Project Summary

UNAVCO supports principal investigators conducting a wide range of scientific research projects in Arctic and Antarctic regions. UNAVCO provides NSF-funded PIs geodetic engineering, equipment, and data management and archiving services. These core services are funded through the UNAVCO NSF Facility and Community 5-year Cooperative Agreement (CA). The core proposal for the Facility CA envisioned, but pending the outcome of associated PI project proposals, did not budget for two areas of enhanced support. The first is for Facility engineering support for continuous GPS network operations, data management and maintenance for PI networks that now includes POLENET, GNET, LARISSA, WISSARD, and other PI networks. The second is engineering support for Terrestrial Laser Scanning (TLS) field projects. In this proposal we request funding for staff for these two areas as well as project costs for four specific newly-funded PI proposals.

Intellectual merit: In support of fundamental advances in geophysics, initiatives undertaken as part of the International Polar Year 2007-2008 resulted in significant investment in network infrastructure for the ongoing geodetic observations in the polar regions. These networks provide first order constraints on the interactions between the cryosphere, lithosphere, hydrosphere, and atmosphere, and the evolving mass balance that governs changes in global sea level and climate. In particular, these observations advance understanding of vertical deformation associated with Glacial Isostatic Adjustment (GIA) of the land surface, glacier dynamics and wasting of the ice sheets, and tectonics. GPS provides important unique constraints on GIA that are critical to enable the retrieval of ice mass loss from the suite of ground, aircraft and satellite observations being made by the international scientific community. Collectively these networks are helping to better characterize the volume and rate of ice mass loss over a spectrum of time scales and improve our understanding of the geodynamics of the lithosphere. They also form a framework for denser observations in pursuit of more focused regional and local investigations.

TLS resources will support a wide range of geoscience investigations including detailed mapping of surfaces and changes in surfaces including fault scarps, geologic outcrops, fault-surface roughness, frost polygons, lava lakes, dikes, fissures, glaciers, columnar joints and hillside drainages.

The IPY investment has stimulated a surge of more detailed scientific investigations that were not anticipated at the time that UNAVCO's current core funding was planned. These investigations require ongoing support for infrastructure, data flow, engineering and data services, as well as community planning activities; these drive the need for this bridge-funding request.

Broader Impacts: Polar science investigations have direct relevance to changing global climate and sea level rise. Greenland and Antarctica are sensitive monitors of Earth systems in flux. Basic observations of the changing mass balance of ice caps, oceans, and the rebounding lithosphere characterize system feedbacks that threaten coastal and other at-risk communities. Direct observations of change rates and acceleration have broad societal impact and support efforts such as the Intergovernmental Panel on Climate Change (IPCC).

The facility support for polar studies lowers the barriers for broad investigator and student involvement in these science investigations, creating infrastructure and data sets that serve broad and diverse investigator communities. The broadest impact of the project is through the university partners whose research is supported. These investigations commonly involve students and early career investigators, and thus directly support workforce development. The impact on national competitiveness, both through science contributions and on workforce development, is largely realized through UNAVCO community investigators whose students and post-docs are enabled by facility support.

Project Description

A. Introduction

UNAVCO is a non-profit membership-governed consortium that facilitates geoscience research and education using geodesy. On behalf of its 155 Members and Associate members and its sponsors UNAVCO supports and promotes scholarly research using high precision geodetic techniques such as GPS, InSAR, LiDAR and Strainmeters. UNAVCO's activities are guided by its community-developed strategic plan for 2009-2013 (Positioning UNAVCO: Advancing Science through Geodesy, 2009). The vision statement in this plan is "*We challenge ourselves to transform human understanding of the changing Earth by enabling the integration of innovative technologies, open geodetic observations, and research, from pole to pole.*" The statement and plan articulate the growing role of polar geodetic activities in the UNAVCO Community research and evolving need for UNAVCO polar support services. Support to the NSF Office of Polar Programs (OPP), NSF Earth Science (non-EarthScope), and NASA research communities is funded under the 2008-2012 Community and Facility Cooperative Agreement (CA) "Geodesy Advancing Earth Science Research".

Through the Facility CA UNAVCO operates one of the world's premier polar geodetic support facilities for the NSF OPP-funded investigators. Projects conducted by polar PIs with support from UNAVCO have made substantial contributions to many of the major advances in polar research over the last 17 years. UNAVCO meets the unique needs of cryospheric research by providing a focused community resource offering specialized technical expertise and support capabilities required for polar regions. The range of services includes equipment, training, project planning, field support, proposal assistance, technical consultation, data processing, and data archiving for PI projects. Glaciology and crustal deformation research are the major applications, but precise geodetic survey capability is used regularly by other disciplines including geology and biology.

The core proposal for the Facility CA envisioned, but pending the outcome of associated PI project proposals, did not budget for two areas of enhanced support. The first is for Facility engineering support for continuous GPS network operations, data management and maintenance for PI networks that now includes POLENET, GNET, LARISSA, WISSARD, and other PI networks. The second is engineering support for Terrestrial Laser Scanning (TLS) field projects. In this proposal we request funding for staff for these two areas. We also request funding for the materials and supplies for four specific newly-funded PI companion projects that exceeds our ability to support using pool resources. These science projects have been peer reviewed and approved by the cognizant NSF program directors, and the UNAVCO costs have been identified and allocated. This proposal serves as the vehicle for routing the necessary funding to UNAVCO for these four projects.

B. GPS Network Research Activities to be Enabled

The establishment of continuously operating GPS networks in polar regions is a key outcome of the increase in funding made available as part of the International Polar Year (IPY) 2007-2008. These networks are designed to measure Glacial Isostatic Adjustment (GIA) of the land surface, tectonics, and glacier dynamics, and they are a major advance in addressing many compelling questions in polar science. UNAVCO is currently providing operation and maintenance support for nearly 100 stations through incrementally negotiated funding with NSF-OPP sponsors, but has been requested to submit this proposal to identify and justify the support required until the end of the current Cooperative Agreement in December 2012. We present below highlights of the science being done by the PI community that will be supported by the facilities and capabilities proposed here. Later in the proposal we provide additional resource justification and a summary of the most important network engineering responsibilities.

