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

Year 2 [1 Oct 2007 – 30 September 2008] progress report

1. 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. This project is developing 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.

New technological achievements in GPS receivers and seismometers make it possible to use off-the-shelf units for autonomous recording in polar regions, and we are developing power and communication systems to permit year-round autonomous station operation. In this development effort, IRIS and UNAVCO are teaming with the Antarctic GPS and seismology scientists 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 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 multiyear operation in severe polar environments; and 2) provide an initial pool of these systems for deployment and testing in science experiments. This progress report provides a summary of the Year 2 UNAVCO effort, along with an updated summary from the Year 1 work.

2. Year 1 Major Milestones and status update:

A) Prototype site for development and engineering evaluation installed near UNAVCO

Installed prior to the Year 1 Antarctic field season at Marshall Colorado, south of Boulder, the polar remote station test bed provides a secure and accessible area where a wide variety of systems and components can be field tested for prolonged periods of time (Figure 1).

The Minna Bluff prototype GPS-Iridium system (a new configuration) was tested here to monitor long term performance. Iridium short-burst data and wind turbine testing was performed at the site. The Iggy Ridge MRI prototype system also underwent burn-in testing here prior to deployment. In August 2007 a new system was deployed based on the Year 1 MRI design to allow a local development site of the same configuration as current field system kits. Tests at this station have included improved configurations for the GPS receiver and Iridium modem, a new Iridium antenna, and optimized Iridium data download techniques.

Further details on testing at Marshall:
http://facility.unavco.org/project_support/polar/remote/test.html

(a) (b)

Figure 1. (a) System DVEL at Marshall, Colorado testbed site.
(b) Burn-in testing of MRI prototype system IGGY (left).

B) Install wind system prototype on Niwot Ridge for winter testing

Niwot Ridge provides a unique alpine proving ground on the continental divide above Boulder, and is exposed to severe (80mph+ gusts) winds, drifting snow, rime icing, and spindrift (Figure 2). Installed in August 2006, the frame and enclosure set-up is a preliminary design, and the field installation highlighted several needed changes that have been incorporated in field kits. This system continues to serve as a wind turbine test site, and the system electronics were updated in September 2007 to match the current MRI best practices design, i.e. a POLENET system with Iridium data retrieval. The intent is to not disturb this site unless there is a problem, when it would become a backyard “failure analysis” opportunity

For a chronology of testing at Niwot Ridge:
http://facility.unavco.org/project_support/polar/remote/test.html
State of health data for station NIWT:
http://facility.unavco.org/project_support/polar/remote/SOH/

(a) (b)

Figure 2. (a) Upgrading site NIWT to POLENET configuration (summer conditions); (b) Winter conditions at the Niwot Ridge.

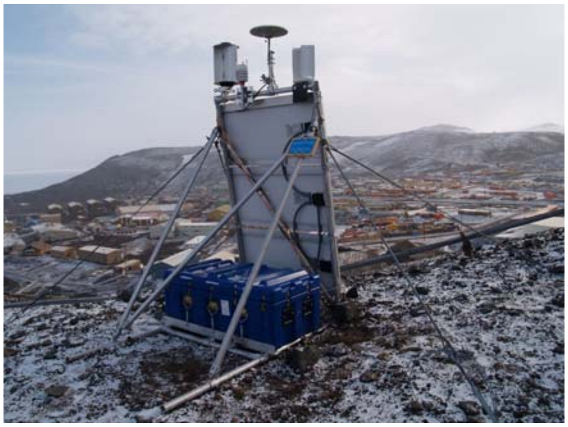
C) Install McMurdo (GPS+ full data retrieval) engineering testbed

The UNAVCO McMurdo test facility was installed in summer 2005-06. This system serves a dual purpose of advanced component testing and acquisition of engineering data on power system performance. GPS data from this site is downloaded daily and archived at UNAVCO.

In summer 2006-07, it was fitted with a Trimble NetRS system utilizing point-to-point Ethernet radio communications to McMurdo Station, along with two wind turbines and a weather station (Figure 3). Eleven channels of engineering data were also recorded and yielded a valuable quantitative history of system behavior during winter shutdown and spring startup.

