7 | POLAR SUPPORT SERVICES

HISTORICAL CONTEXT OF CURRENT OPERATIONS

Of critical importance to humanity is the assessment, understanding, and prediction of environmental change in the polar regions, especially pertaining to the fast- responding elements of the cryosphere. IRIS has had a long history of involvement in the polar studies, including operation of GSN stations in Antarctica, northern Canada and Alaska and support for a variety of portable studies of the crust and lithosphere in Antarctica and Greenland. In recent years, there has been increasing IRIS involvement in cryosphere observations including seismic signals indicative of Earth's changing ice masses and the collection (using active seismic methodology) of seismic data needed to constrain input data used in glaciological forecast models (e.g., measuring sub-ice-shelf seabed elevations and examining sub-ice-stream deformable sediments and lake distributions). These efforts are important because the icy regions of the planet, particularly alpine glaciers, Arctic sea ice, and the marine ice margins of Greenland and Antarctica, are among the most rapidly changing elements of all Earth's environmental systems.

The response of glaciers and ice sheets to climate change is critically important, but poorly understood. Climate change affects ice sheets, which in turn affect climate, and ice discharge from major polar glaciers and mountain glaciers makes a significant contribution to sea-level change and ocean circulation patterns. The Intergovernmental Panel on Climate Change (IPCC) currently estimates that approximately half of Greenland's contribution to sea-level rise comes from dynamic processes such as the discharge of ice from outlet glaciers, which is indirectly tied to surface warming and melting through hydrological feedbacks. But, the possible effects from rapid changes in the dynamic behavior of the ice sheet and glaciers are insufficiently understood—so much so, that the IPCC decided that it was still not possible to issue estimates of large-scale ice sheet contributions to sea-level rise over the next 100 years. In Greenland, the largest outlet glaciers have rapidly and dramatically changed during the last few years, with their mass loss leading to a doubling of Greenland's current contribution to rates of sea-level rise. Variations in glacier flow speed (over time scales from minutes to years) lead to large internal deformations that include dynamic thinning of the ice. Understanding the physical controls on outlet-glacier flow, and the time scales of response to climatic forcing, is necessary for proper modeling of the transfer of freshwater from the polar ice caps to the world's ocean.

Figure A7.1. Helheim glacier, Greenland, on August 19, 2008, during a large calving event that generated a glacial earthquake. View is to the south; glacier flow is to the left (east). In this photograph, the iceberg has reached a horizontal position, exposing its full thickness (~700 m). The height of the calving face is ~70 m. Photo courtesy of M. Nettles.

The glacial processes relevant to the interplay between ice and climate, and between climate change and sea-level rise, generate seismic signals. These seismic signals—both impulsive events and emergent tremor—are associated with internal "viscous flow" deformation of the ice in response to gravitational driving stresses, sliding of ice across a basal substratum that is influenced by subglacial hydrology that induces its own forms of seismic signals, disintegration and capsize of icebergs at the calving front, and drainage of supraglacial lakes into englacial and subglacial conduits. All of these processes are integral to the overall dynamics of glaciers, and seismic signals thus provide a quantitative means for both understanding the processes and for monitoring changes in their behavior over time. Long-term seismic monitoring of the ice sheet can also contribute to identifying possible unsuspected mechanisms and metrics relevant to ice sheet collapse, and could provide new constraints on ice sheet dynamic processes and their potential roles in sea-level rise during the coming decades.

In addition to climate-specific seismology, it is clear that global observatories in the polar regions, at best, provide sparse coverage for the study of the axial symmetric properties of Earth's interior. With only five GSN stations in

