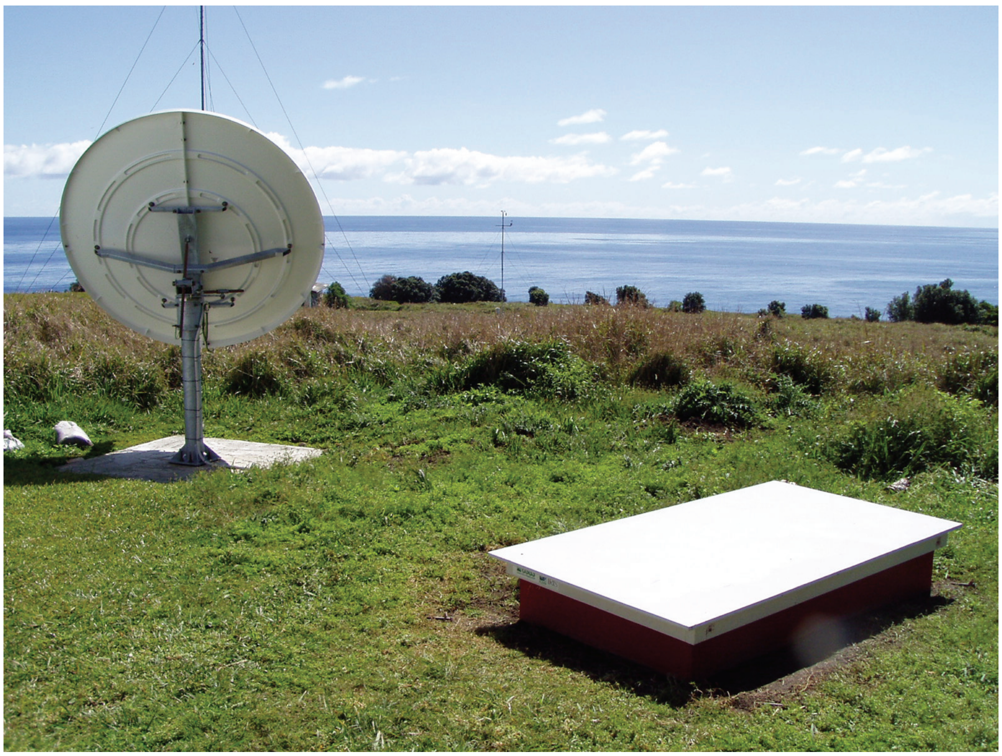


**Figure 8.** On Raoul Island (station code RAO), in the Kermadec Islands, New Zealand, the vault (lower right in the photograph) houses both an STS–1 vertical component seismic sensor and an STS–2. Strong ground shaking is recorded by an accelerometer, located with the data acquisition systems. The communications VSAT is provided by the CTBTO (photograph courtesy of Mark Sharratt, Honeywell Technology Solutions Inc., 2004)

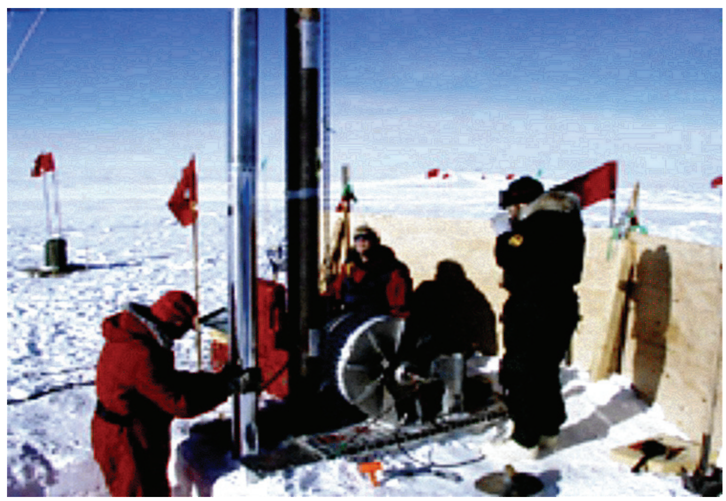
## Research support

Data from the GSN are used extensively in basic and applied research on earthquakes, Earth structure, and other geophysical problems. The principal supporters of this research are the USGS, NSF, Department of Energy, and U.S. Air Force. Some of this research supports improved national security by contributing to the seismic monitoring of nuclear explosions and improving the accuracy of Earth models.

