Collaborative Research: Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica

January 2006

Submitted by

UNAVCO and IRIS
on Behalf of the Polar Community

Submitted to

Major Research Infrastructure
and
Office of Polar Programs
Division of Earth Sciences
National Science Foundation

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-23 NSF 05-515 01/26/06	FOR NSF USE ONLY NSF PROPOSAL NUMBER **0619908**
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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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Incorporated Research Institutions for Seismology

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REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 673,463	36 months	06/01/06	

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Project Summary: Major advances in addressing many compelling questions in polar geoscience require continuous recording of GPS and seismic data. Logistic expenses require systems that can operate unattended for multiple years. We propose to develop a new system that will enable the polar science community to obtain critical new data sets to address many fundamental questions about the nature and behavior of the crust and mantle beneath Antarctica and its relationship to ice sheet dynamics and climate. While new technological achievements in GPS receivers and seismometers make it possible to use off-the-shelf units for autonomous recording in polar regions, there is still no companion power/communication system available to permit year-round autonomous station operation. Decreasing power needs of the GPS and seismic instrumentation, coupled with promising advances in power and communication technologies, have now put us on the threshold of building such a system. Consequently, a development effort is proposed in which IRIS and UNAVCO will team with the Antarctic GPS and seismology scientists to capitalize on these advances to design and build a reliable power/communication system for autonomous polar station operation. The power/communication units built will form the nucleus of a new IRIS/UNAVCO equipment pool, and will allow the science community to achieve the first long-duration deployment of continuously-recording GPS and seismic stations across the Antarctic continent proposed to commence during the International Polar Year (2007-2009).

The goals of this project are to use the latest power and communication technologies, linked with the collective experience/expertise of the science community and IRIS/UNAVCO staff, to 1) design, integrate, and test a scalable power and communication system optimized for ease of deployment and reliable multi-year operation in severe polar environments; and 2) provide an initial pool of these systems for deployment and testing in science experiments. The technical requirements guiding the design of the system were established at two workshops (2004, 2005) and are driven by the needs of the research community, including year-round, continuous operation and real-time delivery of as much data as technically feasible. A robust power module will consist of two parts – one based on solar panels and sealed lead acid (SLA) batteries for summer operation, and one for winter operation that incorporates advanced battery technologies and wind turbines. A system controller will be designed to integrate data handling, charge control, power management, system housekeeping, thermal monitoring, autonomous system reset, and report system state-of-health via the communication device. A three-tiered approach for communication and data retrieval will be adopted that includes: a) radio modems/radio repeaters to connect directly to the Internet via LAN where stations are close to permanent bases, b) a commercial Iridium satellite-based connection for GPS, state-of-health, limited seismic data retrieval, and system control, and c) onboard memory to allow for data uploads during maintenance or opportunity visits (possibly including flyovers and wireless data transmission). Custom environmental enclosures will accommodate thermal and wiring requirements. The system will be deployable from light aircraft in no more than two missions per station and with a three person field team. A staged testing and qualification process will be implemented to ensure that final field units are robust and meet design goals.

Project leadership will be shared between the IRIS and UNAVCO facilities, with an overall project manager at UNAVCO. IRIS and UNAVCO have experience in working together on major projects, e.g., EarthScope. A six member Science Oversight Committee (SOC) will ensure that the MRI effort remains well coordinated with science needs and takes best advantage of existing experience within the PI community. The SOC will appoint a Science Coordinator who will serve as a liaison between the SOC, IRIS, and UNAVCO, via facility site visits and inclusion in regular progress teleconferences between the facilities.

Broader Impacts: A new capability for continuous, year-round seismic and geodetic measurements at remote sites will meet longstanding polar and global geoscience goals that have previously been unattainable. Access to the new systems through UNAVCO and IRIS will open doors for scientists and institutions that do not have the technical and field skills currently required to execute remote polar GPS and seismic research projects, thus stimulating participation in polar science by a new generation of researchers. An upper-level undergraduate student will participate in this MRI effort within an established undergraduate research program called “Research Experiences in Solid Earth Science for Students”.

Collaborative Research: Development of A Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica

Introduction: MRI funding is requested to develop the next-generation power and communication system for GPS and seismic observatories in Antarctica. A new system will enable the polar science community to obtain critical new data sets to address many fundamental questions about the nature and behavior of the crust and mantle beneath Antarctica and its relationship to ice sheet dynamics and climate. It has long been recognized that major advances in addressing many compelling questions in polar geoscience require continuous recording of GPS and seismic data at stations that can operate autonomously for a period of two or more years (e.g., Workshop on Antarctic Neotectonics, 2001; Workshop on Structure and Evolution of the Antarctic Plate, 2003). The technical hurdles that must be overcome to do this are understood and documented (Autonomous Systems in Extreme Environments Workshop, 1999; Antarctic Remote Observatories Workshop, 2004; Antarctic Seismic and GPS Technologies, Challenges, and Opportunities Workshop, 2005). Up to now, year-round continuous recording of seismic and geodetic data has been largely limited to a small number of stations adjacent to permanent operational bases around the Antarctic perimeter (Fig. 1). Temporary deployments at remote sites are logistically intensive and few have been successful at obtaining data through the polar night.

The need for autonomous station operation is amplified by the logistical constraints under which the Office of Polar Programs (OPP) at NSF operates. Support for deep-field deployments is always restricted by the availability of aircraft flights and fuel. One could argue that some of the important science questions might be answered by gathering data over just the summer months using conventional solar and battery power systems, but revisiting sites annually to retrieve data and refresh battery supplies is logistically impractical in most cases and many well-reviewed science proposals have been declined by OPP on this basis.

While new technological achievements in GPS receivers and seismometers make it possible to use off-the-shelf units for autonomous recording in Antarctica, there is still no companion power/communication system available to permit year-round autonomous station operation. Decreasing power needs of the GPS and seismic instrumentation, coupled with promising advances in power (generation and storage) and communication technologies, have now put us on the threshold of building such a system. A development effort is proposed here in which IRIS and UNAVCO will team with the GPS and seismology PI-science community to capitalize on these advances to build a reliable power/communication system that will enable autonomous station operation in the remotest parts of Antarctica for periods of two or more years. The power/communication units built will form the nucleus of a new IRIS/UNAVCO equipment pool for supporting the next generation of polar researchers, (and researchers facing similar remote deployments elsewhere), and will allow the science community to achieve the first long-duration deployment of

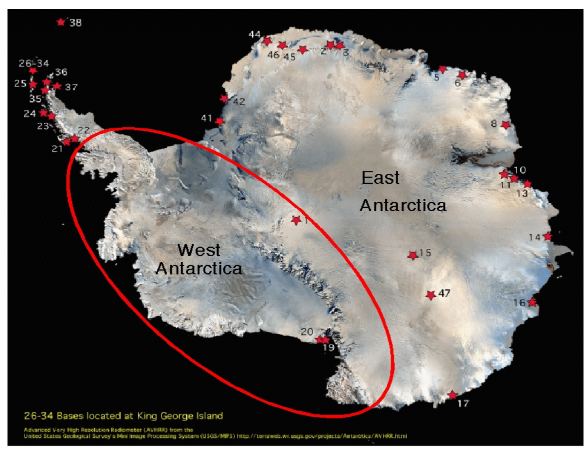


Figure 1. *Although the Antarctic plate comprises about 9% of the planet's lithosphere, less than 2% of the continental surface is exposed rock, and so the geological evolution of Antarctica and its influence on global processes must be largely inferred from geophysical observations. The paucity of permanent bases (red stars) has precluded long-duration observations across the continent. Power and communication systems that can be deployed at remote sites in the interior of Antarctica as early as the International Polar Year (IPY) (particularly deployments proposed in largely uninstrumented West Antarctica, within red oval) will be developed by this proposal.*

continuously-recording GPS and seismic stations across the Antarctic continent as well as in other remote Polar regions, proposed to commence during the International Polar Year (IPY 2007-2009).

A. RESEARCH ACTIVITIES

Below we describe a selection of world-class science projects that would be enabled by autonomous GPS and seismic stations recording data continuously over many years in Antarctica. Parallel, and additional, efforts in the Arctic region would similarly be facilitated by the new observational capabilities.

1. What is the broad-scale pattern of Antarctic crustal uplift and subsidence arising from the Earth's response to ice sheet fluctuations?

This pattern is not currently known (Fig. 2), but could be documented with as little as three years of continuous GPS (CGPS) measurements (Williams et al., 2004). Documenting this response is critical for understanding Antarctica's role in climate and sea-level change in many ways:

a) The pattern and magnitude of past ice sheet thinning, and hence the Antarctic contribution to global sea-level, since the Last Glacial Maximum will be much better understood from modeling of the observed uplift rates (Ivins and James, 2005). CGPS constraints, combined with seismological constraints on mantle rheology, will permit researchers to test the range of predictions yielded by glacial isostatic adjustment (GIA) models (Fig. 2). Results will also have implications for other non-Antartic continental ice sheets, as modifications to the Antarctic contribution will require modifications to northern hemisphere ice sheets in order to satisfy the global sea-level 'budget' (James & Ivins, 1997; Lambeck et al. 2002; Peltier, 2004).

b) The observed crustal uplift is key to deciphering satellite observations of gravity change from the Gravity Recovery and Climate Experiment (GRACE) mission: crustal motion measurements will allow discrimination of gravity change due to present-day ice sheet change and to Earth's ongoing viscoelastic response to past ice change (Velicogna and Wahr, 2002, 2004).

c) Better understanding of past Antarctic ice sheet dynamics is important for projecting future ice sheet change. For example, if Antarctica was the main contributor to a sudden rise in sea-level about

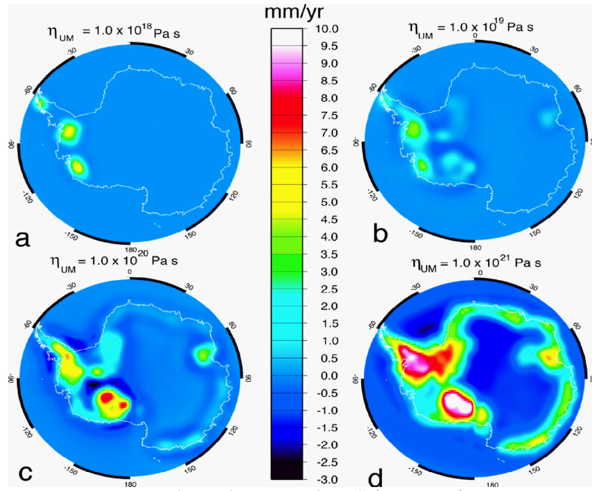


Figure 2. *Predicted vertical uplift rates for increasing upper mantle viscosity (a-d), for ice load history presented in Ivins & James (2005).*

14,000 years ago (Bassett et al., 2005), then there is a clear prospect that the Antarctic ice sheet could again contribute to a rapid rise in sea level.

d) The observed crustal uplift will provide a 'correction' to satellite missions measuring changes to present-day ice sheet elevations. The corrections will improve estimates of the poorly-known present-day Antarctic ice-sheet balance and hence the Antarctic contribution to present-day global sea-level change (Rignot and Thomas, 2002; Davis et al., 2005).

e) The pattern and magnitude of the elastic response of the Earth to contemporary snow and ice mass change will also be measured by CGPS (e.g., Heki, 2001). Where the magnitude of this load is measured independently from satellite measurements, the elastic properties of the lithosphere can be calibrated (Bevis et al., 2004, 2005). This then provides a unique CGPS 'scale' to weigh ongoing mass balance adjustments in response to climate change.