B.1 Solid Earth Geophysics. For the POLENET component of the IPY initiative U.S. and international collaborations were established to install and operate over 100 new GPS stations in remote areas of Greenland (GNET project) and Antarctica (ANET, LARISSA projects). This ambitious goal is nearly completed (Figure 1) with the final installations for POLENET planned for 2010-2011 field season. This achievement is perhaps more remarkable when it is considered that as recently as 2006 in UNAVCO/IRIS NSF OPP-funded MRI proposal "Development of a Power and Communication Systems for Remote Autonomous GPS and Seismic Stations in Antarctica" it was noted that *"Operating [remote] stations for more than one year without servicing* *<u>has not yet been achieved</u>* *because of the lack of a power/communication system sufficiently robust and lightweight to permit autonomous station operation year-round over several years."* The polar MRI was funded as a UNAVCO/IRIS project to provide a focused engineering effort to meet the anticipated needs of projects such as POLENET. This MRI built upon pioneering efforts of UNAVCO, IRIS and the PI community and developments from this project contributed significantly to the successful deployments for POLENET. The power and communications systems designed for the MRI also form the nucleus of new IRIS and UNAVCO equipment pools.

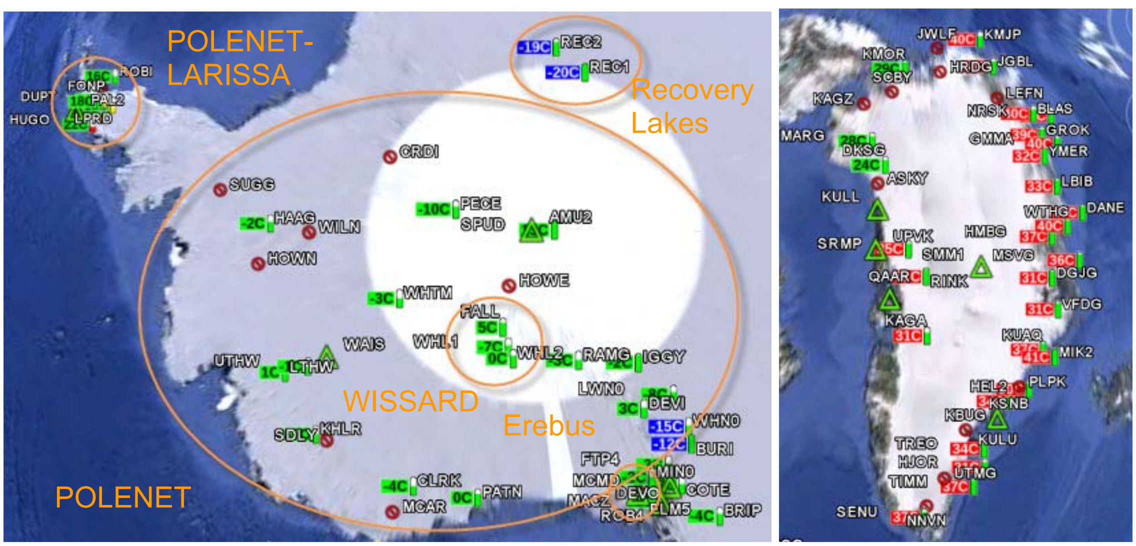

Figure 1. (left) A current view of permanent, continuously operating GPS stations (CGPS) in Antarctica (including POLENET/ANET, POLENET/LARISSA, WISSARD, Erebus and Recovery Lakes) and **(right)** Greenland (including POLENET/GNET) with data available through the UNAVCO Data Center. In addition to daily downloading from most sites, state-of-health data are captured. Receiver on-board temperature and battery voltage is shown through a Google Earth layer developed by the Antarctic Geospatial Information Center.

These continuously operating GPS stations and other geodetic techniques such as InSAR, LiDAR (LVIS, ATM, IceSAT), and gravity (GRACE) are providing valuable observations for a number of polar scientific research areas. Over the longer term (years to decades) geodetic measurements can be used to measure and study postglacial rebound (PGR). For example, spatial variations in the background secular trend of crustal motion derived from bedrock GPS sites are being used to test and improve PGR models in Antarctica (e.g. Bevis, et al., 2009). A complication, and study by its own right, is the superposition of time-variable deformation signals from the elastic response to contemporary changes of ice loads upon the background secular signal (e.g. Khan et al., 2008 and 2010; Jiang, et al., 2010). The combination of ground based GPS measurements, remote sensing, and PGR models allow for better accuracy in the determination of changes in polar land ice mass, an important climate change parameter.

Until the recent installation of POLENET stations the number of longer running CGPS stations in polar regions was limited to locations at or near research stations. However, data from these older existing stations, and additional but sparse campaign observations, have shown the value and promise of acquiring a long time series of GPS data in these areas. The results have been presented in several recent papers that form the basis of the argument for providing continued operational support of these new polar networks. The PIs of the POLENET-ANET network present a comparison of observations from 11 CGPS stations across Antarctica and repeated campaign observations from the 12 station regional West Antarctic GPS Networks (WAGN) in Bevis, et al. 2010. They note that the pattern of GPS-derived vertical velocities is inconsistent with PGR models UH95 and ICE05G that appear to over predict uplift rates in the Transantarctic Mountains and West Antarctica and under predict them in the Antarctic Peninsula north of 65 degrees. The implication is that GRACE-derived ice mass rate estimates, which are dependent upon a PGR correction, over predict ice loss for the continent as a whole. In Antarctica and in Greenland denser networks of CGPS will provide better estimates of crustal velocity which in turn will help constrain PGR models and ultimately provide better estimates of the rate of ice loss. Many of the WAGN sites have been upgraded in the last few years to CGPS as part of POLENET-Antarctica. Continuous observations will provide improved estimates of vertical velocities, enable assessment of annual local environmental loading signals, and will avoid aliasing problems from sparsely observed (in time) episodic campaign surveys.

In Greenland, data from the few available long term GPS data sets have been used to detect rate changes in the vertical crustal motion signal. Figure 2 from Khan et al., 2010, shows a comparison of GPS vertical time series from CGPS stations at Thule Airbase (THU3) in northwest Greenland and Kulusuk (KULU), and Kellyville (KELY) in southern Greenland. Annual, semi-annual and PGA model uplift rates have been removed. Uplift time series derived from GRACE gravity data generally agree well with the GPS data though in detail there are some differences. Station KELY shows generally steady uplift in response to on-going ice mass loss; stations KULU near Helheim Glacier shows an onset of rapid uplift in 2003 followed by moderate deceleration in 2006; and station THU3 shows a rapid acceleration of uplift in late 2005. The spatial patterns apparent in this limited GPS data set and in the GRACE data indicate that the acceleration of ice loss that started in the southeast in 2003 has spread up along the northwest coast.

