Collaborative Research: Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica
NSF ANT-0619908

Final Report

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Project overview

1. Summary

On behalf of the geodetic and seismic research communities, UNAVCO and IRIS partnered to develop, with the community stakeholders, the next generation power and communication systems to enable remote extreme environment year-round geophysical data collection. This project was a departure from previous models where individual projects bore the engineering responsibilities of designing, producing and installing their own custom built solutions. The outcome of the project are systems that were designed to meet the needs of the POLENET and AGAP large IPY projects as well as the needs of smaller PI led projects. The systems are deployed across a wide range of geographical locations and environmental conditions, and the overall data return is nearly 90%. Lessons learned are fed back into the latest best-practices designs, and the initial design effort started via this project continues with system upgrades and improvements. Hosting this community resource at facilities ensures continuous feedback, and system improvements benefit all the users of the systems.

The project objectives and science and logistics motivators were summarized in the proposal as follows:
"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."
"***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 lightweight to permit autonomous station operation year-round over several years***."

The expectations for this project were also made clear:
"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 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)."

Broader impact goals included ***"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."***

Both UNAVCO and PASSCAL have produced designs for the Antarctic Margin and Polar Plateau which met or exceeded the original project goals. This has directly resulted in a reduction of flights and less ground time required for installation. Although full seismic data retrieval is not yet practical with existing communications options at remote sites, full GPS data retrieval has been proven. This eliminates flights for data retrieval, and near real-time data enables new science uses. State of health data is retrieved from both GPS and seismic stations, and advanced network monitoring is provided by both facilities. This allows invaluable observation of system performance and assisting in maintenance planning.

The level of data retrieved from these GPS and seismic stations is unprecedented, with a ~90% data return from more than 100 stations deployed during the past four years. Due to advances in system design, rigorous pre-deployment testing, and optimized field procedures that have accompanied this project, year-round data collection is now the rule rather than the exception. Further improvements in terms of reduced weight, improved reliability, more efficient installations, and incorporating new technologies are ongoing activities that allow the community to benefit from continuously evolving designs. This final report focuses on the UNAVCO-led GPS system development.

2. Scientific Motivation and Technical Goals

Previous research projects 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, for example Transantactic Mountains Deformation Network (TAMDEF) and 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). However prior to this MRI, operating stations for more than one year without servicing had not yet been achieved because of the lack of a power/communication system sufficiently robust and light weight to permit continuous, autonomous operation over several years.

The overall goals of this project were to use the latest power and communication technologies, linked with the collective experience/expertise of the science community and IRIS/UNAVCO staff to

a) 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

b) provide an initial pool of these systems for deployment and testing in science experiments. The intended end result was the provisioning 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.

To accomplish these broad goals, four specific technical objectives were established.

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

b) Achieve dependable state-of-health (SOH) monitoring and data transfer of 1 Mb/day with minimal power consumption.

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.

3. Description of MRI Project Products

a) Instrumentation Systems

This MRI has resulted in mature, proven designs for remote seismic and GPS stations which can operate across the entire Antarctic continent. Both UNAVCO and PASSCAL have developed two versions of the GPS and seismic systems specific to the two major environmental regimes of Antarctica: the Continental Margin and the Polar Plateau. The Margin stations are hardened to resist extreme winds and contain the necessary features for operation in moderate cold. In contrast, the Plateau stations are designed for operation in deep cold and predominantly light winds found in the interior of the continent.

At present, 42 remote permanent GPS stations are operational in Antarctica, 39 in Greenland, and one in Alaska using systems developed by this project. An additional 8 remote stations incorporate elements of the MRI GPS designs. In total, 13 separate PI projects are represented by these stations, with data provided to researchers via the UNAVCO data archive.

b) Facility Collaboration

As a result of this effort, a formal and highly productive collaboration has been established between the UNAVCO and PASSCAL facilities. Frequent communications, shared technologies and test results, and three shared field seasons have resulted in an excellent working relationship both personally and institutionally. Two separately funded projects for independent GPS and seismic stations would not have been nearly as successful as this collaborative MRI. The formal arrangement between facilities, as well as informal collaboration with many other polar researchers during the course of this project, has clearly demonstrated the value of "not designing in a vacuum".

c) Polar Networks Science Committee

The MRI 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 was their 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. As a result, the Polar Networks Science Committee was established during this project. The main directive of this committee, comprised of eight diverse polar geophysics researchers, was to ensure that the MRI effort remained well coordinated with science needs and took best advantage of existing experience within the PI community. Upon MRI project completion the PNSC has taken on a broader advisory role to the seismic and geodetic facilities and communities. Further details of the PNSC are available on the UNAVCO governance web site at http://www.unavco.org/community/governance/committees/committees.html#pnsc.

d) Undergraduate Outreach

Education and Outreach was included in Years 2 and 3 to leverage the RESESS intern program for underrepresented undergraduate participation. A RESESS intern (Ezer Patlan) was hosted for one summer each by UNAVCO and Ohio State University (T. Wilson). The intern worked closely with members of the MRI and POLENET groups to further his scientific education and practical experience.

4. Key Milestones

The following are the major milestones as listed in the MRI proposal, intended to guide systematic design, integration, testing, and deployment of power and communication systems.

a) Year 1 [October 2006 – September 2007]:

i. Prototype sites for development and engineering evaluation installed near UNAVCO and IRIS/PASSCAL facilities.

ii. Install wind system prototype on Niwot Ridge near Boulder for winter testing.