2. What is the neotectonic framework of the Antarctic plate, what is the structure and origin of major tectonic features on the continent (e.g., the Transantarctic Mountains, the West Antarctic Rift System, and East Antarctic Craton), and what is their relationship to Cenozoic lithospheric deformation (Figure 3)?

Combined recording of continuous GPS and seismic data over multiple years at stations across the continent will enable scientists to address these questions in the following ways:

a) The pattern of steady horizontal motion of the Antarctic bedrock can be resolved by CGPS measurements (Dietrich et al., 2004; Donnellan and Luyendyk, 2004), and this information, combined with new knowledge of the location and magnitude of Antarctic earthquakes from the deployment of seismic stations (Bannister and Kennett, 2002; Winberry and Anandakrishnan, 2003), will better place Antarctica in the global tectonic system. On the continental scale, the GPS and seismicity patterns will provide better understanding of the location and nature of zones of intraplate deformation. This will provide fundamental insights into the current tectonic regime of Antarctica. On the global scale, the improved horizontal velocities will allow unambiguous determination of the motion of the Antarctic Plate relative to other global tectonic plates and determine the nature of intraplate deformation in Antarctica. The question of the rigidity of the Antarctic plate is central to understanding discrepancies in the global plate circuit and whether these can be attributed to significant Antarctic intraplate deformation (Steinberger et al., 2004; Gordon et al., 2005).

b) Data recorded from teleseismic, regional and local earthquakes will allow unprecedented resolution of sub-Antarctic Earth structure, yielding important insights into lithospheric structure and sublithospheric mantle processes, such as plume activity and small-scale convection. New seismic images of crust and mantle structure can be compared to surface observations, where available, to better decipher the tectonic history of Antarctica (Fig. 4). This will contribute to our understanding of the structure and evolution of the Antarctic continent, as well as global processes including mountain building, the development of cratonic lithosphere, and continental extension and breakup. Global seismic tomographic models (e.g. Ekstrom and Dziewonski, 1998; Antolik et al., 2003; Grand, 2002; Ritsema et al., 1999) will also benefit substantially from improved south polar coverage.

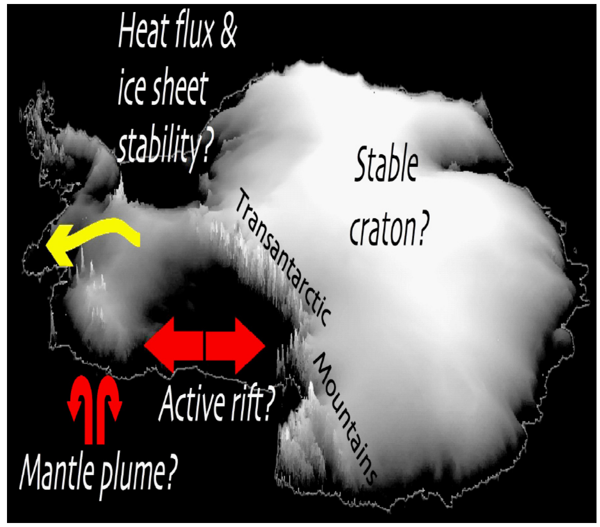


Figure 3. *Active volcanism, the high Transantarctic Mountains escarpment transecting the continent, thin lithosphere, deep subglacial basins, and faults that reach the seafloor, all point to the presence of a recent, and potentially active, rift underlying West Antarctica. A continental-scale seismic and CGPS array can delineate if and where active deformation is occurring within Antarctica, addressing whether East Antarctica is a stable craton, if West Antarctica is underlain by an active rift system, if the Transantarctic Mountains are part of the craton or the rift system, and if mantle plumes are impinging from below and deforming the Antarctic lithosphere.*

3. What is the thermal structure of the Antarctic crust and mantle and how does it influence ice-sheet dynamics?

There is an important link between seismological investigations and climate and sea-level studies via the thermal structure of the lithosphere. Mantle thermal structure can be estimated from experimental relationships between shear velocity and temperature;

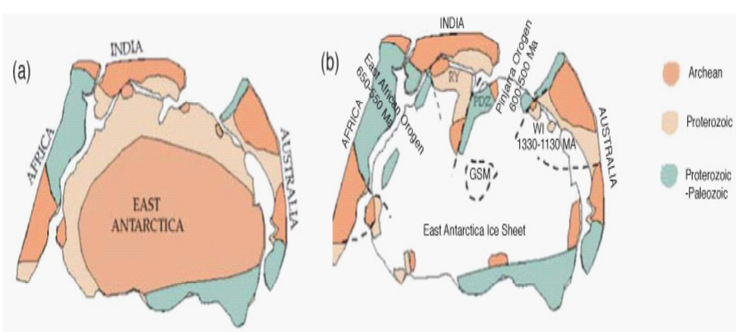


Figure 4. *The interior of East Antarctica may be a vast Archean craton (a) [Tingey, 1991], or may be comprised of several Proterozoic orogenic belts surrounding smaller Archean blocks (b) [Fitzsimmons, 2003]. Hypotheses regarding the evolution of the Archean-Proterozoic crust of Antarctica can be uniquely tested by new seismological studies, since sparse peripheral outcrops provide limited constraints.*

regions with slow seismic velocities correspond to high mantle temperatures (and partial melt in some regions) (Faul and Jackson, 2005). Seismological results indicate one of the most dramatic contrasts on Earth between low upper-mantle seismic velocities in West Antarctica and much higher velocities in East Antarctica (Fig. 5) (Danesi and Morelli, 2001; Ritzwoller, et al., 2001; Lawrence, et al., 2005). From mantle temperature variations surface heat flow and mantle viscosity can be estimated (Shapiro and Ritzwoller, 2004; Figure 5).

a) Heat flow is a fundamental control on the behavior of ice sheets because it helps to determine whether the bottom of the ice sheet is frozen to bedrock or sliding. Better constraints on heat flow throughout Antarctica will be provided as seismic tomography models achieve better resolution, contributing to ice sheet modeling, in addition to our understanding of mantle processes.

b) The thermal structure of the lithosphere is a fundamental modeling parameter needed for determining the response of the Earth to past ice sheet changes (Kaufmann, et al., 2005).

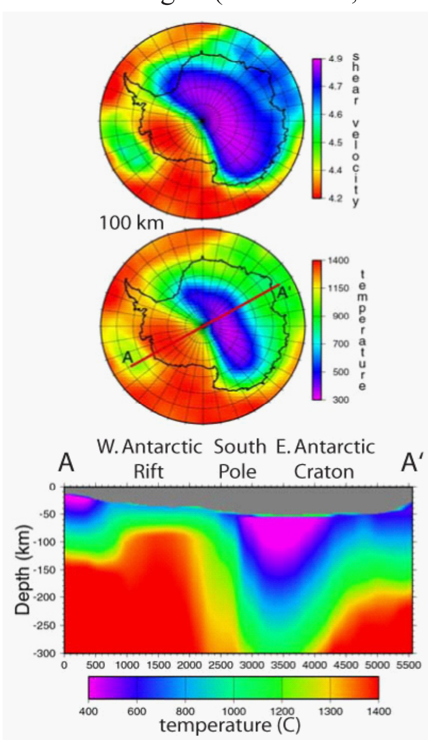


***Figure 5**. Velocity variations indicate a corresponding variable upper mantle thermal structure, with much warmer temperatures under West Antarctica. (Shapiro and Ritzwoller, 2004).*

Seismology can place fundamental constraints on the geologic history and uplift mechanisms of tectonic features in Antarctica, using known relationships between geologic age and seismic velocity structure (Shapiro and Ritzwoller, 2004), and using seismic velocity structure coupled with gravity observations to identify density anomalies and locate sources of buoyancy associated with topography. This is critical for constraining the uplift history of the East Antarctic highlands, where coupled climate-ice sheet models show that the first glaciers in the world associated with the transition from 'hothouse' to 'icehouse' Earth formed ~34 Ma (Deconto and Pollard, 2003).