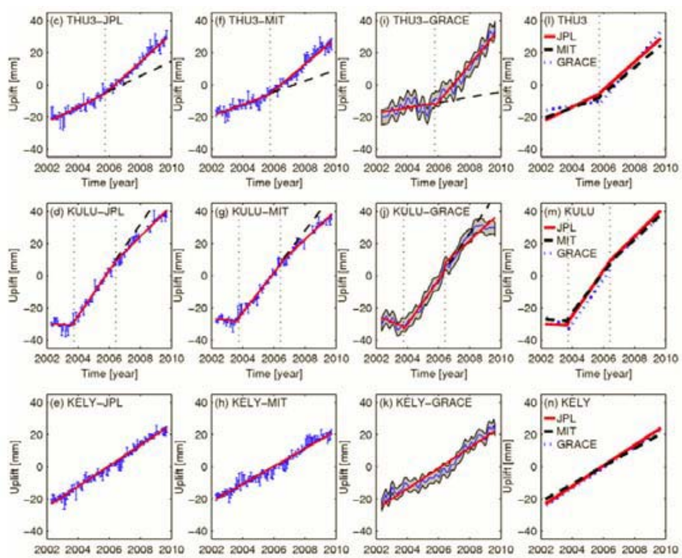

Figure 2. This figure compares 30-day vertical GPS averages for JPL and MIT processing at three sites (THU3, KULU, and KELY) with predicted uplift from GRACE gravity solutions (Khan et al., 2010). Rapid changes in rate and spatial variations are readily apparent in the 8 year long time series.

Jiang et al., 2010, looked at these same three GPS stations but extended the analysis as far back as 1996 and added QAQ1 at the southern tip of Greenland. They looked at perturbations to velocity rather than the velocity field itself since the results of this type of analysis are less sensitive to GIA-related motions. They note positive vertical accelerations that suggest accelerated Greenland melting. They used and elastic half-space model to calculate surface uplift resulting from ice melt along the Greenland's western and southeast coasts to estimate the instantaneous ice loss that corresponds to the vertical accelerations. The acceleration in ice loss estimated from GPS extrapolated along the coasts agrees with that observed with GRACE. Clearly going from a few stations to over ~50 stations with the addition of GNET will allow for better determination of regional variations and calibration of the vertical position data for annual ice oscillations. The results demonstrate the potential to GPS look at decadal time scale changes in the rate and timing of ice loss. An additional target of solid earth geodetic research in polar regions is the tectonics of the West Antarctic Mountains and volcanic deformation of Mt. Erebus.

B.2 Glacial Dynamics. Monitoring the flow of glaciers can be done in a number of ways, including on-the-ice GPS measurements. The distinct advantage of this method, as compared to satellite-based image/InSAR processing is the high time-resolution the GPS data provides. With GPS we can monitor the flow of glaciers (and as importantly, changes in that flow field) at time-scales ranging from seconds to days, whereas the image/SAR based techniques generally depend on differencing data that were collected days or weeks apart. For many applications the longer averaging time is appropriate but some glaciers have shown significant flow speed variations over shorter timescales, and the best way to detect those phenomena is using GPS stations deployed on the ice.

We have supported researchers who have successfully performed a number of summer-only experiments in Antarctica and Greenland that have demonstrated the influence of tides and earthquakes on glacier flow. The winter-over deployment of GPS will allow glaciologists to investigate whether season environmental forcing (temperature and sea-ice cover, for example) could lead to variations in flow speed.

Since 2007 19 MRI developed ice CGPS stations have been deployed across Antarctica, including sites on Thwaites (S. Anandakrishnan, POLENET/ANET) and Pine Island (D. Holland) glaciers (major West-Antarctic outlet glaciers), Whillans Ice Stream (S. Tulaczyk, WISSARD, figure 3 and figure 4) , the Antarctic Peninsula (T. Scambos, LARISSA, figure 5), and Recovery Lakes (T. Scambos). UNAVCO also runs a “Plateau-system” test site at the South Pole station. Twelve more systems are planned for the WISSARD project in 2010 and 2011.

Figure 3. (left) U.C. Santa Cruz researcher Slawek Tulaczyk and British colleague John Woodward set up a UNAVCO-designed GPS station on the Whillans Ice Stream to help them acquire a continuous record of motions of the ice surface above subglacial lakes that regularly drain and fill. **(right)** The UNAVCO GPS systems for ice applications are designed to be transportable by snow machines, capable of providing year-round data and communications, and capable of being installed by researchers and their teams. Photo Credit: Undergraduate student Saffia Hossainzadeh who is also shown in this figure leaving the field site.
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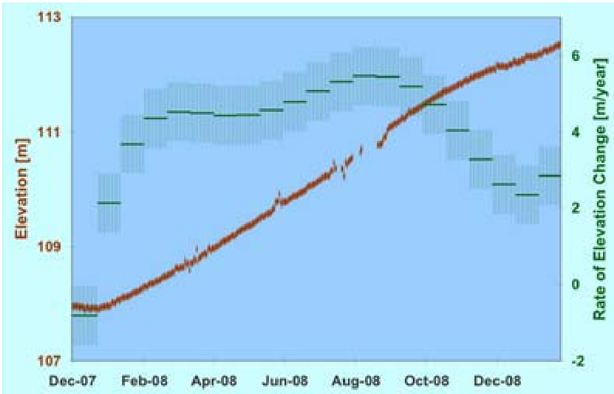

Figure 4. (left) GPS record of ice surface elevation changes (brown symbols, left scale) and the rate of elevation change (green lines, right scale) above subglacial Lake Mercer, located under the West Antarctic Ice Sheet. The rate of elevation change was averaged for 20-day intervals; uncertainties are shown by error bars as one standard error. The measurements from this station (WHL1) installed in 2008, a second one installed in 2010 (WLH2) as well as additional stations planned for WISSARD will enable researchers to quantify dynamics of subglacial water flow beneath the ice sheet and verify if dynamic water flow between these subglacial lakes induces changes in the sliding rate of the overlying ice sheet. Figure provided by Slawek Tulaczyk. **(right)** Image from realtime status maps from the two WISSARD GPS sites equipped with satellite telemetry. GPS data and state-of-health information such as system temperature (shown) are relayed to UNAVCO on a daily basis via Iridium communications satellites.

The LARsen Ice Shelf System, Antarctica, (LARISSA) project is a National Science Foundation funded initiative that brings an international, interdisciplinary team together to address a significant regional problem with global change implications, the abrupt environmental change in Antarctica's Larsen Ice Shelf System. LARISSA includes a continuous GPS network component operating on the Antarctic Peninsula. Six stations of UNAVCO MRI design are installed on bedrock to measure post-glacial rebound to help reconstruct the detailed configuration of the northern Antarctic Peninsula Ice Sheet (APIS) during the Last Glacial Maximum (LGM) and subsequent retreat. Two of the ice system design stations were installed on outlet glaciers from the Bruce Plateau. The bedrock CGPS stations are also a part of the POLENET IPY project.

