1 | GLOBAL SEISMOGRAPHIC NETWORK

HISTORICAL CONTEXT OF CURRENT OPERATIONS

The Global Seismographic Network (GSN) is 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 Earth. The network was built and is operated cooperatively by IRIS and the U.S. Geological Survey, with coordination and contributions from other U.S. government agencies and with the international community. The network has multiple scientific uses in several disciplines of Earth science that serves societal needs for Earth observations, monitoring, research, and education. The instrumentation is capable of measuring and recording with high fidelity all seismic vibrations, from high-frequency, strong ground motions near an earthquake to the slowest fundamental oscillations of Earth excited by the largest great earthquakes.

The GSN concept is founded upon global, uniform, unbiased Earth coverage by a permanent network of over 130 stations (and Affiliates) with real-time data access. The instrumentation is modular, enabling it to evolve with technology and science needs. Equipment standardization and data formats create efficiencies for use and maintenance. Telecommunications are heterogeneous, using both public and private Internet links as well as dedicated satellite circuits. All of the data are distributed without restriction as soon as technically feasible, nearly all of it in real time.

The network is both benefactor and beneficiary of a government-university cooperation involving the NSF, the USGS, the Department of Defense, NASA, and NOAA. GSN is a foundation for both the USGS Advanced National Seismic System (ANSS) and the USArray Reference Network, and provides the critical core data for the U.S. Tsunami Warning Centers and other international tsunami warning systems, and for the international Greenland Ice Sheet Monitoring Network (GLISN). The International Monitoring System for the Comprehensive Nuclear Test Ban Treaty uses data from GSN stations. GSN is an official U.S. observing system component of the Global Earth Observation System of Systems (GEOSS). With IRIS a founding member of the International Federation of Digital Broadband Seismographic Networks (FDSN), GSN serves as key component of the FDSN backbone. GSN serves as a fiducial reference network for PASSCAL experiments and other international portable deployments throughout the world. Primarily operated and maintained through the USGS Albuquerque Seismological Laboratory (ASL) and the University of California at San Diego (USCD), GSN is joined by independent national and international Affiliate stations and arrays. Affiliate stations provide all of the necessary equipment to meet GSN design goals, fund their own operations and maintenance following GSN standards, and distribute their data as a part of GSN. Many GSN stations have been enhanced through international cooperative efforts, including the contribution of seismic equipment, telemetry, and other support in kind. International partners include network operators in Australia, Botswana, Canada, China, France, Germany, Great Britain, Italy, Japan, Kazakhstan, Kyrgyzstan, Korea, Mexico, New Zealand, Norway, Peru, Russia, Singapore, Spain, United Arab Emirates, and others.

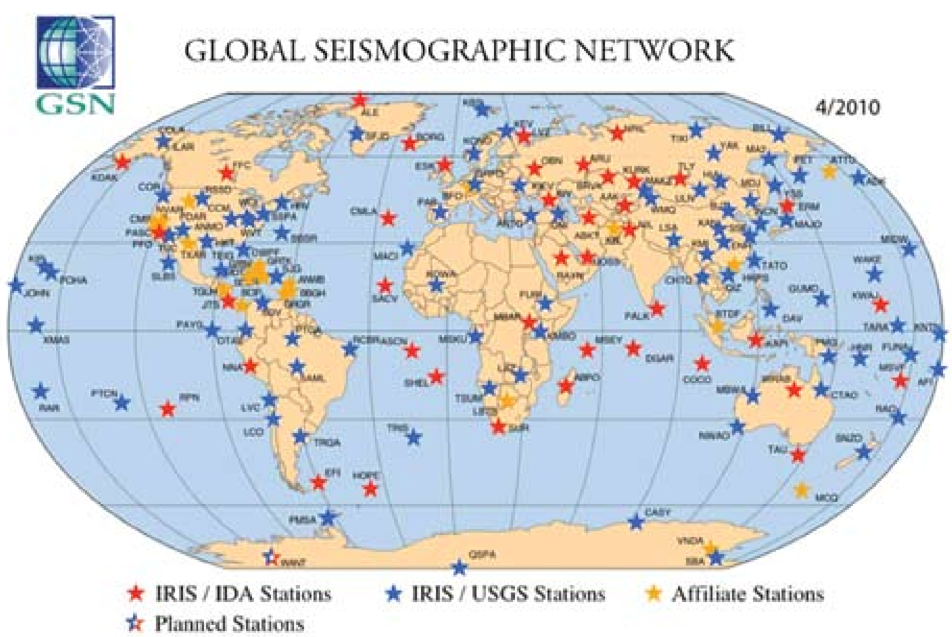


Figure A1.1. Status of the GSN in 2010 showing stations operated by the USGS Albuquerque Seismological Laboratory, the IDA group at the University of California, San Diego, and GSN Affiliates.

GSN is an educational tool for the study of Earth. With the ease of data access and blossoming computer technology, the data are now routinely used in introductory college courses, and high school use is rising. The stations themselves are focal points for international training in seismology. Real-time access to the data has led to rapid analysis of earthquake locations and their mechanisms, bringing public awareness of earthquakes as scientific events, not just news events.

International, global seismographic coverage was born at the beginning of the twentieth century when a network of more than 30 Milne seismographs first spanned the globe—in essence the first global seismographic network. In 1960, the analog World Wide Standard Seismograph Network (WWSSN) of 100+ seismic stations was initiated to provide basic global coverage for seismological research and monitoring nuclear tests. Data from this network formed the core for modem seismology and discoveries leading to plate tectonics. Entering the digital age in the 1970s, the USGS/Advanced Research Projects Agency (ARPA) Seismic Research Observatories (SRO) of both underground and borehole seismometers and the NSF-sponsored UCSD International Deployment of Accelerometers (IDA) initiated a new era of large-scale, digital seismological studies.

In the 1980s, seismometers with feedback electronics became available with very broad bandwidth, high dynamic range, and linearity for recording the largest earthquake signals, and instrumental noise below the lowest natural seismic background noise. Digitizers were developed with more than 140 dB dynamic range to encode the analog signals from these new broadband sensors. Computer costs declined while processing speeds and recording capacities increased exponentially.

This strong technological foundation came at a time when the science of seismology had advanced theoretically beyond its observational capacity. The questions being posed by the science could not be answered with the limited data available. At the same time, the view of Earth as a system was coming into focus. Seismology, with its unique ability to "see" into the planet, was called to image Earth's interior and provide

GSN RELATIONSHIPS AND PARTNERSHIPS

GSN MANAGEMENT HAS DIRECT RELATIONSHIPS WITH:

- Geophysical Survey of the Russian Academy of Sciences
- Chinese Earthquake Administration
- Geoscience Australia
- Geological Survey of Canada
- University of Brazil
- Germany's GeoForschungsZentrum, Bundesanstalt fur Geowissenschaften und Rohstaffe (Geological Survey), and Alfred Wegner Institute for Polar Research
- Italy's Istituto Nazionale di Geofisica e Vulcanologia (INGV)
- Mexican National Seismic Network
- British Geological and Antarctic Surveys
- Japan's National Research Institute for Earth Science and Disaster Prevention (NIED), University of Tokyo Earthquake Research Institute, Japan Marine Science and Technology Center (JAMSTEC), and Japan Meteorological Agency
- France's Institut de Physique du Globe de Paris and Laboratoire de Détection Géophysique (LDG)
- New Zealand Geological and Nuclear Sciences
- Spain's Instituto Geographico Nacional (IGN)
- Chile's Fundacion Andes
- Singapore's Meteorological Service
- Hong Kong Observatory
- Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) International Monitoring System (IMS) and Global Communications Infrastructure (GCI)
- International Ocean Network (ION)
- Greenland Ice Sheet Monitoring Network (GLISN)
- International Federation of Broadband Digital Seismic Networks (FDSN)
- Global Earth Observation System of Systems (GEOSS)