4. What are the response times and spatial gradients in ice sheet movements?

CGPS data on and near glaciers, ice streams and ice sheets, linked with data from a CGPS bedrock reference network, will enable measurements that will accelerate a new understanding of ice dynamics. The "old" view of ice-sheet flow as varying only slowly in time and space is rapidly being replaced by a more nuanced view in which different regions of an ice sheet may exhibit orders-of-magnitude differences in response times and in spatial gradients. Inland East Antarctica seems to have been remarkably stable for at least the majority of the last million years (EPICA, 2004), but ice-shelf collapse caused an almost order-of-magnitude acceleration over months in the Antarctic Peninsula (Rignot et al., 2004; Scambos et al., 2004). Whillans Ice Stream varies even more strongly, stopping and starting in minutes twice every diurnal period (Bindschadler et al., 2003).

a) Switching in response time is of great importance; sea-level projections (e.g., IPCC, 2001) typically have assumed that the response times will remain unaltered, an assumption that may be unjustified. Recent measurements have shown that glaciers and ice streams change velocity and seismicity in response to ocean and tidal forcings (Anandakrishnan et al., 2003; Bindschadler et al., 2003) (Fig. 6) including ice streams deep in the Antarctic interior. Determining whether variations in sea ice conditions can cause fluctuations in ice sheet discharge will provide constraints for models of ice sheet response as ongoing ocean warming and climate change alter sea ice configurations.

b) CGPS measurements of so-called "Super

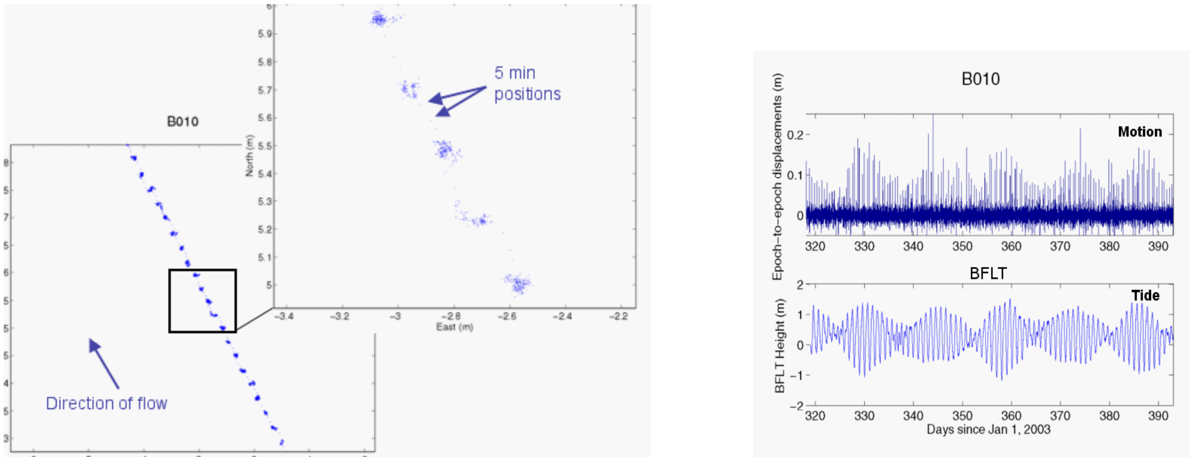


__Figure 6__. Field results showing the northing-easting positions (determined by GPS) at 5 minute intervals on Whillans Ice Stream (upper panel). Upper inset shows enlargement of five slip events. Note the cluster of stagnant positions followed by rapid slip of 10-20 cm in 15 minutes. The displacement history (right panel) shows the relationship between the tide (lower plot) and the slip speed (upper plot is displacement in 5 minute intervals). Note that displacement magnitude scales with tidal magnitude (spring vs. neap), but with a possible long-period offset of 1-3 days, which our current models do not capture. (Courtesy of S. Anandakrishnan)

poles" (where the GPS antenna is effectively buried to depths of 20 or 30 m by freezing in a marker at that depth; see Hamilton et al., 1998) can lead to a better understanding of the balance between accumulation rate variability and long-term ice-dynamics flow variability. These data are critical for interpreting shallow ice cores and ice-penetrating radar data.

5. What is the structure of Earth's inner core?

Antarctica is a unique vantage point to study the inner core (Figure 7). For example, because Antarctica is seismically quiescent, and the Arctic spreading ridge is seismically active, an ideal way to assess inner core anisotropy, which is approximately aligned with Earth's spin axis, is using Antarctic teleseismic observations of Arctic events. Antipodal paths are also important for studying the differential rotation of the core.

B. RESEARCH INSTRUMENTATION

1. Background and Scope

Antarctica presents researchers with one of Earth's harshest environments. Field instruments must operate in extreme low temperatures and survive sustained, extreme wind conditions. Year-round measurements at sites away from the sparse permanent operational bases require a source of power other than solar through the four to six month polar night. Data transfer is limited by the lack of availability of most commercial communication systems. Access to sites in the Antarctic interior is only by small aircraft and is only possible during the U.S. Antarctic Program (USAP) operations in the short summer period. The costs incurred by the USAP to provide deep-field air transport, and the large infrastructure underpinning it, far exceed those for instrument deployment elsewhere in the world.

The solid Earth polar science community has more than a decade of experience with GPS and seismic deployments that will be utilized and built upon during this project (Table 1; Figs. 8, 9). We

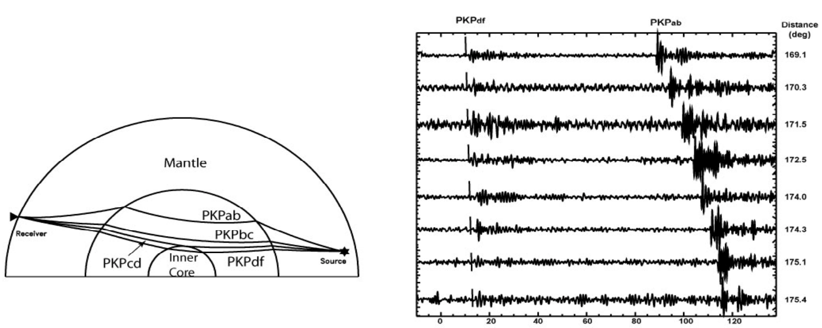


__Figure 7.__ Recording of rare polar path near antipodal core phases across the TAMSEIS array from a Mw 5.2 event on the Arctic ridge (courtesy of TAMSEIS PIs Wiens, Nyblade and Anandakrishnan). Enhanced seismological instrumentation of Antarctica will significantly increase our understanding of the inner core.

have shown that continuous GPS and seismic data can be recorded year-round at locations where logistical support is sufficient to equip stations with large battery banks and to return for annual maintenance visits (e.g. Transantactic Mountains Deformation Network (TAMDEF), Mt. Erebus Volcano Observatory (MEVO). At stations further from permanent bases where large battery banks cannot be delivered, individual PI-led efforts have also proven that a combination of solar power and lesser amounts of batteries provide sufficient power to keep stations running for up to six months through the summer (e.g. Transantarctic Mountains Seismic Network (TAMSEIS). Operating stations for more than one year without servicing has not yet been achieved because of the lack of a power/communication system sufficiently robust and light weight to permit autonomous station operation year-round over several years.

The goals of this project are to use the latest power and communication technologies, linked with the collective experience/expertise of the science community and IRIS/UNAVCO staff to 1) design, integrate, and test a scalable power and communication system optimized for ease of deployment and reliable multi-year operation in severe polar environments; and 2) provide an inital pool of these systems for deployment and testing in science experiments. The technical requirements guiding the design of the power and communication systems are driven by the needs of the research community, including year-round, continuous operation and real-time delivery of as much data as technically feasible. We will follow a systematic development, testing, and prototype demonstration process, including design reviews and process feedback, which will ensure a rigorous testing of new technologies and the integrated sytems. An important additional deliverable will include open documentation of the overall system design, as well as performance of commercial off-the-shelf (COTS) units under polar conditions, providing the community with a 'best practices' manual for polar instrumentation for adaptation to their own experiments. The design roadmap includes:

a) Apply engineering 'best practices' to existing successful systems to achieve absolutely dependable continuous summer recording and recovery from winter hibernation.

Figure 8. *Top: Early GPS time series from JPL site on Mt. Coates, Transantarctic Mountains (Raymond et al, 2004). Bottom: Improved precision and annual signal from continuous GPS site at Cape Roberts. (Terry Wilson, PI)*

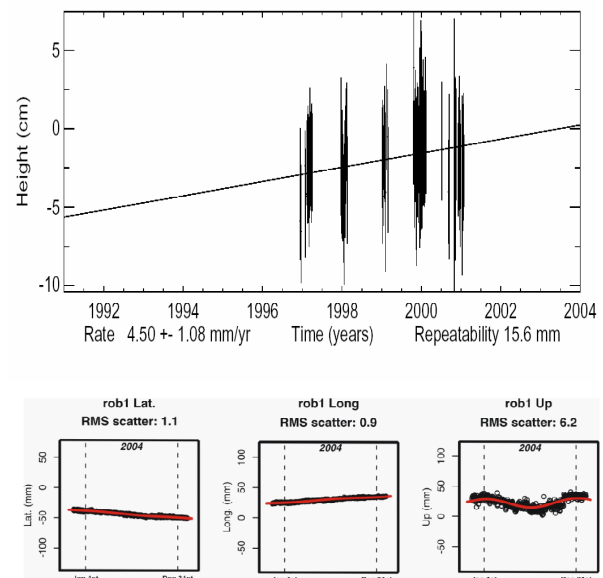
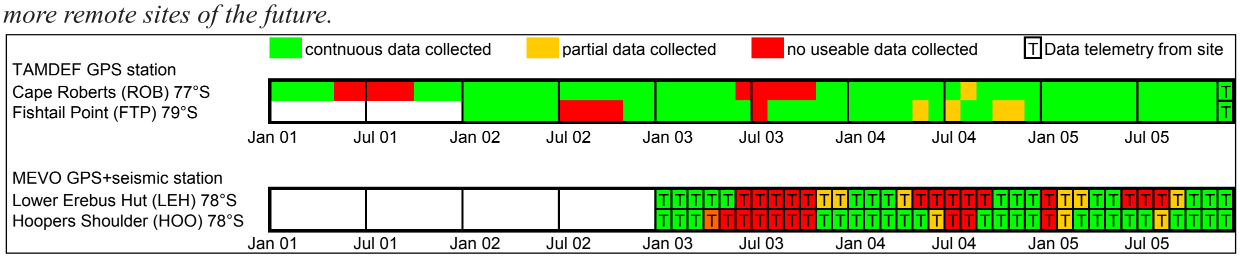


***Table 1**. Operation of TAMDEF (T. Wilson and L. Hothem, PIs) sites (top) at Cape Roberts and Fishtail Point show success in year-round GPS operation using low power GPS receivers (2.5W), solar charging, and a large battery bank for sustained winter operation. Radio (ROB) and satellite (FTP) data links were added to the sites in late 2005 for automated data retrieval to the UNAVCO archive. MEVO (Aster et al, 2004) continuous operation of GPS, broadband seismic, and data telemetry on Mt. Erebus (bottom) show year-round operation of a higher power system (~10W) using a combination of solar and wind turbine charging and a large battery bank. All stations are within helicopter range of McMurdo Station, allowing for more installation visits and heavier payloads than possible for more remote sites of the future.*