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

iv. Install GPS+data retrieval prototype to continent margin site of scientific interest with dataflow.

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

b) Year 2 [October 2007 – September 2008]:

i. Upgrade McMurdo test site to GPS+Seismic+data retrieval.

ii. Upgrade South Pole test site to GPS+Seismic+wind+data retrieval.

iii. Install GPS+wind+data retrieval prototype on Polar Plateau site of scientific interest.

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

v. Update report on "best practice" system.

c) Year 3 [October 2008 – September 2009]:

i. Add seismic and wind to continent margin science site.

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

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

iv. Upgrade field systems installed in Year 1, 2, for long term autonomous operation (as warranted by funded science initiatives).

v. Capability to install sites to standard, proven configurations.

vi. Field proven systems, support, data handling, as-built documentation available off-the-shelf from IRIS and UNAVCO.

All above milestones have been achieved. However, due to the concurrent construction of large IPY networks (POLENET, AGAP), a re-ordering of project priorities was required to meet the technical objectives of the MRI while supporting the unique scientific opportunities provided by IPY. In addition, the funds for this MRI were secured in October 2006, four months after the originally intended start date. Therefore the chronology of the above milestones varied somewhat from the original order. The sequence of specific milestones and technical advances are detailed in the project annual report and are not repeated here.

Design Considerations

1. Technical Goals

The technical requirements guiding the design of the power and communication systems were driven by the needs of the research community, including year-round, continuous operation and real-time delivery of as much data as technically feasible. Prior to this MRI project, the following performance requirements for the power and communications system had been established jointly by the science community and facilities.

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+events)	15MB/day avg (full data retrieval). 27 mo. =12GB
Satellite data link (NAL Resesarch Iridium)	1W/MB	>2MB/day	N/A
Radio data link (FreeWave 900MHz)	0.5W/MB	>16MB/day	N/A
Housekeeping overhead	0.5-1W	N/A	N/A
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

In the MRI proposal the following logistical constraints were established:

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

b) Individual modules weighing less than 100 lbs for 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. Keep design as simple as possible, but no simpler.

g) Compatible with "near year-round" operation in case delivering a year-round power system is not practical. Must demonstrate graceful summertime recovery after winter data outage.

h) Avoid air-transport-restricted materials.

2. Collaboration of UNAVCO and PASSCAL Design Efforts

During this project the two facilities maintained a close collaboration. Regular technical discussions were held, technical information was freely shared, and many design decisions were made jointly. However more design differences exist than originally intended between the final UNAVCO GPS and PASSCAL seismic system designs. There are three main reasons.

First, the inherent differences between equipment and measurement goals involved in GPS and seismic science drive the physical approach to system design. For example a seismic instrument consumes half the power of a GPS system. Also, since full GPS data retrieval is possible with low-bandwidth communications at extremely remote sites whereas retrieval of seismic data is not, additional power is used by the GPS system for communications. Such large differences in power consumption impacts system design decisions and neither facility was in a position to compromise on the end product at the expense of its primary constituency. Furthermore, the duration of a seismic experiment is often much shorter than with GPS, with many seismic experiments deployed for 1 year while many GPS systems need 3-5 years minimum. Therefore a central focus of PASSCAL development has been power systems with non-renewable components (e.g. lithium-ion batteries) whereas UNAVCO has more aggressively pursued renewable energy, specifically wind power. Compatibility of MRI-developed systems with existing equipment pools at both facilities was also a design consideration and ultimately overrode an initial effort to standardize.

Second, facility-specific design strategies and schedules were necessary to build polar instrument networks for simultaneous large-scale IPY projects. Although both facilities maintained a separation between MRI technology development and specific PI projects, in under six months from the start of the MRI both UNAVCO and PASSCAL were required to begin design and construction of IPY projects POLENET and AGAP. This influenced the division of labor between the two facilities and resulted in a re-ordering of technical priorities for the MRI. Specifically, PASSCAL initially focused more on a polar plateau design while the first priority for UNAVCO was a continental margin design. Enforcing commonality of design would have diverted already stretched resources from the more pressing demand of meeting field deployment deadlines.

And finally, achieving commonality between well established independent organizations is hard to do at the best of times, let lone combined with the pressure of supporting multiple large IPY projects. While this was a goal of the project, the management structure of a collaborative proposal does not lend itself to "forcing the issue" since each organization is operating independently under separate, albeit linked, grant awards.

Description of GPS Systems

Detailed up to date documentation for the GPS system designs is available at www.unavco.org/polartechnology (Figure 1) which is the repository for all relevant technical information related to the GPS portion of this project. The GPS system development focused on two primary designs for distinctly different polar environments. The Continental Margin system, intended for deployment on rock around the periphery of the Antarctic continent, is hardened against extreme winds and is capable of operating in “moderately” cold temperatures. The Polar Plateau system, deployed on snow surfaces, is engineered to operate in extreme cold while withstanding moderate winds. A third design naturally arose as a hybrid from the primary two. For deployments on snow surfaces which experience warmer conditions similar to the Antarctic continental margin, such as West Antarctica and the Ross Ice Shelf, structural elements from the Polar Plateau system are merged with electronic and thermal elements from the Continental Margin system to create a design tailored for this environment.