NATIONAL PARTNERSHIPS INCLUDE:

- National Science Foundation (Earth, Oceans, Atmospheres and Polar Programs)
- USGS (Albuquerque, Reston, Golden and Menlo Park)
- National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS)
- Pacific Tsunami Warning Center (PTWC) and West Coast and Alaska Tsunami Warning Center (WC/ATWC)
- National Aeronautics and Space Administration (NASA)/Jet Propulsion Laboratory (JPL)
- Air Force Technical Applications Center (AFTAC)
- U.S. State Department Verification Monitoring Task Force
- UNAVCO Inc.
- University of California at San Diego (UCSD)
- Harvard University
- Caltech/University of Southern California
- Saint Louis University
- Oregon State University
- University of Arizona
- University of California at Berkeley
- Penn State University
- University of Texas at Austin
- Carnegie Institution of Washington
- University of Hawaii at Manoa

GSN AND MONITORING: EARTHQUAKES, TSUNAMI WARNING, NUCLEAR TREATY VERIFICATION

GSN is a real-time network whose data are routinely used by operational monitoring groups, both in the United States and internationally. In the United States, 19 GSN stations are included in the USGS Advanced National Seismic System. The National Earthquake Information Center receives data from all real-time GSN stations globally for earthquake locations. GSN data are essential input to the USGS PAGER (Prompt Assessment of Global Earthquakes for Response) automated alarm system used to rapidly and accurately assess the severity of damage caused by an earthquake and to provide emergency relief organizations, government agencies, and the media with an estimate of the societal impact from the potential catastrophe. PAGER rapid assessments of the disastrous, 2008 Wenchuan, China, 2010 Port-au-Prince, Haiti, and 2010 Maule, Chile, earthquakes were used by the United States Office for Disaster Assistance, United Nations, World Bank, and others. Thirty-three GSN stations (and seven Affiliates) now participate in the Comprehensive Test Ban Treaty International Monitoring system, and nearly 50 will participate when communications arrangements are completed. GSN is used by the Air Force Technical Applications Center to augment research data from its U.S. Atomic Energy Detection System. The Pacific Tsunami Warning Center and West Coast/Alaska Warning Center each use data from over 100 real-time GSN stations, which were fundamental to the tsunami warning for the Mw 8.8 Concepcion, Chile, earthquake of 2010. The Japan Meteorological Agency, Geosciences Australia, and GeoForschungsZentrum (Germany) each augment their own stations with over 100 GSN stations for tsunami warnings. The 12 GSN stations in Russia and the 10 in China form a core for their respective national seismic networks. Canada, Australia, and Kazakhstan link to real-time GSN stations in their respective countries to augment their national networks. GSN is an official contribution of the United States to the Global Earth Observation System of Systems.

fundamental physical data for other branches of the geosciences. Further, the deaths of several hundred thousand people in a single earthquake in Tang Shan, China, in 1976 and the billions of dollars lost worldwide in earthquake damage accentuated the need to understand better the dynamics of earthquakes in order to mitigate their hazards.

Meeting these opportunities and challenges, the IRIS Consortium initiated the GSN in 1986 with funding from the National Science Foundation, and in cooperation with the USGS. GSN built upon the foundation infrastructure of WWSSN, SRO, and IDA stations, which it extended to create new and more uniform coverage of Earth. The USGS ASL and UCSD IRIS/IDA were established as the prime network operators. Collaborations with IRIS member universities helped to establish higher density of GSN coverage within the United States. Growing slowly at first, then accelerating with funding from the nuclear verification community in anticipation of the Comprehensive Nuclear Test Ban Treaty, GSN is now the state-of-the-art digital network with terabytes of multi-use data from its 154 stations worldwide.

GSN's design goal is to record with full fidelity all seismic signals above Earth's background noise. GSN system bandwidth meets the diverse requirements of the scientific community, national/regional/local earthquake monitoring, tsunami warning networks, the strong-ground-motion engineering community, and nuclear verification programs. GSN sites have been selected to achieve the best possible quiet noise conditions, while balancing cost and logistics. With few exceptions, all GSN data are telemetered in real time to mission agencies and the IRIS Data Management Center. Established for seismology, the GSN infrastructure now hosts the world's largest microbarograph infrasound network, one of the major global GPS networks, as well as geomagnetic and weather sensors.

OPERATIONS & MAINTENANCE

The operations and maintenance of GSN are fundamentals, as GSN has shifted from deployment/installation to long-term sustainability of the network. Basic O&M responsibilities for the IRIS/IDA part of GSN are funded by IRIS/NSF, and for the IRIS/USGS part of the network by ASL/USGS, with substantial coordination and collaboration between the groups. GSN underwent a significant cost analysis of the operation and maintenance of the entire network in 2008. This analysis focused on GSN sustainability, and reviewed personnel, equipment, telemetry, international support, and other areas in the context of current and recent budgets.

Staffing costs are the largest single line item in GSN network budgets, with overhead costs second. IDA personnel are UCSD employees; ASL personnel include both USGS government employees and contractors (currently, Honeywell Technology Services Inc. [HTSI]). The HTSI contract provides for personnel, travel, and other services for USGS, and has its own program manager. ASL and IDA management work closely with each other and with IRIS management (together, forming the GSN Operations Group—chaired by the GSN Operations Manager), and interact directly and indirectly with the IRIS scientific community.

Both network operators fulfill the same basic functions in operating and maintaining GSN, and interact with each other through the Operations Group to share technology and techniques and develop procedures for standardized operations. Field, facility, and software personnel must manage the stations, not only the equipment (sensors, data acquisition, power, and telemetry), but also the data flow and metadata to ensure well-calibrated systems. Equipment must be procured, received, tested, integrated, inventoried, warehoused, shipped, and repaired. Station information, maintenance and installation reports, records of system modifications, export licenses, and shipping documents, supplies, and equipment schematics must be organized and maintained. Software and source codes must be maintained and tested across a variety of station configurations and throughout the data collection system, from the station data acquisition system, to the telemetry interface, to data archiving and delivery, to the IRIS DMS. Station state-of-health, telemetry systems, and data quality control must be monitored routinely. Close collaboration between GSN and DCC personnel is essential to diagnose and resolve data-quality problems. In addition to equipment and data issues, key to quality station operations is the establishment and maintenance of a rapport with the local hosts.

The staffing levels at IDA and ASL are ~11.4 and 22.8 FTEs, respectively, for about one-third and two-thirds of the GSN, respectively. These personnel levels supported field operations with station up time at about 85%—at historic highs—with high data quality overall. Enhancement of station performance beyond these levels requires additional personnel and increases in personnel productivity. The acceleration of GSN upgrades initiated in 2009 included supplemental personnel at IDA and ASL, as well as augmented travel support. By reducing the burden for maintaining obsolete equipment, the productivity of our GSN field staff with the new, standard equipment will allow for a shift in emphasis toward improved data quality and productivity for the whole network. This personnel-efficiency gain further underscores the fundamental importance for completing next-generation system (NGS) rollout expeditiously.