Research efforts using GSN data that have received recent attention include: secondary earthquake triggering by nearby large earthquakes, the three-dimensional structure of the Earth's mantle, and the structure and seismic properties of the Earth's crust and upper mantle in central Asia, the Middle East, and northern Africa. The latter studies have applications in the verification of nuclear testing treaties. As an example of the importance of GSN data to current research, over sixteen journal articles have been published on the December 26, 2004 Sumatra-Andaman Islands earthquake and tsunami in the scant ten months since the event occurred, many of them based on GSN data.

In an example of a non-traditional use of GSN data, researchers are beginning to mine the global seismic “noise” field for information on the Earth, including processes related to the oceans, cryosphere, and atmosphere. The long record of GSN observations makes it uniquely suitable to examine a broad range of climate-related questions. Topics under investigation include the observation and analysis of “glacier quakes” in Antarctica and Alaska and the exploration of the relationship between long-term microseism observations and climate related observations of oceanic wave height, storm intensity, ocean temperature, and atmospheric carbon content.

**SPRESSO:** The South Pole is one of the quietest places on the planet, except for wind and human activity. At the Amundsen-Scott station, the seismic instrumentation is installed away from human noise at the station and deployed in boreholes 300m (1,000 ft) deep in the ice to get away from the wind noise near the surface. The South Pole Remote Earth Science and Seismological Observatory (SPRESSO) is 8 km from the Pole, and serves as an outpost for seismology and other experiments requiring quiet conditions. The completion of the first seismic borehole installations in 2003 achieved the world’s record for quiet conditions (at >1 Hz).



The South Pole also has a unique vantage for seismology. Seismic energy from earthquakes on the other side of the globe travels deep into the Earth all the way to the South Pole, where the GSN station has a window to the ‘underside’ of the earthquake. With most of the Southern hemisphere covered in ocean, the global coverage from Antarctica and the South Pole is crucial for unbiased studies of the Earth’s internal structure. Although Antarctica itself has few earthquakes, the South Pole station is the reference for all tectonic and structural studies of this continent and the southern oceans (photograph courtesy of Kent Anderson, Honeywell Technology Solutions Inc., 2003).

## Education and outreach

Given the high rate of significant earthquakes around the world, the GSN is an important tool in earthquake-related education and outreach. The USGS has worked with IRIS to develop educational museum displays based on data from the GSN. These displays explain the basic concepts of seismology and earthquake occurrence and have proven to be quite popular with the public. Displays are in place at the Smithsonian Institution in Washington, D.C., the American Museum of Natural History in New York, the Carnegie Museum in Pittsburgh, USGS Headquarters in Reston, the New Mexico Museum of Natural History in Albuquerque, and as part of the Franklin Institute's traveling "Powers of Nature" exhibit. Over the next few years, displays such as the “Museum Lite” (an Internet-based display showing seismicity, helicorder images, and other customizable information) will play a large role as part of the outreach to GSN station operators and host countries.

### Long-term goals

Long-term goals for the GSN include:

- Continued operation at a data availability rate of 95 per cent or higher
- Improved cost efficiency and reliability
- Incorporation of new seismic sensors and data acquisition systems as they become available
- Reliable real time telemetry from 100 per cent of GSN stations in support of earthquake monitoring, tsunami warning, and other real time missions
- Improved noise performance
- Observation of geophysical parameters in addition to ground motion
- Increased geographic coverage in under-sampled areas, particularly the oceanic and polar regions

## Program 5-year goals

Goal 1: Improve station reliability through more timely maintenance, an expanded inventory of spare parts, replacement of obsolete technologies and standardization of equipment. This 5-year goal addresses long-term goals 1, 2, and 3 above.