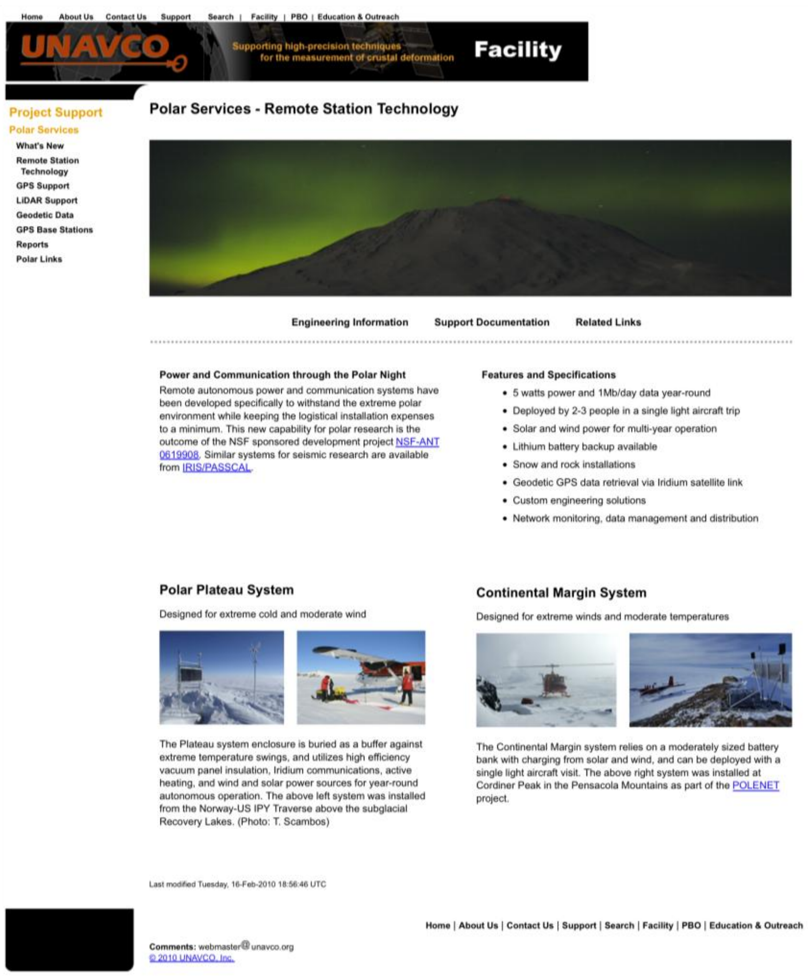
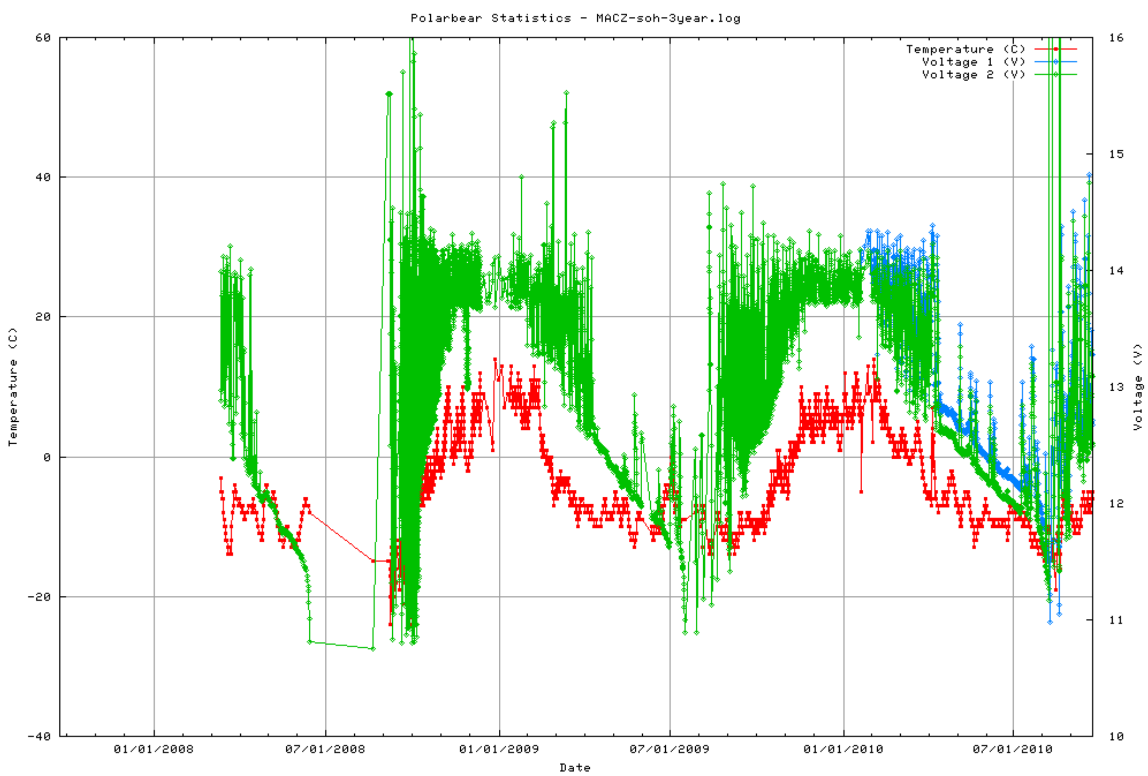


Figure 1 – Project outcomes including design drawings and technical reports are freely available.