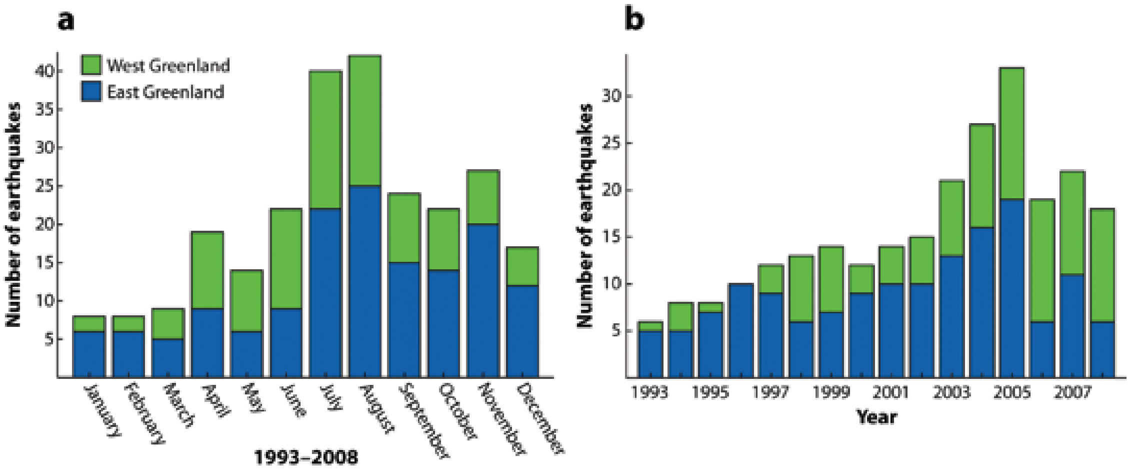


Figure A7.2. (a) Histogram showing seasonality of glacial earthquakes in Greenland based on detections for 1993–2008. Bars show the number of earthquakes per month detected in Greenland. (b) Histogram showing the number of glacial earthquakes detected in Greenland each year since 1993. From Figure 3 in Nettles and Ekström. 2010. *Annual Review of Earth and Planetary Sciences* 38:467–491.

Antarctica delivering real-time data, there are significant gaps in coverage for high-resolution, deep Earth structural studies beneath this large continent. Although international colleagues operate a handful of seismic stations around the perimeter of Antarctica, very few are offered in real time and all are subject to previous limitations of being collocated with scientific bases of operations, and thus are subjected to increased background noise contamination typical of generator-powered camps. Adding to the noise problem is the fact that most of these stations are near the ocean, subject to coastal noise. Similarly, Northern Hemisphere coverage is further limited due to the lack of landmasses for simple installations at the northern axis. In both cases, enhanced permanent station coverage will require the further development of remote, autonomous, real-time observatories that will operate in extremely harsh climates with minimal logistics support.

IRIS Polar Support Services (PSS) has facilitated this emerging area of seismologic interest by designing observatories that can be moved from teleseismic distances—thousands of kilometers away—to regional and local distances—hundreds to tens of kilometers and can operate robustly in the extremely cold, windy, high-altitude, and high-latitude environments. Instrumentation that can operate on or near the ice vastly improves the quality and quantity of high-definition signal recorded from glaciers. By incorporating state-of-the-art seismometers into these extreme designs, we retain the high-fidelity ground motion recordings required for concurrent global/teleseismic observations. In addition to the observatory equipment, the personnel ready, willing, and able to design and fabricate this unique equipment, and deploy it in these harsh environments, are highly specialized. To operate observatories under these conditions requires advancing the capabilities of the IRIS facilities above and beyond the "standard" station work currently supported.

IRIS founding principles are not only related to the collection and distribution of seismological data, but also the education of the seismological community. As we improve our capabilities in polar regions, we have the ability to offer education and engineering support to our national and international colleagues in successful deployments of polar seismological experiments. IRIS currently provides design drawings and documentation on this polar work, which are free and open to all (for online versions, go to http://www.passcal.nmt.edu/content/polar-programs) and consultation to other science disciplines such as climatology, glaciology, and physics.

With the increased interest in the study of polar environments, IRIS has developed capabilities that have allowed seismologists as well as glaciologists access to year-round broadband seismic data from study areas previously out of reach. With successes of the AGAP and POLENET Antarctic experiments, there is growing interest in expanding studies in these areas and enhancing permanent observations around

Figure A7.3. Deployment of MRI-developed autonomous station as part of the POLENET experiment, western Antarctica (photo courtesy of B Bonnett).

Earth's poles. With the new capabilities IRIS has developed, we have opened doors in the ability to study with high resolution, seismological phenomenon associated with the delicate polar regions. As such, the gap between the traditional global-scale permanent observatories (GSN) and regional, temporary experiments (PASSCAL) has been bridged, creating a capability to operate permanent regional- to local-scale observatories in polar climates. This resource will allow further understanding of bi-polar climate-related seismological phenomenon and improve the study of axial symmetric global properties in these sparsely covered areas of Earth.