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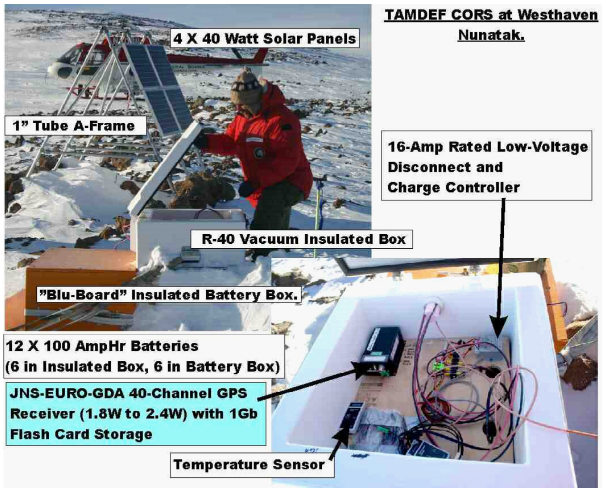

***Figure 9**. TAMDEF continuous station at Westhaven Nunatak, Courtesy of Mike Willis, Ohio State University.*

b) Achieve dependable state-of-health (SOH) monitoring and data transfer of 1 Mb/day using low power (see below).

c) Attain continuous, year-round station operation, including low-bandwidth data transfer.

d) Improve communication bandwidth for data transfer and support higher-power systems using new technologies.

While the immediate effort will serve the community need for instrument systems to be deployed during the International Polar Year (IPY; 2007-2009), it is also intended to initiate a continuous process of developing and supporting state-of-the-art in autonomous remote station operations as power and communications technologies evolve. Effort beyond the duration of this proposal will be included within the scope of IRIS' and UNAVCO's on-going and future support to NSF. Table 2 provides a comparison between current proven operating practices and what will be achieved with the new power/communications system. The system will be designed specifically for GPS and seismic needs, but we note that it may also serve other users with similar data and power needs.

A similar MRI effort is in progress, entitled "D*evelopment of an Autonomous Real-time Remote Observatory" (ARRO)* (Lessard 2005), but that initiative is fundamentally different from our proposed effort in that it addresses power (50W) and communication (20Mb/day) challenges an order of magnitude larger than we require, with a corresponding tenfold increase in deployment logistics unrealistic for the future deployments we envision. However, there are synergies between the ARRO MRI and our proposed effort, particularly in areas related to Iridium communications and wind

***Table 2**. The MRI will build on a decade of experience with autonomous station technology in Antarctica to achieve the next step of reliable, modularized stations*

Technology proven in Antarctica	**Advances to be achieved through this MRI effort**
Quasi-continuous and logistics-intensive GPS and seismic data collection	Reliable year-round data collection, minimizing logistical cost of installation, operation, and maintenance; "plug-and-play" deployment
Geodetic GPS receivers	Selection of next generation GPS receivers (low power, high memory, remote controllable, robust power management)
Seismic sensors and datalogger	Develop cold sensor testing and harden data recording system
Line of sight radio links	Higher bandwidth technology, flyover data retrieval
Solar power	Standard components, and improve ease of field deployment
Power control components	Integrated, robust power controller packages
Iridium satellite data modems, intermittent operation	Robust and efficient Iridium data retrieval, sensor-communications integration
Wind turbines with highly variable success	Select already proven units, test and optimize for different environmental conditions
Sealed lead acid batteries	Optimal battery selection, quantified extreme cold performance, lithium battery backup

Table 3. *Technical requirements. Lower power consumption is a critical design specification, and data requirements are defined to meet science needs described in the Research Activities section and take advantage of proven communication and storage technology.*

Operating Mode	Allowable power use	Data telemetry requirement	Data storage Requirement
GPS data collection	2.5W	1Mb/day average	27 months = 830Mb
Seismic data collection	2W	1Mb/day (SOH and events) 15Mb/day average (full data retrieval)	27 months =12Gb
Satellite data link (NAL Resesarch Iridium)	1W/Mb	>2Mb/day	na
Radio data link (FreeWave 900MHz)	0.5W/Mb	>16Mb/day	na
Housekeeping overhead	0.5-1W	na	na
Lowest power configuration (single sensor, no winter data comms)	2.5W year-round	1Mb/day average, store-and-forward	Up to 12Gb
Combined GPS and seismic (with low bandwidth link)	7W year-round	2Mb/day average, store-and-forward	830 Mb + 12 Gb
Highest power configuration (combined sensors, year-round large data volume comms)	10.5W year-round	2Mb/day year-round	830 Mb + 12 Gb

turbine application. The ARRO PIs have expressed enthusiasm to collaborate with us and to allow us to build upon their work. (M. Lessard, pers.comm.).

2. Technical Requirements

The design requirements (Table 3) for the power/communication system were established at two meetings (Antarctic Remote Observatories (UNAVCO, 2004), and Antarctic Seismic and GPS Technologies, Challenges, and Opportunities (Washington D.C., 2005)), and by an ad-hoc working group consisting of facility and science community members.

3. Power System

A reliable power system, capable of providing 2.5W to 10.5W continuous, is necessary to provide the data sets required to meet the desired scientific objectives. Solar charging is not possible for four to six months of the year, extreme winter cold significantly reduces battery capacity (Fig. 9), and aircraft cargo limitations (as well as limited aircraft availability) prohibit deploying sufficiently large sealed lead acid (SLA) battery banks for year-round operation at remote sites. We will develop a system that can withstand the Antarctic environment and can be deployed with just two De Havilland Twin Otter or Bell 212 helicopter flights. This will require keeping the entire system weight, dominated by the power system, to under 1500 lbs (see 6. Logistics). System design will also feature a single visit "summer-only" deployment option (where the system either recovers gracefully from the winter power loss or uses lithium primary batteries for winter power) with potential to upgrade to full capability systems on the next visit. We propose four specific activities that will result in reliable year-round power at a practical weight budget:

a) Choose the best performance components. Basic solar/SLA systems (Figs. 9 and 10) will be based on quantitative comparisons rather than anecdotal evidence. This includes cold chamber environmental testing and performance comparison of different battery types (eg. gel cell, absorbed glass mat) and power control systems from different manufacturers at temperatures that are often off the manufacturer's performance curves.

b) Adopt primary (on-demand) lithium batteries. Lithium batteries promise a roughly 15 fold increase in energy density compared to SLA

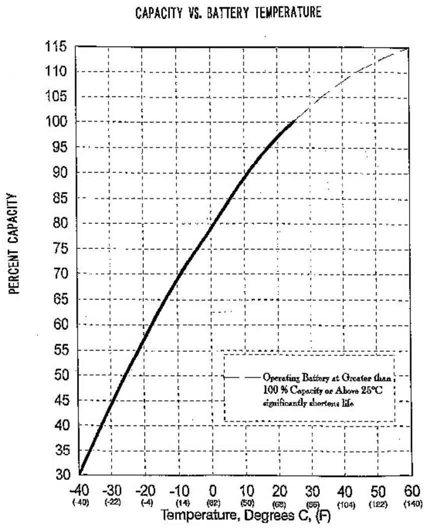

Figure 8 SLA battery performance curve from Concorde Batteries.

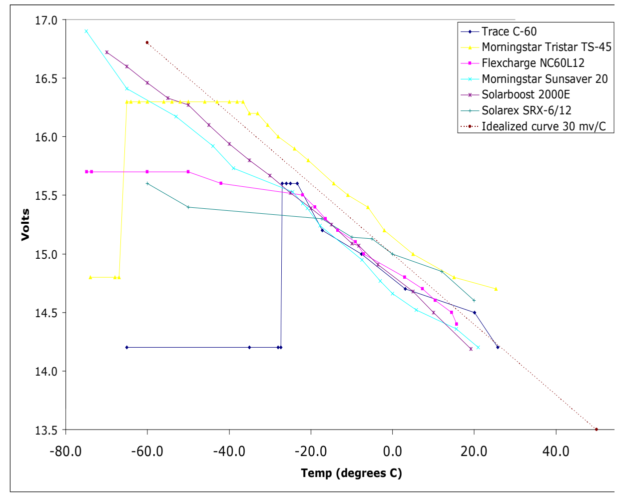

***Figure 10**. Cold chamber tests of commercially available charge controllers "cold qualifies" the units with the best performance below -20C. Courtesy of Bill McIntosh, New Mexico Tech.*

technology at -30°C (Tadiran, Saft manufacturer literature). These can be cost effective for deployment scenarios where their use in the power system reduces the need for additional flights, in spite of their higher cost and one-time use. We will test COTS units for performance and suitability, integrate primary batteries into the power system design, and demonstrate use at a field prototype site. We envision lithium batteries as a necessary component in the suite of power system options available from IRIS and UNAVCO, while recognizing that their cost-effectiveness will be determined on a case-by-case basis based on logistics, impact of data loss, and intended lifespan of the data collection effort.

c) Select, test, and deploy reliable wind turbines. Individual projects have demonstrated success with wind turbines (Table 4) as a source of year-round power generation, yet the challenges in deploying reliable small (<1KW) units have not yet been solved for more general applications. Polar specific problems include mechanical damage from extremely strong winds at some mountain and coastal locations, lack of wind on the Polar Plateau, and mechanical ceasing and misbalancing from rime ice. The moving parts add complexity, and in extreme cold special grease and custom bearings must be used. We will review the wind turbine experience of the current *Development of an Autonomous Real-time Remote Observatory* MRI (Lessard 2005) effort for polar plateau applications, build upon the considerable horizontal and vertical axis wind turbine experience gained through the recent MRI effort "*Development of Integrated Seismic, Geodetic and Volcanic Gas Surveillance Instrumentation for Volcanic Research*" (Kyle and Aster 2001), and apply experiences of OPP logisitics contractors Veco Polar Resources and Raytheon Polar Services.

