2013 – 2018 UNAVCO Community Project Report
Geodesy Advancing Geosciences and EarthScope: GAGE Quarterly Report

Y3Q2: 01 January 2016 – 31 March 2016
EAR – 1261833
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0. Introduction

In this report, we present the program activities and broader impact of the second quarter of the third project year (Y3Q2) for Geodesy Advancing Geosciences and EarthScope: the GAGE Facility, under the NSF Award EAR-1261833 to UNAVCO, Inc. The report includes four sections: (1) UNAVCO Community, Governance and Management, (2) Geodetic Infrastructure Program, (3) Geodetic Data Services Program, (4) Education and Community Engagement Program, and three Attachments: UNAVCO Proposal Log, Budget and Variance Reporting, and Project Concerns. Each section is accompanied by performance metrics that chart the contributions and progress of the GAGE Facility. Throughout this report, we differentiate the work of the UNAVCO GAGE Facility and its activities from those of the UNAVCO university consortium, which is a community of scientists with associated university membership, governance, and oversight of the nonprofit corporation UNAVCO, Inc. and its management.

1. Community, Governance & Management

1.1 THE UNAVCO CONSORTIUM AND COMMUNITY

UNAVCO, a non-profit, university-governed consortium, facilitates geoscience research and education using geodesy. The consortium membership increased to 111 US academic Members, nearly all of which are degree-granting institutions that participate in UNAVCO governance and science community. Another 101 Associate Members include organizations that share UNAVCO’s purpose at home and abroad, giving it global reach in advancing geodesy. During the Y3Q2, three new Members finalized their membership:

- California State Polytechnic University - Pomona (Member)
- Colorado State University (Member)
- The Australian National University (Associate Member)

Three Geodetic Science Snapshots were published featuring results from community work including:

- Peering into a Volcano’s Interior with Lidar (University of South Florida)
- Geodetic Data Yields Rapid Earthquake Assessment (University of Iowa, Jet Propulsion Laboratory, Natural Resources Canada, California Institute of Technology)
- GPS Sensors Capture Glacial Earthquakes (University of Michigan)

Highlight

Community Science Workshop: Geosphere Science - Positioning UNAVCO, Advancing Geodesy

The theme of the 2016 UNAVCO Science Workshop: Geosphere Science – Positioning UNAVCO, Advancing Geodesy brought together over 200 community members in Broomfield, Colorado 29-31 March 2016. Geodesy is fueling discoveries in increasingly diverse disciplines. Recent key scientific findings span Earth’s cryosphere, lithosphere, hydrosphere, ionosphere, and atmosphere. Participants in the biennial UNAVCO Science Workshop explored how geodesy is enabling researchers to quantify processes that connect these spheres and tackle grand challenges in Earth Science. The two and a half day workshop included plenary sessions, special topics sessions, poster and interactive displays, short courses, field trips, Ignite! presentations, and an invited keynote speaker, Dr. Maria Zuber, Massachusetts Institute of Technology. Over 190 participants attending including with over 15 students supported by the GAGE Facility.
Dr. Maria Zuber of the Massachusetts Institute of Technology was the special guest speaker. Dr. Zuber’s presentation Adventures in Planetary Gravity. Dr. Zuber’s research bridges planetary geophysics and the technology of space-based laser altimetry and gravity systems. She recounted her personal journey of planetary and lunar exploration, contributing to and leading NASA science missions. She emphasized and modeled the importance of being able to effectively communicate your science to both scientists and non-scientists.

Five plenary sessions were organized around the cross-cutting themes of the geosphere with invited presentations leading scientists in each of the areas of cryosphere, lithosphere, hydrosphere, ionosphere, and atmosphere. Nine breakout Special Topic Sessions (STS) were convened by community and staff. The goal of each STS was to further planning for foundational and frontier science that relies on geodesy. Input was sought to guide the GAGE Facility in prioritizing resources to support science directions over the coming months and years under the current award as well as inform longer term planning within and across subdisciplines of the geosciences. Additional opportunities for community interaction included field trips, short courses, poster sessions, mentoring programs and organized themed-lunch discussions.

1.2 UNAVCO GOVERNANCE AND MANAGEMENT

UNAVCO Governance and Management activities for Y3Q2 included two face-to-face and two teleconference board meetings, as well as a meeting of the ECE Advisory Committee. Staff members represented UNAVCO at meetings and workshops as detailed below, including some PI foreign travel.

The 2016 UNAVCO Strategic Plan was published in March. The final Strategic Plan: Advancing the Geosciences through Community Support and Leadership, 2016-2020, is the result of six months of work by key stakeholders including UNAVCO governance and UNAVCO staff. Planning began with a June 2015
facilitated retreat of the Board of Directors, committee and working group chairs, and senior management with UNAVCO project managers and key staff provided input to the draft plan.

1.2.1 Governance Activities

Drs. Adrian Borsa, Estelle Chaussard, and Charles DeMets were all newly elected to the 2016 Board of Directors, which convened in Arlington, VA in January. The meeting culminated in a half-day session with 18 representatives from six different federal organizations, with the goal of coordinating geodesy resources in support of the National Plan for Civil Earth Observations. Two teleconferences and a second face-to-face board meeting were convened, the latter in Broomfield, Colorado during the week of the 2016 UNAVCO Science Workshop, in two different sessions.