With sustained core support, PSS will be able to continue development efforts for improved cold region systems as part of ongoing field support. This team could form the core of a more active design group, available to respond on a project-specific basis for enhanced design requirements identified by the community, including polar observations in many geophysical disciplines.

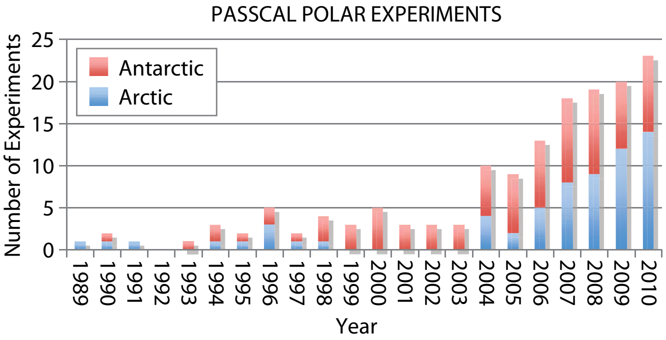
DEVELOPMENTS UNDER THE CURRENT COOPERATIVE AGREEMENT

ENHANCED POLAR-SPECIFIC CAPABILITIES

Over the past several years, the NSF Office of Polar Programs (OPP) has made a large investment to establish more robust capabilities at IRIS for seismological observations in extreme polar environments. With MRI awards for development (*Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica*) and acquisition of cold-hardened equipment, IRIS has successfully designed and developed smaller, lighter, and more robust observatory platforms that have greatly improved data return from experiments in the most remote and extreme parts of the Arctic and Antarctic. With these new capabilities, IRIS established Polar Support Services (PSS) at the PASSCAL Instrument Center (PIC) to retain specialized personnel, not only to support funded polar experiments, but also to maintain the polar observatory infrastructure and equipment as technologies continue to evolve and experiments are requested that continue to push the requested capabilities of the platforms.

The last five years have seen a significant increase in both the number of polar experiments and the time PIC staff spends supporting these experiments. Of approximately 60 experiments the PIC supports per year worldwide, now 10% to 20% receive funding from OPP. Standard support for experiments includes a suite of services, from equipment testing and maintenance, to shipping and handling, to data archiving. Polar projects require a level of support beyond what is supplied as standard, including cold-related engineering solutions, equipment fabrication and preparation for extreme conditions, and extended field support—often many man-months in the field, which is far beyond the field support that is typical for other experiments.

Although IRIS has been supporting PI-driven experiments in polar regions since 1989, it wasn't until the early 2000s that significant, over-winter seismic deployments were considered. In order to ensure a high level of data return and data quality for these OPP-funded projects, the PSS group focuses on: (1) developing successful cold station deployment strategies, (2) collaborating with vendors to develop and test -55°C rated seismic equipment, (3) establishing a pool of instruments for



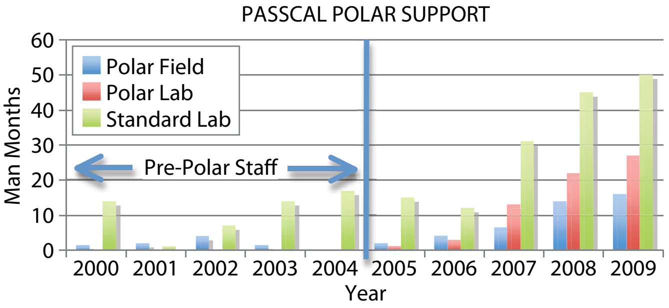
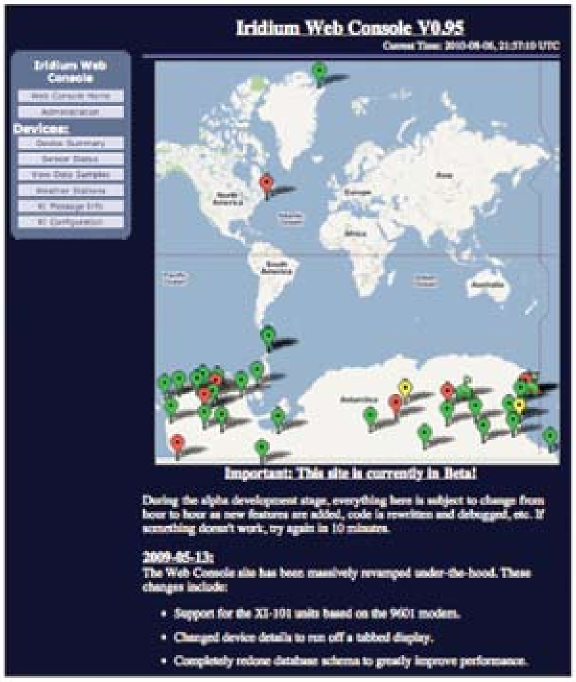