Goal 2: Improve the network’s utility for hazard warning (earthquake and tsunami) by expanding and improving real-time data communication links and by increasing geographic coverage. This 5-year goal addresses long-term goals 4 and 7 above.

Goal 3: Enhance network performance through relocating noisy stations to quieter sites and through the use of new seismometer and installation technologies. This 5-year goal addresses long-term goals 3 and 5 above.

Goal 4: Enhance data quality control operations. This 5-yr goal addresses long term goal 2 above.

Goal 5: Incorporate the GSN into the GEOSS effort and cooperate with IRIS, NSF, and other agencies in continuing to use the GSN as a platform for general geophysical observations. This 5-year goal addresses long-term goal 6 above.

Goal 1 Objectives:

A. Upgrade all USGS GSN stations with new, standardized data loggers. (The new equipment is expected to be funded by NSF, through IRIS.) Replacing obsolete data loggers with modern, low power equipment will increase reliability with a resulting increase in data availability and a lower cost per Gbyte of seismic data. Data availability and cost/Gbyte are both Bureau and Government Performance Results Act (GPRA) measures.

B. Establish a more robust spare parts inventory at ASL. Pre-position spare parts at sites where shipping lines are long and difficult (such as Antarctica and in countries where customs clearance take a long time).

C. Perform frequent maintenance visits as necessary to keep stations operating a high percentage of the time. The USGS expects to receive increased Operation and Maintenance funding from the “Tsunami

Goal 2 Objectives:

A. Install new telemetry links so that a minimum of 95 per cent of GSN stations have real time telemetry links.
B. Upgrade existing telemetry links to increase usable bandwidth and reliability.
C. Install new GSN stations in ocean and polar regions to achieve more uniform geographic coverage.
D. Install nine new GSN stations in the Caribbean region to provide real-time seismic data for tsunami warnings.

Goal 3 Objectives:

A. Perform background noise and signal-to-noise ratio studies of the GSN stations to determine which stations could benefit from being re-located.
B. Participate in the development and testing of new sensor technology. Existing STS–1 seismometers are no longer produced, are aging, and are beginning to fail. A replacement for this seismometer is necessary to support network performance.
C. Continue to develop and test innovative seismometer installation techniques and noise-reduction techniques.

Goal 4 Objectives:

A. Automate some of the current data quality control operations so that analysts can focus on other measures.
B. Develop new tools for data quality control, such as the use of synthetic seismograms, to facilitate identification of problems in station operation or instrument responses.
C. Coordinate activities with the ANSS in order to improve data quality operations overall.

Goal 5 Objectives:

A. Participate in international workshops on GEOSS
B. Establish cooperative relationships with GEOSS partners to explore ways of using GSN stations as platforms for geophysical observations.
C. Install equipment and begin making such observations.

## Partners and customers

Goal 1: Partners for this goal are NSF and IRIS. IRIS, NOAA, AFTAC, CTBTO, and the USGS NEIC are customers. All parties, including the NEIC, will benefit by receiving data more reliably from the GSN in support of their respective missions. Funding for replacement of obsolete data loggers with standardized, modern data loggers is expected to be provided by NSF, through IRIS. Both NSF and USGS will supply funding for additional spare parts.

Goal 2: Partners are IRIS and NSF. Customers are IRIS, NOAA, and USGS NEIC. The NEIC will benefit by receiving more real time data from more stations, thus improving their ability to quickly locate and characterize earthquakes. The tsunami warning centers operated by NOAA will benefit for the same reasons.

Goal 3: Partners are NSF and IRIS. Customers are USGS NEIC, IRIS, AFTAC, NOAA, and CTBTO. All of these customers will benefit from improved noise performance at stations through the ability to detect, locate, and characterize smaller seismic events.