The O&M review included a systematic review of over 6,000 sensor-years of GSN seismometer failure and replacements rates. This study has yielded long-term expectation values for sensor replacements rates necessary to sustain GSN, and represents a quantitative improvement over prior "rules of thumb" for equipment amortization. Based upon actual GSN numbers, the yearly rates of seismometer procurements necessary for maintaining the network have been measured, and now serve as the sustainability metric for GSN. These measures have already affected GSN practice, with the network moving away from sensors with low mean-time-between-replacement (MTBR) to better-performing sensors. In particular, GSN has stopped purchasing prior-generation borehole sensors (relying on repairs instead), is supplementing borehole sites with higher-reliability broadband surface sensors, and is actively pursuing the establishment of specifications for the next-generation borehole sensors with better performance. Similarly, GSN is replacing problematic vault sensors having demonstrably low MTBR with better units.

The manufacturing lifetime of a data-acquisition system (DAS) is about 10 years, after which the manufacturer discontinues the product line (the original components become impossible to obtain) and no longer supports repairs. This progression has been observed in the past in GSN and was quoted by the vendor as the expected manufacturing life span of the NGS DAS. In the subsequent transition period, GSN must maintain and repair units internally, and may resort to

HISTORICAL REPLACEMENT RATES FOR GSN SEISMOMETERS

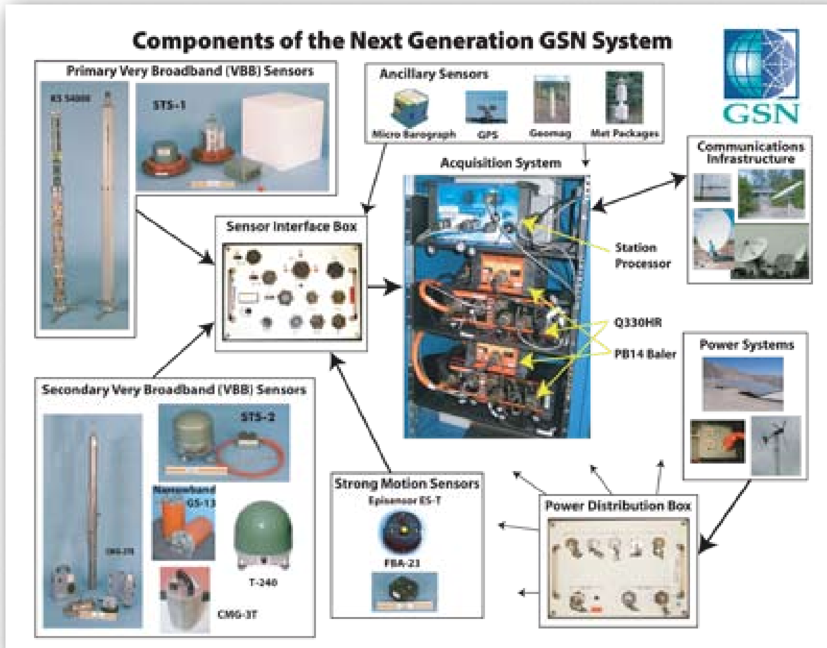
GSN has undertaken a systematic review of over 6,000 sensor-years of GSN seismometer failure and replacements rates. Based upon actual GSN statistics, the mean-time-between-replacement (MTBR) has been calculated for each sensor system. Note that this is not mean-time-between-failure (MTBF), because some sensors are replaced for reasons other than intrinsic technical failure; for example, for a lightning strike, the electronics may be harmed (sometimes affecting one sensor but not another at the same location, reflecting robustness of the electronics and luck). Thus, the replacement events take into account the real conditions in which the sensors are deployed throughout GSN, and reflect historical rates in dealing with both intrinsic and extrinsic factors. Expected yearly sensor replacement rates may be calculated by dividing the numbers of sensors deployed by their respective MTBR.

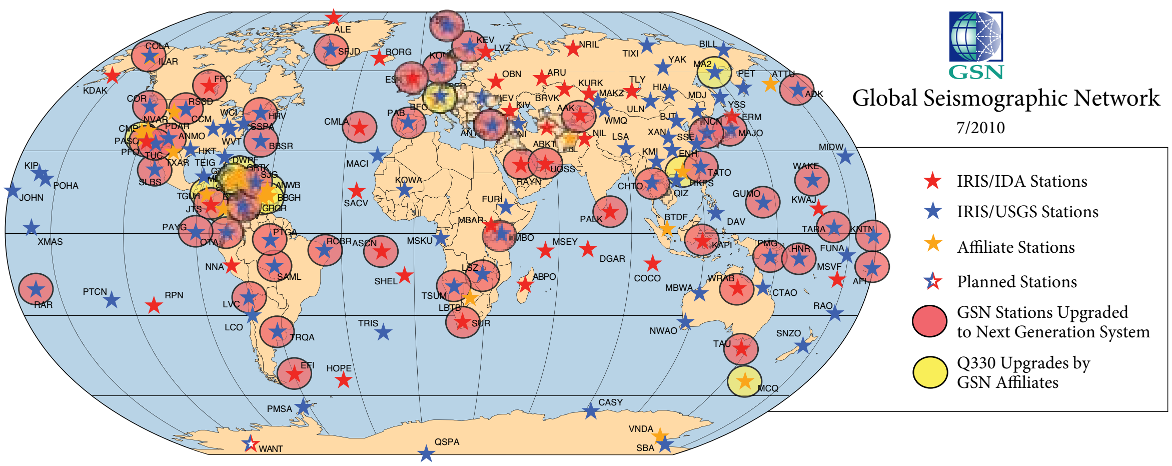
SENSOR	SENSOR YEARS	MTBR YEARS
STS-2	559	24.9
STS-1 per component	2928	49.9
KS54000	433	15.3
GS-13	546	485.4
FBA-23	1134	24.1
CMG-3T,3TB	412	16.6

For broadband sensors, the STS-1 and STS-2 have significantly better MTBR than the KS54000 and CMG sensors. The GS-13 is a narrow-band sensor with passive electronics, and is very robust. The FBA-23 is a strong-motion sensor.

THE NEXT GENERATION SYSTEM (NGS) FOR THE GSN

Based on the Quanterra Q330 HR data acquisition system, the next generation field system was co-designed by the USGS and IDA network operations center under the guidance of IRIS GSN management. This provides the GSN with a standardized, state-of-the-art recording system to optimize field operations and allow for more consistent and complete command and calibration of the GSN network. Rollout of the NGS is expected to take us through the proposed Cooperative Agreement.





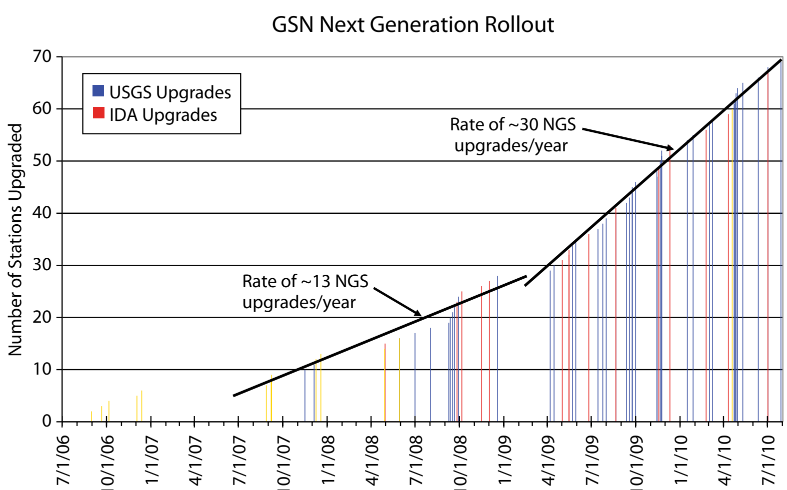


Figure A1.2. IDA field engineer installs the NGS equipment in a vault in Saudi Arabia (RAYN).

cannibalization (as seen with the legacy systems). Sufficient transition spares will need to be available. Assuming a "field-able" life cycle of about 12 years, our initial NGS installation in 2008 will be followed by a renewal in about 2020. Therefore, in the 2016–2017 time frame, GSN will need to review its design goals, draft new specifications, and begin the procurement process for the "next NGS." In the short term, maximum advantage of NGS is made in its rapid deployment throughout the network, which is taking place now. This creates efficiencies for GSN through standardization across the network, improved and automated system monitoring, remote calibration capabilities, and reduced troubleshooting requirements (complete system swaps for maintenance).