In summer 2007-08 the station was modified to test a solar + SLA battery system with lithium battery backup. Operation of seismic equipment on lithium batteries on the polar plateau has been proven by PASSCAL and this station is a step toward a remote plateau GPS system by demonstrating power switching between dual power supplies of SLA and lithium batteries. Since June 25 2008, this receiver has been running on lithium batteries.

For a chronology of testing at McMurdo:
http://facility.unavco.org/project_support/polar/remote/test.html
State of health data for station MILF:
http://facility.unavco.org/project_support/polar/remote/SOH/



(a)

(b)

Figure 3. (a) McMurdo Station Testbed configuration for winter 2007.
(b) Configuration for winter 2008 showing lithium battery backup.

A simplified GPS system was also installed at the IRIS-GSN SPRESSO seismic site near South Pole Station. This installation consisted of a small plastic case buried 12” under the snow surface and received power and ethernet communications directly from the SPRESSO building. This station operated continuously throughout the winter, demonstrating that GPS equipment can survive plateau deployments with a small amount of tight-fitting foam insulation. This station also provided useful ice strain data to the GSN group.

In late 2007 the receiver was remotely power cycled and allowed to cold soak between restarts. The receiver failed after approximately 50 cycles, demonstrating limited ability of the equipment to restart after extreme cold exposure. The receiver has been returned to the manufacturer for failure analysis.

D) Install GPS+data retrieval prototype to continent margin site of scientific interest with dataflow

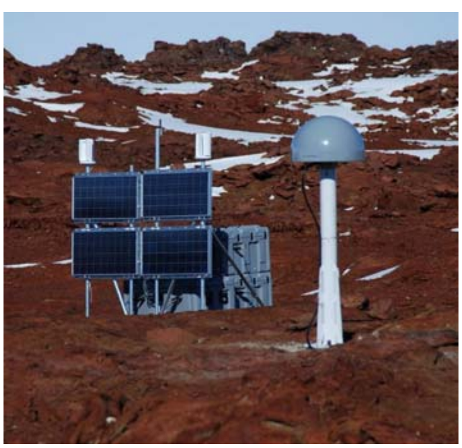
A prototype GPS station was built on Minna Bluff in February 2007 (Figure 4). This location was chosen due to its extremely windy conditions and usefulness as a future POLENET site. The goal of this effort was a field shakedown of a mass-producible system that is easy to transport and set up, withstands the harshest environments, and has the potential to provide year-round power. The station was installed in two flights on a Bell 212 helicopter with a three-person crew. With an overall station weight was less than 1300 lbs, it met the MRI design requirement to keep the total system weight below 1500 lbs. Although an intermittent power connection resulted in data gaps and the turbine itself was damaged by windborne debris, the wind turbine provided enough power for this system to run through winter 2007. The mechanical and electrical components were also proven during this test.

State of health data for station MIN0:
http://facility.unavco.org/project_support/polar/remote/SOH/
Data volume summary for station MIN0:
http://archive.unavco.org/query/data_volume_all?stn=min0


(a) (b)

Figure 4. (a) Original installation of Minna Bluff Prototype MIN0. (b) MIN0 antenna.

The design of station MIN0 has since been refined to increase reliability and minimize field installation time to a single day visit, and the improved design was used as a basis for POLENET GPS deployments (Figure 5). The MRI effort and the current POLENET activities in Greenland and Antarctica have resulted in a great leap forward for remote polar permanent GPS systems, and many of the system assemblies have been outsourced for mass production. More detailed information on the polar GPS system:
http://www.unavco.org/polartechnology




(a) (b)

Figure 5. (a) POLENET Antarctica site BURI. (b) POLENET Greenland site SRMP.

E) Report on recommended 'best practice' system configuration, provided to science community to implement for IPY installations in 2007-08

i) UNAVCO Polar Technology website

Rather than producing a verbose report, we have built the UNAVCO Polar Technology website www.unavco.org/polartechnology and regularly update it to provide a current view of best-practices components and GPS system designs, test reports, and related information. It is consistent with what we are recommending for remote polar applications and is the key product of the MRI project as it documents the outcome of the development effort. Our intent is to seek out expertise, critique, and assistance from the appropriate greater community experts, and we expect the field kits that we provide to reflect "best practices". This site is crosslinked to the PASSCAL Polar web page for seismic focused content, and to the PolarPower page for a broader overview of polar power systems.

ii) Summary of continental margin system design Version 1.0

Although the system continues to evolve, the UNAVCO continental margin GPS design has reached a level of maturity that Version 1.0 has been reviewed and documented. Following are technical details on this system.

