Geodetic Support to the National Science Foundation Office of Polar Programs Arctic Sciences

2008 Annual Report

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Office of Polar Programs
Arctic Sciences

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Cover photo from the CAUSE project in Iceland using the new UNAVCO LiDAR system.

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Summary

UNAVCO is the National Science Foundation's and NASA's pre-eminent national facility for earth science applications of the Global Positioning System (GPS) and complimentary equipment including LiDAR and related power and communications systems. The range of services provided to the National Science Foundation's Office of Polar Programs Arctic Sciences Section (NSF-OPP/ARC) includes equipment, training, project planning, field support, proposal assistance, technical consultation, data processing, and data archiving on a year-round basis. Permanent station network support services are also provided, from the initial engineering and installations through operations, maintenance, and data archival and distribution. Sustaining engineering activities are ongoing to meet the technical challenges such as providing robust telemetry and power systems at remote high-latitude locations. Resources and expertise from the other core UNAVCO support areas, including NSF-EAR investigator support, NASA-Global GNSS Network (GGN) operations, the EarthScope/Plate Boundary Observatory facility construction and operation, and the UNAVCO community data archive are leveraged to apply state-of-the-art technologies at a reasonable cost.

Development activities of the ongoing MRI funded engineering effort *Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica* focused on minor refinements to the "continental margin system", and design of systems to operate in the extreme cold environment of the Polar Plateau. Three Plateau systems were built – two to be deployed in early 2009 at the Recovery Lakes area from the Norway-US IPY traverse, and one as a test-bed to be deployed at the South Pole also in early 2009. Concurrently with this development project systems continue to be fielded for the GNET (see below), POLENET, and other PI projects. As a result of this MRI project UNAVCO now offers standardized power and communication system kits for rapid installation and robust data collection, including attention to long-term operation and maintenance issues. The polar technology project website, www.unavco.org/polartechnology, provides a community resource and includes technical reports and detailed information on individual components and systems for users interested in adopting any of the products from this MRI funded effort.

In 2007 UNAVCO received MRI funding for the proposal *Acquisition of a Terrestrial Laser Scanning System For Polar Research* and purchased a terrestrial laser scanner (TLS) LiDAR system for NSF-OPP funded research support. An Optech ILRIS 3D system was purchased at the end of the year, and operational support capability was built up during 2008 with pilot projects in Antarctica, Iceland, and the US. This survey instrument is complimentary to the suite of GPS equipment already available, allowing for much higher spatial density surveys of short distances. Considerable demand is expected for applications such as soil surface mapping, quantification of landforms, and change detection of slopes, rock glaciers, and glaciers. Current efforts are focused on the hardware, software, and workflow needed to best meet LiDAR data processing requirements.

Twenty-two Principal Investigator based Arctic projects encompassing a range of applications were supported during 2008 (Figures 1 and 2). Three infrastructure and operational projects were also supported, including training users of the Barrow and Summit Camp DGPS systems, and providing technical support for the Toolik Field Station GPS system. Table 1 summarizes projects supported, and Appendix A provides more detailed descriptions of the individual projects. The UNAVCO web site (www.unavco.org/polar) provides comprehensive and historical information related to Polar Programs support.

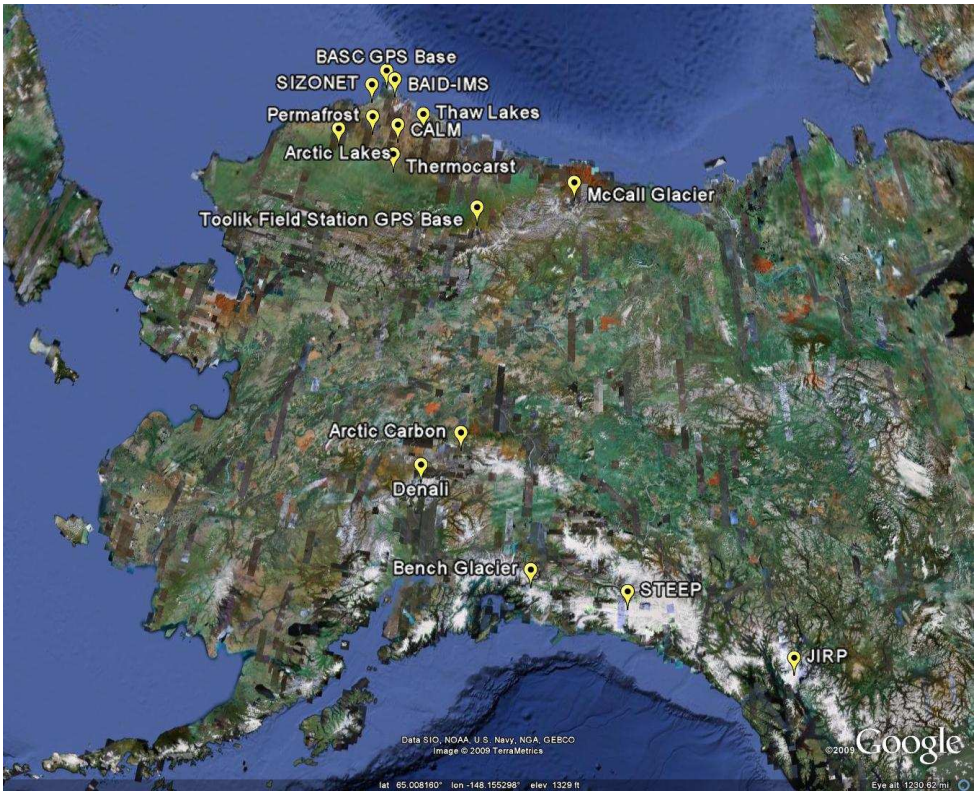


Figure 1 – Alaska research project locations in 2008.

Figure 2 – Greenland and Iceland research project locations in 2008.