Two models will be selected – one for Polar Plateau low wind speed applications, and one for severe coastal weather conditions. Both will be tested and integrated for satisfactory operation with our power system, including winter high wind evaluation at the University of Colorado Mountain Research Station at Niwot Ridge (Fig. 11). We expect to deploy both models in Antarctica in Year 2 to provide power for year-round system operation.

***Table 4.** Examples of small wind turbines with successful Antarctic applications.*

Manufacturer and model	Location used (user)
Windside WS-015B Vertical Axis	TAM (JPL), McMurdo (RPSC), Mt. Erebus (MEVO)
Ampair Pacific 100 Horizontal Axis	Mt. Erebus (MEVO)
Forgen 500	Peninsula (British Antarctic Survey)

d) Develop a robust system controller specific for this application. A system controller will be designed and fabricated based on the requirements approved at the preliminary design review. This controller will integrate the data handling, charge control, power management, system housekeeping, thermal monitoring (and control if needed), autonomous system reset, and report system SOH via the communication device. The goal is to design this controller to be extremely low-power, electrostatic-discharge resistant, and ruggedized for field handling. Field-proven COTS components (such as FlexCharge or Morningstar charge regulators) and existing custom devices (such as the power controller used by the Alaska Volcano Observatory for their seismic array, the system microcontroller used in JPL Transanarctic Mountains (TAM) GPS sites, and the SOH monitoring system used by MEVO) will be considered in the new design. We will seek a commerical provider to design and fabricate the custom electronics.

4. Communication System

Communication systems are indispensable to minimize site visits, an essential requirement for long-duration deployment of instruments at very remote sites. First-hand experience has shown the benefits of quasi-real time data communications in terms of scientific productivity, station maintenance and troubleshooting, overall data availability and quality, and the streamlining of downstream data quality control and processing. In addition, there are some scientific objectives and monitoring functions of remote observatories (such as earthquake and tsunami hazards, GPS-meteorology) that require real-time telemetry of data. Communication with the sensors will utilize standard serial and IP protocols for raw data retrieval and SOH information such as system voltages, current draws, temperatures, etc.

Full GPS data transfer (30 second logging rate) requires 1Mb/day of bandwidth and is well within the capabilities of both 900MHz spread spectrum radios and Iridium satellite data modems. As a result, full data communication solutions will be standard for all GPS deployments. Site specific designs will allow for options including winter power saving (deferred data transfer) mode, minimal latency (hourly data file retrieval), and secondary data logging for high rate data too voluminous for transfer.

Continuous seismic data, due to its much greater volume, will be archived on site and retrieved during maintenance visits or flyovers. Up to 1 Mb per day of event-based data and SOH information will be transmitted as part of the standard Iridium-based configuration. This configuration assures the retrieval of valuable event-based seismic data (using a standard STA/LTA triggering algorithm) and station SOH in near-real time, while providing on-site storage and backup of the compete continuous data stream. We will also apply high-bandwidth radio communications options such as WiMax (currently capable of 10's of Mbps/second transfer rates; e.g. www.wimax.com) to facilitate seismic data downloads from low-flying aircraft. At presently available rates (e.g. 45 Mbps), 12 months (approximately 5.5 Gbytes) of continuous seismic data could be retrieved in approximately 16 minutes without landing in years where ground-based maintenance is not scheduled.

A three-tiered approach for data retrieval and command-and-control will be adopted as follows:

a. Radio modems/radio repeaters will be used to connect directly to the Internet via LAN where the sites are close to permanent research stations or communication nodes.

b. If the distance to an Internet node exceeds the distance capability of radio modems, then a commercial Iridium satellite-based connection will be used for GPS, SOH, limited seismic data retrieval, and system control.

c. Onboard memory will serve as backup in the event of loss of the communication link or inadequate bandwidth on the link, allowing for manual data retrieval during the next maintenance visit or opportunity visits. Fly-over data downloads for seismic data using high speed radio modems will also be possible at sites where it is undesirable to land.

We will integrate Iridium satellite data modems with sensor hardware, combine data streams from multiple acquisition systems (GPS, seismic, met, SOH, etc.) over a common data link, address system performance limitations in extreme cold conditions with passive thermal management, and develop software to handle automated data retrieval with very low bandwidth (~2400bps), large latency, and frequent dropped connections. This design effort will also optimize transmission protocols

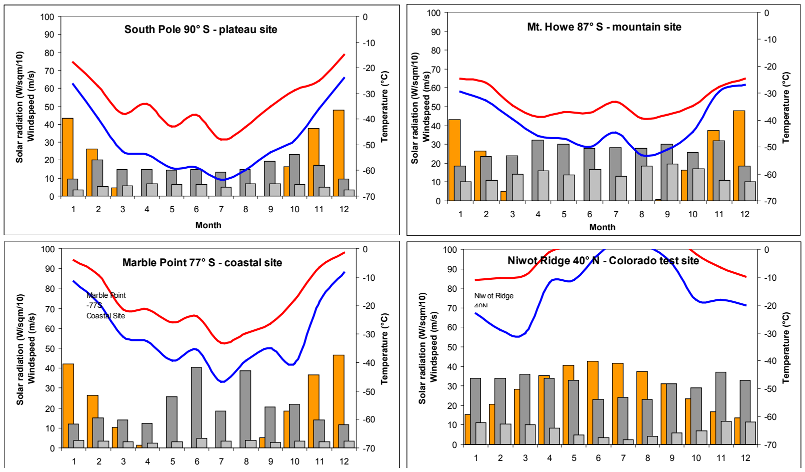

Figure 12. The extreme Antarctic environmental conditions must be addressed in reliable system designs. Typical weather conditions at plateau, mountain, and coastal sites are shown, along with the Colorado Niwot Ridge test site for comparison. Data includes monthly average (red) and minimum (blue) temperatures, solar radiation (orange), monthly average wind (light grey), and peak wind (dark grey).

(e.g. direct serial connections, Short Burst Data (SBD)) to reduce system up time and overall power consumption without sacrificing system reliability. NAL Research, the commercial provider of Iridium data modems, offers custom firmware options that may be applied to this effort.

UNAVCO uses FreeWave radio links worldwide including Antarctica, and they are universally accepted as robust field units in the most extreme environments including the JPL TAM sites and the MEVO Erebus Network (Table 1). UNAVCO is currently downloading full GPS data from three remote Antarctic sites: via Iridium as a proof-of-concept from TAMDEF site Fishtail Point (79° S), and via radio and repeater from TAMDEF sites Mt. Fleming(78° S) and Cape Roberts (77° S).

5. Environmental Considerations

The proposed system development will achieve the efficiency of standardization while allowing flexibility for site specific temperature and wind conditions by adopting a minimal, but necessary, variation of field systems tailored for the different environmental conditions of the Antarctic continent (Fig. 12). The systems will be designed for ease of field installation in a hostile environment with a limited time budget and little contingency for extra time on-site.

We will provide two thermal designs, for "plateau" extreme cold and the milder "margin" temperatures. Enclosures will be selected to ensure that adequate operating temperatures are maintained for the equipment - both cold and overheating can be problems. A system designed to maintain an operating environment of -20°C in ambient surface temperatures as low as -80°C (polar plateau winters) may overheat if deployed to a coastal environment where summer temperatures may reach +10°C. Basic West Antarctica and coastal margins environmental enclosures will be deployed near McMurdo Station for evaluation. The plateau system, built to accommodate the colder polar plateau environment, will be deployed at the South Pole station for evaluation. Enclosure insulation allows the heat produced by the instrument package, power and communication systems to be retained to keep components within their operational temperature limits (passive thermal management). The added complexity of active thermal management will be carefully considered for applications such as providing graceful startup in case of winter shut-down and cold soaking. Thermal analyses of both evacuated chamber (vacuum) insulation boxes and foam insulated boxes will be performed, and all prototype sites will include internal and external temperature collection for follow on engineering analyses. Enclosures will be custom made to specification to ensure both ease of use and thermal efficiency.

We will also apply separate design criteria for wind loading of mountain and coastal sites vs. the calmer plateau sites. Standard design will be for windspeeds up to 100 kts and 70 kts, respectively, and options for additional wind hardening will be available for sites where conditions exceed these specifications. Where meteorological data exist from services such as the Antarctic Meteorological Research Center (amrc.ssec.wisc.edu) they will be used to ensure the correct system options are applied.

6. Logistics

The major goal of this effort is to develop a system specifically for light aircraft deployment with the minimum number of missions and minimum amount of required installation time. Development will be tailored to the available logistical support within the USAP. In order to be deployable, the systems must be able to meet the following logistical criteria:

a) Light aircraft deployable design (compatible with Bell 212 helicopter, Twin Otter fixed-wing aircraft), <1500 lbs total system weight*.

b) Individual modules weighing less than 100 lbs (2 person handling).

c) Designed for two year minimum service interval.

d) Optimized for three person field teams.

e) Designed for minimal field wiring.

f) Designed to minimize fieldwork with simple status checks, component swaps, etc.

g) Compatible with "near year-round" operation in case delivering a year-round power system is not practical.

h) Avoid air-transport-restricted materials.

*We assume conservative Twin Otter allowable cargo load (ACL) of 1500 lbs, two flights, 1200lbs allotted for passengers and 300lbs for tools.

7. Testing

All systems will be designed, tested and deployed through a methodical process to ensure that final field systems are mature. We propose a staged testing and qualification process:

a) Low temperature functionality testing will be performed at the PASSCAL and UNAVCO environmental chambers which allow for up to 3'x3'x3' items to be operated as low as -70°C. This will allow testing of individual components at expected polar ambient temperatures. Full integration testing will occur at prototype test sites near the PASSCAL and UNAVCO facilities to ensure that these systems work from end-to-end prior to deployment.

b) Test-bed sites will be set up at McMurdo Station and at South Pole Station to allow year-round testing in actual conditions while still allowing real-time communications via Internet and technical support from the local science technician if required. These sites speed up the design, testing, and validation process without requiring substantial logistical support, and will serve as test platforms before incorporating new technologies to future operational network sites. UNAVCO already deploys staff to McMurdo during the summer for field support activities, and IRIS deploys staff to South Pole for Global Seismic Network (GSN) activities.

c) Prototype systems will be installed at accessible field locations of scientific interest and evaluated under true field conditions. The data collected will be relevant to on-going and planned projects.

d) Ten units will be provided as a new polar instrument pool for science community use beginning with the 2007 field season. These will provide support for IPY science projects as well as other funded efforts in the GPS and seismology programs, and will provide extensive testing in a range of different environments by different users. Valuable data on reliability and ease of deployment will be obtained, analyzed and applied in the development process.

e) Finally, we propose to build an 11W system to demonstrate the capability of scaling up basic systems to provide power and communications to joint, multi-sensor seismic and geodetic deployments.