Logistics performance:

a. Light aircraft deployable design. Compatible with Bell 212, 222 helicopters, Twin Otter fixed-wing aircraft. ~1100 lbs total system weight.
b. Individual modules weigh 70 lbs or less.
c. Designed for two year minimum service interval. POLENET Greenland network is approaching 12 month interval. POLENET Antarctica network is entering its first winter.
d. Installation procedure and toolkits optimized for three person field teams.
e. Minimal field wiring with "plug-and-play" connectors.
f. Fieldwork is minimized with simple status checks, component swaps, etc.
g. Compatible with autonomous "*near* year-round" operation in situations where delivering a year-round power system is not practical. This was tested with MRI year 1 system OBH1 and POLENET Greenland system SCBY which both demonstrated smooth spring startup after winter shutdown.
h. No air-transport-restricted materials.

Power system:

http://facility.unavco.org/project_support/polar/remote/power.html

a. Wind turbines: Forgen 500, low-temperature version.
b. Solar panels: 2x80W poly-crystalline silicon photovoltaic modules.
    Solar panel model will vary base on current availability.
c. Solar regulator: Flexcharge NC30L12.
d. Power board: custom board with breakers and spring-loaded terminal blocks.
e. Battery: Deka 8G31ST sealed lead acid gel cell.
f. Battery wiring: Custom quick-connect battery jumpers.
g. Power connections: ITT Cannon military connectors and cable assemblies with rugged, cold-flexible cable. Unique pin-outs for batteries, solar, and wind connections to eliminate possibility of field connection errors.
h. System schematic diagram: see link from above webpage.

Communication system:

http://facility.unavco.org/project_support/polar/remote/comms.html

a. Near-field sites: Intuicom Ethernet bridge radio and Yagi antenna provide Ethernet connection to Trimble NetRS receiver and point-to-point communications to research station.
b. Deep field sites: Iridium A3LA modem and SAF-2040B antenna provide serial link to Trimble NetRS receiver from UNAVCO.
c. Iridium download hub: A robust, scalable Iridium download hub is operational at UNAVCO, and is currently downloading 40+ remote stations.
d. Iridium SBD study: A feasibility study and proof-of-concept deployment was performed using Iridium short burst data (SBD) mode to stream data to an IP socket on a data collection computer.

Structural system:

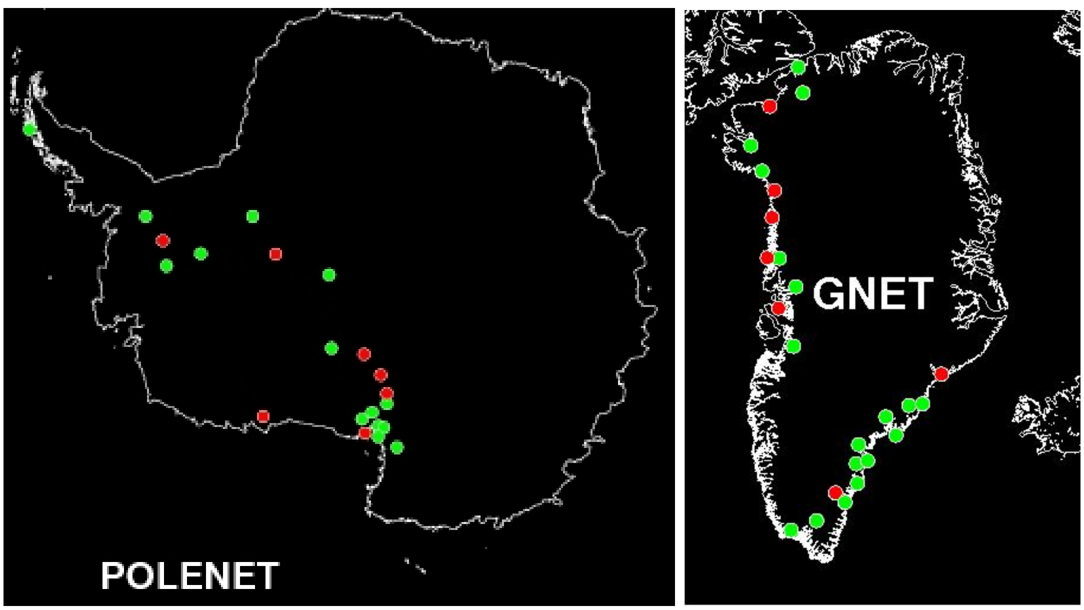
http://facility.unavco.org/project_support/polar/remote/structural.html