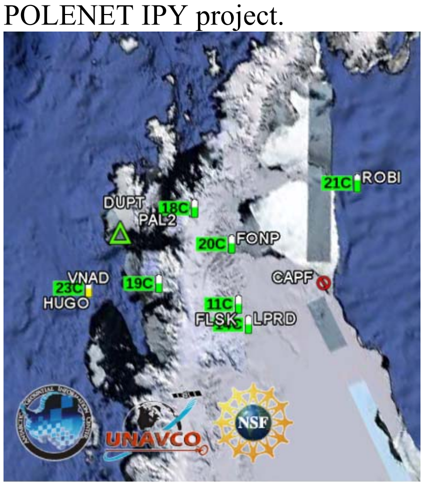

Figure 5. (left) The LARISSA bedrock CGPS network. Eugene Domack of Hamilton College is shown installing one of the stations in 2010 **(center)**. Materials were transported by helicopter from the N. B. Palmer research vessel **(right)**. (http://www.hamilton.edu/news/exp/LARISSA/index.html)

B.3 Polar Networks Science Committee. The Polar Networks Science Committee (PNSC) was chartered to coordinate input to IRIS and UNAVCO from the science community regarding polar geodetic and seismic instrumentation, networks and science requirements, and to provide information to the research community on the capabilities of the facilities. This eight member committee is charged with engaging and advising on polar GPS and proposal initiatives and assisting with the development of acquisition proposals for polar remote station components and systems. The PNSC reports to both the IRIS and UNAVCO Boards of Directors. It is the forum 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. The PNSC meets annually and UNAVCO and IRIS share the responsibilities of providing travel and meeting logistical support (http://www.unavco.org/community/governance/committees/committees.html).

B.4 GPS Network Operations and Maintenance Support. The MRI proposal Collaborative Research: Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica has resulted in power/communication systems that form the nucleus of a new support capability. During the past three years there has been a major push in both the Arctic and Antarctic to deploy remote, autonomous GPS and seismic systems, and the development gains of the MRI project have been applied almost immediately to field deployments. With this capability UNAVCO is facilitating long-duration deployments of CGPS stations, and is currently in a position to take on the operation and maintenance responsibility for nearly 100 stations (Table 1) in networks across the Arctic and Antarctic as described above. Access to the new systems has opened doors for scientists and institutions that do not have the technical and field skills currently required to execute remote polar GPS research projects, thus stimulating participation in polar science by a new generation of researchers. This proposal specifically requests the funding to transition from development activities to an operational role in supporting the polar autonomous CGPS networks, provide a systematic approach to keeping up with ever changing technologies, and make the MRI developed systems available to the broader community. We are requesting funding for one FTE with the following responsibilities:

1. Network Operations – Monitoring, Maintenance, and Upgrades
    a. Monitor, remotely troubleshoot and repair, and maintain station configuration database for:
        i. NSF-OPP supported PI CGPS networks such as POLENET and GNET (Table 1).
        ii. Community GPS base stations such as McMurdo, South Pole, Palmer, Barrow, Summit, Atqasuk, Jakobshavn, etc.
    b. Direct, advise and support field maintenance activities.
    c. Maintain dataflow from field sites to the UNAVCO data archive.
    d. Establish and maintain rigorous procedures for pre-deployment system testing, hardware culling, and change control appropriate for the extreme locations the systems are destined for, resulting in improved reliability.
    e. Compile and evaluate system performance information and recommend system improvements.
2. Sustained engineering, development and testing
    a. Provide design engineering support to field engineers and PIs for NSF-OPP funded science projects applying CGPS systems and networks. Examples include applying MRI proven "plateau system" wind turbine solutions to broader environmental regimes, and improving Iridium communication performance (RUDICS, cold hardening, and extending communications to instruments beyond GPS).
    b. Apply engineering development results to emerging projects.
    c. Incorporate feedback to maturing system designs which will result in improved reliability.
    d. Maintain South Pole, McMurdo, and Colorado test beds as appropriate.
    e. Provide new component testing and integration as necessitated by current product obsolescence (e.g., new GPS receivers, Iridium modems).
3. In-field support for polar networks O&M activities

Table 1. CGPS Stations with UNAVCO responsibility for O&M that fall under the oversight responsibilities of the proposed network engineer position.

	Site ID	Institution		Site ID	Institution		Site ID	Institution
ANT POLENET			**ANT WISSARD**			66	ASKY	OSU
1	BRIP	OSU	36	WHL1	U.Calif.	67	DKSG	OSU
2	BURI	LINZ	37	WHL2	U.Calif.	68	MARG	OSU
3	CAPF	Hamilton	**ANT EREBUS**			69	KAGY	OSU
4	CLRK	OSU	38	CONZ	NMT	70	SCBY	OSU
5	COTE	OSU	39	MACZ	NMT	71	KMOR	OSU
6	CRDI	OSU	**ANT LARISSA**			72	HRDG	OSU
7	DEVI	OSU	40	FLSK	U. Colo	73	JWLF	OSU
8	DUPT	Hamilton	41	LPRD	U. Colo	74	KMJP	OSU
9	FALL	OSU	**ANT INFRASTRUCTURE**			75	JGBL	OSU
10	FLM5	OSU	42	AMU2	UNAVCO	76	LEFN	OSU
11	FONP	Hamilton	43	PAL2	UNAVCO	77	BLAS	OSU
12	FTP4	OSU	44	MCMD	UNAVCO	78	NRSK	OSU
13	HAAG	OSU	45	DEVO	UNAVCO	79	GROK	OSU
14	HOWE	OSU	46	SPUD	UNAVCO	80	GMMA	OSU
15	HOWN	OSU	47	WAIS	UNAVCO	81	YMER	OSU
16	HUGO	Hamilton	**GREENLAND GNET**			82	DMHN	OSU
17	IGGY	OSU	48	MIK2	OSU	83	LBIB	OSU
18	KHLR	OSU	49	PLPK	OSU	84	DANE	OSU
19	LWN0	OSU	50	KSNB	OSU	85	WTHG	OSU
20	LTHW	PSU	51	HEL2	U. Lux	86	HMBG	OSU
21	MCAR	OSU	52	KBUG	OSU	87	MSVG	OSU
22	MIN0	OSU	53	LYNS	OSU	88	DGJG	OSU
23	PATN	OSU	54	TREO	OSU	89	VFDG	OSU
24	PECE	OSU	55	HJOR	OSU	90	KULU	U. Lux
25	RAMG	OSU	56	UTMG	OSU	**GREENLAND INFRSTRCT.**		
26	ROB4	LINZ	57	TIMM	OSU	91	SMM1	UNAVCO
27	ROBI	Hamilton	58	NNVN	U. Lux	**ALASKA YAKUTAT GLACIER**		
28	SDLY	OSU	59	SENU	OSU	92	SDS1	UAF
29	SUGG	OSU	60	KAGA	UNAVCO	**ALASKA INFRASTRUCTURE**		
30	UTHW	PSU	61	QAAR	OSU	93	BASC	UNAVCO
31	VNAD	Hamilton	62	RINK	U. Lux	94	ATQK	UNAVCO
32	WHN0	OSU	63	UPVK	DTU			
33	WHTM	OSU	64	SRMP	U. Lux			
34	WILN	OSU	65	KULL	OSU			
ANT RECOVERY LAKES								
34	REC1	U. Colo						
35	REC2	U. Colo						