Goal 4: Partners are USGS NEIC and IRIS. Customers are USGS NEIC, IRIS, AFTAC, NOAA, and CTBTO. All of these customers will benefit from improved data quality control procedures.

Goal 5: Partners are GEOSS, NSF, and IRIS. Customers include GEOSS, IRIS, and the USGS (for example, the USGS Geomagnetism program). The GSN will benefit from cooperation with GEOSS collaborators by expanding the user community support for the observation platform. In August 2005, the USGS and NSF funded an international workshop on the "GSN within GEOSS". Long-term funding sources remain to be identified, but are likely to be USGS, NSF, and GEOSS collaborators.

## Program review

The USGS receives advice and scientific guidance from the IRIS GSN Standing Committee (GSNSC), which meets twice annually. USGS/ASL and UCSD/IDA representatives attend all GSNSC meetings. The following description of the GSNSC is from the GSN Annex to the USGS-NSF Memorandum of Understanding on Cooperation in Development and Support of Research Activities and Facilities for the Earth Sciences:

"Both IRIS and USGS management policies require external advisory or consultative committees for the GSN program. Both sides recognize that their institutions and the scientific community as a whole will not be well served with two such bodies offering possibly conflicting guidance. Therefore, all Parties agree to accept the IRIS GSN Standing Committee as a joint advisory committee for the GSN. IRIS shall consult with NSF and the USGS in the appointment of the membership of the GSN Standing Committee. There shall be a permanent seat on the GSN Standing Committee for a voting USGS member in addition to the seat of the Network Operator filled by a representative of ASL."

"Both IRIS and the USGS recognize that the ultimate responsibility of GSN matters rests with appointed program managers or coordinators in their respective organizations. The guidance issued of the IRIS GSN Standing Committee shall be considered by both sides to be advisory in nature. However, both IRIS and the USGS mutually agree to follow the advice of the IRIS GSN Standing Committee in good faith and to the extent possible within the limits of practical considerations and available funding."

In addition to the oversight provided by the GSN Standing Committee, the GSN program was reviewed by the USGS (Filson and Shedlock, 2002) and by IRIS (IRIS, 2003).

This five-year plan (and previous five-year plans for the GSN) has been coordinated with IRIS and NSF. A list of external reviewers of this plan is given in Appendix 1.

During the period of this plan, the GSN program will undertake regular internal and external reviews of its activities. Reviews follow the bureau policy on program review and the requirements for achieving and reporting on bureau performance measures developed in accordance with the Government Performance and Results Act as well as PART measures identified by OMB.

The *GSN Standing Committee* develops policies to facilitate a timely and successful installation of the Global Seismographic Network, and the rapid dissemination of the data collected by the GSN. The following is the original charge to the GSN Standing Committee, available at http://www.iris.edu/hq/about_iris/governance/gsn (IRIS, 2005). A revised charge is currently being reviewed by the USGS and IRIS Board of Directors. Note that this charge refers to a design goal of 128 stations – the current target is approximately 150, including affiliated stations.

1. Set standards for GSN instrumentation and data collection.
2. Develop and maintain a siting plan that ensures the timely deployment of GSN instruments and accounts for the contributions of other 'equivalent' networks in maximizing the global coverage afforded by the GSN.
3. Set standards/policies to ensure the timely flow of data from the GSN stations to the Data Collection Centers.
4. Develop and evaluate strategies for the successful procurement and installation of GSN equipment so as to complete the global seismographic network by 2002 (128 'goal' stations).
5. Cooperate with the USGS, the Federation of Digital Broad Band Seismograph Networks (FDSN) and other groups interested in establishing digital stations for global studies, to establish a well-distributed network in an expeditious manner.
6. Develop plans for the long-term maintenance of the GSN.
7. Coordinate with the Ocean Seismic Network Steering Committee to facilitate the deployment of ocean bottom stations, so as to reach the GSN goal of uniform global coverage.
8. Develop new initiatives to enhance the effectiveness of the GSN.
9. Advise the Program Manager and the IRIS President on program planning and yearly budgets.