a. Structural frame: collapsible 1.5" aluminum pipe frame.
b. Enclosures: Hardigg MM24 and MM36 enclosures.
c. Solar Panel reinforcement: Backing plates to add strength and resist abrasion.
d. Simple rigging systems that can be rapidly installed.

3. Year 2 Major Milestones and status update:

A) Basic systems (with no wind or advanced battery technology) available for research deployments, testing, and community feedback

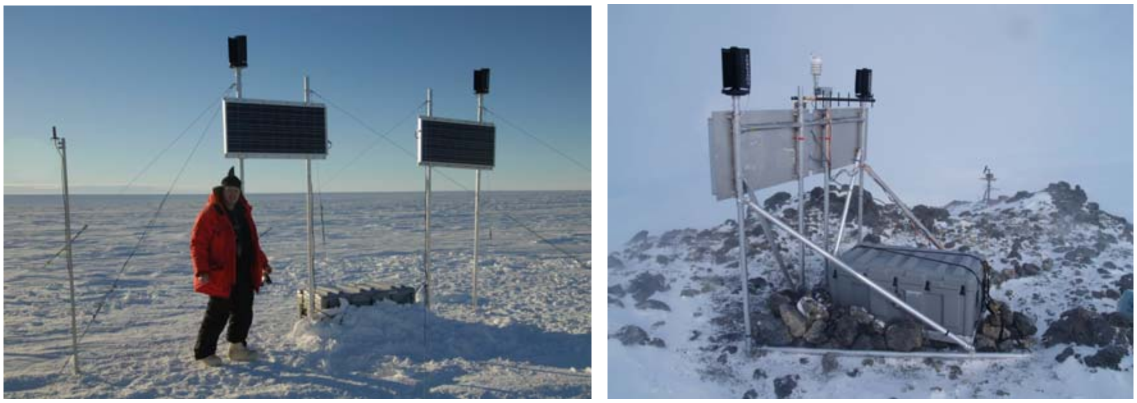
Over 40 GPS stations based on the MRI continental margin design have been fielded in Greenland and Antarctica since July 2007, a majority installed under the POLENET project. As of July 2008 the status of POLENET networks is shown in Figure 6, where green indicates that data files are currently being retrieved typically on a daily basis. Red dots indicate data are not current with problems ranging from loss of communications (where data may be on receiver memory) to battery failures. Evaluation of system performance and design improvements are an ongoing part of this project.



(a) (b)

Figure 6. (a) Status of POLENET Antarctica network as of July 2008.
(b) Status of POLENET Greenland network as of July 2008.

Also, the MRI project provided five best-practice “science kit” systems for community evaluation and feedback during the 2007-08 Antarctic field season (Figure 7). Two of these became POLENET sites CRDI and PECE, differing from the other POLENET sites in that they had a single enclosure and half the number of batteries and solar panels. One system was delivered to Slawek Tulaczyk’s glaciology project on Whillans Ice Stream in west Antarctica (station WHL1), one to Robert Bindschadler’s project on Pine Island Glacier (PIG1), and one to Philip Kyle’s Mt. Erebus project (MACZ). All of these systems were successfully fielded by the PI field teams except for MACZ which, due to weather, was installed by UNAVCO during a late-season break in the conditions. Useful feedback on the system design was solicited and obtained from the PI field teams.



(a) (b)

Figure 7. (a) MRI Science Kit PIG1 near Pine Island Glacier.
(b) MRI Science Kit MACZ on Mt. Erebus.