About 55% of the network will have been upgraded under this current Cooperative Agreement, and the remainder will take place during the years covered by this proposal. Repairs of the Q330HRs are outsourced to the manufacturer (MTBF is about 80 years, verified by experience in the 400-station USArray Transportable Array), saving GSN engineering staff resources for more productive O&M and data-quality functions.

In addition to sensors and NGS, ancillary equipment and material and supplies (items with individual costs < $5K) represent a significant portion of the total GSN equipment. These items range from communications and power infrastructure, to routine station supplies. They are not inventoried and tend to wear out much faster than major items. The long-term budgeting must accommodate these yearly expenditures.

When establishing GSN, a significant portion of the budget was dedicated to civil works and site preparations. Forty-five GSN installations were based on existing USGS or IDA facilities, many of which date to WWSSN installations of the 1960s. For many of the other 85 core GSN stations, the infrastructure was established substantially "from scratch." Costs varied significantly, depending upon the installation and location. New vault sites in Africa cost upwards of $245K, and remote borehole sites on islands cost $277K in 1995 dollars. Most costs were less than half of these extremes.

This infrastructure is significantly aging. Boreholes have been abandoned due to water leakage into sealed casing on both Midway and Johnston atolls, and to tectonic deformation of near-surface casing in Colombia. Some vaults built into rock outcrops (Mali and Gabon) or lava tubes (Canary Islands) for quiet conditions have turned out to have corrosive and/or high-temperature conditions (up to 50°C). The encroachment of civilization is producing higher noise levels (even at the South Pole). Hurricanes (Wake Island) and landslides (GSN affiliate in Singapore) have wrecked otherwise good sites. Even in cases where best practices were used in the initial site selection or where logistics dictated pragmatism, noise conditions at some GSN sites proved to be very high. Several GSN sites could benefit from relocations, including BILL in Siberia, KOWA in Mali, MSKU in Gabon, and NRIL in northern Russia. For a network of over 130 core stations, a proactive program of site improvements/upgrades will be necessary to address known issues as well as rarer (but not unexpected) catastrophic losses due to hurricanes, fires, and other hazards.

To sustain the GSN, long-term requirements in 2008 for replacing and modernizing equipment, plus upgrading site infrastructure was estimated to be ~$1.5M/year. Note that the 2009 stimulus funding enabled the GSN to "catch up" with many long-standing equipment needs, and to procure additional equipment for the coming years. Therefore, in the near-term, equipment needs are much more modest, as reflected in the 27-month budget. Further, GSN expects a number of ancillary equipment items to decrease in cost, yielding further savings. Nonetheless, long-term aggregate equipment and infrastructure needs must be monitored and projected to ensure a sustainable network. These costs are in addition to "fixed" costs for personnel, overhead, travel, shipping, telemetry, and stations stipends, which are typically considered to be the base O&M budget. As the NGS upgrades are completed, we will be assessing the personnel structure required in the shift from installations/upgrades to O&M and sustainment, and may redistribute personnel as necessary to assure high-quality data return in the most efficient manner. Aggregate, gross telemetry and stipends costs (2008) for GSN were about $400K and $500K, respectively. These costs do not include telemetry contributed by national (USGS ANSS and NOAA/NWS) and international partners (e.g., CTBTO, China, Russia, Australia). All of these costs are subject to inflation.

ACTIVITIES UNDER THE CURRENT COOPERATIVE AGREEMENT

TSUNAMI RESPONSE

The great Sumatra-Andaman earthquake and consequent Indian Ocean tsunami disaster of 2004 brought focus and resources to GSN as a key element of the international tsunami warning system. Real-time telemetry was expanded from 88% coverage to 96%, now 148 of the 154 current sites, and system robustness was improved with back-up communication links. The USGS established a nine-station Caribbean Network, which is affiliated with GSN, and brings enhanced coverage between North and South America. Via a Memorandum of Understanding with IRIS, telemetry collaboration with NOAA increased with 10 sites now satellite-linked directly to the Pacific Tsunami Warning Center in Hawaii. The network links NSF, USGS, and NOAA, recognized in law in the Tsunami Warning and Education Act of 2006.

CORE NETWORK

In parallel with the tsunami augmentation, the basic global coverage plan was completed with the installation of six new stations—TARA and KNTN in the Republic of Kiribati (central tropical Pacific Ocean); ABPO Madagascar; SLBS Mexico; MACI Canary Islands; and UOSS United Arab Emirates—plus Affiliates KBL Afghanistan and HKPS Hong Kong. As of 2010, 23 affiliate stations join a core network of 80 USGS-operated, 41 IDA-operated, and 10 China-operated stations (collaborating with the USGS). In addition, the complement of installed microbarographs was expanded from 40 to 70 stations, and participation in the International Monitoring System (IMS) increased from 23 stations to 33 core stations and seven affiliate stations.

Figure A1.3. USGS-Honeywell field engineer Jared Anderson takes and opportunity to teach basic seismology to the school children on Kanton, Republic of Kiribati (GSN station KNTN).

PERFORMANCE REVIEW

A comprehensive review of agency usage and performance of core stations concluded that every active station is routinely used by some monitoring agency and that even island sites, which tend to be the noisiest stations, are very valuable to the tsunami warning centers. Agency metrics included importance, quality, and usage by the Pacific and the West Coast and Alaska Tsunami Warning Centers, the *Air Force Technical Applications Center (AFTAC)*, the IMS, and the National Earthquake Information Center (NEIC) in determining epicenters and W-phase earthquake moments. Data performance metrics included vertical and horizontal noise levels at 1 Hz, 300 sec, and broadband. A metric of contribution to global coverage is based upon distance to the nearest neighboring station. A survey of the scientific community ranked GSN stations for merit/importance in scientific studies. These metrics now serve as an objective basis for decisions regarding station relocation/closure and commitment, prioritization, and allocation of GSN resources.

INTERNATIONAL COLLABORATIONS

New partnerships with Spanish, German, Australian, and Russian organizations exemplify GSN's continuous engagement in international collaboration. The Instituto Geographico Nacional (IGN) of Spain has collaborated at a new GSN site MACI Canary Islands (a relocation from the prior site at TBT), providing the STS-1 sensors, data acquisition, and telemetry as part of their local network, and primary maintenance responsibilities. Bundesanstalt für Geowissenschaften und Rohstoffe upgraded the DAS at Grafenberg and took primary responsibility for maintenance, while GeoForschungsZentrum Potsdam (GFZ) installed a geomagnetic observatory next on St. Helena Island in the South Atlantic that shares the communications circuit for station SHEL. Geosciences Australia has undertaken expanded responsibilities and provides major maintenance assistance in and around Australia, extending to sites on Papua New Guinea, Solomon Islands, Fiji, Tuvalu, Rarotonga, and Kiribati that are crucial to Australian tsunami warning. The Russian Academy of Sciences' Geophysical Survey (GS-RAS) in Obninsk now provides for all telemetry within Russia, ensures data flow based on a new intergovernmental MOU, and has started purchasing, importing and installing NGS systems from IRIS—including Q330 DASs, STS-2 seismometers, and STS-1 electronics—expanding their role to O&M of all GSN stations in Russia and opening possibilities for more instrumentation upgrades and data exchange with the Russian National Network.