1. Continental Margin GPS system

The Continental Margin GPS system relies on solar power and standard lead-acid batteries for a majority of its power production. While year-round operation can be achieved at any latitude simply by the addition of enough batteries, the weight of such a system is often impractical and does not meet the project design goal of <1500 lb total system weight. Therefore, wind turbines are used to provide power through the late winter months when solar panels and batteries are insufficient. The combination of rechargeable batteries and renewable energy sources provides a system that operates indefinitely until there is a critical component failure. The vertical axis Forgen 500 turbine was chosen based on its compact vertical-axis design and survivability in extreme winds. The units are ordered with low temperature cables and fitted with custom bearings. They produce relatively little power, however with extreme winds the primary goal is survivability and not efficiency. Successful year-round operation of these turbines has been demonstrated at several difficult locations. A robust charge regulation system has been proven that handles input from various combinations of solar and wind power sources.

Physically the Continental Margin system consists of an aluminum pipe frame, enclosure(s) containing batteries and electronics, solar panels, high-speed wind turbines, a communications antenna, and an optional weather station. The frame bolts directly to a rock surface without guy wires, relying on the frame's rigidity to withstand severe winds. The systems batteries sit on the frame and provide substantial anchoring ballast. The solar panels mount near vertical to capture maximum sunlight at start and end of the winter season. The system uses simple foam insulation to keep electronics within operating range by self-heating. It also uses standard rechargeable sealed lead acid batteries which are essentially unheated. Active heating was avoided as an unnecessary complexity for margin sites since the batteries perform very well under year-round conditions, delivering roughly 70% capacity in wintertime, and being recharged to full capacity at the warmer summer temperatures. The system can also accept non-rechargeable lithium battery packs as wintertime backup.



Figures 2 and 3 –MRI GPS site MACZ on Mt. Erebus. Figure 3 shows the state of health data from station MACZ as example of Continental Margin system performance. After sunset in late April the batteries voltage (green line) draws down, however power input from the wind turbines slows down the battery drainage. Although the batteries ultimately draw down completely through the winter, the wind turbines provide an additional two months of station operation, resulting in less than one month data outage. Improved charging regulation prevents the voltage spikes seen in the 2008-09 summer during periods of very high wind. (The spikes seen in August 2010 are an artificial product of the automated plotting scripts.)

Two communications options have been demonstrated for full GPS data retrieval: point-to-point 900 MHz radio and Iridium satellite links. For sites suitably close to research stations, the point-to-point method is more reliable and cost effective than Iridium, and higher data transfer rates are possible. However, most Antarctic and Greenland sites do not permit this option and Iridium is the only global, 24/7, bi-directional communications system available. We developed a robust Iridium download system which is employed at over 70 remote locations. Full 30-second sample rate GPS data retrieval (0.8 MB/day) is achieved, as well as state of health and full system control. Retrieval of 1 Hz GPS data via Iridium (~15 MB/day) was also demonstrated.