## Expertise and capabilities

Since 1961, the ASL has been the installation, maintenance and data center for various global seismic networks including the WWSSN, the High Gain Long Period (HGLP) network, the Seismic Research Observatories (SRO), the Digital version of the WWSSN (DWWSSN), and the Modified High Gain Long Period network. During the 1980s and 1990s, ASL developed and deployed the 9 stations of the China Digital Seismic Network (CDSN) and the 9 stations of the Global Telemetered Seismograph Network (GTSN). In 1984, the USGS/ASL began working closely with IRIS in developing and installing the GSN. ASL currently operates 85 GSN stations in 60 countries, and is in the process of installing 4 more. In addition, the ASL is actively collaborating with the USGS NEIC to install 35 backbone stations of the ANSS/Earthscope USArray project and 9 new stations in the Caribbean, as described earlier.

The USGS ASL has extensive expertise and capabilities in station installation, network support and maintenance, seismometer test and development, and data collection, quality control, and distribution. The ASL staff takes pride in its abilities to install, operate, and collect data from seismographic stations on a global basis in over 60 countries — and in the high quality of the resulting data. In 2005, ASL staff consist of six U.S. Geological Survey staff, filling management and oversight positions plus one programming position, with contract personnel composing the majority of the staff. Contract personnel are currently provided by Honeywell Technology Solutions Inc.

The various functions performed at ASL are enumerated below:

- Seismograph network installation
    - Equipment design and development
    - System integration and testing
    - Software development
    - Site selection and permitting
    - Site surveys and preparations
    - Station operator training
    - Station installation and calibration
- Long-term operations
    - Equipment repair and replacement
        - Seismometers
        - Digital acquisition systems
        - Software testing systems
    - On-site maintenance
    - Training — Both on-site and at ASL
    - Technical Support — Email, faxes, phone calls
    - Spare parts
    - Station supplies
    - Logistics and administrative support (shipping, customs, travel, and so forth)
- Data collection, distribution, and archive
    - Quality assurance
    - Data production
    - Database maintenance
    - Software development
    - Computing facilities
- Network and information technology support
- Instrumentation test facility
    - Seismometer evaluation
        - Dynamic range, noise (side-by-side comparison in quiet vault or borehole), linearity, clip level, accurate transfer function determination, determination of sensitive axis (accurate orientation), cross-axis coupling, temperature performance, and so forth.
    - Data acquisition system evaluation

    - Dynamic range, clip level, linearity, sensitivity, crosstalk, common mode rejection, temperature performance, timing accuracy, and so forth.
  - Cooperation with Sandia National Laboratory
- Warehousing, receiving, packing, shipping
- Instrument lab (special parts fabrication and modification)

As of 2005, the USGS portion of the GSN had grown from 72 to 85 stations since 1998, soon to be 89 stations. At the same time, the budget for operating and maintaining the network has decreased from $3.4 million in 1998 to just over $3.3 million in 2005. If the GSN is to remain operational and viable in the long term, this decreasing operations and maintenance funding trend will need to be reversed. While some reliability gains can be made through equipment replacement, there is no substitute for qualified personnel and maintenance visits to stations.

Moreover, the GSN faces potential staffing issues. Several critical personnel are approaching retirement age. The GSN risks the loss of their unique capabilities, skills, and corporate knowledge unless replacement staffing can begin soon.

**Figure 9.** Installation of the CTBTO VSAT at Raoul Island (RAO) (figure courtesy of Ted Kromer, Honeywell Technology Solutions Inc., 2004).