Further details on the timeline and milestones for design, integration and testing of system components are provided in section D3. Important details about specific equipment to be purchased or manufactured are provided in the budget notes, along with a breakdown of the workloads for all aspects of the design, integration and testing phases.

C. IMPACT OF INFRASTRUCTURE PROJECTS

1. Next-Generation Infrastructure for Polar Geodetic and Seismic Measurements

a) Resources for the Polar Geoscience Community.

A new capability for continuous, year-round seismic and geodetic measurements at remote sites will meet longstanding polar and global geoscience goals that have previously been unattainable. With the ability to deploy observatory systems optimized for light aircraft to the interior of Antarctica and other remote polar settings, the community will have an opportunity to achieve systems-scale observations for the first time. Current and new science teams will have access to both a pool of systems available from UNAVCO and IRIS and the documentation for building state-of-the-art observatory systems for their experiments. Faculty, postdoctoral researchers, graduate and undergraduate students at academic institutions actively conducting polar research will be involved in the science experiments to be carried out with the new instrumentation, including field deployment and analysis of data telemetered from remote field sites.

b) Capacity-building: Reduced barriers to Entry for New Polar Geoscientists.

This MRI will provide a robust, standardized power and communications package optimized for polar research that is fully supportable by the IRIS and UNAVCO facilities, from procurement through data management. Access to these polar observatory systems through UNAVCO and IRIS polar support will open doors for scientists and institutions that do not have the technical and field skills currently required to execute remote polar GPS and seismic research projects, and will stimulate participation by a new generation of researchers.

c) Building Global Infrastructure and Partnerships.

This MRI initiative is intended to both develop a long-term geophysical measurement capability for extreme polar environments and to support the imminent need for observatory systems designed for remote polar deployments during the International Polar Year (IPY 2007-2009; see www.ipy.org). Numerous geodetic and seismic science programs have been proposed in both Arctic and Antarctic regions for the IPY, and these activities will be coordinated under a designated 'IPY core activity' called POLENET: Polar Earth Observing Network (see:www.ipy.org/development/eoi/proposal-details.php?id=185). The POLENET program, which currently includes scientists from 24 nations, aims to deploy autonomous observatories in the Antarctic and Arctic for a pulse of activity during IPY, and it is anticipated that a subset of these stations will remain in place.

This IPY effort is complementary to national/international programs studying the dynamic Earth, the geoid, and sea-level: e.g., Geonet (Japan, New Zealand), EarthScope (USA), CAGENET (Canada), and ESEAS (European Sea Level Service). The results of an observatory program will bring polar regions into the global geodynamic framework and will allow cutting-edge analysis methods developed in the context of these national programs to be applied to the polar regions. The GPS, seismic and meteorological data envisioned will be used by a global community that extends beyond the traditional polar community.

2. Research Training Activites for Students and Young Scientists.

a) Targeted Undergraduate Internships.

We propose to fund an upper-level undergraduate student to participate in this polar technology project within the structure of an established undergraduate research program called "Research Experiences in Solid Earth Science for Students" (RESESS). The main goal of RESESS is to increase the number of individuals from underrepresented populations who complete Masters' and PhD degrees in solid Earth geoscience through a program of multiple research experiences, mentoring of individuals, and building a learning community of students from underrepresented populations. The program, administered by UNAVCO, also has a strong mentoring and leadership component, a strong evaluation component, and meets the educational goals of UNAVCO and IRIS (see resess.unavco.org). Funding a RESESS student in conjunction with this MRI will be an efficient means of broadening participation because it leverages an established program.

The polar RESESS intern will participate in two 10-week summer internships in consecutive summers in years 2 and 3 of the project. The research experience will focus on the engineering aspects of the project described in this proposal, and the student will be mentored by the UNAVCO project manager and a polar scientist at an academic research institution associated with the project. The intern will also have an experience of living and working with other students from underrepresented populations in science and participate in multidimensional mentoring from writing and communication, community, and peer mentors.

b) Participation of Graduate Students and Young Scientists

Science projects anticipated to use the technology and instrumentation derived from this MRI, including the U.S. component proposed for POLENET for IPY, plan to have graduate students actively involved in their research programs. The international POLENET group plans to develop an exchange program to exploit the tremendous training opportunity that this large multinational consortium provides, including exchange visits by postdoctoral fellows and graduate students for collaborative research. In this way, the consortium will help to build globally-oriented polar scientists.

D. MANAGEMENT PLAN

1. Project Management

The overall leadership of this MRI will be shared between the IRIS and UNAVCO facilities with the Principal Investigators (PIs) David Simpson and Will Prescott (IRIS and UNAVCO, respectively). Dr. Simpson and Dr. Prescott are both PIs on the Earthscope Major Research Equipment and Facilities Constrcution project (www.earthscope.org), with respective responsibility for the seismic (USArray) and GPS (Plate Boundary Observatory) components. These PIs take their authority from their respective consortia Boards of Directors (BoDs). Focused engineering and technical support will be provided by staff at these facilities, and activities that require specialized expertise not appropriate for UNAVCO or IRIS will be subcontracted. The PIs will appoint project managers from the facilities to represent the facilities consortia in the activities of this MRI. Project managers take the technical lead on this MRI and ensure close cooperation between facilities and the community. Personnel management will be provided by the existing facility management structures. Responsibility for overall project coordination, logistical coordination, and for reporting will reside with the UNAVCO Project Manager. Overall project authority and decision making will reside with the UNAVCO PI.

2. Science Oversight Committee

This proposal was developed in cooperation with the Antarctic GPS and seismic research communities, with full consideration of their science requirements. One of the strengths of this proposal is our effort to include knowledge of the technical successes/failures from past field deployments, as well as comprehensive experience with planning and executing Antarctic remote deep-field work, which resides with research communities. To meet the goals of the proposed development effort, a robust means of incorporating this expertise into the ongoing system design and testing work to be carried out by dedicated facility engineers is required. We plan to establish a six member Science Oversight Committee (SOC) that will ensure that the MRI remains well coordinated with the science needs and takes best advantage of existing experience within the community. The SOC will be recommended by the current ad hoc committee (Table 5), many of whom had input on this proposal. The SOC will be approved by, and report to, the IRIS and UNAVCO BoDs. Additional non-voting members include facility project managers and other key contributors as appropriate. The head of this committee will approve prototype siting and will have the final authority to recommend changes in project scope (if required) to NSF. We also recognize the value of this proposal to Arctic researchers and glaciologists not represented here, and we intend to expand representation to the broader Polar community.

SOC meetings at the facilities will include a preliminary design review (June 06), a mid-course design review (February 07), and a final review and follow-on activities planning meeting (March 08). The SOC will also select a Science Coordinator, a funded position that will report to the elected SOC chair and serve as a liaison between the SOC, IRIS, and UNAVCO, via more frequent facility site visits and inclusion in regular progress teleconferences between the facilities. The Science Coordinator (SC) will contribute collective community expertise to the design team so that the design team can concentrate on the engineering details and not on coordinating input from the science/research community. In Year 1 of the effort, the Science Coordinator will prepare a summary of data from the large number of remote instrument deployments performed by science PIs over the last decade, to serve as a 'best practices' baseline to build from in the MRI design process. Through active participation in the design team, and acting as a conduit between the science community and the design team, the Science Coordinator will allow the facility design team to remain focused on their task as well as ensure that the end product meets the needs of the community it is intended for.

3. Facilities

UNAVCO and IRIS already have the data, engineering, and warehousing facilities required for this effort. Location of the project effort at IRIS/

Table 5. *Key community members who have contributed to this proposal effort and will be called upon to form the Science Oversight Committee.*

Sridhar Anandakrishnan, Pennsylvania State University	Philip Kyle, New Mexico Tech
Rick Aster, New Mexico Tech	Bruce Luyendyk, University of Calif., Santa Barbara
Alberto Behar, JPL	Bill McIntosh, New Mexico Tech
Mike Bevis, Ohio State University	Carol Raymond, JPL
Ian Dalziel, University of Texas	Mike Ritzwoller, University of Colorado, Boulder
Andrea Donnellan, JPL	Bob Smalley, University of Memphis
Larry Hothem, USGS	Doug Wiens, Washington University
Andy Nyblade, Pennsylvania State University	Terry Wilson, Ohio State University (acting chair)

PASSCAL (www.passcal.nmt.edu) and UNAVCO (facility.unavco.org) takes advantage of existing system integration capabilities, experience with Antarctic field operations and logistics, lab and field testing facilities, and international and domestic network operations including the NASA GPS Global Network, the IRIS Global Seismic Network, and EarthScope (Plate Boundary Observatory and USArray). The facilities also provide many established vendor relationships, reducing project risk from delayed deliveries of key components. We request the authority to reprogram up to 10% of salary to subcontract tasks not appropriate for the facilities, including board-level electrical engineering design and review, and adopting complex designs (e.g., wind turbines, advanced batteries) that have been field proven by other efforts.

4. Project Milestones

The following are the major milestones to design, integrate, test and deploy power and communication systems, with the end result being provision of complete systems for remote polar geophysical research as part of the UNAVCO and IRIS/PASSCAL equipment pools, in direct support of IPY and future science initiatives.