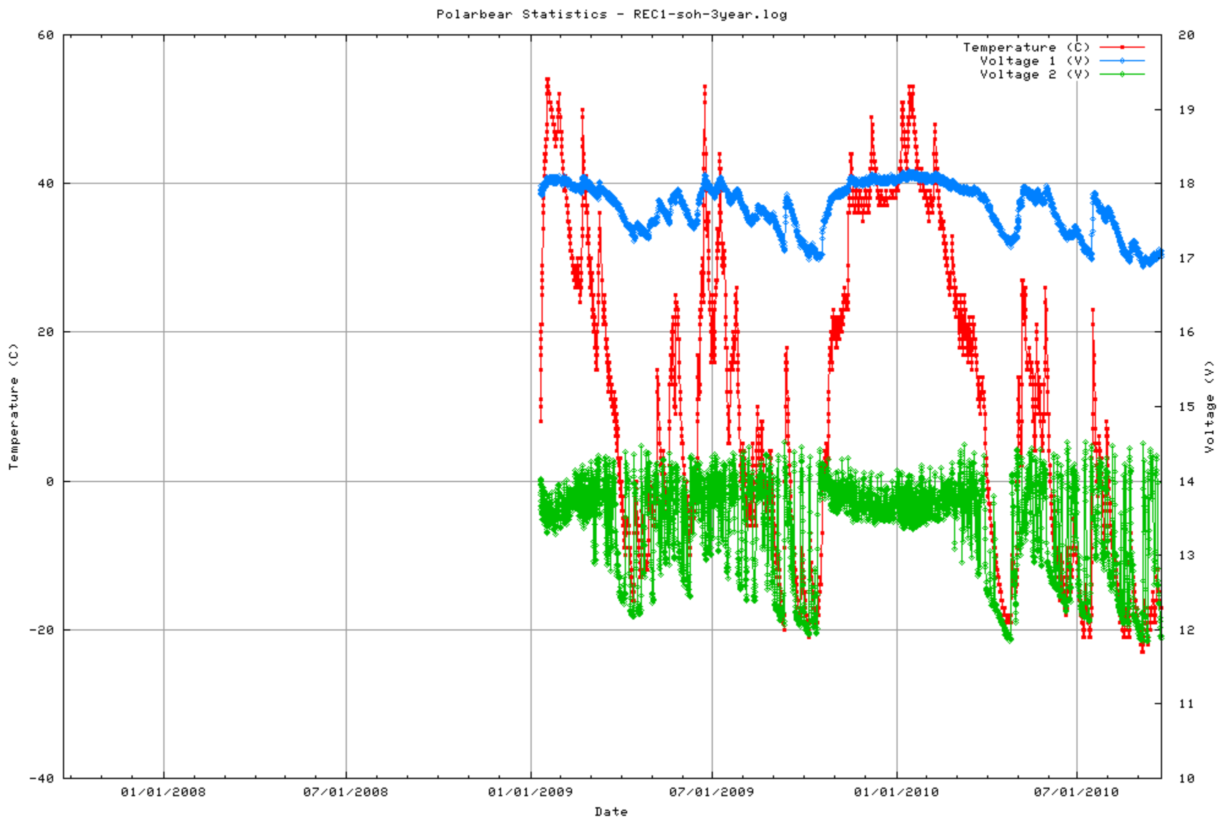
2. Polar Plateau GPS system

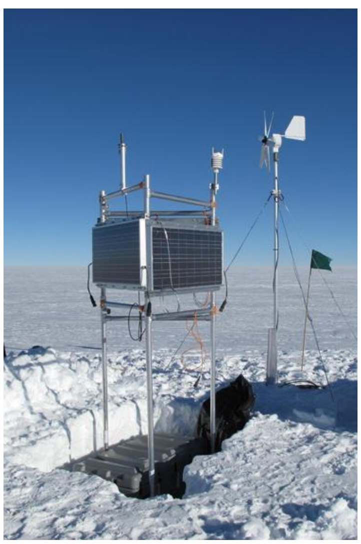
The Polar Plateau GPS system is similar to the Continental Margin system in many regards, but with substantial differences in the structural frame, thermal design, and wind power system.

The structure of a snow-surface system is a tall, three-post triangular structure which holds three solar panels each oriented 120 degrees apart. This omni-directional panel arrangement ensures at least two panels will remain free of electrostatic snow buildup arising from persistent, low-speed, unidirectional winds found on the Plateau. The third panel provides heat to the batteries, maximizing battery charge during early and late summer periods and optimizing the winter battery lifetime. The frame is guyed with wire rope to simple snow anchors, and can be easily extended during periodic site visits to prevent burial over time.

While lead-acid batteries perform well under margin conditions, their performance can be reduced to under 50% by plateau temperatures, and they will not charge adequately even at ambient summer temperatures. Therefore, high-efficiency vacuum panel thermal insulation and heating are used to warm the electronics and batteries. The outer enclosure is the same as that used for the Continental Margin system.

Finally, a customized wind turbine is employed to maintain power through the extended winter months. For a Plateau turbine, startup torque in extreme cold and power production at low wind speed are essential, and high wind survivability is less of a concern. Therefore a horizontal-axis turbine, the non-furling Aero4gen with modified bearings, is used for Plateau stations. This turbine is significantly more powerful than the Forgen 500 turbine and is mounted on its own mast rather than the solar panel frame. It provides both battery charging and system heating for the enclosure. A passive thermal management scheme is employed using an arrangement of self-regulating heat pad elements.





Figures 4 and 5 – System State-of-Health information from the MRI Polar Plateau design system REC1 at Recovery Lakes since it was installed in January 2009. This plot shows the effect of a wind and solar powered heating and charging system, with the system temperature (red) well above ambient, a healthy lead-acid battery voltage (green) through the winter, and a backup lithium battery (blue) that is available but so far not needed. The system enclosure is buried as a buffer against extreme temperature swings and has high efficiency vacuum panel insulation.

3. Modularity and Adaptability

The GPS system designs have been adapted to provide power for systems between <1W and 8W. The proposal goal of a 10.5W system could be constructed if the demand arose simply by using a larger number of the same basic power-generation and power-storage components. Structurally and electrically the Continental Margin and Polar Plateau systems have no GPS-specific features, and the design provides a ready power and communications platform for other instruments. The basic design has been adapted to serve as a power supply for three polar Automatic Weather Stations, and has also been integrated with a PASSCAL seismic system to share a single power supply and communications link.

4. Specifications

a. General

- 5W watts power and 1Mb/day data year-round
- <1300lbs, can be deployed by 2-3 people in a single light aircraft trip
- Aluminum pipe structural frame
- Solar and wind power for multi-year operation
- Snow and rock installations
- Trimble NetRS GPS receiver
- Geodetic GPS data retrieval via NAL Research A3LA-SA Iridium modem/SAF5350-A antenna satellite link
- Network monitoring, data management and distribution
- Optional radio modem point-to-point communication
- Optional Vaisala WXT-520 weather station
- Optional lithium battery backup

b. Margin System

- Hardigg enclosure, unheated, with minimal foam insulation
- Two wind-hardened 80W solar panels
- Ten 100 amp-hour lead-acid batteries
- Two vertical axis Forgen 500 wind turbines
- Optional lead-acid auxiliary battery packs

c. Plateau System

- Hardigg enclosure, heated, with vacuum panel insulation
- Three wind-hardened 50W solar panels
- Ten 100 amp-hour lead-acid batteries
- One horizontal axis Aero4gen wind turbine

5. System Testing, Qualification, and Installation

Test procedures, installation manuals, and troubleshooting checklists have been developed and are available online. The electronics for polar permanent GPS stations undergo a three-day cold-cycle test to -40C, followed by a one week burn-in period prior to deployment.