TELEMETRY

In the past few years, new communications systems were installed in FURI Ethiopia, RAYN Saudi Arabia, MSVF Fiji, and JOHN Johnston Atoll, and system robustness was improved by providing for redundant links at key sites in the Pacific. As mentioned above, the GS-RAS has taken over the Russian telemetry links and now fully funds the data flow. A substantial component of this expansion was funded by the USGS following the Sumatra earthquake. The telecommunications infrastructure is diverse, with portions funded by IRIS, USGS, Russia, China, Australia, the Department of Defense, NOAA, and the CTBTO, with Internet connections provided by local hosts. Although the diverse telemetry topology adds to the management burden, the system minimizes costs as well as maximizes robustness by not having all communications routed through a single point of failure.

SEISMIC INSTRUMENTATION

IRIS completed a comprehensive, multiyear process to evaluate, test, select, and procure the next-generation GSN DAS, and selected the low-power systems (<10W) Quanterra Q330HR to improve robustness in remote locations and offer remote calibration via the telemetry link. A standard installation allows resources to be shared across the entire GSN, optimizing the equipment depots at both network operations facilities. By the end of this proposed Cooperative Agreement, DASs will have been fielded across GSN, freeing resources previously tied down to obsolete equipment.

Long-term changes in the response of some Streckeisen STS-1 sensors, the primary GSN vault sensor that has not been produced 1996, has raised concerns. Further testing of STS-1 electronics has shown that the aging systems may be adversely affected by humidity, with amplitude-dependent effects in some frequency bands. This nonlinearity was not easily detectable with our past quality assurance techniques, and thus, new quality metrics are being implemented to allow us to track sensor aging. In addition, with funding from IRIS in 2006, Metrozet LLC and UC Berkeley successfully developed new feedback electronics for the STS-1, which is now in production, and is being fielded and used at stations of the GSN and other FDSN networks. With the lack of an immediate replacement for the STS-1 mechanical assembly, improved installation techniques for secondary sensors are providing for a better long-period response, enabling the replacement and relocation of STS-1s at sites that have relatively high background noise, and improving the relative performance of the secondary sensor at other sites where both are installed.

Current GSN borehole sensors have been problematic but, because replacement and repair costs are high, IRIS is focusing on a future sensor. A revised borehole seismometer specification is being prepared in consultation with the IRIS Instrumentation Committee and AFTAC/DoD, which also has substantial needs for borehole instrumentation, and IRIS plans to work with potential manufacturers to test and evaluate new sensors. Under the new IRIS Instrumentation Services structure, GSN will coordinate with PASSCAL and USArray in this and other areas related to the exploration of new sensor technology.

CALIBRATION, AZIMUTH, AND DATA QUALITY

Degradation of the STS-1 electronics and the past QC system's inability to measure this decay brought into focus the need to place data quality on a par with data availability as a true measure of GSN's performance. Calibrations performed on initial site installation and during site visits were augmented with remote calibrations where the DAS, telemetry link, and local hosts were capable. The NGS systems have remote calibration capabilities, so with the completion of the NGS upgrade, the entire GSN can be routinely calibrated (with local political permission, in some cases). Apparent problems noted (Ekström et al., 2005, *Seismological Research Letters,* doi:10.1785/gssrl.79.4.554) regarding instrument sensitivity defined a need for absolute field calibration to complement and verify independent checks based on earthquake free oscillation modal data and tidal amplitudes (Davis and Berger, 2007, *Seismological Research Letters*, doi: 10.1785/gssrl.78.4.454; Davis et al., 2005, *Seismological Research Letters*, doi:10.1785/gssrl.76.6.678).

At the same time, subtle azimuthal errors in sensor orientation were being determined and refined using the data themselves and measures of great circle paths from many earthquakes. In response, network operators defined rigorous best practices for location, orientation, and calibration of sensors using field kits that included a reference broadband seismometer, precise azimuth determination equipment, and a well-calibrated DAS. The kit has been in use during site visits since 2008, and the reference sensor is absolutely calibrated on a shake table before and on return from each visit. Network operators are systematically assaying site infrastructure that may affect apparent response to determine and plan long-term site refurbishment needs.

In 2009, GSN adopted a new calibration policy wherein absolute calibrations would take place during field visits (both before and after major station upgrades), and yearly relative calibrations would take place at all sites where both telemetry and local DAS permitted remote calibrations. In 2009 during the initiation of DAS upgrades, 27 absolute calibrations and 66 relative calibrations took place, building upon historical calibrations and network-wide calibration efforts during

2003–2006. Procedures for calibration and updating metadata are being reviewed and standardized among the network operators as part of a pan-IRIS assessment of data quality.

As a result of concerns about data quality related to the aging of the STS-1 sensors and the tracking of metadata, the IRIS Board established a GSN Data Quality Panel in 2010 to assess the quality of GSN data, review current quality control procedures, and make recommendations for implementation of standard metrics and practices to measure and report on GSN waveform quality. Based on the recommendations of the Panel, the GSN Operations Group will expand the routine quality-control procedures that are implemented by the network operators, routinely tracked, and published on IRIS web sites. The goal is to provide both the scientific user and network operator the same view of data quality so that each may effectively use the open information, and to create an archive of the state of data quality for a sensor. GSN will continue to work with the Lamont Waveform Quality Center (WQC) to track station performance and review prior calibration and data quality, supported by QC analysts collaborating between the IRIS DMS and GSN. Collection of data problem reports has been reinstituted, and the scientific community has been encouraged to offer their own problem assessments at GSN stations.

GSN AUGMENTATION FUNDING 2009

Both NSF and USGS received substantial additional funding in FY09 through the American Recovery and Reinvestment Act of 2009 (ARRA), which has led to over $9M supplementary funding for GSN. Through coordinated efforts between USGS and IRIS/NSF, a comprehensive, integrated plan was developed, encompassing both ASL and IDA. Funds for a broad renewal of GSN equipment focused on immediate procurements, including all DASs needed to complete the GSN upgrade, secondary broadband sensors, replacement FBE systems, and many other urgent needs. The supplementary funding also accelerated deployment of NGSs and sensors. During 2009, 25 stations were upgraded, electronics were replaced in 12 STS-1s, and 12 secondary broadband sensors were replaced. Through the June 2011, well over half of the core GSN will have been upgraded and enhanced.

USGS GSN FUNDING

Funding by the USGS has substantially increased in recent years. As a part of the 2005 Tsunami Supplement, the USGS received funds for expanding GSN's real-time telemetry infrastructure at stations operated by both ASL and IDA, for the installation of the nine-station Caribbean Network (Affiliated with GSN), and for a step increase in their base budget (about $600K) to operate and maintain these additional facilities. The university community has worked closely with the USGS in the past few years, stressing the importance of the GSN as a multi-use, multi-agency facility, and encouraging consideration of funding increases for the USGS GSN line in the Department of Interior budget. This request has resonated with Congress, and funding added in FY08 ($500K) and FY09 (~$1M), has now been adopted by the Administration, increasing the base of the USGS GSN program in FY10. With each of these increases, the USGS has stepped forward and taken an equal role in funding GSN equipment and upgrades, which heretofore had been the role of NSF/IRIS. The more equitable collaboration between USGS and NSF/IRIS is a new paradigm for the GSN, with both parties taking primary roles for their network operations and also jointly funding the network to take best advantage of resources and capabilities. IRIS now has more latitude to focus GSN funds toward new ways to improve the GSN for science and to continue its O&M role through IDA.