C. Terrestrial Laser Scanning (TLS) Support

Terrestrial Laser Scanning (TLS), based on Light Detection and Ranging (LiDAR) technology, is part of a suite of new geodetic and imaging technologies that are becoming increasingly important for use in myriad research applications in polar regions. TLS, also known as ground based LiDAR or tripod LiDAR, offers an unprecedented capability to image at centimeter-level resolution 2.5-dimensional surfaces such as topography and fully 3-dimensional shapes such as rock or ice outcrops with overhanging features.

C.1 TLS Research Activities Enabled. TLS instruments are extremely precise, reasonably portable, relatively easy to operate, and have been used successfully to support a wide range of geoscience investigations including detailed mapping of fault scarps, geologic outcrops, fault-surface roughness, frost polygons, lava lakes, dikes, fissures, glaciers, columnar joints and hillside drainages. Moreover, repeat

TLS surveys allow the imaging and measurement of surface changes through time due, for example, to surface processes, volcanic deformation, ice flow, beach morphology transitions, and post-seismic slip. TLS is applicable to problems with areal extents at the 10-meter to kilometer level where detailed analysis is needed. Concurrent GPS measurements can provide accurate georeferencing of the TLS data and absolute 3D coordinates. Coincident high-resolution digital photography allows for the generation of photorealistic 3D images. TLS measurements complement SAR, airborne LiDAR, and spaceborne LiDAR techniques in providing smaller-scale, higher-resolution plots of important areas and by filling in areas inaccessible by these other techniques.

UNAVCO moved into TLS support for PI projects in 2007 with the funding of the polar TLS MRI project entitled “Acquisition of a Terrestrial Laser Scanner for Polar Research” (ANT-0723223). An Optech ILRIS-3D TLS and ancillary equipment were purchased, outfitted and deployed on a number of experiments over the next three years. During this period UNAVCO became expert in the operation and first phase of processing of TLS data. UNAVCO was also engaged in the NSF-EAR-funded INTERFACE project (EAR-0651566), a community collaborative project to develop TLS capabilities. UNAVCO engineers participated in OPP scanning projects and helped train PIs and their students in the collection and processing of TLS data. Starting with a few projects, the demand grew rapidly oversubscribing both equipment and UNAVCO engineer resources. As a result in 2009 UNAVCO and collaborators at Central Washington University submitted a successful proposal “Collaborative Research MRI: Acquisition of Terrestrial Laser Scanning Systems for Earth Science Research” (EAR- 0923539). Through this proposal, and supplementary funding to the UNAVCO core Facility and Community Cooperative Agreement, UNAVCO subsequently purchased four new TLS scanners and has six months of access to the CWU scanner. Though funded through NSF EAR, through agreement with the EAR-I&F Program Director, these scanners are available for use for OPP PI projects. As TLS technology is rapidly evolving it is highly desirable to postpone replacing the UNAVCO Optech which is now near end of life. The UNAVCO EAR TLS pool also has a broad range of capabilities that complements the Optech’s ~1,500m range. The newer instruments also have considerably faster data collection rates and more structured work flows than the Optech (Figure 6).

			
Leica ScanStation C10	**Riegl VZ-400**	**Riegl LMS-Z620**	**Optech ILRIS 3D**
• Short range (up to ~120 m) • Very fast data collection • Green laser, small spot size	• Moderate range (up to ~500 m) • Very fast data collection • Waveform analysis	• Long range (up to ~2000 m) • Fast data collection • Very robust	• Long range (up to ~1500 m) • UNAVCO unit accessorized for polar deployments

Figure 6. UNAVCO has four TLS instruments that have capabilities ranging from short to long range. It also shares a fifth Riegl VZ-400 with Central Washington University for community use.

To date the engineering resources to support OPP TLS projects have been absorbed under core funding as a background task. However, as the demand and availability of instruments has grown over the last several years this is no longer sustainable and so funding for a full time OPP TLS engineer is requested in this proposal. In addition to direct project support, this resource is needed to help develop documentation and to provide training for the new scanners. The new TLS engineer also needs to contribute to development of the archive of TLS data at UNAVCO so that we can ensure long term curation and distribution of valuable PI project data. TLS data are diverse including scan data, photos, GPS data and project metadata as well as first level processing such as merged scans. We present an example TLS project below and summarize in Tables 2 and 3 a list of the past and some of the 2010-2011 anticipated science projects utilizing TLS. Later in the proposal we provide additional resource justification and expectation for demands for OPP TLS project support in the future.

Example TLS Project: McMurdo Dry Valleys Long Term Ecological Research (LTER) Project. PI Peter Doran.

As part of the interdisciplinary McMurdo Dry Valleys LTER project (http://www.mcmlter.org/), UNAVCO is supporting Andrew Fountain in scanning of Canada Glacier (Figure 7). Initial scans of the glacier provide remote documentation and 3D mapping of the structure of this very ephemeral feature. Repeat scanning of the glacier toe allows for precise estimates of mass change. Overall the project is investigating the mass and energy balance of the glaciers in Taylor Valley. TLS measurements complement other mass balance measurements and data from a network of metrological stations. In the broader picture, the dry valleys represent a region where life approaches its environmental limits, and is an end-member in the spectrum of environments included in the LTER Network.