6. System Cost and Logistical Cost Savings

a. System Costs

Continental Margin system - $20,000:

- GPS receiver and antenna: $9,000
- Iridium modem and antenna: $2,000
- Batteries: $2,000
- Wind turbines with cables and regulator: $2,000
- Enclosure with fittings and insulation: $1,500
- Frame structure kit: $1,500
- Hardened solar panels with cables: $1,500

Power board: $500

Polar Plateau system $30,000:

Vacuum insulation, heating, and system complexity add ~$10,000 to the cost of a margin system

Optional auxiliary 1000Ah battery pack (Continental Margin system only) $3,000

Optional lithium battery backup $12,000

Optional weather station $2,500

b. Logistical Cost Savings

A primary motivation for this project was reduction of logistics costs, specifically the number of flights required to install and maintain remote polar instrumentation systems. Potential logistical cost reductions have been achieved by this project in several ways. First, system weight has been reduced to the point that the hardware can be delivered to the site for installations in a single Bell 212 or DeHavilland Twin Otter flights and the installation process has been optimized to allow for complete system installation within the aircraft operators "crew day". Second, the design and pre-deployment qualification process is intended to achieve a two-year mean-time-between-failure service interval or better meaning sites only need to be visited if they are broken. Third, full data retrieval via Iridium satellites eliminates the need to visit the site to retrieve data while state-of-health information allows for better maintenance planning. These achievements provide opportunities for major reductions in USAP logistics expense and facilitate better science with timely access to data.

7. Performance and Reliability

Prior to the commencement of this project, there had been a handful of efforts to operated year-round remote Polar GPS systems, with various levels of success. The state of this technology at the beginning of 2006 was stated succinctly in the proposal:

"***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 lightweight to permit autonomous station operation year-round over several years***.*"*

The expectations for this project were also made clear:

"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 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)."

As of September 2010 standard, mature systems and documentation are available from UNAVCO for PI project support. 42 remote permanent GPS stations are operational in Antarctica, 39 in Greenland, and one in Alaska using using alpha, beta, and first "production" versions of the MRI system design. An additional 8 remote stations incorporate elements of the MRI GPS designs. Figure 6 shows the data return rate for these stations and the rapid increase in UNAVCO-supported remote polar GPS sites since this project began in October 2006. A total of 13 separate PI projects are supported by these stations.

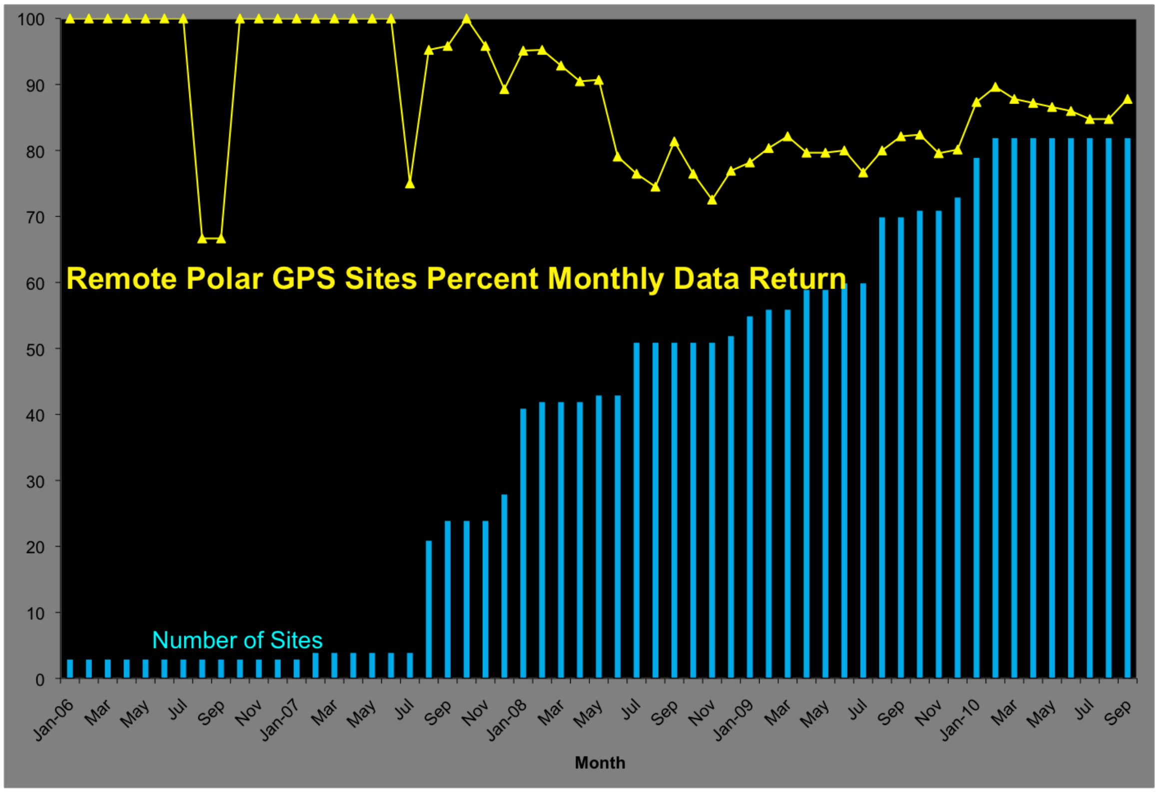


Figure 6 – Data return rate and total number of stations since 2006.
The rapid increase in the number of stations in Figure 6 is the result of fielding systems for the GNET and POLENET science projects simultaneously with the MRI project engineering development. As a result, some of the MRI project tasks were rescheduled by necessity to meet the immediate needs of funded science projects. Also, the concurrent construction of GNET and POLENET went against the intent to methodically test and qualify systems before fielding on science projects and introduced substantial risk to both the science and development projects. However, these projects also provided the unique opportunity for fielding systems and refining the design under a variety of conditions, and the end result is more a robust MRI final product. While it is too early to produce meaningful MTBF statistics from the 82 GPS stations currently deployed, we expect to see a rising MTBF from the more mature systems deployed at the later stages of the project.