## Facilities

The USGS Albuquerque Seismological Laboratory has been in existence since 1961. It was established as a quiet site for testing seismometers for the WWSSN, but quickly became the installation and maintenance depot and data collection center as well. Today, the ASL occupies a 160-acre site located in the Manzanito Hills, a remote area of the Isleta Indian Reservation adjacent to the south boundary of Kirtland Air Force Base, about 15 miles southeast of Albuquerque, New Mexico. The relatively isolated location provides a site where seismograph instruments can be operated and tested without major disturbance from manmade noise sources. The ASL consists of 15 structures, 2 subsurface vaults mined into a granite hill, 5 boreholes, and several surface vaults. The extremely low-noise seismometer test facilities at ASL are quite important in evaluating and further developing seismic instrumentation for the GSN and the ANSS.

This land and facilities are leased from the Pueblo of Isleta Indian Tribe for a 5-year period ending in December 2008, for an annual fee assessed every five years by an independent appraiser approved by the Secretary of the Interior. Access to ASL is provided through Kirtland Air Force Base, and the last 2.5 miles to the lab is over a dirt road that is sporadically maintained (and occasionally washes out).

**Figure 10.** The ASL facilities are located on the Isleta Pueblo, immediately south of Kirtland Air Force Base. The major structures of the ASL are visible in the fore ground; the 2 subsurface vaults are visible in the shadows of the foothills, just above the road (photograph courtesy of B. Hutt, USGS, 2002).

**Figure 11**. Left: Location of the ASL boreholes, including the borehole used for the GSN station ANMO. Middle: Entrances to the east vault. Right: ASL staff working on an instrument test in the granite vaults (photographs courtesy of Bob Hutt, USGS, 2002).

## Performance measures, goals and targets

The GSN Program contributes to the DOI Strategic Goal (2003) of *Serving Communities*, the USGS Hazards Mission Goal to "*Provide science... focusing efforts to predict and monitor hazardous events in near-real time and to conduct risk assessments to mitigate loss.*" Under the Government Performance Results Act of 1993, the GSN has been tracked and reported under "networks maintained" by USGS.

In 2003, the USGS GSN Program was reviewed by the White House Office of Management and Budget (OMB), together with the other USGS geologic hazards programs (Earthquake Hazards, Volcano Hazards, Landslide Hazards and Geomagnetism), using the Performance Assessment and Management Tool (PART). The programs were rated by OMB as "Fully Successful". At the same time, new PART performance measures were developed for GSN, which are currently being tracked and reported on by USGS.

The following table lists the USGS performance measures that are specific to the GSN program. Note that the GSN also contributes to the performance reporting of the Earthquake Hazards Program, through workshops and training provided and number of ANSS stations (some of which are installed by GSN personnel). The table lists performance measures, targets and 2008 goals as of 15 December, 2005.

**Table 1: GSN Performance Measures** — End Outcome Goal 4.1: Serving Communities: Protect lives, resources and property.

| End Outcome Measures, Inter-mediate or PART Measures/PART Efficiency or Other Outcome Measures | FY 2005 Plan | FY 2005 Actual | Change from 2005 Plan | FY 2006 Enacted | 2006 Change from 2005 | FY 2007 OMB Plan | 2007 Change from 2006 | Long-term Target (2008) Pres. Req. |
|---|---|---|---|---|---|---|---|---|
| % of earthquake monitoring GSN stations that have telemetry (to increase earthquake reporting speed from one hour to 20 min.) (1) | 80% | 86% | +6% | 89% | +3% | 93% | +4% | 95% |

| End Outcome Measures, Intermediate or PART Measures/PART Efficiency or Other Outcome Measures | FY 2005 Plan | FY 2005 Actual | Change from 2005 Plan | FY 2006 Enacted | 2006 Change from 2005 | FY 2007 OMB Plan | 2007 Change from 2006 | Long-term Target (2008) Pres. Req. |
|---|---|---|---|---|---|---|---|---|
| X% data availability for real-time data from the GSN **(PART)** [(2)] | 90% | 88% | -2% | 90% | +2% | 87% | -3% | 90% |
| Data processing and notification costs per unit volume of input data from sensors in monitoring networks (in cost per gigabyte) **(PART** Efficiency Measure) [(3)] | 0.99 $k/GB | 1.15 | +0.6 | 1.42 | +0.27 | 1.33 | -0.09 | TBD |

[(1)] This is a new measure for FY06. Formula used includes 9 new Caribbean Network Stations

[(2)] Rebaselined beginning FY05. New formula includes 9 new Caribbean Network Stations. Decrease in FY07 due to aging equipment for which recapitalization funds are not in passback.