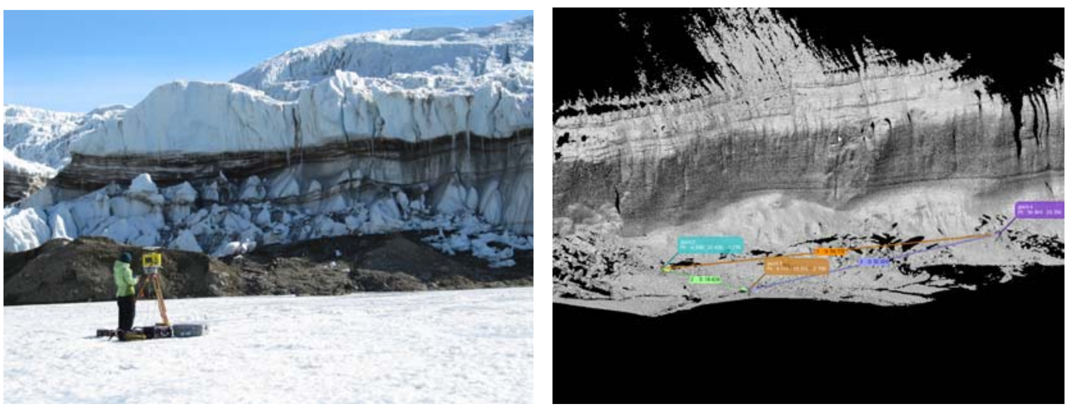

Figure7. UNAVCO Engineer Marianne Okal using the Optech scanner on Taylor Glacier in support of researcher Peter Doran’s requirement to tie the 3-D topography of the above lake glacial front to the underwater topography obtained from ROV sonar observations. The figure at the right is a “point cloud” of millions of precisely located (few cm-level) 3D scan points. Also shown are the locations of scanner setup locations and reference reflector points. GPS is used to tie the survey into a global reference frame. High-resolution optical photographs are taken from the scanner at the same time. These photographs can be used to colorize the point cloud or processed 3D surfaces.

UNAVCO provides archiving support for all data and metadata acquired with UNAVCO TLS instrumentation. Essential LiDAR data include the position and intensity of discreet laser returns that collectively form a "point cloud". Supplementary data typically include calibrated photographs for RGB coloring of point clouds and GPS data for georeferencing and point cloud alignment. Each TLS instrument owned by UNAVCO outputs a unique and proprietary data format that requires proprietary software to read and manipulate (e.g. Riegl RiScan Pro, Leica Cyclone, Optech Parser). Additional software is required for TLS data analysis (e.g. Innovmetric PolyWorks, Quick Terrain Modeler). UNAVCO currently makes these software programs available to PIs via remote access server. It should be noted that annual maintenance fees are required for several of these software packages. UNAVCO is working with the community to develop and implement best practices and exchange formats for optimal long term TLS data archiving and distribution.

C.2 Terrestrial Laser Scanning Support. One FTE is requested to meet the needs of NSF-OPP funded projects requesting TLS support until the end of the current UNAVCO Facility Cooperative Agreement

(31 December 2012). The MRI award *Acquisition of a Terrestrial Laser Scanning System for Polar Research* did not include any staff time, and since the instrument acquisition we have generated a large demand from the community as shown in Table 2, This position will report to the UNAVCO Polar Services Project Manager, with the following duties and responsibilities:

1. PI project support
This position will allow UNAVCO to continue to support this technology to NSF-OPP funded investigators in the future (the 2010-11 Antarctic season and beyond). Table 3 provides an overview of projects supported to date, and we anticipate this position will support six Antarctic and four (more distributed) Arctic field projects per year. Support includes pre-season planning, shipping, field support, training, data management and archiving, and post-season follow-up to ensure the appropriate resources are at the PIs disposal for processing and obtaining the desired data output.
2. Support capability development
This position will also be responsible for building the NSF-OPP LiDAR support program with attention to the development of equipment, software, procedures, instruction, and data management. This effort will be coordinated with the UNAVCO Geodetic Imaging Project Manager and the INTERFACE project to ensure the sharing of knowledge and expertise and the development of a consistent suite of equipment and support procedures.

Table 2. History of Antarctic TLS support and projects requested to date.

2007-08 Season:
-Pilot Projects at McMurdo Station, Dry Valleys UNAVCO
2008-09 Season:
-Lake Fryxell streambed channels. Science objective: Measure geomorphology of stream channels in response to summer melting and stream flow. Diane McKnight
-Canada Glacier calving face and surface topography Science objective: Measure evolution of "skirt" ice at the glacier/land interface as calving and melting occur. Andrew Fountain
-Wright Valley rock glacier Science objective: Observe ablation and movement of the rock glacier in order to determine the relationship between the rock glacier and hyper-saline pond. Andrew Fountain
-Mt. Erebus lava lake Science objective: Measure the change in lava lake levels on hourly and annual scales. Philip Kyle
-Beacon Valley polygons Science objectives: Quantify crack growth rates and polygon geometry changes. Ron Sletten
-Asgaard Range scarps Science objectives: Geological landform mapping of sandstone cliff features to identify erosional controls of area. Robert Ackert
-Upper Taylor Glacier scarps Science objectives: Create 3D map of scarps where prehistoric fossils were found. Allen Ashworth
-AGIC pilot project Science objectives: Create a 3D map of the Bull Pass area for pilot terrain mapping project. Paul Morin
2009-10 Season:
-Dry Valley snow patches Science objectives: Determine the ratio of snow absorbed by ground to snow ablated with the goal of determining the role the absorbed water has in bacteria colonies in ground. Michael Gooseff
-Mt. Erebus lava lake, fumaroles Science objectives: Measure the change in lava lake levels on hourly and annual scales. Quantify volumetric and geometric changes of fumaroles year to year. Philip Kyle
-Lake Bonney narrows, Taylor Glacier toe Science objective: Mesh TLS data of these features with underwater topography map of Lake Bonney to create a DEM of this portion of the Taylor Valley. Peter Doran

-Lake Fryxell streambed channels Science objective: Measure geomorphology of stream channels in response to summer melting and stream flow. Diane McKnight
-Dry Valley gullies, Science objective: Determine the role of water in gullies in the Dry Valleys, as compared to similar gullies on Mars. Barry Lyons
-Dry Valleys wind sculpted sand and gravel features Science objectives: Measure rate and quantify direction of motion of wave-like sand and gravel features. Jack Gillies
-Canada Glacier calving face and surface topography Science objective: Measure evolution of “skirt” ice at the glacier/land interface as calving occurs. Andrew Fountain
-Wright Valley rock glacier Science objective: Observe ablation and movement of the rock glacier in order to determine the relationship between the rock glacier and hyper-saline pond. Andrew Fountain
2010-11 Season requested:
-Dry Valley snow patches Science objectives: Determine the ratio of snow absorbed by ground to snow ablated with the goal of determining the role the absorbed water has in bacteria colonies in ground. Michael Gooseff
-Mt. Erebus lava lake Science objectives: Measure the change in lava lake levels on hourly and annual scales. Philip Kyle
-Garwood Valley ice cliffs, Canada Glacier calving front, Wright Valley rock glacier Science objectives: See above, continuation of previous years’ projects. Andrew Fountain
-Lake Fryxell streambed channels Science objective: Measure geomorphology of stream channels in response to summer melting and stream flow. Diane McKnight
-Oden shipboard TLS Science objective: Characterize the relationships between surface properties of sea ice and ice thickness and determine the impact of the sea ice cover on heat exchange. Stephen Ackley
-Beacon Valley frost polygons Science objectives: Quantify crack growth rates and polygon geometry changes. Ron Sletten

Table 3. History of Arctic TLS support and projects requested to date.