Science Kit Distribution and Feedback

Five GPS systems were provided to PI projects using MRI funds for the dual purposes of obtaining performance data in a variety of physical environments and soliciting feedback from diverse members of the science community:

Investigator	System	Location and Station ID
Terry Wilson	Margin (2)	Cordiner Peak (CRDI) Pecora Escarpment (PECE)
Philip Kyle	Margin	Mt. Erebus (MACZ)
Slawek Tulaczyk	West Antarctic (hybrid Margin/Plateau)	Whillans Ice Stream (WHL1)
Bob Bindschadler	West Antarctic (hybrid Margin/Plateau)	Pine Island Glacier (PIG1)

Feedback was actively solicited from these and all other users of the UNAVCO polar systems, and on many occasions the feedback has been directly incorporated into design improvements. In addition to the 5 MRI Science Kits, two Polar Plateau design systems were successfully installed by Ted Scambos in Year 3 at the Recovery Lakes sites from the Norway-US IPY Traverse. These are the only true Polar Plateau systems fielded by UNAVCO – the vast majority of geodetic GPS users are operating in the continental margin regime.

Conclusions

1. Lessons Learned

A comprehensive listing of learning experiences and wisdom gained is outside the scope of this report. However, some key lessons learned pertaining to the design, testing, installation, and operation of remote polar instrumentation and of general interest are given here.

a) GPS Hardware. The UNAVCO polar GPS system, based on the Trimble NetRS receiver and NAL Research A3LA-SA modem, can be operated on the Antarctic continental margin and many parts of the interior with simple foam insulated enclosures (minimal R5 insulation), no active heating, and no thermal control system.

b) Iridium. **Development of a robust Iridium solution is a major undertaking.** Iridium modem-to-modem dial-up connectivity is a practical method for retrieving full GPS data at 30 seconds sample rate (~1MB/day), and 1Hz data retrieval (~15 MB/day) has been demonstrated. Dial-up is a viable solution even though its not an optimal connection technique, and one master modem can handle up to ten remote sites. Iridium RUDICS has the potential to provide Ethernet connectivity and increased bandwidth, but implementation adds substantial systems complexity due the requirement that the remote site initiates a connection. The NAL Research SAF5350-A is a robust antenna for Polar applications. Fostering information sharing between polar Iridium users is necessary due to the complexity involved and frequent advances in applications.

c) Point-to-Point Communications. **Intuicom and FreeWave 900 MHz modems provide superior performance and reliability in polar environments.** 7-element Yagi antennas work well, and a reliable 100-mile radio link has been operated for several years using these components.

d) Wind Turbines. **Small, vertical-axis turbines are the optimal wind turbine design for low-power remote polar systems in extreme wind conditions due to their simplicity.** Although the Forgen 500 wind turbine is a low-power device which can be connected directly to battery banks in some situations, many extreme polar locations require regulation to avoid battery damage**.**

e) Wind Turbines. T**he Aero4gen horizontal-axis turbine has been demonstrated with good success on the Polar Plateau.**

f) Wind Turbines. **For all polar wind turbines, proper (usually custom) bearing selection and testing is critical to avoid seizing during sustained operation.**

g) Regulators. **The FlexCharge series of solar and wind regulators has been proven in the UNAVCO polar GPS systems.**

h) System Watchdog Timer **The ability to perform a remote power cycling of all system electronics is desirable, but can also introduce undesirable system complexity if not implemented properly.**

i) Lead-Acid Batteries. **Sealed lead-acid batteries perform very well in the (relatively) moderate cold temperatures found on the Antarctic margin when used in a summer charge/winter discharge mode.** Very little difference has been observed between Gel and AGM types when used for low-power polar instrumentation with solar and wind input. Overall battery capacity of 70% is observed for systems during wintertime operation. Fully charged lead-acid batteries can be stored long term outside in the Antarctic cold.

j) Lithium Batteries. **Lithium thionyl chloride batteries provide very high power delivery and retain excellent capacity in extreme cold.** Their high cost and non-rechargeable nature limit their utility, however they are an excellent and proven component for certain applications such as short-duration stations, where logistics are extremely limited, or where the critical nature of year-round data justifies their use as a wintertime insurance policy.

k) Vacuum Insulation. **Vacuum panels are thermally effective, but expensive, fragile, and labor intensive to incorporate into enclosure design.** High efficiency insulation is essential to retain the small amount of heat generated by electronics and/or wind turbines to maintain system operation during wintertime on the Plateau.

l) Testing. **Cold chamber testing is indispensable to pre-qualify components.** During the course of this project components have been rejected in the cold-culling process and an entire faulty batch of Iridium modems was discovered. Further pre-deployment burn-in testing of completed systems is essential to ensure reliable operation of remote sites. A final round of testing with the complete system at the field staging area is highly recommended to uncover damage from shipping and to ensure all hardware is accounted for prior to deployment. A higher risk of failure in the field must be accepted if delayed funding and fixed logistical constraints do not allow time for proper testing.

m) Optimizing Installation Procedures. **A system design that includes minimal field wiring, a straightforward mechanical assembly, and a clear-cut division of labor between field team members is invaluable.** Many small improvements in usability will result in a large overall increase in both efficiency of installation and reliability of the system. A set of high quality and well thought out tools is essential. A system that is simple to install requires a refined, robust design and a great deal of work in advance.