Table 1 – 2008 Projects Supported

Project	Funding Source	Point of Contact	Eqp Loan	Quantity Rcvrs	Field Support	Training
Alaska:						
Arctic Carbon	ARC-0516326	Ted Schurr	X	2		
Arctic Lakes	ARC-0713903	Ken Hinkel	X	2		X
Barrow BAID	ARC-0454996	Craig Tweedie	X	1		X
Barrow SIZONET	ARC-0632398	Matt Druckenmiller	X	2	X	X
BASC GPS Base	ARC-UNAVCO CA	Glenn Sheehan	X	3	X	X
Bench Glacier	ARC-0454717	Josh Nichols	X	2		
CALM	ARC-0352958	Nikolay Shiklomanov	X	4		
Denali	ARC-0713974	Karl Kreutz	X	2		
Juneau Icefield Research Program	PI internal*	Scott McGee	X	4		
McCall Glacier	ARC-0229705	Matt Nolan	X	6		
Permafrost	ARC-0520578	Ronald Daanen	X	2		
STEEP	EAR-0409426	Jeff Freymueller	X	6		
Thaw Lakes Dynamics	ARC-0713813	Ken Hinkel	X	1		
Thermocarst	ARC-0732735	Guido Grosse	X	2		
Toolik Field Station GPS Base	ARC-UNAVCO CA	Jason Stuckey	X	2		
Greenland:						
East Greenland Glacier Dynamics	ARC-0710891	Meredith Nettles	X	26	X	X
Jakobshavn Isbrae	NNG06GB49G*	Martin Truffer	X	5		
Jakobshavn Mapping	ARC-0752848	Bea Csatho	X	3		
Jakobshavn MUSCOX UAV	CU/NOAA	John Adler	X	1		X
POLENET-GNET	ARC-0632320	Michael Bevis	X	12	X	X
Quarrasup	NASA	Ian Howat	X			
Southeast Greenland Mass Balance	DNSC*	Abbas Khan	X	6		
Summit GPS Base	ARC-UNAVCO CA	Bjorn Johns	X	2	X	X
Supraglacial Lakes	ARC-0520077	Sarah Das	X	5		X
Other:						
CAUSE-LiDAR	Penn State	Peter LaFemina	X	LiDAR	X	X

Science Support

The UNAVCO Facility provides GPS project management, equipment and field engineering support for principal investigator projects and for installing, operating and maintaining continuous GPS networks world-wide. UNAVCO also undertakes new technology development and evaluation of commercially available products for research applications, and archives GPS data and data products for future applications. The following highlights some of the resources and capabilities available for science project support:

- Expertise in program and project management, field engineering, technical support, and training
- Equipment and laboratory facilities for maintaining repairing, testing, and deploying equipment
- Systems integration and software development capabilities for custom applications
- Formal systems for property management, import/export, shipping and logistics; grant administration, project financial management, tracking, and reporting; established processes and procedures for supporting scientific research

These capabilities are drawn upon to provide support tailored to the needs of Arctic research projects as summarized below.

Training

Flexible options for field team training include training before deployment to the field, training in the field, and direct field engineering support during the project. The level of training is tailored to the experience of each research group. Training was provided in Boulder and Greenland for Summit Camp staff to familiarize them with the camp GPS survey system, and refresher training was provided in Barrow for several users of the GPS system at the Barrow Arctic Science Consortium (BASC). Project specific training was also provided for eight science projects as noted in Table 1.

The following courses from UNAVCO's Short Course Series and Workshops were relevant to, and attended by, several polar investigators:

Processing and Analysis of GPS Data with GAMIT/GLOBK/TRACK

September 23-25, 2008 UNAVCO: Boulder, Colorado. This course will provide group and (some) individual instruction in GPS data analysis, with Day 1 devoted to GAMIT and GLOBK for tectonic studies, Day 2 to polar and other kinematic applications of TRACK, and Day 3 to tutorials and in-depth discussion of advanced topics for both static and kinematic analysis. Faculty: Tom Herring, Bob King, and Simon McClusky, MIT; Matt King, University of Newcastle.

Processing and Analysis of GeoEarthscope and Other Community LiDAR Topography Datasets

April 29 - May 1, 2008 Arizona State University: Tempe, AZ. LiDAR—Light Detection and Ranging (also Airborne Laser Swath Mapping-ALSM) topographic data are of broad interest to earth scientists. Many datasets are or will be available freely to the scientific community, especially for fault systems in the western United States via the GeoEarthscope project. These data have exciting and powerful applications in geomorphology, active tectonics, and geoscience education. Participants in this course learned about LiDAR technology, access to publicly available datasets, software and hardware considerations for working with the data, data processing (raw or classified point clouds, digital elevation models, other derived products), and approaches for analyzing the data to answer their research questions. Faculty: Chris Crosby, GEON Project, SDSC; Ramon Arrowsmith, Arizona State University; David Phillips, UNAVCO.

Field Support

Field support is provided to groups that desire technical assistance for their geodetic GPS surveys. Direct field support was provided as noted in Table 1. Remote technical support is also provided via telephone, email, and documentation on the web.

Data Processing

Post-processing of differential GPS data is required to achieve millimeter to centimeter level precision, and UNAVCO supports data processing for field projects using Trimble TGO software, GAMIT/GLOBK/TRACK (see above), and the Canadian Spatial Reference System on-line data processing service The EarthScope/Plate Boundary Observatory data analysis system may be used to generate daily positions and position timeseries for permanent station data collected on the North American tectonic plate. Precipitable water vapor data can also be determined from GPS permanent station data using the University Corporation for Atmospheric Research (UCAR) COSMIC program's GPS-met analysis capabilities. In addition, GPS position timeseries are provided for GNET station KAGA, Summit Camp, and Barrow, and GPS-met data are produced for Atqasuk, Barrow, and Summit Camp.

Data Archiving

All GPS data handled by UNAVCO are archived at the Boulder archive to ensure data safeguarding and future accessibility. The data are organized by project name and year in an open access, searchable on-line database. Archiving services are available to all NSF sponsored geodetic GPS projects, not just those directly supported by UNAVCO, and all investigators are encouraged to archive their data immediately after project completion.