NEW OPPORTUNITIES AND DIRECTIONS

The next 27 months will see the culmination of the first major upgrade cycle in GSN equipment since the initial installation of the network. Through funding supplements related to the federal stimulus package in 2009 from both NSF and from USGS, GSN is being transformed from a network that has been focused on basic operations and maintenance of an aging equipment base, to one focused on sustaining a standardized system of state-of-the-art equipment, incorporating efficiencies in operations, maintenance, monitoring, and quality. The most important task in the short term is to get the new equipment fielded so that the network may begin to accrue those benefits. GSN will maintain the installation rates of NGS and sensors that were accelerated in 2009. Through this effort, the refreshed network will also be able to address many data-quality issues that suffered from an inadequate equipment replacement budget, bringing GSN data quality back to the forefront. At the same time, GSN looks toward exciting new directions to reinforce its successes both as a network and as an integral program for global seismology. Toward this end, GSN will take stock of the station infrastructure and test

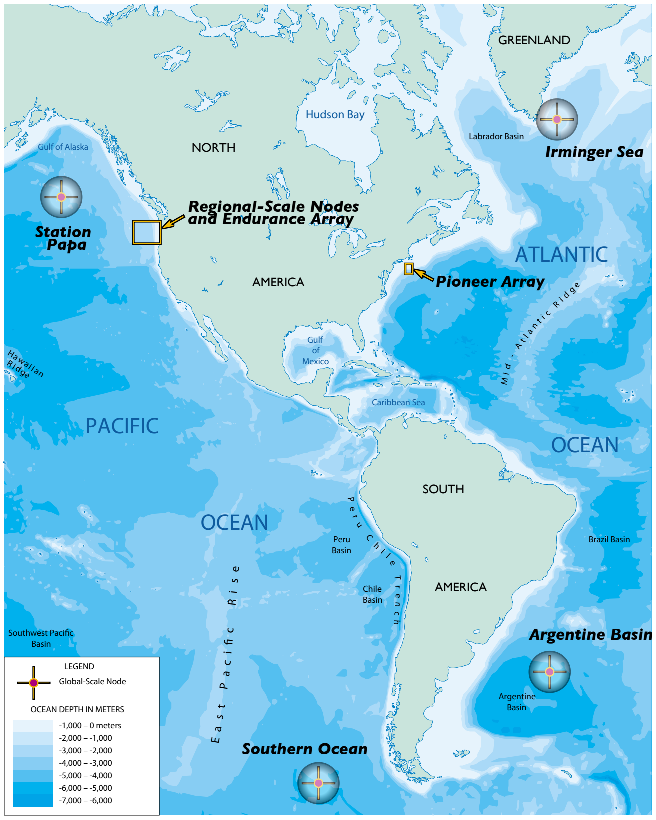


Figure A1.4. Possible locations for the OOI global buoys.

new prototype primary sensors, will review with the community advances in science that may be made through the implementation and use of arrays, will engage through FDSN a systematic assay of national broadband networks and their respective means where the international community may gain access to these data, and actively engage with the ocean seismic community through the Ocean Observing Initiative.

Looking forward, GSN will be renewing and invigorating techniques and procedures to ensure the GSN dataset is of the highest quality. The network is in place, and has captured with full fidelity the third and fifth largest earthquakes ever measured since the dawn of instrumental seismology. GSN real-time data are used at more than tenfold their acquisition rate. Operationally, the GSN envisioned in the mid 1980s is now in place. The new dimension for growth is quality. This focus extends beyond instrumentation and infrastructure. GSN is a champion of open data, and must also embody the principle of open information regarding its data quality. Here, GSN leadership can potentially bring about improved data-quality practices beyond GSN.

NETWORK

The 154-station GSN multi-agency network model with IRIS management coordinating the primary network operators USGS/ASL (IU, IC subnetworks) and IRIS/IDA (II), and independent GSN Affiliates, has proven to be a robust collaboration. Funding and resources have been effectively shared for the broad benefit of GSN. IRIS continues to fund UCSD/IDA. With the increase in the USGS base budget for GSN beginning in 2009, USGS funding for ASL's components of GSN have expanded beyond O&M to equipment, installations, and station upgrades—many which were funded by IRIS/NSF under the prior Cooperative Agreement. Nonetheless, whereas both IRIS/NSF and ASL/USGS have parallel funding for their respective GSN components, successful collaboration between IRIS/NSF and ASL/USGS seen during the ~$9M federal stimulus funding in 2009 underscores the efficiencies achieved in combining and collaborating resources. In this regard, the IRIS GSN budget continues some support for ASL activities that may be more efficiently funded through IRIS. Complementary to this, USGS funds will be coordinated with pan-GSN activities.

The GSN Standing Committee (GSNSC) provides oversight for both IRIS/NSF and USGS, under the NSF-USGS-IRIS MOU Annex. The IRIS and USGS GSN program managers have parallel responsibilities to coordinate GSN for IRIS/NSF and USGS, respectively. IRIS funds a GSN office, and provides support for the GSNSC, and for GSN management. GSN management also has roles and responsibilities for IRIS polar activities (including the Greenland Ice Sheet Monitoring Network).

The completion of the NGS upgrade effort is the crucial foundation for the GSN's long-term operation and maintenance efficiency and improved data quality. To accelerate the rate of upgrade for the network, both ASL and IDA augmented their personnel (3 and 1 FTE, respectively) in support of the field activities and station maintenance as well as enhancement to their shipping and travel funds to allow more station visits. Both groups are sustaining this level of effort throughout the 27 months covered by this proposal in order to finish upgrades as expeditiously as possible. All IRIS/IDA upgrades are planned for completion by 2013, barring difficulties with Russia. ASL upgrades are planned for completion by 2015, barring difficulties with Russia and China.

Network standardization improves functionality and creates efficiencies. Equipment standardization will permit ASL and IDA to coordinate and collaborate on station maintenance, which was not possible before. Within the context of such GSN collaboration, the network configuration is being analyzed with a view toward making more efficient use of logistics, shared resources, and personnel. Long-term perspectives for possible restructuring GSN will take into close account the important relationships with station hosts. Further, when GSN equipment is standard across their territory, large national partners (e.g., Russia and Australia) may take a greater role in station operation and maintenance. On a single station, case-by-case basis, international hosts may wish to take greater responsibility, or even full responsibility, for local GSN stations. These arrangements and discussions will be constructively met, and encouraged insofar as GSN data quality may be assured and the design goals of the GSN can continue to be met.

STATION PERFORMANCE

GSN (both IRIS/USGS and IRIS/IDA) operated with about 85% data availability, prior to the funding augmentation in 2009. With the new, low-power NGS, and adequate stock of secondary sensors and STS-1 electronics, we anticipate data availability increasing toward our 90% target. New GSN data-quality metrics are being developed to assess the variance of sensor data from our published design goals, and include noise level, linearity, calibration accuracy, and orientation. These web-published metrics, uniformly applied across the core network, will not only offer a clear status and history of sensor data quality for the scientist using the data, but also better enable GSN network operators to monitor quality, to bring engineering expertise to problems identified, and for making decisions on the allocation of resources for field repairs and site visits. This data-quality transparency for the community enhances the GSN data, and offers leadership to other international networks for raising the global awareness of data quality.