2009 Season:
-Thermocarst features Science objective: Determine physical, chemical, and biological characteristics and dynamics that collectively define “surface processes” at the hillslope to landscape scale. Michael Gooseff
2010 Season:
-Thermocarst features Science objective: Determine physical, chemical, and biological characteristics and dynamics that collectively define “surface processes” at the hillslope to landscape scale. Michael Gooseff
-North Slope tundra topography Science objective: Assess organic matter accumulation and ground heave in arctic tundra in North Slope area, Alaska. Craig Tweedie
-North Slope tundra topography Science objective: Identify ground heave and thaw subsidence measurements in Alaska. Nikolay Shiklomaonov
-Toolik Field Station support Objective: Toolik Field Station provides support to a variety of research in northern Alaska. The support team will use our TLS equipment to support different projects in the area. Jason Stuckey
2011 requested:
-Russell Glacier region topography Science objective: Examine the ice marginal marine environment in relation to monitored ice flow and ice structure at future natural dam site. Joel Harper
-Thermocarst features

Science objective: Determine physical, chemical, and biological characteristics and dynamics that collectively define "surface processes" at the hillslope to landscape scale. Michael Gooseff
-North Slope tundra topography Science objective: Assess organic matter accumulation and ground heave in arctic tundra in North Slope area, Alaska. Craig Tweedie
-North Slope tundra topography Science objective: Identify ground heave and thaw subsidence measurements in Alaska. Nikolay Shiklomaonov
-Shetland Islands Climate and Settlement Project Explore relationships among climate trends, severe and abrupt transformations of northern, coastal environments, and the ways in which human populations have adapted to these environmental crises and sometimes contributed to them. Gerald Bigelow
-McCall Glacier (not aware of funding decision yet) Science objectives: Computer annual mass-balance measurements. Matt Nolan

D. Antarctic project equipment budgets

As part of this proposal we are requesting the funds for equipment procurement to meet the needs of four Antarctic PI projects that exceeds what can be provided from the UNAVCO equipment pool. These science projects have been peer reviewed and approved by the cognizant NSF program directors, and the UNAVCO costs have been identified and allocated. This proposal serves as the vehicle for routing the necessary funding to UNAVCO since there is limited capacity for supplements to the UNAVCO Cooperative Agreement. The necessary equipment and materials for each project are identified in individual budget sections.

Project ANT-0632322: Collaborative Research: IPY: POLENET Using Bedrock Geodesy to Constrain Past and Present Day Changes in Antarctica's Ice Mass. PI Terry Wilson (Table 4).
The budget request is for materials needed for annual maintenance of the POLENET Antarctica GPS sites. The budgeted amount for 2010 reflects the specific new station installations and maintenance planning and accounts for materials already staged in Antarctica. 2011 and 2012 amounts are estimates based on past experience, and the specific annual requests will be affected by the latest network performance data and the specific field season logistics plans.

Table 4. Polenet support budget

Antarctic Polenet (July 1, 2010 - Dec 31, 2012)				
	7/1/10-12/31/10	1/1/11-12/31/11	1/1/12-12/31/12	TOTAL
OTHER DIRECT COSTS				
Materials and Supplies				
Misc. Materials and Supplies		71,617	75,195	146,812
GPS surge protector (35 @ $200 ea)	7,000			7,000
Power board PPS-DC-007 (11 @ $600 ea)	6,600			6,600
Iridium antenna + cabling (10 @ $450 ea)	4,500			4,500
Iridium surge suppressor (33 @ $100 ea)	3,300			3,300
Weather station + cabling (6 @ $2400 ea)	14,400			14,400
Structural frame PPS-TF-008 (6 @ $1100 ea)	6,600			6,600
Wind turbines Forgen 500 (15 @ $1000 ea)	15,000			15,000
Large enclosure Hardigg MM24 (3 @ $1000 ea)	3,000			3,000
Small enclosure Hardigg MM36 (3 @ $750)	2,250			2,250
Enclosure cradles (11 @ $150)	1,650			1,650
Toolkits (2 @ $500 ea)	1,000			1,000
Misc hardware, per site (36 @ $100 ea)	3,600			3,600
Total Materials and Supplies	**68,900**	**71,617**	**75,195**	**215,712**
Other				
Mailing/Shipping Costs (Domestic)	1,500	2,200	2,200	5,900
Total Other Costs	**1,500**	**2,200**	**2,200**	**5,900**
Total Other Direct Costs	**70,400**	**73,817**	**77,395**	**221,612**
Total Direct Costs	**70,400**	**73,817**	**77,395**	**221,612**
Total MTDC	**70,400**	**73,817**	**77,395**	**221,612**
UNAVCO, Inc., Overhead Rate (15.37%: 2010 & 16.25%: 2011-2012)	10,821	11,995	12,577	35,393
Total Costs - Engineering Group	**81,221**	**85,812**	**89,972**	**257,005**

<u>Project ANT-0944597: Collaborative Research: Byrd Glacier Flow Dynamics. PI Leigh Stearns (Table 5).</u>
The project will deploy a dense network of GPS receivers on the grounded glacier and floating ice shelf to examine the timescales of variability in the flow of the glacier. The field data will be used to constrain numerical models of the glacier's response to external forcing and understand its future mass balance characteristics. This budget is for hardware costs above and beyond the level of support that can be provided under the UNAVCO Cooperative Agreement. The budget estimate is based on the acquisition of 10 summer continuous GPS systems and eight year-round systems, four with wind turbines.