Science Advisory Committee

The Polar Network Science Committee allows for the direct participation of the polar science community in UNAVCO as a consortium that provides them with considerable resources in the era of large polar GPS networks such as POLENET. This committee, which reports to both the IRIS and UNAVCO Board of Directors is expected to coordinate input from the science/research community regarding polar networks and science requirements, advise and engage on polar GPS and proposal initiatives, and assist with the development of acquisition proposals for polar remote station components and systems. In 2008 the committee expanded adding two now members to provide better representation of Arctic investigators. Current membership is:

Doug Wiens, Washington University - Chair
Terry Wilson, Ohio State University – Vice-Chair
Sridhar Anandakrishnan, Pennsylvania State University
Rick Aster, New Mexico Tech
Mark Fahnestock – University of New Hampshire
Meredith Nettles – Columbia University
Carol Raymond, Jet Propulsion Laboratory
Bob Smalley, University of Memphis

Equipment and Technology

GPS Equipment Pool

GPS equipment is available for geodetic surveying, mapping, and permanent station applications. Fifteen new Trimble NetRS geodetic survey receivers were purchased (9 for GNET) for a total of 85 NSF-OPP Arctic Sciences receivers in the UNAVCO pool (Table 2).

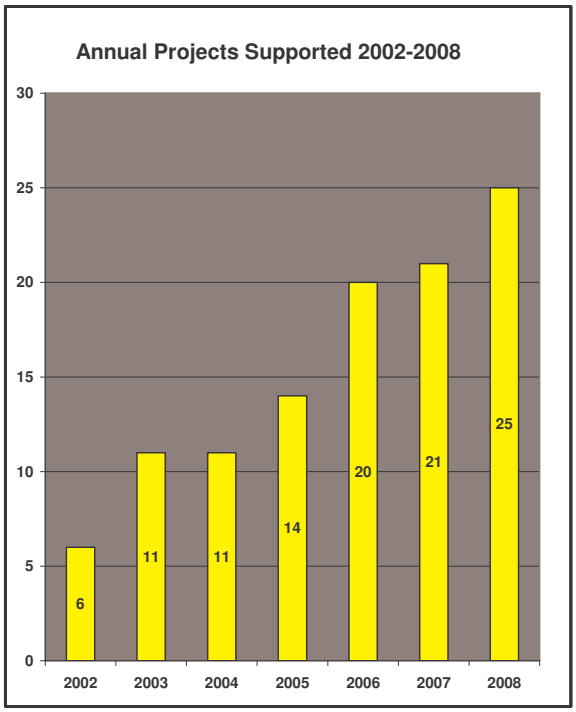
Eight of these receivers are deployed long-term at Atqasuk, Barrow, Summit Camp, and Toolik Field Station, and 29 are deployed as part of the GNET network (Table 3), including one at OSU as a "practice system" and one staged in Sodalen for installation in 2009. The equipment at the remaining five GNET sites was paid for by the University of Luxemburg and the Danish Technical university (DTU). Twenty-five additional receivers from the UNAVCO pool were provided for project support throughout the field season to meet high-precision GPS demands from the Arctic research community (Figures 3 and 4). Ancillary equipment such as data processing software, solar panels, batteries, chargers, tribrachs, tripods, and cables is also provided.

Table 2 – Arctic Equipment Pool

Item	Qty	Features and Applications	Average Age (yr)
Trimble 5700	7	Modern low power, high memory receiver suited for both short term and continuous data collection.	
Trimble R7	20	Same as the 5700, but also capable of tracking the new L2C GPS signal.	1
Trimble R8	1	1 TNL HB450	1
Trimble NetRS	57	State-of-the-art reference station receiver with computer and web browser interface, well suited for continuous data collection applications.	1
LiDAR scanner	1	Optech ILRIS 36D Terrestrial laser scanner	

Table 3 – Equipment Deployed Long Term at Remote Facilities

Location	GPS receivers	Radio modems	Other equipment (value > $1000)
Atqasuk ARM Facility	1 TNL NetRS		
Barrow Arctic Science Consortium	1 TNL NetRS 1 TNL R8 1 TNL R7	1 TNL HB450 2 PC RFM96-2W	2 TSC2 survey controllers
Summit Camp	1 TNL NetRS 1 TNL R7	1 TNL HB450	1 TSC2 survey controller 1 Vaisala WXT510 metpack
Toolik Field Station	1 TNL NetRS 1 TNL 5700	1 PC LPB Base 3 PC RFM96W Rovers 1 PC RFM96-35W	1 TSC2 survey controller
GNET (OSU+UNAVCO)	29 NetRS	27 Iridium	



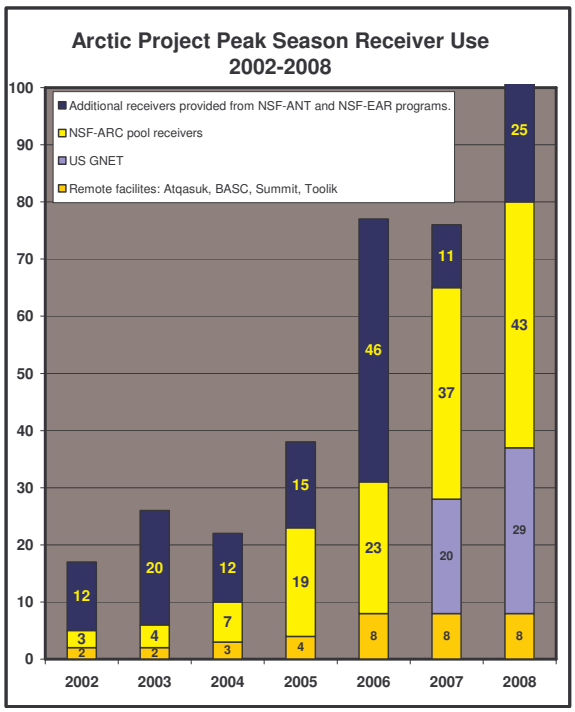


Figure 3 (left) - Support to Arctic research projects continues to grow.