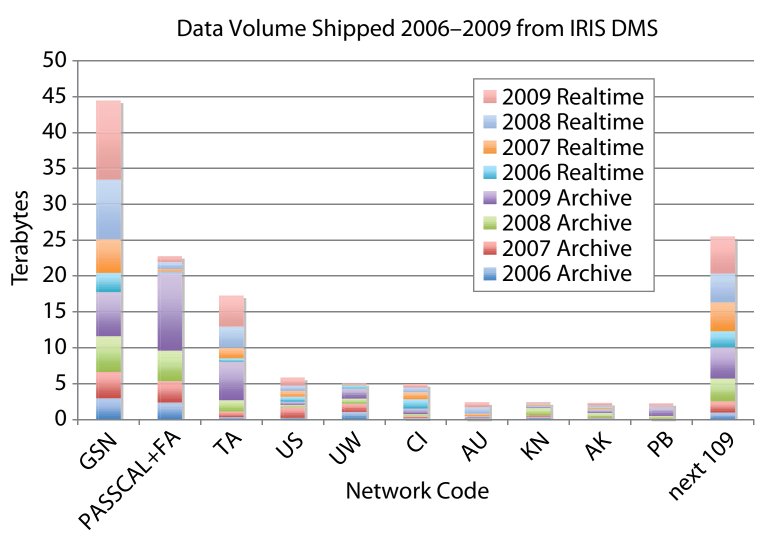
DATA QUALITY

Informed by the recommendations of the GSN Data Quality Panel (expected the fall 2010), quality metrics and assessment tools will continue to be developed and utilized to share information on data quality with both network operators and data users. Additional resources will be coordinated with ASL to ensure close collaboration with the USGS. This enhanced data-quality focus includes reviewing the historic data archive and metadata, end-to-end tracking of data problems reports, implementing new and improved tools for measuring and assuring data quality, tracking and publishing QC metrics, and publishing sensor problems and calibrations on a GSN/DMS web site. In addition, the data problem report process will be revitalized along with the development of a data user interface to allow feedback directly from the data users to the Operations Group. The GSN Operations Group will continue to coordinate with the Lamont Waveform Quality Center on metrics, techniques, and quality-related information. Working through the new IRIS Instrumentation Services and Data Services structure, there will be a renewed

GSN DATA USE

Data from the Global Seismographic Network are the most widely accessed dataset in the IRIS Data Management System, with over 44 Terabytes (TB) of data shipped in 2006–2009, both in real time and from the archive (see figure). Over 11 TB were distributed in real time in 2009 by DMS. Nonetheless, GSN data are also distributed in real time to a broad spectrum of users separate from the DMS distribution.

Many networks or large data users access GSN data directly from USGS and UCSD data collection centers, via tsunami warning centers, through software operating at various seismic networks, or from the GSN station itself. These real-time users include USGS/NEIC, U.S. and international tsunami warning centers, Global CMT, CTBTO IMS, and national networks and organizations in Australia, Austria, Canada, Chile, China, Colombia, Czech Republic, Dominican Republic, El Salvador, France, Germany, Guatemala, Hong Kong, Iceland, Indonesia, Italy, Japan, Kuwait, Malaysia, Mauritius, Mexico, Morocco, Netherlands, Puerto Rico, Nicaragua, Norway, Oman, Philippines, Romania, Russia, Singapore, Spain, Sweden, Taiwan, Thailand, Turkey, United Arab Emirates, United Kingdom, and 31 local station hosts, and others. Tracking the amount of data requires a certain amount of detective work and engagement in correspondence with international users.



An estimate of GSN real-time data usage not distributed by DMS is about 6.9 TB/yr, or about half of the DMS rate. This estimate does not count multiple uses of GSN data within an organization. The estimated total GSN real-time data usage rate (circa 2010) is therefore about 18 TB/year, compared with a nominal GSN data logger rate of about 1.1 TB/year.

and increased collaboration between the GSN and the DMS (through the Operator's DCC and the DMC) to continue to produce, enhance, and automate quality metrics for GSN data that assure the seismological community of current state of the GSN dataset.

EQUIPMENT

GSN's near-term equipment needs were substantially fulfilled by the funding augmentation in 2009. Procurement of secondary sensors, based upon GSN historic replacement rates, will continue to ensure that adequate stocks are maintained. NGS failures will be met through repairs based upon known USArray Transportable Array repair rates. Ancillary small equipment for station maintenance must also be budgeted. IRIS and USGS will coordinate these purchases between IDA and ASL, in proportion to relative numbers of GSN stations.

DEVELOPING NEW PRIMARY SENSORS

It is critically important that replacements are developed and tested for the GSN primary broadband sensors—the STS-1 (surface) and KS-54000 (borehole). Additional urgency for this task has come from recent analyses by the Waveform Quality Center, which indicates that the Metrozet E300 does not solve all of the issues with the STS-1. High failure rates of the KS-54000 have caused the network operators to cease purchasing them. GSN quality will continue to deteriorate if these problems are not solved in the coming years.

During the term of this proposal, GSN proposes to purchase and field test several prototype primary sensors. Both Metrozet and USCD are now developing prototypes that may approach STS-1-quality. New broadband sensors are being offered by several manufacturers, with the potential to be packaged for borehole deployment. USGS is supporting development in FY11 of a borehole version of the UCSD optical seismometer, which presents a new option for borehole installations. To actively engage the market for primary sensors, this proposal requests funding for instrument manufacturer engagement, procurement, and testing. The path forward will stimulate production of new GSN primary sensors, which may then be proposed for volume procurement in the five years hence.

Figure A1.5. GSN station AFI (Afiamalu, Samoa) vault infrastructure issues (courtesy of ASL/USGS).

NEW STATIONS

Whereas GSN now has achieved its goal of global coverage, there are still gaps in geographic coverage in a few subcontinental areas (e.g., North Africa, India, Nepal) and, of course, in the broad ocean area. There are ongoing discussions with Libya and Egypt (North Africa), and Italy (for a site near Mt. Everest), and there are siting possibilities for West Antarctica following PoleNet temporary deployments. Engagement continues quietly with India. In addition, there are occasionally favorable opportunities to relocate, or completely re-install an existing station to be responsive to changing political situations or natural disasters (recall past experience with our stations in Colombia, Canary Islands, and Wake Atoll). In order to fully leverage such opportunities, GSN requests $250K funding for the equipment necessary for a new site, civil works for site preparation, and installation costs.

SITE INFRASTRUCTURE

Aging of the network is also reflected in its site infrastructure, including vaults, piers, boreholes, buildings, power, and telemetry equipment. For instance, WWSSN vaults used by GSN are nearly 50 years old. Some of this infrastructure directly impacts GSN data quality. As noted earlier, as part of NGS roll out, GSN is systematically assessing the condition of its infrastructure. Annual funding is requested to repair site infrastructure to coordinate effectively with ongoing field activities.

POLAR ACTIVITIES

GSN management will continue its active engagement in polar activities in collaboration with PASSCAL (discussed in the section on Polar Support Services), both through the international collaboration in the GLISN project in Greenland, as well through development of long-term sites in West Antarctica for monitoring its ice sheet. Coordination of the specialized equipment and installation techniques between the two core IRIS programs is important to ensure high quality and data return in these challenging environments.

NEW DIRECTIONS

Three exciting new directions are proposed for GSN, which both serve to expand the capabilities for GSN science and naturally link with existing GSN activities: incorporating arrays into GSN, working with FDSN to expand and enhance international data exchange, and engaging with the Ocean Observing Initiative to provide GSN-quality sensors for seafloor deployment.

Seismic Arrays

The "Seismological Grand Challenges" report recognizes that seismic arrays offer great potential for resolving important questions regarding such diverse topics as the nature of the lithosphere-asthenosphere boundary, how temperature and compositional variations control mantle and core convection, and how Earth's internal boundaries are affected by dynamics. Moreover, arrays can be used to greatly improve earthquake detection capabilities on a global scale. While events as large as magnitude 5.5 can hide from current networks, a global array of arrays would lower detection thresholds by one to two magnitude units. Complete and accurate earthquake catalogs are a fundamental dataset for addressing several of the Grand Challenges. Whereas some of these questions may be answered with temporary PASSCAL portable array deployments, the others will require long-term to semi-permanent monitoring and hence fit within a framework that bridges the gap between GSN's permanent global observatories and PASSCAL's higher-resolution temporary deployments.