Byrd Glacier	
	2010 TOTAL
Equipment	
GPS receivers - Trimble NetR8 (18 @ $7,500 ea)	135,000
Total Equipment	**135,000**
OTHER DIRECT COSTS	
Materials and Supplies	
Polar Campaign Enclosure PCH-AS-001 (10 @ $900 ea)	9,000
18Ah batteries for PCH-AS-001 (20 @ $50 ea)	1,000
Batteries-100Ah gel cells (80 @ $240 ea)	19,200
Enclosures, with connections & insulation-MM24 (8 @ $1,000 ea)	8,000
Solar panels-50W (24 @ $500 ea)	12,000
Power board-UNAVCO (8 @ $260 ea)	2,080
Solar panel tower (8 @ $1,000 ea)	8,000
Wind turbines (4 @ $2,000 ea)	8,000
Misc material and supplies (8 @ $750)	6,000
Total Materials and Supplies	**73,280**
Total Other Direct Costs	**73,280**
Total Direct Costs	**208,280**
Total MTDC	**73,280**
UNAVCO, Inc., Overhead Rate (15.37%)	11,263
Total Costs - Engineering Group	**219,543**

Table 5. Byrd Glacier support budget

<u>Project ANT-0944794: Collaborative Research: Geophysical Study Of Ice Stream Stick-slip Dynamics. PI Paul Winberry (Table 6).</u>
This project will investigate the ongoing deceleration and stick-slip motion of Whillans Ice Stream (WIS), West Antarctica. Understanding the dynamic behavior of ice streams is essential for predicting the future of the West Antarctic Ice Sheet (WAIS). Recent estimates indicate that the WIS may stagnate within 50 years, resulting in a significant change to the mass balance of the Siple Coast sector of West Antarctica. This budget is for hardware costs above and beyond the level of support that can be provided under the UNAVCO Cooperative Agreement. The budget estimate is based on the acquisition of 12 summer cGPS systems.

Whillans Ice Stream (WIS)	
	2010 TOTAL
Equipment	
GPS receivers - Trimble NetR8 (12 @ $7,500 ea)	90,000
Total Equipment	**90,000**
OTHER DIRECT COSTS	
Materials and Supplies	
Polar Campaign Enclosure PCH-AS-001 (12 @ $900 ea)	10,800
18AH batteries for PCH-AS-001 (24 @ $50 ea)	1,200
Total Materials and Supplies	**12,000**
Total Other Direct Costs	**12,000**
Total Direct Costs	**102,000**
Total MTDC	**12,000**
UNAVCO, Inc., Overhead Rate (15.37%)	1,844
Total Costs - Engineering Group	**103,844**

Table 6. Whillans Ice Stream support budget

Project ANT-0838914: Investigating Antarctica's Role in Cenozoic Global Environmental Change: Phase 1 Site Survey. PI Frank Rack (Table 7).
In preparation for rock/sediment coring from the sea floor below the Ross Ice Shelf, the ANDRILL project needs to collect data concerning the movement of the Ross Ice Shelf (RIS) above the Coulman High seafloor formation. This movement includes the flow of ice as it moves from the Antarctic continent into the Southern Ocean as well as tidally-induced motions (horizontal and vertical) of the shelf. Part of the site survey includes the placement of GPS equipment to characterize the movement of the RIS over the course of a summer season and over the course of an entire year. This budget is for hardware costs for the year-round power and communication system, which is above and beyond the level of support that can be provided under the UNAVCO Cooperative Agreement.

Andrill	
	2010 TOTAL
OTHER DIRECT COSTS	
Materials and Supplies	
Batteries-100Ah gel cells (16 @ $240 ea)	3,840
Enclosures, with connections & insulation-MM24 (2 @ $1,00	2,000
Solar panels-50W (3 @ $500 ea)	1,500
Power board-UNAVCO (1 @ $260 ea)	260
Solar panel tower (1 @ $1,000 ea)	1,000
Iridium communications (1 @ $2,500 ea)	2,500
Misc material and supplies (1 @ $750)	750
Total Materials and Supplies	**11,850**
Total Other Direct Costs	**11,850**
Total Direct Costs	**11,850**
Total MTDC	**11,850**
UNAVCO, Inc., Overhead Rate (15.37%)	1,821
Total Costs - Engineering Group	**13,671**

Table 7. Andrill support budget

E. Management Plan

Enhancement and growth in both polar activities and TLS support has been specifically targeted as part of UNAVCO's new community developed Strategic Plan. The network engineering function of this proposal will be managed by the UNAVCO Polar Services Project Manager with the Polar Network Engineer position as a direct report. This is consistent with the current interim management. Network PIs are major stakeholders and it is expected that their needs are met with regards to the network engineering and monitoring services provided by UNAVCO.

The LiDAR engineering function will likely be spread amongst two or more polar field engineers and as such will be managed within the UNAVCO Polar Services section to ensure the most efficient project scheduling and PI support. A lead LiDAR engineer will be identified for the sake of ongoing support capability development, and will work closely with the UNAVCO Geodetic Imaging Project Manager to ensure that a unified and coordinated support capability is developed across the organization.

The project specific materials identified for the four Antarctic research projects will be managed by the UNAVCO lead engineer for each project, with overall accountability from the UNAVCO Polar Services Project Manager.

F. Broader Impacts

Polar science investigations have direct relevance to changing global climate and sea level rise. Greenland and Antarctica are sensitive monitors of Earth systems in flux. Basic observations of the changing mass balance of ice caps, oceans, and the rebounding lithosphere characterize system feedbacks that threaten coastal and other at-risk communities. Direct observation of change rates and their acceleration have broad societal impact and support effort such as the Intergovernmental Panel on Climate Change (IPCC).

The facility support for polar studies lowers the barriers for broad investigator and student involvement in these science investigations, creating infrastructure and data sets that serve broad and diverse investigator communities.

The broadest impact of the project is through the university partners whose research is supported. These investigations commonly involve students and early career investigators, and thus directly support workforce development. The impact on national competitiveness, both through science contributions and on workforce development, is largely realized through UNAVCO community investigators whose students and post-docs are enabled by facility support.

G. Results of Prior NSF Support

NSF Cooperative Agreement EAR-0735156, "UNAVCO Community and Facility Support: GeodesyAdvancing Earth Science Research", 1/1/2008–12/31/2012, PIs:
Meghan Miller, Charles M. Meertens, UNAVCO.

UNAVCO, Inc. is a non-profit member-governed organization that supports and promotes Earth science by advancing high-precision geodetic and strain techniques such as the Global Positioning System (GPS), InSAR, and borehole strain and tiltmeters. There are currently over 155 UNAVCO Members and Associated Members. Through this core NSF Cooperative Agreement, UNAVCO operates a Facility that provides engineering, an equipment pool, data, archiving, and information technology support to NSF (EAR and OPP), and NASA-funded peer-reviewed projects to study earthquake processes, mantle properties, active magmatic systems, plate boundary zone deformation, intraplate deformation and glacial isostatic adjustment, global geodesy and plate tectonics, global change, and polar processes. Through this award and with JPL UNAVCO operates and maintains the NASA Global GNSS Network. Additionally, UNAVCO supports UNAVCO Community activities including bi-annual national Science Workshops, short courses at the Facility, external advisory committee meetings, and support for education and outreach activities. Detailed reports of UNAVCO Facility activities and PI projects supported can be found at: http://www.unavco.org. Through a separate Cooperative Agreement with NSF UNAVCO maintains and operates the over 1,200 permanent stations of the EarthScope Plate Boundary Observatory.

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