Figure 4 (right) - Demand for receivers continues to increase with more research projects deploying larger number of receivers for ice dynamics and bedrock geodesy measurements in Greenland, and new receiver acquisition continues in response to this trend.

LiDAR

In 2007 UNAVCO received MRI funding for the proposal *Acquisition of a Terrestrial Laser Scanning System For Polar Research* and purchased a terrestrial laser scanner (TLS) LiDAR system for NSF-OPP funded research support. An Optech ILRIS 3D system was purchased at the end of the year, and operational support capability was built up during 2008 with pilot projects in Antarctica, Iceland, and the US. This survey instrument is complimentary to the suite of GPS equipment already available, allowing for much higher spatial density surveys of short distances. Considerable demand is expected for applications such as soil surface mapping, quantification of landforms, and change detection of slopes, rock glaciers, and glaciers. Current efforts are focused on the hardware, software, and workflow needed to best meet LiDAR data processing requirements.

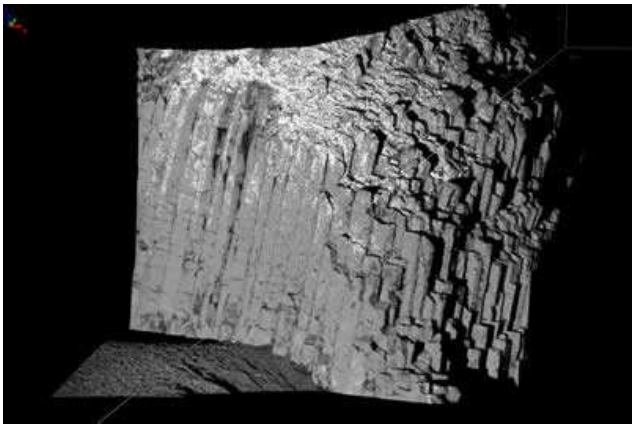


Figure 5 (left) – Caroline O'Hara and Caitlin Walsh scan a dike on a wall opposite Svinafellsjokull, in Skaftafell National Park, Iceland, as part of the Pennsylvania State University CAUSE undergraduate course.

Figure 6 (right) – An image of a 3-D point cloud generated by a scan of a spectacular set of columnar joints on a beach near Vik in southern Iceland.

Technology Development

Development activities of the ongoing MRI funded engineering effort *Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica* focused on minor refinements to the "continental margin system", and design of systems to operate in the extreme cold environment of the Polar Plateau. Three Plateau systems were built – two to be deployed in early 2009 at the Recovery Lakes area from the Norway-US IPY traverse, and one as a test-bed to be deployed at the South Pole also in early 2009. Concurrently with this development project systems continue to be fielded for the GNET (see below), POLENET, and other PI projects. As a result of this MRI project UNAVCO now offers standardized power and communication system kits for rapid installation and robust data collection, including attention to long-term operation and maintenance issues. The polar technology project website, www.unavco.org/polartechnology, provides a community resource and includes technical reports and detailed information on individual components and systems for users interested in adopting any of the products from this MRI funded effort.

Features of the MRI developed systems include:

- Solar panels and wind turbines for power
- Scalable battery bank size to accommodate various logistical capabilities and power requirements
- Small aircraft transportable
- Rapid set-up requiring a few hours of ground time rather than remote camping or multiple visits
- Ruggedized for the extreme polar environment
- Iridium communications for up to 1Mb/day data retrieval
- Scalable Iridium data download hub at UNAVCO, with GPS data delivery directly to archive
- Available to community as kits from UNAVCO

Atqasuk GPS Base Station

The Atqasuk, Alaska GPS station continued to operate without any major attention of field visits. The main purpose of this base station (ATQK) is to provide a local source of geodetic quality differential corrections for GPS data post-processing of surveys in the Atqasuk area on the Alaska North Slope. The station is located at the ARM Climate Research Facility (ACRF) which provides security, power, and Ethernet communications. The Trimble NetRS receiver is operated remotely by UNAVCO specifically for users who have requested base GPS data in Atqasuk similar to that provided by UNAVCO and the Barrow Arctic Science Consortium in Barrow. The station runs continuously and data are available to the public from UNAVCO. Higher sample rate data are also recorded on the receiver in hourly files, and are made available to users as needed. All data are available via the Internet, and there is no need for users to have physical access to the receiver.

Barrow Differential GPS System

Two Trimble real-time kinematic (RTK) differential GPS (DGPS) rover systems are available for dedicated use at the Barrow Arctic Science Consortium (BASC) to meet the surveying needs of researchers working at BASC. UNAVCO provides year-round technical support to users of this system and maintains a web page with the relevant system technical information, while BASC provides the day to day operational support including equipment scheduling and issue. To ensure the continued success of the Barrow system to local science users, UNAVCO staff makes annual maintenance/training visits, often in conjunction with related project requests. In April field engineer Marianne Okal visited Barrow to perform system maintenance and provide on-site training to science and BASC staff. System information, including access to GPS data, is available on the station web page at www.unavco.org/polar.

Summit GPS Base System

A permanent GPS base station and rover system is maintained at Summit Camp with real-time kinematic (RTK) surveying capability. The system consists of a continuously operating base receiver and a roving receiver with ancillary equipment. UNAVCO provides training to Summit science techs on demand, year-round technical support to users of this system, and a web page with the relevant system technical information. In addition to providing precision mapping and topographic surveying capability, the system also allows measurement of ice motion and yield data for atmospheric studies. Pressure, temperature, humidity, and column water vapor data derived from GPS are available on-line from UCAR. Station information, including access to GPS and met data, is available on the station web page at www.unavco.org/polar.

Toolik Field Station Differential GPS System

A permanent GPS base station and rover system is maintained is maintained at the Toolik Field Station to meet the surveying needs of researchers working in the vicinity of Toolik Lake on the north side of Alaska's Brooks Range. The real-time capability increases the system versatility in proximity of the station (for example it allows for stakeouts of pre-determined points), while the post-processing capability using Trimble Geomatics Office software extends the system radius to over 100km from the station. This year UNAVCO provided assistance to troubleshoot and repair the RTK radios. All other support was handled by the GIS/GPS staff at Toolik Field Station.