Figure A7.4. Number of polar experiments supported by IRIS PASSCAL (left) and number of person-months spent on support (right). Support is broken out into three categories: Polar Field = time spent in-field supporting polar network installations; Polar Lab = specialized lab preparations for polar experiments largely performed by OPP-funded positions; Standard Lab = routine procedures provided for all PASSCAL experiments and proportional to the total number of stations.

MONITORING OF HIGH-LATITUDE STATIONS

Using Iridium technology through design work contracted with Xeos Technologies (Halifax), the IRIS Polar Support Service group has develop command, control, and monitoring web interfaces to permit remote monitoring of high-latitude seismic stations. Work is underway to allow continuous data to flow through these same links.



Iridium Web Console V0.95

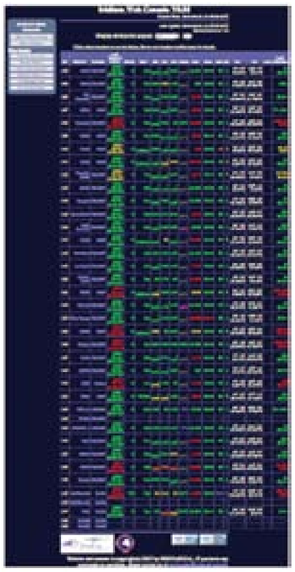
Current Time: 2010-08-06, 21:57:10 UTC

Important: This site is currently in Beta!

During the alpha development stage, everything here is subject to change from hour to hour as new features are added, code is rewritten and debugged, etc. If something doesn't work, try again in 10 minutes.

2009-05-13:
The Web Console site has been massively revamped under-the-hood. These changes include:

- Support for the XI-101 units based on the 9601 modem.
- Changed device details to run off a tabbed display.
- Completely redone database schema to greatly improve performance.



use in cold environments, (4) building a pool of cold station ancillary equipment, and (5) creating an open resource repository for cold station techniques and test data for seismologists and others in the polar sciences community.

Under the current Cooperative Agreement, the funding mechanism for this work has been through annual or as needed supplemental proposals to OPP. Current funded capabilities include: 3.5 FTE; a pool of 40 cold-hardened broadband stations (currently deployed at POLENET and AGAP); a 60-channel seismic snow streamer; 100 quick-deploy boxes for summer-only stations; and a cold chamber capable of testing equipment for the extreme cold of the Antarctic Polar Plateau.

COMMUNICATIONS

Work under MRI awards for the International Polar Year (IPY) and Greenland Ice Sheet Monitoring Network (GLISN) as well as support from the core PASSCAL program has included development of Iridium-based communications interfaces with cold-rated equipment that allows for several levels of remote interaction. At the simplest, lowest-power end, network operations centers can receive state-of-health information and data snippets, and process command-and-control functions. At the other extreme, we are working with Xeos Technologies to expand the Iridium system to incorporate real-time data flow in addition to simple data transfers. Communications in high latitudes is evolving, and PSS technical staff will keep current on new developments in this area to ensure return of as much data as possible from these remote stations.

GREENLAND ICE SHEET MONITORING NETWORK

In 2009, IRIS was awarded $1.9M in MRI funding from NSF for the three-year development of GLISN. The development effort is a coordinated international collaboration for a new broadband seismic capability for Greenland. Initially, this was a partnership of eight nations—Denmark, Canada, Germany, Italy, Japan, Norway, Switzerland, and the United States, but Poland has since added on as a contributing nation and France is looking to contribute a new station as well. GLISN will contribute to our understanding of ice sheet dynamics by establishing a real-time sensor array of 25+ stations, including upgrading the performance of the scarce existing Greenland seismic infrastructure for detecting, locating, and characterizing glacial earthquakes and other cryoseismic phenomena. The development of the telemetry infrastructure linking the sites together into a coherent framework creates the temporal resolving capability and potential for rapid scientific response that can also be applied to other, future seismological efforts in other remote areas of the world. All data from GLISN are and will continue to be freely and openly available.