B) Integrate McMurdo test site to GPS+Seismic+data retrieval, year-round operation.

A new integrated GPS+seismic station was installed on Observation Hill in February 2008 (Figure 8). This station (MCMX) combines a PASSCAL polar seismic system with a UNAVCO polar GPS system on a single structural frame, with a single power supply system and battery bank. A single point-to-point ethernet radio was also shared, allowing full GPS and seismic data retrieval. It is anticipated that this system will demonstrate shared Iridium communications during Year 3.

This station demonstrates that although the UNAVCO and PASSCAL polar remote systems often use different hardware, the two designs can be seamlessly integrated as a single system, requiring only custom power and communications cables between the two enclosures and a slight modification to the standard UNAVCO structural frame.

State of health data for station MCMX:
http://facility.unavco.org/project_support/polar/remote/SOH/

(a) (b)

Figure 8. (a) Integrated GPS/seismic station MCMX at McMurdo.
(b) GPS and seismic enclosures on structural frame.

C. Add South Pole test site w/ GPS+Seismic+wind+data retrieval upgrade existing seismic system as necessary.

The first prototype GPS system for plateau operation was deployed at South Pole in January 2008. This system incorporates two Forgen 1000 wind turbines, a vacuum insulated enclosure, and active system heating. The batteries are enclosed in a vacuum insulated chamber while the electronics are housed above in a foam enclosure and use their own power for self heating. The mechanical design and rigging scheme were optimized for efficient installation on snow surfaces. Finally, a separately-powered datalogger continues to record thirteen channels of voltage, current, and temperature data during winter 2008. A mid-winter download was performed by the station Cusp Technician, yielding valuable engineering data about system behavior during the onset of winter.

This station was an attempt to operate a plateau system of minimal complexity, using SLA batteries and an electrical design similar to our proven continental margin system. The electronics performed flawlessly and the station ran continuously through the onset of winter; however power ran out in mid-June. There are two primary reasons for this shortened lifetime. First, the vacuum panels used were ruggedized for field use, which resulted in a diminished insulating capability due to poor fit. Second, the wind turbines used were larger versions of the Forgen 500, which we have used with reasonable success at continental margin sites. However, these turbines were simply not powerful enough to take necessary advantage of light but steady plateau winds and did not deliver sufficient heat and charge to the battery bank.

A more advanced plateau design is being developed and will be deployed in early 2009. This system will incorporate a more powerful wind turbine with bearings rated for extreme cold, more advanced power and thermal management, and improved insulation.

State of health data for station SPUD:
http://facility.unavco.org/project_support/polar/remote/SOH/

(a) (b)

Figure 9. (a) Plateau prototype system SPUD at South Pole
(b) Electronics and datalogging system.

D. Install GPS+wind+data retrieval, year-round, prototype on Polar Plateau site of scientific interest.

In conjunction with POLENET and with recon assistance from ANSMET, a second plateau prototype was installed in the Miller Range at the edge of the plateau. Since the site experiences extreme winds, the continental margin mechanical design was employed. However this station also employed high efficiency foam insulation and active heating from a solar panel to improve late-season charging and extend lifetime of the SLA batteries. In this sense, station IGGY is a hybrid which incorporates elements of both margin and plateau designs (Figure 10). The station was also fitted with an integrated weather station.

Communications with the site were lost in late March during a storm. The most likely problem is a broken Iridium antenna. These antennas have proven to be somewhat fragile, and such a failure was observed at a site in Greenland where the system otherwise ran continuously through the winter. More robust Iridium antennas have been purchased and tested which will be installed at all future GPS sites and retrofitted at existing sites as opportunity arises. We expect to obtain recon in early season 2008-08 to identify the problem, and a site visit is planned for later in the season.

State of health data for station IGGY:
http://facility.unavco.org/project_support/polar/remote/SOH/

Met data plot at:
http://www.geology.ohio-state.edu/TAMDEF/Data/iggy_time1.png

(a) (b)

Figure 10. (a) “Iggy Ridge” in the Miller Range.
(b) Plateau “hybrid” system IGGY.