[(3)] Rebaselined beginning FY05 to limit reporting to only the USGS portion of the network. FY06 cost increases are due to 2005 negotiated increase in contractor costs (Honeywell contract). These are ameliorated in FY07 due to expected increased data volume. Level cost efficiency in FY07 depend on install of 4 additional stations

Three factors will lead to an expected decrease in the performance of the network in FY2007:

- Because of expected increases in fixed costs, mostly due to a federally-negotiated increase in the main GSN support contracts, we anticipate a decrease in contractor support that will, in turn, result in less frequent visits to stations for scheduled and unscheduled maintenance. This will result in an expected lower performance on the metric for data availability.
- It is expected that aging equipment will degrade station performance at some sites. Because of the increased fixed costs noted above, funds are not available to increase stocks of replacements sensors and other critical parts.
- Consequently, an anticipated lower data availability will result in a lower cost efficiency; this is reflected in an increase in the performance metric for the cost per volume of input data from GSN sensors.

Program managers are seeking ways of reducing dependence on contract-supported station maintenance, but we do not expect significant changes by the FY2007 budget year.

## Records management

All data and metadata from the USGS component of the Global Seismographic Network are quality-controlled and transferred to the National Science Foundation for archiving. Data received in real-time are quality-controlled within 24—72 hours. Final archive of the data depends on media transmitted from the station and is typically complete within 60 days. The data are archived at the IRIS Data Management Center in Seattle, Washington, and made freely available to the public.

## References

Agnew, D., Berger, J., Buland, R., Farrell, W., and Gilbert, F., 1976, International deployment of accelerometers: a network for very long period seismology: EOS Transactions of the American Geophysical Union, v. 57, p. 180-188.

Butler, R., Lay, T., Creager, K.C., Earle, P., Fischer, K.M., Gaherty, J.B., Laske, G., Leith, B., Park, J. , Ritzwoller, M.H., Tromp, J., and Wen, L., 2004, The Global Seismographic Network Surpasses Its Design Goal: EOS Transactions of the American Geophysical Union, v. 85, p. 225-229.

Committee on the Science of Earthquakes, Board of Earth Sciences and Resources, 2003, Living on an Active Earth: Perspectives on Earthquake Science: Washington, D.C., National Research Council of the National Academies, 418 p.

Ekstrom, G., Dalton, C., and Nettles, M., 2004, Observations of Time-dependent Errors in Long-period Instrument Gain at Global Seismic Stations: Seismological Research Letters, v. 77, p. 12-22.

Engdahl, E. R., Peterson, J., and Orsini, N., 1982, Global Digital Networks–Current Status and Future Directions: Bull. Seis. Soc. Am., v. 72, p. S243-S259.

Filson, J. R., and Shedlock, K., 2001, Report of the Review of the Global Seismographic Network Program of the U.S. Geological Survey: U. S. Geological Survey Open-File Report 2001-460, 29 p.

Group on Earth Observations, 2008, What is GEOSS?: Group on Earth Observations web page at http://earthobservations.org/geoss.shtml/. (Last accessed on Dec 9, 2008.)

IRIS, 1984, Science Plan for a New Global Seismographic Network: Washington, D.C., IRIS Consortium, 132 p.

IRIS, 2003, Review of the Global Seismographic Network, prepared for the Instrumentation and Facilities Program, Earth Sciences Division, National Science Foundation: Washington, D.C., IRIS Consortium, 30 p.