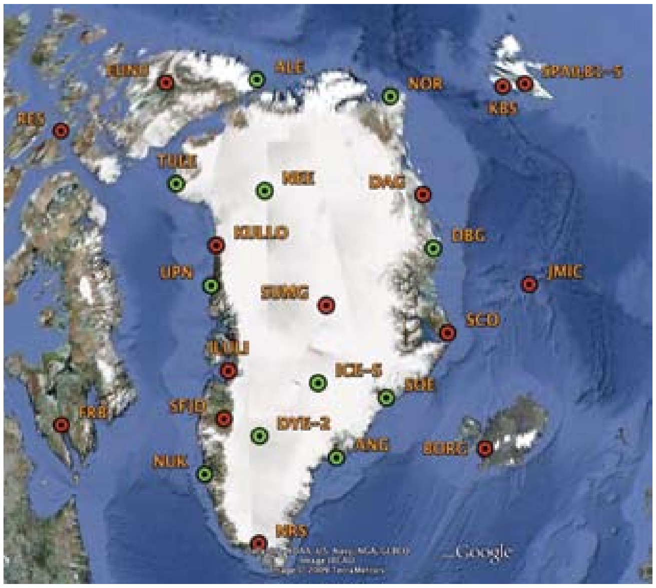


Figure A7.5. Map of GLISN.

Engineering and technical work by the PSS field engineering staff for GLISN is focused on: (1) upgrading equipment and adding real-time telemetry to existing seismic infrastructure in Greenland; (2) installing new, telemetered, broadband seismic stations on Greenland's perimeter and ice sheet; (3) coalescing telemetry from existing real-time, high-quality, broadband stations in and around Greenland into the GLISN network; and (4) distributing the real-time data to users and international data centers. In collaboration with GLISN, the Global Centroid Moment Tensor Project at Lamont-Doherty Earth Observatory will provide a near-real-time catalog of glacial earthquakes. The development incorporates state-of-the-art broadband seismometers and data acquisition, Iridium and local Internet, power systems capable of autonomous operation throughout the polar year, and stable, well- coupled installations on bedrock and the ice sheet. GPS will also be installed at sites on the ice sheet.

Oversight of the GLISN effort is provided on the U.S. side by the IRIS GLISN Science Advisory Committee (SAC) and includes as observers management and technical personnel from the PSS. The chair of the GLISN SAC as well as the GLISN Project Manager participate in the international GLISN steering committee to coordinate the NSF-funded GLISN effort with those of our international collaborators.

Due to the efforts of PSS, we were able to assure successes in the GLISN proposal and share our capabilities with our international partners

ACHIEVEMENTS

The polar seismology community has greatly benefited from the recent focused efforts of PSS. With OPP's investments in improving the designs of remote autonomous observatories and the procurement of cold-hardened equipment pools using the design efforts from this work, along with enhanced field support, we have achieved year-round recording for autonomous broadband seismic stations on the Polar Plateau, with data returns of over 90% (about the same or better than our fair-weather experiments). At the same time, we have minimized logistics support obligations to NSF by keeping designs small and light. Maintaining the existing capabilities and building on the progress achieved will require a sustained funding environment and a coordinated effort with the user community through the Polar Network Science Committee (a joint IRIS/UNAVCO advisory committee populated by polar PIs who provide guidance on required polar network capabilities).

NEW OPPORTUNITIES AND DIRECTIONS

To date, funding scenarios for the support of this facility have been on a year-to-year basis, depending on the scope of successfully funded annual OPP awards. Equipment resources are procured through yearly supplemental funding requests, based on funded projects for that year. Timing of these requests generally allows very little time to acquire, fabricate, test, and ship prior to the deployment to the field—sometimes as little as one week. With such specialized equipment working in areas of very expensive logistics and so little turn-around time, there is a risk that robustness of equipment rushed out the door cannot be assured. PSS has been successful in this "reactive" mode of funding, but risks the loss of staffing expertise in the long term without some assurance of continuous support. In addition, as the equipment in the pool begins to age (we are suspecting that the harsh environments for these installations will take a higher-than-normal toll on the instrumentation), we will need to replenish and, if possible, grow the pool to keep up experiments instrumented with the most robust systems possible. To ensure that specialized staffing can be retained to support these new capabilities at state of the art, continue the successes realized by OPP on the IPY seismic experiments, and protect the investment made to establish this polar-specific facility, we request a base level of funding to IRIS aligned with the IRIS core program Cooperative Agreements.