Year 1 [June 2006 – May 2007]:

a) Prototype sites for development and engineering evaluation installed near UNAVCO and IRIS/PASSCAL facilities [Aug. 2006]

b) Install wind system prototype on Niwot Ridge near Boulder for winter testing [Sept. 2006]

c) Deploy and install McMurdo (GPS+ full data retrieval), South Pole (seismic+advanced battery+state-of-health data retrieval) engineering testbeds [Nov. 2006]

d) Install GPS+data retrieval prototype to continent margin site of scientific interest with dataflow [Dec. 2006]

e) Report on recommended 'best practice' system configuration, provided to science community to implement for IPY installations in 2007-08 [Apr. 2007]

Year 2 [June 2007 – May 2008]:

a) Upgrade McMurdo test site to GPS+Seismic+data retrieval [Nov. 2007]

b) Upgrade South Pole test site to GPS+Seismic+wind+data retrieval [Nov. 2007]

c) Install GPS+wind+data retrieval prototype on Polar Plateau site of scientific interest [Nov. 2007]

d) Basic (no wind or advanced battery technology) systems available for research deployments (such as IPY POLENET), testing and community feedback [Aug. 2007]

e. Update report on "best practice" system [Feb. 2008]

Year 3 [June 2008 – May 2009]:

a) Add seismic and wind to continent margin science site [Nov. 2008]

b) Analysis of data on all prototype and community instrument deployments, identify improvements required for systems [March 2008]

c) Advanced systems (wind, lithium battery capable, but not provided from MRI funding) available for research deployments (such as IPY POLENET), testing and community feedback [Aug. 2008]

d) Upgrade field systems installed in Year 1, 2, for long term autonomous operation (as warranted by funded science initiatives) [Nov. 2008]

e) Capability to install sites to standard, proven configurations [Nov. 2008]

f) Field proven systems, support, data handling, as-built documentation available off-the-shelf from IRIS and UNAVCO [May 2009]

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Budget Justification (UNAVCO):

We provide the following project roll-up budget and Work Breakdown Structure (WBS) as a complete view of this IRIS and UNAVCO collaborative project. This justification specifically addresses the UNAVCO portion.

			Year 1				Year 2				Year 3			
		Basis of	IRIS		UNAVCO		IRIS		UNAVCO		IRIS		UNAVCO	
	Unit cost	Estimate	Qty	Cost($)	Qty	Cost($)	Qty	Cost($)	Qty	Cost($)	Qty	Cost($)	Qty	Cost($)
SALARIES AND WAGES														
Project Management			[redacted]											
Engineering/tech			[redacted]											
Student Intern			[redacted]											
Fringe Benefits			[redacted]											
Total Salaries and Wages				**13688**		**119918**		**14099**		**132457**		**14521**		**139232**
EQUIPMENT														
Cold qualified seismic sensors	$27,000	VQ	2	54000										
Lithium batteries (4500 Ah)	$30,000	VQ												
Socorro, Boulder prototypes	$30,000		1	30000										
McMurdo, South Pole Test-beds	$30,000		1	30000			1	30900						
Field sites	$30,000													
GPS receivers and antennas	$12,000	EXP			2	24000								
Wind turbine high wind (OY Windside)	$10,000	VQ			1	10000								
Wind turbine low wind	$5,000	EXP			1	5000	1	5150	1	5000				
Total Equipment				**114,000**		**39,000**		**36,050**		**5,000**				
MATERIALS AND SUPPLIES														
Bailer memory	$4,000	VQ	2	8000										
Iridium satellite modems (NAL Research A3LA-X)	$1,900	VQ+												
Socorro, Boulder prototypes	$1,900		2	3800	2	3800								
McMurdo, South Pole Test-beds	$1,900						1	1957						
Field sites	$1,900								1	1900				
Science kits	$1,900								5	9500	5	10078		
RF telemetry radios	$1,500	VQ+												
Socorro, Boulder prototypes	$1,500		2	3000	2	3000								
McMurdo, South Pole Test-beds	$1,500		2	3000	2	3000								
Enclosure (custom fabrication)	$4,000	EXP												
Socorro, Boulder prototypes	$4,000		1	4000	1	4000								
McMurdo, South Pole Test-beds	$4,000		1	4000	1	4000								
Field sites	$4,000				1	4000	1	4120	1	4000			1	4000
Science kits	$4,000								5	20000	5	21220		
Solar panels (160W)	$1,000	VQ												
Socorro, Boulder prototypes	$1,000		1	1000	1	1000								
McMurdo, South Pole Test-beds	$1,000		1	1000	1	1000								
Field sites	$1,000				1	1000			1	1000			1	1000
Science kits	$1,000								5	5000	5	5304		
Sealed lead acid batteries (1000Ah)	$1,200	VQ												
Socorro, Boulder prototypes	$1,200		1	1200	1	1200								
McMurdo, South Pole Test-beds	$1,200		1	1200	1	1200								
Field sites	$1,200				1	1200			1	1200				
Science kits	$1,200								5	6000	5	6364	1	1200
Charge controller system	$1,500	EXP												
Socorro, Boulder prototypes	$1,500		2	3000	2	3000	1	1545						
McMurdo, South Pole Test-beds	$1,500		1	1500	1	1500								
Field sites	$1,500				1	1500			1	1500			1	1500
Science kits	$1,500								5	7500	5	7958		
Mounting hardware, cabling	$1,000	EXP												
Socorro, Boulder prototypes	$1,000		1	1000	1	1000								
McMurdo, South Pole Test-beds	$1,000		1	1000	1	1000								
Field sites	$1,000				1	1000			1	1000			1	1000
Science kits	$1,000								5	5000	5	5304		
Computer for indergraduate intern	$2,000								1	2000				
Total materials and supplies				**36700**		**37400**		**7622**		**65600**		**56228**		**8700**
PURCHASED SERVICES														
Shipping between facilities		EXP		300		300		489		500		504		500
Shipping to Port Hueneme		EXP		300		300		979		1000		318		300
Conference calls						2000				2000				2000
Total purchased services				**600**		**2600**		**1468**		**3500**		**822**		**2800**
TRAVEL														
Fac staff - inter-fac mtgs, vendor mtg, deployment	1000	EXP	4	4000	4	4000	4	4120	4	4000	4	4243	4	4000
Student travel	2500								1	2500			1	2500
Advisory committee - 1 meeting/year		EXP				6000		6180						6000
Total travel				**4000**		**10000**		**10300**		**6500**		**4243**		**12500**
SUBAWARDS														
PASSCAL-New Mexico Tech (1 FTE eng/tech, w/overhead/fringe)				106795				106795				106795		
Science Coordinator (w/overhead and fringe)	150000				0.2	30000			0.2	30000			0.2	30000
Science Coordinator Travel - meetings	1500				2	3000			2	3000			2	3000
Education and Outreach - RESESS Program		EXP								8958				9241
Total subawards				**106795**		**33000**		**106795**		**41958**		**106795**		**42241**
INDIRECT COSTS				12969		18774		9296		24847		16472		24086
TOTAL				288,752		260,692		185,630		279,862		199,081		229,559

Basis of Estimate: VQ -Vendor Quote | VQ+ - Vendor quote plus 25% for custom modifications | EXP - Experience with application

Project Work Breakdown Structure

			YR1		YR2		YR3	
Task Name	**WBS**	**Facility**	**IRIS**	**UNAVCO**	**IRIS**	**UNAVCO**	**IRIS**	**UNAVCO**
Project Management	**1.1**	UNAVCO		5		5		5
UNAVCO	1.1.1	UNAVCO						
_management	1.1.1.1	UNAVCO		35		35		35
IRIS	1.1.2	IRIS						
_management	1.1.2.1	IRIS	25		25		25	
Power Systems	1.2	IRIS	5		5		5	
Batteries	1.2.1	IRIS						
_SLA	1.2.1.1	UNAVCO	10	10				
_Lithium	1.2.1.2	IRIS	15		10		10	
Solar	1.2.2	UNAVCO	10	10	5	5	2	2
Wind	1.2.3	UNAVCO						
_Horizontal Axis	1.2.3.1	UNAVCO	5	15	5	25	5	20
_Vertical Axis	1.2.3.2	UNAVCO	5	25	5	20	5	20
Integration	1.2.4	IRIS						
Control systems	1.2.4.1	IRIS	15	5	5	5	5	5
Physical integration	1.2.4.2	IRIS	15	15	13	15	15	15
Vendor travel	1.2.5	Joint	3	3	3	3	3	3
Communications	1.3	UNAVCO		5		5		5
Low Bandwidth	1.3.1	UNAVCO						
_Iridium	1.3.1.1	UNAVCO	5	40	5	25	5	20
High Bandwidth	1.3.2	IRIS						
_Iridium	1.3.2.1	IRIS	10		10		10	
_LOS	1.3.2.2	IRIS						
__continuous (direct)	1.3.2.2.1	IRIS	10	5	5	5	5	
__batching (flyover)	1.3.2.2.2	IRIS	15		15		20	
Integration	1.3.3	Joint	10	15	15	15	10	5
Vendor travel	1.2.5	Joint	3	3	3	3	3	3
Enclosures	1.4	IRIS	5		5		5	
Vacuum insulated	1.4.1	IRIS	10		5		5	
Foam insulated	1.4.2	UNAVCO	5	10	5	5	5	5
Integration and local testing	1.5	Joint	5	5	5	5	5	5
Interconnects	1.5.1	Joint	5	5	5	5	5	5
Modularity-scaling	1.5.2	Joint	5	5	5	5	5	5
Prototype fabrication	1.5.3							
_Seismic	1.5.3.1	IRIS	20		20			
_Geodetic	1.5.3.2	UNAVCO		25		25		
_Multi sensor experiment	1.5.3.3	Joint			10	10	10	10
Alpha-version Kits	1.5.4	UNAVCO						
_design	1.5.4.1	Joint			5	5	5	5
_fabrication	1.5.4.2	Joint			5	5	5	5
Inter-facility shipping	1.5.5		5	5	5	5	5	5
Deployment (Note 1)	1.6	UNAVCO		10		15		15
Testbeds	1.6.1							
_McMurdo	1.6.1.1	UNAVCO	17	20	17	20		
_South Pole	1.6.1.2	IRIS	10	10	10	10		
Prototypes	1.6.2							
_Plateau	1.6.2.1	UNAVCO				10		25
_Margin	1.6.2.2	UNAVCO	5	5		5	20	5
_Science kits	1.6.2.3	Joint			15	20	20	15
Data Management	1.7	IRIS	5		5		5	
Engineering Data	1.7.1		8	10	10	10	20	20
documentation	1.7.2		5	5	5	5	12	12
Science Data	1.7.3		5	15	10	15	15	15
Total FTE:			1.1	1.284	1.1	1.384	1.1	1.16
Notes:								
1. First field task includes 2 week travel and 1 week orientation/prep at McMurdo								

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Salaries and Wages: The Work Breakdown Structure (WBS) provides an overview of the specific project tasks that will performed. The lead responsibility for key tasks is explicitly assigned to either IRIS or UNAVCO to facilitate efficient use of the engineering staff. However, the expertise of both organizations will be tapped for most tasks and coordinated by the cognizant manager. The WBS shows that the UNAVCO project effort is above 1.1 FTE each year – the additional staff time will be provided from existing UNAVCO resources for support to NSF-OPP.