GNET

The POLENET Greenland IPY project (GNET) is an international effort led by Michael Bevis of the Ohio State University to install approximately fifty continuous GPS stations around the Greenland perimeter to apply bedrock geodesy to measure the response to past and present day ice sheet mass change (Figure 7). The US NSF funded portion of this project provides for 38 stations (including the UNAVCO led site KAGA). Most of the sites are remote and rely on solar and wind power and satellite data retrieval. Data management is provided by UNAVCO, and an Iridium based download system allows for full data retrieval from the remote stations, with on-line access at facility.unavco.org/data. Stations situated in villages are managed by GNET Danish collaborator Danish Technical University (DTU) and are currently downloaded as the opportunities arise. Figure 8 and Table 4 show the network and status at the end of December 2008.

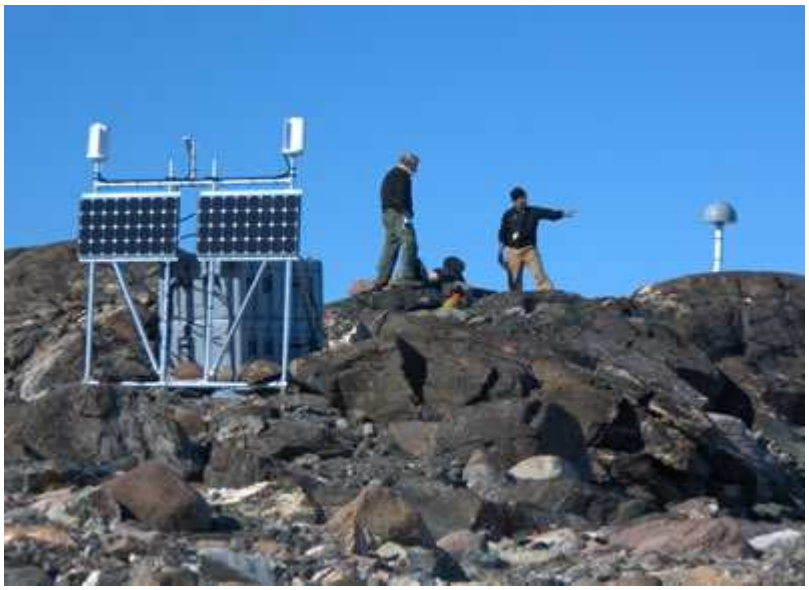


Figure 7 - Eric Kendrick and Finn Bo Madsen at Norske Oye (NRSK) site in northeast Greenland.

2008 was the second year of field installations, and UNAVCO provided, procurement, shipping and field support with very little lead time. Field engineer Thomas Nylen took the lead on the planning, preparation, and field deployment portion of project which resulted in 11 stations being installed in May and July. The entire GNET 2008 project was an international group effort that also included significant efforts by OSU, DTU, and CH2MHill Polar Services.

Figure 8 – Construction of the POLENET/GNET GPS network continued in 2008, with stations added in the north and southwest. When completed GNET will provide bedrock GPS sites around the entire circumference of Greenland.

Table 4 – GNET network status as of 31 December 2008

Site ID and health	Site "owner"	Communication link	Status 30 November 2008
MIKI	OSU	Iridium	Operational for 3 months per year, but buried in snow the rest of the time.
PLPK	OSU	Iridium	Operational
KSNB	OSU	Iridium	Operational
HEL2	U. Lux	Iridium	Operational
KBUG	OSU	Iridium	Modem answers, but no comms to receiver since Dec. 08, A maintenance trip in May 2008 found a defective Iridium modem but no loss of data.

LYNS	OSU	Iridium	Comms link down Jul. 08, SIM card is disabled, maintenance TBD
TREO	OSU	Iridium	Operational
HJOR	OSU	Iridium	Operational
UTMG	OSU	Iridium	Comms link down since Sep. 07, SIM card is disabled, maintenance TBD
TIMM	OSU	Iridium	Operational
NNVN	U. Lux	Iridium	Modem answers, but no comms to receiver since Dec. 08, A maintenance trip in May 08 found a broken Iridium antenna, but no loss of data.
SENU	OSU	Iridium	Operational
KAGA	UNAVCO	Iridium	Operational
QAAR	OSU	None	Data download by DTU
RINK	U. Lux	Iridium	Operational
UPVK	DTU	None	Data download by DTU
SRMP	U. Lux	Iridium	Operational
KULL	OSU	None	Data download by DTU
ASKY	OSU	Iridium	Comms link down since Nov. 07, SIM card is disabled, maintenance planned Sep. 09.
DKSG	OSU	Iridium	Operational
MARG	OSU	Iridium	Operational
KAGZ	OSU	Iridium	No satellite tracking since Jun. 08, SIM card is disabled, maintenance planned Sep 09.
SCBY	OSU	Iridium	Operational Apr. – Oct., needs power system upgrade, maintenance TBD
KMOR	OSU	Iridium	Operational
HRDG	OSU	Iridium	Modem answers, but no comms to receiver since Oct. 08, maintenance TBD
JWLF	OSU	Iridium	Comms link down since Sep. 08, SIM card is disabled, maintenance TBD
KMJP	OSU	Iridium	Operational
JGBL	OSU	Iridium	Operational
LEFN	OSU	Iridium	Modem answers

			occasioanlly, but no comms to receiver since Oct. 08, maintenance TBD
BLAS	OSU	Iridium	Comms link down since Sep. 08, maintenance TBD
NRSK	OSU	Iridium	Comms link down since Oct. 08, maintenance TBD
GROK	OSU	Iridium	Operational
Green	Station is operational with real-time data retrieval.		
Yellow	Station is most likely collecting data, but without communications we can not be certain. A site visit is required for data retrieval and communications maintenance/upgrade. Of the two sites visited for maintenance in 2008, both had experienced communication hardware failure but no data loss.		
Red	A site visit is required to resume data collection.		