Beyond simply sustaining the new IRIS polar facility, there is exciting new equipment development for the PSS staff to pursue with NSF support. These new directions will further push the bounds of the polar environments in which we can record high-quality broadband seismic data. The following sections describe the sustainment and growth potentials proposed for the IRIS polar facility.

SUSTAINING SPECIALIZED POLAR SUPPORT CAPABILITIES

Personnel

A dedicated and well-trained staff that can focus on the unique requirements of polar experiments is critical to maintaining IRIS's support activities and to sustaining the investments NSF made on enhanced services during the IPY. IRIS has devoted personnel at the PIC and currently has 4.5 FTEs in PSS (3.5 directly funded by OPP and one funded under GLISN). Having dedicated PSS FTEs allowed IRIS to transform the 2008/09 field-season experiments by reducing logistics requirements and increasing data returns. Until now, this established polar support has been ephemeral in that retention of the 3.5 OPP-funded FTEs depended on yearly supplements; this way of funding FTEs creates the perception of an insecure job and makes it difficult to keep qualified staff. The GLISN position is funded only through September 2012. IRIS cannot maintain the levels of excellence currently represented in PSS without stable funding. An example of the benefits of a trained and stable polar staff was our ability to respond to the recent increase in polar climate research. Although specialized equipment for this kind of fieldwork requires development and planning in the time frame of years, because we had core PSS staff, IRIS was able to quickly provide a working solution for these challenging deployments. We are requesting that this Cooperative Agreement fund staff throughout the length of the award (synchronized with the IRIS core funding) and assume the cost of retaining the GLISN staff after that MRI award ends.

Equipment

To maintain an innovative polar station pool, IRIS will continue to pursue incremental development and modifications to the existing station, communications, and power-system designs. Battery technologies are continually evolving and will likely realize a surge in design innovation over the next several years. Although the station power system design is effective and compact, its cost is high. Having knowledgeable staff to monitor battery development, to design new systems, and to test emerging battery technologies for cold weather applications will be essential to ensure the most cost-effective solution is maintained. Like battery technologies, high-latitude communications are quickly evolving. The current polar station design has a solution for state-of-health communications, but the science community continually stresses the need for a real-time, full-bandwidth solution (currently unavailable). With better communications and advanced battery technologies, we could truly approach an infrequently visited, autonomous station, thus reducing long-term logistics costs.

The current pool of polar equipment is allocated through 2012–2013 Antarctic field season. As such, we cannot sustain further field requests without a responsive supplemental proposal to OPP based on current-year funded experiments. As mentioned above, in a reactive mode, robust designs are difficult to procure, fabricate, and deploy in an extremely abbreviated time frame, and as such, the benefits we have gained from the development work cannot be assured. In addition, due to the harsh environments, the equipment that

Figure A7.6. The work of the Polar Support Services engineers have allowed for vast improvements in low-power cold-rated, robust, super-insulated seismic systems for deployments in the some of the harshest polar environments. All designs are available at http://www.passcal.nmt.edu/content/polar-design-drawing currently constitutes the pool deteriorates at a higher rate relative to other instruments. Therefore, we are requesting basal sustainment funds for the polar pool that will permit continuation of the pool at its current deployment rate as well as allow for moderate growth to be responsive to the growing interest in climate-related monitoring in polar environments.

BACKBONE STATION HARDENING FOR POLENET AND AGAP

There is scientific interest in establishing a core reference network for Antarctica for long-term observations. A logical starting point for this network would be based on a subset of stations from the AGAP and POLENET experiments, but both of these experiments were designed and deployed as temporary installations. For long-term operation, station hardening will be required. PSS can leverage knowledge gained during the development MRI and GLISN projects to design and modify these stations to increase longevity and minimize logistics support requirements. Station modifications will most likely include a rugged metal station, a semi-permanent seismometer vault, upgraded communications, and an enhanced power system.