Arrays have several advantages over three-component stations. An array provides directional information on an arriving wavefield, including both azimuth and "slowness" (inverse apparent velocity of the wave), and individual sensor channels can be combined as a beam to improve signal to noise and to focus on aspects of the wavefield. There are diverse designs for arrays, depending upon the particular purpose, which include high-frequency and broadband elements, as well as three-component and only vertical elements. The aperture (array width) and the organization and spacing of array elements can enhance or attenuate features of the wavefield being viewed. Whereas a GSN station occupies a relatively small footprint, extending this framework for an array may be constrained by local host considerations and can limit collocation with existing GSN sites. Finally, the array is a passive sensor—like the GSN station, it records seismic phenomena that propagate to it.

Four Affiliate arrays are part of GSN, installed and operated by AFTAC or DOE/Southern Methodist University, which are also IMS arrays. There are 18 additional IMS primary arrays, but unfortunately the CTBTO confidential data policy limits scientific community access to these valuable resources. Open access has been obtained on a bilateral basis with Canada, Australia, Germany, Kazahkstan, and Norway. Efforts continue for more open release of array data from the other 11 IMS primary arrays, in coordination with FDSN. Nonetheless, most of these arrays have been narrowly designed for their sole purpose—to detect and monitor nuclear explosions. The Southern Hemisphere has only two Australian arrays. "Sweet-spots" for viewing a particular feature may require an array installed at an entirely new site. To use the array for specific imaging of Earth structure, the geometry of the earthquake sources, the array, and the lithosphere-asthenosphere-mantle-core structures to be illuminated must be refined.

IRIS proposes to study these broad scientific and technical questions in workshops, and perform a pilot experiment during the coming 27 months, in order to reach a consensus with the scientific community of the best course forward. The focus of these two workshops are: (1) the specific scientific objectives and priorities for augmenting GSN with fixed arrays, and (2) the technical plan (array geometry, siting, instrumentation, and international coordination) needed to achieve the scientific objectives. The pilot experiment will demonstrate with an existing array—for example, the SIEDCAR experiment (Seismic Investigation of Edge Driven Convection) and the High Lava Plains (HLP) project—the capability for resolving targets of future arrays. Exploration of the technical aspects of array development will be coordinated through the new IRIS Instrumentation Services structure to ensure that these effort draw on the extensive experience of PASSCAL and USArray/TA as well as GSN. Because the science will drive the array design(s), the second workshop must await the outcome of the first.

Enhancing International Data Exchange

IRIS is proactive in advocating for open data sharing, and GSN is an example of the practice. GSN openness has generated substantial goodwill globally. Many organizations that never openly shared data internationally now provide data to the IRIS DMS, in part because of their own active usage of the open GSN data. Two such examples are the Japan Meteorological Agency (JMA) and Malaysian Network—both have opened real-time access to seven of their broadband stations.

GSN actively participates in the FDSN working group on station siting, which attempts to keep an active inventory of all broadband networks participating in FDSN, as well as the means for accessing data. FDSN has been very successful in bringing together the international seismic community. However, as an unfunded federation, the "simple" task of listing all broadband stations lies beyond current abilities of the volunteer organization. Moreover, there are also many nations that operate broadband networks (e.g., installed by Kinemetrics, Nanometrics, and others), which do not openly participate in FDSN. Although attempts have been made to compile inventories of broadband seismic stations in Europe by ORFEUS, and in the United States by NEIC, there is no substantial global inventory of broadband stations.

To open up new sources of seismic data, we first must determine what is there. Then, we need to determine how a scientist can request data access. These two simple steps are a substantial undertaking, requiring engaged discussions with networks worldwide. Such engagement has as a prerequisite a friendly reception. As a U.S. scientific entity, IRIS and GSN face the political baggage (both good and bad) carried by the United States in its global relations. However, FDSN carries no such baggage as an international organization of 52 nations. Its credentials as a Commission of the International Association of Seismology and Physics of the Earth's Interior (IASPEI) are impeccable. Further, FDSN's Terms of Reference provide for *pursuing free and open access to data*. Nonetheless, FDSN has no resources for this task. The International Seismological Centre (ISC) has an internationally recognized office, but does not currently address waveform data exchange.

Therefore, IRIS proposes to work with FDSN and ISC to fund a person to lead this task. An individual is needed with scientific credentials and with a good sense of diplomacy and skills in database management. The task deliverables are a substantial inventory of all broadband stations worldwide (including sensor characteristics, updated yearly), and documentation of the methods and procedures for accessing data. Both FDSN and ISC chairs have been approached, and are receptive to the idea. Some FDSN members have already indicated interest in collaborative funding for such a position.

This activity is being coordinated with the IRIS DMS role in archiving and exchanging data between data centers. As is their prerogative, some networks do not exchange data. However, they may provide data to an individual scientist. Making known what data exists and how it may be accessed is the initial step—that in some instances may lead to a broader exchange with a data center.

Building Toward Collaboration with the Ocean Observatories Initiative

During 2011–2013, the Ocean Observatories Initiative (OOI) will begin to construct and install a new generation of permanent observatories in the ocean with real-time telemetry that will revolutionize oceanography. The particular focus of the OOI Global Buoy program on high-latitude sites such as the Southern Ocean is of great interest to the GSNSC. While the current OOI science plan does not include seismometers at the Global Buoy sites, OOI still represents an important opportunity for GSN. Expanding GSN coverage into the ocean is a requirement if it is to achieve its original design goals and to provide the uniform coverage necessary for many science and monitoring objectives. The three locations that are of most interest to GSN due to their remoteness are the Southeast Pacific site (55°S, 90°W), the Argentine Basin site (42°S, 42°W), and Station Papa (50°N, 90°W) in the Northeast Pacific. Both the Southeast Pacific Ocean and Argentine Basin sites are located approximately 1500 km from shore and ~1700–1900 km from the nearest GSN station. If the Southeast Pacific site already existed, it would have provided the first seismograms west of the trench for the 2010 Mw 8.8 Chile earthquake.

During 2011–2013, the GSNSC will initiate a working group to develop a detailed plan for adding broadband seismic instruments to the OOI global buoys that can be incorporated into the following IRIS five-year proposal. Because the instruments will be telemetered and likely require burial, we will not be able to use the instruments currently in the national Ocean Bottom Seismometer Instrument Pool (OBSIP) directly. However, the instrumentation groups within OBSIP have already demonstrated most of the technical capabilities required for installing a buried broadband ocean bottom seismometer with acoustic telemetry to the global OOI buoys. Of particular concern will be the quality of the horizontal component data that are often extremely poor at frequencies <1 Hz for freefall OBS deployments. However, the Ocean Seismic Network (OSN) Pilot Experiment demonstrated that even shallow burial of the sensor pressure housing greatly reduces current-generated tilt noise. Because most of OOI cruises will likely not involve a remotely operated vehicle (ROV), any OBS system will require the ability to bury the sensor without an ROV. This type of technology only exists as a prototype at present. GSN will invite proposals from OBSIP groups for a subcontract to test a prototype burial system in a deepwater environment during 2011–2013. Through the combined efforts of the working group and the field testing of a burial system(s) by OBSIP groups, GSN will be well positioned to begin filling the current gaps in the ocean as part of the five-year IRIS proposal to be submitted in 2013.