Table 4 raises some issues about the GNET station reliability. Only one site is definitely not collecting GPS data, but the loss of communications to many of the remote sites is a concern. It is worth noting that rigorous pre-deployment testing should be standard operating procedure due to the expense of deploying these systems, but there has not been enough time to accomplish this between the time equipment orders are placed to when system are deployed in the field. Several actions are in progress to attempt to improve the reliability of future deployments:

[Note: Communications to six of these sites has been restored as temperatures increased in spring 2009. Winter rime ice or a batch of Iridium modems that do not meet temperature specs are suspected as the like loss of communication in the winter. There was no data loss from the sites and the winter data has been retrieved remotely.]

a. **Development of Standard Operating Procedures for qualifying remote location polar GPS systems.** This will include standard GPS receiver QC checks, testing the built up system board (GPS receiver, Iridium data modem, and power control components) in the UNAVCO environmental chamber when destined for extreme cold locations, and performing a "burn-in" test to capture infant mortality cases and allow for corrective action if problem components are identified. For future deployments, adequate lead time and staff time will need to be built into project planning, or the decision made to proceed with the acceptance of greater risk.

b. **Implementation of a change control process.** GNET and POLENET field deployments have occurred in parallel with development activities, thus there has been a tendency to propagate system improvements to the next field systems slated for installation. At this stage the design is mature enough to implement stricter change control. The process is simply a requirement that any changes to the baseline configuration are documented and approved by both UNAVCO and the project PI, which allows for expediency or further evaluation as appropriate

c. **Compile and evaluate system performance information as problem stations are visited.** Several stations in Antarctica will be visited during the 2008-09 field season and a thorough diagnostic procedure has been developed. This information will be evaluated and is expected to shed more light on what the issues are at the problem GNET stations. Isolated component testing will also be performed as warranted to substantiate plausible failure scenarios that arise.

d. **Attempt to coordinate GNET maintenance visits with other activities in the area.** Most maintenance visits can be accomplished with one person and about 100 lbs of science equipment and tool. As a result, it is possible to piggyback on other projects, as well as access several sites with fixed wing aircraft and

walk the remaining distance to the site. In practice this will require planning and coordination amongst the greater GNET stakeholder community well in advance.

e. **System design review meeting.** Development activities of the power and communications development MRI project have been pushed by the need to concurrently field systems for GNET and POLENET. The MRI project is in its third and final year and a small design review meeting is proposed to solicit feedback from community experts who have not been intimately involved in the design process.

f. **Additional test-beds at McMurdo station.** UNAVCO maintains a GPS testbed at McMurdo station to test new technologies or configurations before they are applied on science projects. There is a possibility that, in conjunction with POLENET, there may be an opportunity to set up several additional systems to duplicate remote GNET systems in a similar environment but with nearby technical support via the winter-over research associate.

Appendix A - Detailed Summary of Support Provided

ALASKA:

Arctic Carbon (Ted Schurr – University of Florida Gainesville)

Two receivers were provided to accurately map field site topography for the project goal to measure the carbon balance of Arctic tundra in response to permafrost thawing.

Arctic Lakes (Ken Hinkel – University of Cincinnati)

This project studies changes in lake dynamics on the Arctic coastal plain of North America over the past half century. Two GPS receivers were provided to validate remote sensing observations.

Barrow BAID-IMS (Craig Tweedie – University of Texas at El Paso)

The Barrow Area Information Database and Internet Map Server (BAID-IMS) is designed to help scientist, land managers, educators and the local comunity access spatially relevent information for northern Alaska. A dedicated rover RTK receiver system was provided to University of Texas at El Paso students and technicians to collect information on current and historical research sites and infrastructure which will be hosted in BAID-IMS. The GPS unit is also be used for monitoring coastal erosion of the Barrow region which will serve as data collection for a masters thesis.

Barrow SIZONET (Matt Druckenmiller – University of Alaska, Fairbanks)

The Seasonal Ice Zone Observing Network (SIZONET) project is researching the state of the Arctic sea ice cover. UNAVCO provided two RTK receiver systems and training for the fieldwork campaign on the sea ice near Barrow for mapping ice features and surface topography.

BASC GPS Base (Glenn Sheehan – Barrow Arctic Science Consortium)

Two Trimble real-time kinematic (RTK) differential GPS (DGPS) rover systems are available for dedicated use at the Barrow Arctic Science Consortium (BASC) to meet the surveying needs of researchers working at BASC. UNAVCO provides year-round technical support to users of this system and maintains a web page with the relevant system technical information, while BASC provides the day to day operational support including equipment scheduling and issue. To ensure the continued success of the Barrow system to local science users, UNAVCO staff makes annual maintenance/training visits, often in conjunction with related project requests. In April field engineer Marianne Okal visited Barrow to perform system maintenance and provide on-site training to science and BASC staff. System information, including access to GPS data, is available on the station web page at www.unavco.org/polar.

Bench Glacier (John Bradford - Boise State University)

This project is studying water storage and routing within glaciers and a new model of glacier hydrology. Two receivers were provided for GPS positioning control for GPR surveys and for geodetic precision measurements of glacier motion.

Circumpolar Active Layer Monitoring Network - CALM (Frederick Nelson – University of Delaware)

This was the eighth season this project used GPS to measure seasonal elevation changes in the permafrost active layer on the Alaskan North Slope. UNAVCO provided four GPS receivers.

Denali (Karl Kreutz – University of Maine)

Two receivers were provided to collect kinematic GPS data along the GPR lines for position control, to survey mass balance poles for velocity measurements, and to collect GPS locations for various ice core and snowpit sites in the park.