IRIS, 2004, Twenty Years of Support for Seismological Research: Washington, D.C., IRIS Consortium, 68 p.

IRIS, 2005, GSN Standing Committee: IRIS web page at http://www.iris.edu/hq/about_iris/governance/gsn/. (Last accessed on Dec 9, 2008.)

Kintisch, E., 2005, Global Tsunami Warning System Takes Shape: Science, v. 21, p. 331.

Oliver, J., and Murphy, L., 1971, WWNSS: Seismology's Global Network of Observing Stations: Science, v. 174, p. 254-261.

Park, J., Bulter, R., Anderson, K., Berger, J., Benz, H., Davis, P., Hutt, C.R., McCreery, C.S., Ahern, T., Ekstrom, G., and Aster, R., 2005, Performance Review of the Global Seismographic Network for the Sumatra Andaman Megathrust Earthquake: Seismological Research Letters, v. 76, 331-343.

Peterson, J., Butler, H.M., Holcomb, L.G., and Hutt, C.R.,1976, The Seismic Research Observatory: Bull. Seis. Soc. Am., v. 66, p. 2049-2068.

Peterson, J., and Orsini, N., 1982, Design concepts for a Global Telemetered Seismograph Network: U. S. Geological Survey Open-File Report 82-703, 38 p.

Romanowicz, B., Cara, M., Fels, J. F., and Rouland, D., 1984, GEOSCOPE: a French initiative in long period three component global seismic networks: EOS Transactions of the American Geophysical Union, v. 65, p. 753-756.

Smith, S.W., 1986, IRIS – A program for the next decade, EOS Transactions of the American Geophysical Union, v. 67, p. 213-219.

U.S. Department of Interior, 2003, U.S. Department of Interior Strategic Plan FY2003-2008, http://www.doi.gov/ppp/strat_plan_fy2003_2008.pdf, 83p.

Wielandt, E., and Streckeisen, G., 1982, The leaf-spring seismometer: Design and Performance: Bull. Seis. Soc. Am., v. 72, p. 2349-2367.

## Data sources

FDSN: http://www.fdsn.org/ (Last accessed on Dec 10, 2008.)
GEO: http://earthobservations.org/ (Last accessed on Dec 10, 2008.)
IRIS: http://www.iris.edu/hq/ (Last accessed on Dec 10, 2008.)
IRIS Data Management Center: http://www.iris.edu/data/ (Last accessed on Dec 10, 2008.)
IRIS GSN Program: http://www.iris.edu/hq/programs/gsn (Last accessed on Dec 10, 2008.)
NOAA Tsunami Program: http://www.tsunami.noaa.gov/ (Last accessed on Dec 10, 2008.)
USGS Albuquerque Seismological Laboratory: http://earthquake.usgs.gov/regional/asl/ (Last accessed on Dec 10, 2008.)
USGS Earthquake Information: http://earthquake.usgs.gov/eqcenter/ (Last accessed on Dec 10, 2008.)
USGS Global Seismographic Network: http://earthquake.usgs.gov/research/monitoring/gsn/
USGS National Earthquake Information Center: http://earthquake.usgs.gov/regional/neic/ (Last accessed on Dec 10, 2008.)
USGS PAGER project: http://earthquake.usgs.gov/eqcenter/pager/ (Last accessed on Dec 10, 2008.)

## Appendix 1. List of external reviewers of this plan

Kent Anderson, IRIS GSN Program Manager

Rhett Butler, IRIS GSN Program Director

Thorne Lay, Chair, IRIS Board of Directors

Charles McCreery, Director, Pacific Tsunami Warning Center

Jeffrey Park, Chair, GSN Standing Committee

David Simpson, President, Incorporated Research Institutions for Seismology (IRIS)

Bruce Varnum, Air Force Technical Application Center, Patrick AFB, Florida

Paul Whitmore, Director, West Coast/Alaska Tsunami Warning Center

Ray Willeman, IRIS Director of Program Development