Project management: 0.1 FTE is requested for Bjorn Johns, UNAVCO Polar Services Manager, who will oversee the UNAVCO contribution to this effort and serve as the overall project manager, point of contact, and logistical coordinator. This position will frequently communicate with project collaborators and is responsible that the stated work remains well coordinated with related activities.

Project engineering: 1.0 FTE is requested for a project engineer. This position will be dedicated full time to this effort and will report directly to Mr. Johns. The incumbent will have a solid engineering background (advanced degree desired), good technical skills for fabrication activities, and relevant field experience from Antarctica. The scope of this effort (development, testing, prototyping, field deployments, and documentation) will require full time attention.

Equipment:
a)The acquisition of two GPS systems (one with a Dorne Margolin choke ring antenna for the continent margin prototype) is included in this proposal to support the integration and prototyping effort. Qualified receivers will be tested at UNAVCO. Upon successful testing and field qualification, additional GPS receivers will be acquired under the regular NSF-OPP support funding to UNAVCO for PI Project Support.
b) One high speed and one low speed wind turbine will be purchased for testing in Colorado and deployment in Antarctica. A second low speed unit will remain at the local Colorado prototype site to accommodate additional testing and integration activities.

Materials and supplies: These items are low cost materials and supplies (<$5,000) and include the following:
a) Iridium data modems and line-of-sight radio modems will be purchased for the local prototype, test-bed, field prototype demonstration sites, and the 10 science kits. The budget allows some flexibility for custom firmware options that may be applied to this effort. The exact breakdown between Iridium and radio modems will vary depending on specific locations. Iridium services charges will be provided as logistical support from OPP.
b) Enclosures will be fabricated by commercial vendors to accommodate our specific thermal size, and interconnect requirements. Budgeted cost allows for the more expensive vacuum insulated technology as well as foam insulated metal and plastic enclosures.
c) Power systems include standard batteries (sealed lead acid) and solar panels, and custom system controllers that will be designed specifically for project requirements.
d) Cable and mounting hardware include cables, connectors, and construction materials to build solar panel frames.
e) 10 "science systems" for deployment in Year 2 and 3. These are additions to what the facilities would normally support in yearly field efforts. This will allow IPY specific experiments to also contribute to this MRI. Engineering data from these test systems will be collected by the individual PIs and reported to the Science Coordinator for distribution to the facilities.

Purchased Services: Purchased services includes 1) the costs of shipping items between facilities, for integration testing and distribution of shared infrastructure, 2) for shipping to Port Hueneme, CA for deployment to Antarctica and 3) conference calls for regular inter-facility and Science Coordinator meetings.

Travel:
Three trips per year are budgeted for collaboration between IRIS, UNAVCO and the scientific community, and to coordinate with vendors on component design and integration. UNAVCO will also host the scientific advisory committee meetings in Year 1 and 3.

Subawards:
A subaward is included for the Science Coordinator position described in the Management Plan. Part-time salary funds (0.2 FTE) are requested to the explicit responsibilities and deliverable associated with this position. Three domestic trips per year are also included for site visits. The amount budgeted is padded to include institution overhead and fringe.

Education and Outreach is included in Year 2 and 3 to leverage the RESESS intern program for underrepresented undergraduate participation. Costs include a student stipend, a subcontract to the UCAR SOARS Program, travel costs, and a computer. Evaluation and UNAVCO administration of the project including recruitment, staff travel, and publications are at no cost to this project. The subcontract to UCAR/SOARS includes housing, a percent of administration of SOARS, a 9 week writing seminar and a one week leadership seminar.

Budget Justification
IRIS Consortium
For
Collaborative Proposal: Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica

Submitted under program announcement # NSF-05-515
To
NSF EAR – Major Research Instrumentation
1/26/06

IRIS Consortium is pleased to provide its cost proposal to NSF for the Collaborative Proposal between UNAVCO and IRIS: Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica. The project period of performance is June 1, 2006, through May 31, 2009. The budget is therefore estimated for three years. Cost estimates are based on cost research conducted during the preparation of this cost proposal, and draw on our several years' experience implementing similar other NSF funded projects.

Several of these budget items are linked between UNAVCO and IRIS as they involve integration and associated communications between the two facilities and the scientific community.

The following provides a detailed justification for the line items presented in the attached budget. Escalation is budgeted annually at 3.0% for all direct costs except subawards.

A. Salaries and Wages ($30,881)

Salaries and Wages are budgeted to cover the cost of overall project management of the IRIS side of the MRI. It is based on the estimated time required by the task leader (Kent Anderson) at 10% of the FTE at his current pay rate. As this position requires very frequent communication with the collaborators on this MRI, the workload is expected to remain constant throughout the MRI.

B. Fringe Benefits ($11,426)

Fringe benefits have been budgeted at 37% of total salaries. Fringe benefits include: health-related insurance (major medical, hospitalization, dental), employer retirement contribution, life insurance, long-term disability insurance, accidental death and dismemberment insurance, educational and training benefits, employer contribution for Social Security and unemployment insurance, and workmen's compensation.

C. Equipment ($150,050)

Equipment purchases valued > $5,000/unit cost are budgeted here. This includes two special cold-rated Guralp 3T broadband seismometers ($27,000 per unit) needed to test the power/communications system at ambient temperatures on the polar plateau (~ - 55 C during the winter). Current facilities pool instruments are limited in their lower operating temperatures (~ -25 C) and cannot withstand the extreme temperatures expected during plateau deployments (~ -55 C). The seismometers required for testing the power/communications system at high elevations (plateau sites) will need to be procured as a part of this

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MRI. Seismometers to test the power/communications system at lower elevations (i.e., West Antarctica) will be provided by the PASSCAL instrument facility and will require no charge to the MRI. Data loggers (data acquisition systems) will also be provided from the PASSCAL instrument pool and require no charge to the MRI. The data loggers are rated by the manufacturer to operate at temperatures as low as -55 C.

We also propose three advanced lithium battery packs ($90,900) required to provide continuous power through the Antarctic winter. The primary charging system of the MRI design will be solar and wind. However, during the Antarctic winter, solar is not available and wind may not be adequate. The lithium battery packs are one-time use power sources that will extend operations through the winter months and provide a continuous seismic record during time of darkness and inaccessibility. Of the three, one will be used for testing and monitoring at the PASSCAL instrument center, one will be deployed at the South Pole test bed during Year 1, and the third will remain for replacing or upgrading the South Pole test bed as necessary in Year 2 or Year 3 (depending on first winter performance of the first deployed systems).

One low speed Wind Turbine ($5,150) is proposed in Year 2 for testing of the charging system at the South Pole test bed (test in plateau environment).

Basis of estimate for all equipment are vendor quotations.

D. Travel ($18,543)

These costs are budgeted to support travel required for the collaboration between IRIS, UNAVCO and the scientific community. Three trips per year are scheduled for meetings between UNAVCO and IRIS and coordination with vendors on component design and integration ($7,727). IRIS will host the scientific advisory committee meeting in Year 2 ($6,180) that will bring the committee and UNAVCO personnel to the PASSCAL facility for the second year project review. This item also includes an estimate of costs associated with the deployment of the test bed at the South Pole (Antarctic travel) ($4,636). Basis of costs are experience on recent domestic and foreign travel.

E. Materials and Supplies ($100,550)

Materials and Supplies are consumable items valued < $5,000/unit cost and include the following:

a. Cable sets ($7,300) – interconnects and cable/connectors to facilitate power and communications transfer between components. These will be used at various test sites.

b. Communications – These include four RF radios ($6,000) to test line of site data transmission of the high bandwidth data, and to provide the possibility of down loading data via a "flyover" when landing an aircraft at the remote site is not practical or safe. Eight Iridium satellite communication systems ($15,837) will also be procured to allow integration into the system and provide for low bandwidth communications (state-of-health and event data).

c. Power Systems ($30,073) – These include batteries (standard sealed lead acid photo voltaic (PV) batteries) for summer operations and will be installed at the various test beds. These systems also include the procurement of PV panels and charge controlling boards, which may be procured or designed.

d. Enclosures ($33,340) – These will be specifically designed by commercial vendors to accommodate our specific thermal and interconnect requirements using COTS evacuated enclosures. These will be used at all test beds and will be a part of the vendor kits.

e. Miscellaneous – Bailer memory ($8,000) will be required to augment the PASSCAL contributed data acquisition systems to allow them to operate in the cold environment. Again, the basic unit will be provided at no charge to the MRI, but these will need to be outfitted with specifically designed long term memory that are not a current part of the PASSCAL pool.

Basis of estimate for all materials and supplies are vendor quotations.

F. Subawards ($365,985)

Work on the engineering and technical side of the IRIS proposal will be performed by the field engineering staff at New Mexico Tech as a supplement to the PASSCAL instrument subaward. The budget includes fringe and overhead charged by NMT. Work will be the equivalent of one full time engineer (senior field technician). Basis of estimate is quotation from NMT.

G. Other Direct Costs ($2,890)

We have budgeted expected costs of shipping items between facilities (UNAVCO and IRIS) for integration testing and distribution of shared infrastructure. This also includes costs estimates for shipping to Port Hueneme, CA for deployment to the Antarctic. Costs are based on recent shipping experience.

H. Indirect Cost Rates: ($40,769)

As per IRIS' Negotiated Indirect Cost Rate Agreement (NICRA) IRIS' current budgeted indirect cost rates are as follows:

- Overhead: This is calculated on Washington, DC and Seattle, Washington employee salaries. As our staff in this proposal is based in New Mexico overhead is not assessed in this budget.
- G&A: 17.0% Base: Salaries, Fringe, Overhead, Travel, Materials & Supplies, the first $25,000 of a subaward each year, Other Direct Costs.

IRIS' NICRA for FY06 is currently in review status with NSF.