Juneau Icefield Research Program (Scott McGee – JIRP)

Four RTK receivers were provided to the Juneau Icefield Research Program in Alaska. JIRP was established in 1946 and is an annual glaciological research and educational program. Its goal for the past 62 years and into the future is to investigate and monitor the geology, ecology, glaciology, and meteorology of the Juneau Icefield, near Juneau, Alaska. Glacier survey work on the Icefield has been accomplished using theodolites and EDMs, and beginning in 1992, survey-grade GPS. The goal of the survey program is to determine and monitor annually the temporal and spatial velocity distribution of the glaciers on the Juneau Icefield, and to determine surface height changes of the glaciers and relate this information to the mass balance regime. Other GPS-related activities include topographic mapping of glaciers and bedrock outcrops and to provide GPS support for allied geology, botany, geophysics, and meteorology projects. Since this program is not NSF funded, JIRP covered the incremental costs of UNAVCO support.

McCall Glacier (Matt Nolan – University of Alaska, Fairbanks)

Mass balance measurements, surface velocities, cross-section profiles and continuous topography of McCall Glacier were made using real-time kinematic (RTK) surveys. The mass balance profiles were first measured in the 1990s with an airborne laser survey. These same points were re-occupied to determine vertical changes. The original network of velocity stakes was installed in 2003 and since then has been measured twice a year. Six receivers and RTK ancillary equipment were provided. The research on the glacier is part of a multiyear project funded by the National Science Foundation's Freshwater Initiative to study the hydrologic regimes of the several rivers flowing from the Brooks Range. Previous mass balance measurements on the glacier have been made during the International Geophysical Year in 1957-58, the International Hydrological Decade in 1969-1975 and the latter half of the 1990s. Because of this history, McCall Glacier has the longest monitoring record of any glacier in Arctic Alaska.

Permafrost (Vladimir Romanovsky – University of Alaska, Fairbanks)

Two receivers were provided for the survey needs of this project identifying the circumpolar thermal state of permafrost.

St. Elias Erosion/Tectonics Project (STEEP) (Jeff Freymueller – University of Alaska, Fairbanks)

The St. Elias Erosion/Tectonics Project (STEEP) is a multidisciplinary project to address the tectonics of the St. Elias Range, Alaska, and the linkage between tectonism and erosion in major orogenic belts. This project received funding from both NSF-EAR and NSF-OPP, and UNAVCO provided six receivers for the 2008 season.

Thaw Lakes Dynamics (Ken Hinkel – University of Cincinnati)

This project assesses dynamics of thaw lake morphology over the past 50 years. It has a collaborative component whereby lakes are assessed on multiple time scales and across multiple disciplines; determining lake energy budgets and evaporation rates seasonally and annually, determining decadal morphological characteristics with respect to sedimentation and erosional processes, and conducting surface area measurements to determine long term lake expansion or contraction via historical satellite imagery and aerial photography. One receiver was provided for surveys in the Barrow north slope area.

Thermocarst (Katey Walter – University of Alaska, Fairbanks)

Two receivers were provided for kinematic surveys of lake shoreline locations and elevations of lake shore bluffs and thermokarst relief features. The goal is to detect and monitor rates of change in lake extent as well as lateral and vertical changes in thermokarst basin extent. Digital elevation models will be generated from DGPS data of the shore bluffs.

Toolik Field Station Differential GPS System (Andrew Balser - University of Alaska, Fairbanks)

A permanent GPS base station and rover system is maintained is maintained at the Toolik Field Station to meet the surveying needs of researchers working in the vicinity of Toolik Lake on the north side of Alaska's Brooks Range. The real-time capability increases the system versatility in proximity of the station (for example it allows for stakeouts of pre-determined points), while the post-processing capability using Trimble Geomatics Office software extends the system radius to over 100km from the station. This year UNAVCO provided assistance to troubleshoot and repair the RTK radios. All other support was handled by the GIS/GPS staff at Toolik Field Station.

GREENLAND:

East Greenland Glacier Dynamics (Meredith Nettles - Lamont-Doherty Earth Observatory)

Outlet glaciers on the perimeter of the Greenland Ice Sheet continuously feed fresh water into the Atlantic Ocean at the zone where the cryosphere, hydrosphere, and atmosphere meet, a highly complex and insufficiently understood area. A large-scale remote sensing project was recently developed by a group of researchers from Lamont-Doherty Earth Observatory, Harvard University, the University of Maine, and the Institute for Space Sciences in Barcelona, Spain, with the aim of using GPS to better determine the dynamics of the glacial flow of these outlet glaciers. UNAVCO provided support for both the development and field portions of the project.

This study focuses on Helheim and Kangerdlugssuaq glaciers, which are located on the South-East coast of Greenland and together drain approximately 8% of the Greenland Ice Sheet. The project proposed to install 30 single-frequency (L1) GPS receiver systems equipped with radio communications on each glacier for a 15-month period from June of 2008 through August of 2009. The data are stored locally at each receiver site and transmitted

to one of six nearby dual-frequency GPS sites located on stable rock out-crops above the glaciers. Each rock-site will be equipped with a small computer to manage communications and store all incoming data, and with satellite (Iridium) communications that will transmit all data back to UNAVCO. The dual-frequency data recorded at the rock sites were used to obtain space and time corrections for the L1 ice data.

While the US and Spanish researchers developed the software, firmware, and communications portions of the project, UNAVCO created designs for and fabricated both the L1 ice-site enclosures and dual-frequency rock-site stations. 20 dual-frequency receivers from the UNAVCO pool were deployed on Helheim and Kangerdlugssuaq glaciers in June in order to collect a complete set of data for the summer. Four dual frequency rock sites were also installed on the nunataks in between the glaciers in June.

Development efforts continued through July, and in mid-August, the 20 dual frequency receivers were pulled from the glaciers, returned to UNAVCO, and replaced by 10 L1 systems. The units showed initial success in relaying data from the glaciers to the rock sites via radio communication, and then to UNAVCO via Iridium communication, but more development work is needed before the system is declared operational. The group will continue to develop the software and firmware throughout the fall, winter, and spring, with an anticipated deployment of the remaining units on Helheim and Kangerdlugssuaq glaciers at the beginning of the summer of 2009. The units that are already on the glaciers and software at the rock sites will also be upgraded at this time. Data will be collected all summer long and relayed back to UNAVCO as planned via Iridium satellite communications.