E. Visit Minna Bluff to add 2nd Forgen 500, add collocated seismic site.

Year 1 prototype MIN0 was revisited in February 2008, the first time a remote MRI design GPS station had been visited after a year’s operation (Figure 11). A full site inspection was performed which revealed no damage to the GPS antenna, solar panels, wiring, or structural system. The intermittent power problem observed during 2007 was repaired and a co-located but independent seismic prototype station was also installed at the site.

The only damaged component was the Forgen 500 wind turbine, which was impacted by windborne debris. Although it would still spin and produce power in high winds, it would most likely not have powered the system through winter 2008 as it did through winter 2007. However, the success of this turbine during its first winter at an extreme location – a south-facing cliff edge at Minna Bluff - demonstrates the validity of a small size, low power, and vertical axis wind turbine for use on the continental margin. It is our opinion that such a turbine with an improved mechanical design would be optimal for these applications. Two new Forgen 500 turbines were installed and as of July 2008 they are still providing power to the system, which has run continuously since the site visit with no data gaps.

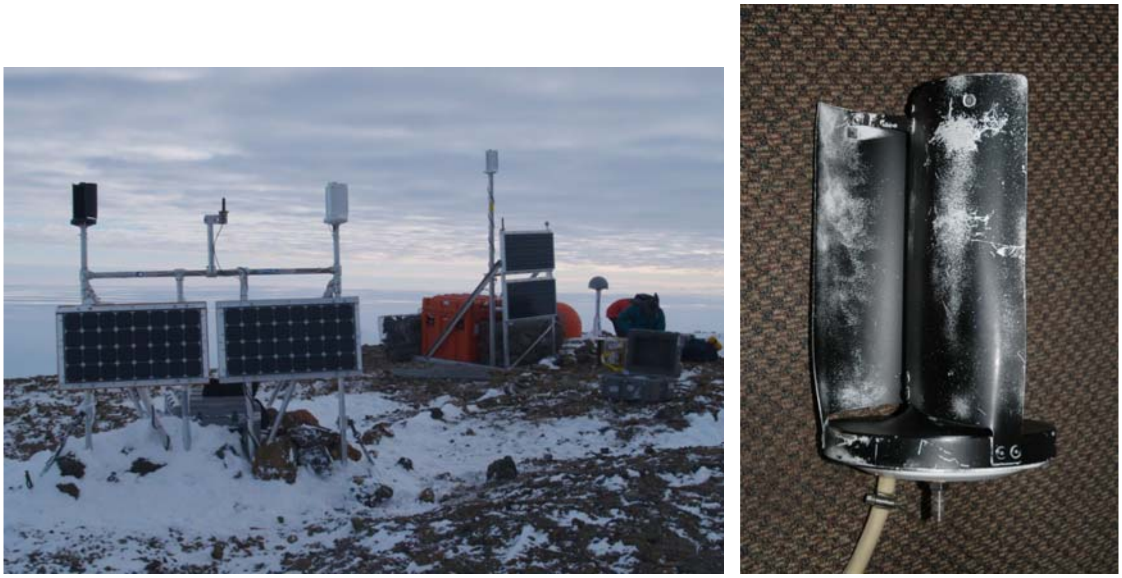

(a) (b)

Figure 11. (a) GPS station MIN0 and co-located seismic station at Minna Bluff.
(b) Damage sustained by original Forgen 500 wind turbine at MIN0.

F. Analysis of data on all prototype and community instrument deployments, identify improvements required for systems.

i) Feedback from community deployments

Between the MRI prototypes and testbed systems, POLENET networks, the five MRI science kits, and other PI deployments, a large number of GPS systems based on the MRI design have been installed at polar locations. UNAVCO has actively solicited feedback from the diverse array of personnel who have used this hardware and incorporated many suggestions into the design. The installation procedure has been optimized for a three person team and an instruction manual will be produced prior to the 2008-09 Antarctic field season. Reliable suppliers for all hardware and production capability at UNAVCO have been established. This system is now mature enough that in spring 2008, version 1.0 of the continental margin GPS system was finalized and documented.