COLD, WET STATION PACKAGE

OPP has funded more than 15 glaciology projects with a seismology component. With the establishment of GLISN and the heightened interest in monitoring rapid glacial change, we expect that the number of proposals to perform higher-resolution experiments on the Greenland glacier systems and in other high-latitude environments will increase. These projects have proposed using short-period or broadband seismometers in environments with a high probability of flooding in the summer months, while still requiring extreme cold-hardening for winter operations. Flooding due to high surface melt rates poses challenges for both surface and borehole sensor installations. IRIS now has several prototype waterproof borehole instruments acquired with supplemental funding from OPP, but we currently lack waterproof short-period seismometers and digital recorders. Supporting these projects has required compromises in experiment design and high risks to existing instrumentation. To better support projects in these extremely wet ice-sheet environments, IRIS needs to pursue the development of a waterproof, quick-deploy seismic station. In addition to being waterproof, IRIS is working with manufacturers to test a borehole sensor with high tilt tolerance for recording in the dynamic glacial environment. This effort is in the early development phase, but stable polar staffing is required to continue progress and to provide the specialized support for these experiments.

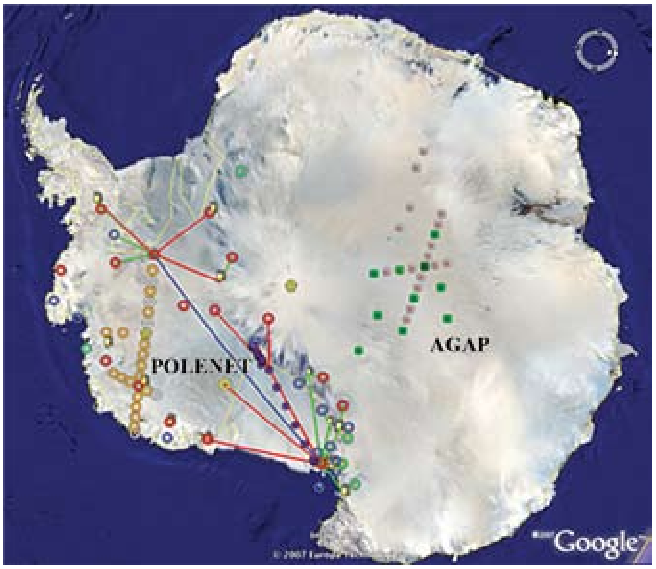


Figure A7.7. Map of POLENET and AGAP stations.

Figure A7.8. Meltwater river near the margin of the inland ice. Illulisat, Greenland (photo courtesy of Geological Survey of Denmark and Greenland).

ANTARCTIC FIELD SUPPORT FACILITY

Support of Antarctic experiments could be enhanced, while minimizing logistics costs, by establishing an observatory support facility at McMurdo station. This concept has been supported on an interim basis through funding of temporary projects, and has proven to be beneficial to the support of Antarctic field efforts. With no long-term funding assured, however, the on-ice support cannot be optimized. These on-ice concepts include:

- Establishment of a cold test site in McMurdo. Although an OPP-funded cold chamber is installed at the PIC, testing of fully integrated systems requires long-term runs in field conditions. McMurdo is ideal for this purpose because of its year-round Internet access. Little or no support would be required from Raytheon, other that IT support for communications links. This concept was introduced as part of the development MRI and it proved to be very valuable in the over-winter testing of system enhancements in actual field conditions.

- Establishment of a storage depot in McMurdo to store polar-specific equipment between seasons, reducing shipping cost and logistics. Current usage of a milvan is viewed as a temporary solution by Raytheon and requires yearly requests to maintain.
- Establishment of a small amount of dedicated lab space in McMurdo for test and computer equipment. The current use of Crary Lab loading docks is workable, but not ideal, particularly with the increased size of recent seismic and geodetic experiments.

It would be helpful to explore possibilities for a future dedicated geophysics facility that would provide the appropriate space for storing, staging, and supporting seismic, geodetic, and other geophysical experiments supported in part by IRIS and UNAVCO. An example of an existing building that would provide the necessary space is the Berg Field Center. The size and layout make it ideal for staging large geophysical experiments and the proximity to the future science cargo center in the expanded science support complex will reduce the logistics involved in getting the equipment prepared for field deployments.

Figure A7.9. IRIS (center) and UNAVCO (left) cold station development testbeds overlooking McMurdo Station, Antarctica. These testbeds were used to proof MRI designs in field conditions in Antarctica (photo by T Parker).