Jakobshavn Isbrae (Martin Truffer – University of Alaska Fairbanks)

Five receivers were provided for this project to measure velocities of Jakobshavn ice stream with high time resolution GPS, with the goal of finding the effect of the recent terminus retreat on the inland ice. Since this project is not NSF funded, the PI covered the incremental costs of UNAVCO support.

Jakobshavn Mapping (Jason Briner – University of Buffalo)

This project will link the paleo-record with historical data on the behavior of the Greenland Ice Sheet's fastest and most dynamic outlet glacier, Jakobshavn Isbræ, to quantify its sensitivity to temperature change. Specifically, this project will: 1) determine the rate of retreat of the Jakobshavn margin during the early and middle Holocene, a time period that was warmer than today; and 2) determine the timing of advance/retreat of the Jakobshavn ice margin during the Little Ice Age, quantify associated volumetric changes, and estimate the sensitivity of the margin to temperature change. The findings will constrain the sensitivity of the Greenland Ice Sheet to temperature change, knowledge that is urgent in the face of rapid contemporary changes in the ice sheet. Three receivers were provided to (1) survey glacial geological features, such as terminal moraines and melt water channels and (2) establish GCPs for precise orientation of satellite imagery and stereo aerial photographs

Jakobshavn MUSCOX UAV (Jim Maslanik – University of Colorado)

One GPS base station receiver and training were provided the Arctic MUSCOX (Arctic MUltisensor Cryospheric Observation eXperiment) project, a CIRES collaborative project between the National Oceanic and Atmospheric Administration and the University of Colorado at Boulder. The scientific goal of the 2008 Greenland Ice Sheet project is to assess the total amount of surface water in a region of the Jakobshavn Isbrae in the transition zone from an ice sheet at 1200 meter elevation, to an outlet glacier at sea level. The water volume of the supraglacial lakes, and their movements across the surface are not well understood, including how much water penetrates the glacier through crevasses and moulins. These fluvial processes could increase glacial velocity by lubrication of the ice/rock sediment interface at the bottom of the ice sheet.

Key to understanding the supraglacial water storage and flow patterns is the creation of a high-resolution digital elevation model (DEM) of the glacial region by using a near-IR laser and differential kinematic GPS onboard an unmanned aerial vehicle (UAV), and the UNAVCO GPS receiver was used as a reference base station

POLENET (GNET) (Michael Bevis – Ohio State University)

The POLENET Greenland IPY project (GNET) is an international effort led by Michael Bevis of the Ohio State University to install approximately fifty continuous GPS stations around the Greenland perimeter to apply bedrock geodesy to measure the response to past and present day ice sheet mass change. The US NSF funded portion of this project provides for 38 stations (including the UNAVCO led site KAGA). Most of the sites are remote and rely on solar and wind power and satellite data retrieval. Data management is provided by UNAVCO, and an Iridium based download system allows for full data retrieval from the remote stations, with on-line access at facility.unavco.org/data. Stations situated in villages are managed by GNET Danish collaborator Danish Technical University (DTU) and are currently downloaded as the opportunities arise. Figure 8 and Table 4 show the network and status at the end of December 2008.

2008 was the second year of field installations, and UNAVCO provided, procurement, shipping and field support with very little lead time. Field engineer Thomas Nylen took the lead on the planning, preparation, and field deployment portion of project which resulted in 11 stations being installed in May and July. The entire GNET 2008 project was an international group effort that also included significant efforts by OSU, DTU, and CH2MHill Polar Services.

Quarrasup (Ian Howat – Ohio State University)

A tribrach and tripod were provided for this project to measure short-term variations in flow speed near the calving front of a large Greenland outlet glacier.

South Greenland Mass Balance (Abbas Khan – Danish Technical University)

Data from the GRACE gravity satellite show there has been significant mass loss in southeast Greenland over the last several years. Most of this is presumably due to increased mass loss from the outlet glaciers in that region. Estimates of this mass loss could be much improved through the use of repeated GPS measurements on the glaciers (to obtain measurements of both the glacier thinning and changes in the flow speed); and of repeated GPS observations on bedrock near the ice (to detect uplift of the crust caused by the removal of nearby ice). Six receivers were provided for this effort. Since this project is not NSF funded, the PI covered the incremental costs of UNAVCO support.

Summit GPS Base (Bjorn Johns - UNAVCO)

A permanent GPS base station and rover system is maintained at Summit Camp with real-time kinematic (RTK) surveying capability. The system consists of a continuously operating base receiver and a roving receiver with ancillary equipment. UNAVCO provides training to Summit science techs on demand, is available for year-round technical support to users of this system, and maintains a web page with the relevant system technical information. In addition to providing precision mapping and topographic surveying capability, the system also allows measurement of ice motion and yield data for atmospheric studies. Pressure, temperature, humidity, and column water vapor data derived from GPS are available on-line from UCAR. Station information, including access to GPS and met data, is available on the station web page at www.unavco.org/polar. This year UNAVCO sent a field engineer to Summit Camp to perform system maintenance and science tech training.

Supraglacial Lakes (Sarah Das – Woods Hole Oceanographic Institute)

This project uses geophysical field measurements and remote sensing to investigate the role of Greenland's supraglacial lakes in delivering melt water to the ice sheet's bed and in modulating ice flow on short time scales. Recent results demonstrate a correlation between ice velocity and surface melt draining through moulins to the bed, which may provide a mechanism for rapid response of the Greenland Ice Sheet to climate change. Supraglacial lakes are one of the critical links between surface melting and enhanced basal flow, have the potential to rapidly respond to future climate change, and are the focus of the research project. The deployment of five receivers from UNAVCO was extended for another year of data collection.

OTHER:

CAUSE-LiDAR (Peter LaFemina – Pennsylvania State University)

CAUSE is a Penn State undergraduate course in the college of Earth and Mineral Sciences. The goals of this course are to study the implications of climate change, volcanism and tectonics on human society using examples from Iceland. UNAVCO provided a terrestrial LIDAR unit and field engineering support to investigate the morphology of glacial moraines, deformation of glacier toes and deformation associated with fissure eruptions.