n) Attention to Detail. **A sustained design effort allows for attention to the critical details that otherwise are not systematically addressed.** Innumerable remote polar stations, including early designs from this MRI, have failed due to small oversights in design. Reliable, secure, unique connectors are essential, as are cold-flexible cables and cold-qualified components. Proper choice of materials and fasteners is critical when operating in the earth's harshest environments. The cost of high-quality components is trivial when considered against success vs. failure of an expensive logistical deployment.

o) Design Cycles. **The nature of Antarctic logistics results in two year design cycles if one wishes to implement systematic improvements learned from field prototypes.** This project implicitly applied one year design cycles to the development process.

p) Integrated GPS / Seismic Systems. **An integrated GPS/seismic system is a large effort to coordinate between separate facilities and communities.** UNAVCO and PASSCAL built an integrated station prototype at McMurdo Station as a project demonstration exercise, sharing a single power and communications system. If a scientific demand arises an upfront development could produce a more mature integrated station design.

q) Science Projects versus Technical Development. **Immediately fielding large projects like POLENET and AGAP conflicts with the intent to methodically test and qualify systems and introduced substantial risk to both the science and development projects.** However, a large amount of statistical system performance data was gained from the sheer numbers of stations deployed under these projects and contributed substantially to the system designs.

r) Hardware interchangeability between UNAVCO and PASSCAL. **Achieving interchangeability of hardware was a noble but unrealistic goal.** During this project it quickly became apparent that interchangeability in seemingly common hardware was a larger task than originally anticipated, and enforcing commonality of design would have diverted already stretched resources from more pressing tasks. Hurdles to achieving interchangeability include the desire to maintain commonality with existing facility instrument pools, divergent demands from the similar but different geodetic and seismic scientific communities, and legacy systems deployed in large quantities during the development project, and the lack of "enforcement authority" in the project management structure.

2. Documentation

At the onset of the project we decided that the project documentation will be in the form of online repositories, replacing the originally proposed "best practices report". Online information will not become dated like a printed report, and will make technical information easily accessibly to the largest number of people. UNAVCO maintains a comprehensive online repository of all relevant technical information pertaining to remote polar GPS stations at www.unavco.org/polartechnology. For all hardware, manufacturer and part number information is given along with engineering drawings where applicable. Project reports, installation manuals, testing procedures, installation checklists, testing reports, and toolkit lists are also provided. This website represents current best practices for polar remote instrumentation and is regularly updated to maintain currency with advances in components and system design.

3. Unique Outcomes of this MRI

a) Development Approach

In this MRI two facilities in related technical areas were funded to focus solely on advancing the design of power, communications, and mechanical aspects of remote stations. Hardware was selected which was specifically suited to the polar environments, components and systems were rigorously and systematically tested, and in many cases outside suppliers were identified to produce custom assemblies, thereby reducing costs and conserving engineering time when responding to PI equipment requests.

The systems developed under this project are modular for different power consumption needs, adaptable for a variety of instruments, and fully documented. Prefabricated kits are now available upon request for GPS and seismic experiments covering the entire Antarctic continent, and the power/comms systems are adaptable for a wide variety of other scientific instruments. Overall, the longevity of facilities with field expertise and sustained engineering has resulted in a better community product. In addition, from this project a formal, highly productive collaboration has been established between PASSCAL and UNAVCO.

b) Logistics Savings

Both UNAVCO and PASSCAL have produced designs for the Antarctic Margin and Plateau which met or exceeded the original project goals. This has directly resulted in a reduction of flights and less ground time required for installation. Although full seismic data retrieval is not yet practical with existing communication options at remote sites, full GPS data retrieval has been proven. This eliminates flights for data retrieval, and near real-time data enables new science uses. State of health data is retrieved from both GPS and seismic stations, and network monitoring is provided by both facilities. This allows invaluable observation of system performance and assisting in maintenance planning.

c) System Performance

The level of data retrieved from these GPS and seismic stations is unprecedented. Due to advances in system design, rigorous pre-deployment testing, and optimized field procedures, year-round data collection is now the rule rather than the exception.

Appendix – Iridium RUDICS development

UNAVCO requested a fourth year no-cost extension to this project for the sole purpose of developing an Iridium RUDICS capability that will allow Ethernet communications to the remote site and eliminate the need for a master dial-out modem.

A contract was issues to Xeos Technologies to leverage work they had already performed for PASSCAL to develop the UNAVCO XI-100e terminal. The UNAVCO XI-100e terminal design is based upon existing IRIS XI-100 terminal design (for the basic functionality such as timers, heaters, modem interface, SBD and RUDICS operations) and will extend its capability to provide Internet connectivity to a remotely deployed Data Acquisition System over the Ethernet 10 BASE-T network. New generations of Data Acquisition Systems (such as modern geodetic GPS receivers), so called Network Appliances, utilize the Ethernet interface and TCP/IP protocol instead of RS-232 and SLIP or PPP protocols as their primary means of communication. As such they can be easily connected to any type of networks.

As part of this contract Xeos will provide 2 units to UNAVCO for field evaluation. Upon successful field testing the intent is to use this product as the next generation Iridium communication link which has several enhancements over the current modem to modem dial-up method:

Lower power
Better cold performance
Ethernet communications to support multiple instruments
No need for a modem at the data hub
Better throughput

At the time of this report UNAVCO has just received the first unit for evaluation.