ii) Acquisition of engineering data

UNAVCO continues to retrieve valuable datasets from remote GPS sites. Temperature and voltage data are obtained during each data download and are made available online at:

http://facility.unavco.org/project_support/polar/remote/SOH/

Three detailed year-round engineering datasets have also been obtained from Antarctic locations. Data from GPS systems at Observation Hill were recorded during 2006 and 2007, and data collection is ongoing at South Pole during 2008. Combined with laboratory tests at UNAVCO, these comprise a comprehensive, objective, and very relevant set of technical information on performance of systems and components. Where applicable, technical information is presented in report form at

http://www.unavco.org/polartechnology

iii) Ongoing development

Since the nature of remote polar instrumentation essentially results in a one-year design cycle, the limited number of deployments under the MRI project will not yield a large statistical picture of system failures. However, since the POLENET project is occurring simultaneously with MRI technology development, a much more comprehensive picture of system reliability is being obtained. Every visit to an existing site is taken as an opportunity for detailed troubleshooting and retrieving valuable information about long-term system health. Post-mortem analyses are performed on failed components. State of health data from remote sites are also closely monitored and archived. As a result, the continental margin GPS system design continues to be refined.

G. Update best practices documentation.

Several times per year, as new data is obtained and changes are made to system design, updates to the UNAVCO polar technology website are performed. This resource is kept current with the best practices that we are recommending.

New additions to the website include updated information on all continental margin system components, CAD drawings for custom-fabricated parts, current state-of-health data plots for all remote polar GPS stations, detailed test reports for system power consumption, and notes on why we selected and designed various components for polar use. An instruction manual for installation of this system will be completed prior to the 2008-09 Antarctic field season.

H. Advanced systems available for research deployments, testing, and community feedback.

The continental margin systems available from UNAVCO for the 2008-09 Antarctic season contain several improvements over the previous year's version. For example, the fragile Iridium antennas are being replaced by more robust models, and several configuration changes to the GPS receiver, Iridium modem, and UNAVCO download system have improved communications reliability and data throughput. Also, increased power output from the new Forgen 500 design may require power diversion, which can be used as a measure of active heating for margin systems. Integration of lithium battery packs as backup power for GPS systems is also being tested.

4. Community activities:

A Polar Networks Science Committee and charter were formed per the proposal plan. This committee is recognized by, and reports to, both the IRIS and UNAVCO boards of directors, and consist of Terry Wilson (chair), Doug Wiens (co-chair), Sridhar Anandakrishnan, Rick Aster, Carol Raymond, and Bob Smalley. A PNSC section on the www.unavco.org/polartechnology web page contains the committee charter and other related committee information.

The first PNSC meeting was held at UNAVCO in March 2007 with two days of productive technical discussions related to upcoming science project needs and some significant differences in system requirements between the GPS and seismic communities. UNAVCO E&O Director Susan Eriksson joined the PNSC meeting to discuss Polar E&O. Susan summarized a wide range of polar efforts ranging from RESESS/SOARS interns to professional meetings activities. In 2008, the UNAVCO E&O department is also working in conjunction with IRIS/PASSCAL on an Active Earth display which highlights the achievements of the POLENET project.

UNAVCO supported four interns during year 1, including one (UNAVCO RESESS student Ezer Patlan of the University of Texas at El Paso) funded by the Polar MRI project. In Year 2, UNAVCO supported 9 interns, also including Ezer Patlan who continues to funded by the MRI and is conducting his summer research at Ohio State University with the polar group.

The second PNSC meeting was held at PASSCAL in March 2008. Year 2 progress was presented to the committee and direction was received as to the most important areas on which to concentrate future work. Finally, Year 3 major milestones were reviewed along with the project logistics assumptions:

Major Milestones Year 3 [1 Oct 08 – 30 Sep 09]

- Upgrade field systems installed in year 1, 2, for long term autonomous operation (as warranted by funded science initiatives)
- Capability to install sites to standard, proven configurations, “best practice” documentation
- Field-proven systems, support, data handling, as built documentation available off-the-shelf from IRIS and UNAVCO

Review of logistics criteria (from proposal)

- Light aircraft deployable (< 1500 lbs total system weight)
- 100 lbs or less individual modules
- Designed for two year minimum service interval
- Optimized for three-person field teams

Minimal wiring

Minimize fieldwork with simple status checks and swaps

Compatible with autonomous seasonal operation as well if year-round power not feasible

Avoids restricted materials transportation issues