The 2016 Education and Community Engagement Advisory Committee (ECE-AC) includes new members David Bice (Pennsylvania State University), Sarah Stamps (Virginia Tech), Peter Wehner (Austin Community College), Board of Directors liaison Chuck DeMets (University of Wisconsin), and graduate student representative Carson MacPherson-Krutsky (University of Montana). Andrew Goodwillie (Lamont-Doherty Earth Observatory) is chairman of the committee. The full membership is available online. The ECE-AC met twice during GAGE Y3Q2. A teleconference of the committee was held February 25. In advance of the meeting D. Charlevoix provided backup materials about the scope of work of the ECE Program. The meeting offered opportunity for additional review of scope of work as well as a discussion of pending proposals to support future initiatives including education materials, video development, internship program, and field education activities. Discussion included the role UNAVCO could play in a collaborative NSF-INCLUDES proposal with IRIS and other partners. A. Goodwille charged the committee with reviewing the NSF-INCLUDES (Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science) solicitation as well as the NSF-NGEO (National Geophysical Observatory for Geoscience) solicitation in advance of the March face to face meeting.

The ECE-AC met in person March 27-28 with a focus on developing and providing input related to ECE activities as they relate to the NSF-NGEO to the Board of Directors. All committee members were present for the meeting. ECE staff members shared updates on key activities including UNAVCO membership in the Portal to the Public network to facilitate community scientist outreach and unmanned aerial systems (UAS) for use in field education and K-12 education (as a part of the ESIP Federation Education Group). The majority of the meeting focused on identifying foundational activities of the ECE, frontier opportunities, and potential future synergies with other organizations and partners. The ECE-AC provided a formal report to the Board of Directors for their review.

1.2.2 Management Activities

During Y3Q2, two staff members left the organization, only one of whom will be replaced. The second position was funded from an award that is expiring. An Administrative Assistant for Human Resources and Business Affairs joined the organization.

1.2.3 UNAVCO Staff Representation at Meetings and Workshops, PI Foreign Travel

UNAVCO staff represented community interests and presented facility contributions at a number of meetings and workshops. UNAVCO governance and some informational meetings are also included here.

Attended by S. Baker.

- Septentrio PolaRx5 GNSS receiver training, Boulder, CO, February 17-18. Presented by Septentrio technical staff. Coordinated by F. Blume and attended by 46 staff members from GI and GDS.

### 1.2.4 Publications, Abstracts, and Other Products Created by UNAVCO Staff

#### Abstracts and Presentations:

- Blume, F., H.T. Berglund,, and Gallaher, W., (2105); Testing the Susceptibility of GNSS Receivers to Radio Frequency Interference; presented at IGS Workshop 2016, Sydney, Australia, February 8-12, 2016.
- Galetzka, J., TLALOCNet Project Update, Thursday Lecture Series at CICESE, Ensenada, Mexico, January 28, 2016.


1.2.5 GAGE Facility Products

UNAVCO supports community science and education through the development of products available via the UNAVCO website and Knowledgebase (Table 1-1). Products are publically available and accessed by community members as well as the general public.

Table 1-1. GAGE Facility products.

<table>
<thead>
<tr>
<th>GAGE FACILITY PRODUCTS</th>
<th>GAGE Y3Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datasets Published by DOI</td>
<td>24</td>
</tr>
<tr>
<td>Knowledge Base Documents Created</td>
<td>6</td>
</tr>
<tr>
<td>Knowledge Base Documents Updated</td>
<td>16</td>
</tr>
<tr>
<td>Highlights Published</td>
<td>6</td>
</tr>
<tr>
<td>Science Snapshots Published</td>
<td>3</td>
</tr>
</tbody>
</table>

UNAVCO Program Highlights are featured on the homepage of the UNAVCO website and provide summaries of UNAVCO activities, technology, engineering, education, and support. Six Highlights were published in GAGE Y3Q2. A short description follows each Highlight title.

- **New Google Community for UNAVCO Geodetic Data Services Technical News.** The GDS Technical News Page features information of interest to expert users in the geodetic community.
• **Back to the Mothership: How PBO Data Gets from Everywhere to Somewhere.** A summary of ongoing efforts to improve reliability and performance as well as expand capabilities by creating and upgrading multipoint radio networks throughout the PBO.

• **Data Event Response to the 24 January 2016 Mw 7.1 Earthquake 83 km E of Old Iliamna, Alaska.** Data only event response including high rate GPS data, GPS velocities, and borehole strainmeter data.

• **Data Available for Winter Storm Jonas.** A summary of data available for over 30 continuously operating GPS stations in the UNAVCO that fall within the footprint of the winter storm.

• **Data Event Response to the 2 March 2016 Mw 7.8 Earthquake Southwest of Sumatra, Indonesia.** Data only event response featuring borehole strainmeter data.

• **Installation of CORS cGPS Station in Sitka, Alaska.** In November 2015, UNAVCO engineers in collaboration with the City of Sitka installed station AKSI in Sitka, Alaska, on the historical Sitka Post Office.

### 1.2.6 Broader Impacts for Community, Governance and Management

**UNAVCO Websites.** The UNAVCO websites are managed by the Web Team (Web Editor in Chief and Web Administrators), Section Editors, and subject matter experts who contribute web content. Content for the seven main sections of the primary UNAVCO website (Community, Projects, Instrumentation, Data, Software, Science, and Education) are the responsibility of seven Section Editors.

As part of our Web Integration project, our goal is to retire pbo.unavco.org and facility.unavco.org once all dynamic content and applications have been migrated to www.unavco.org. In the interim, we use URL redirects to pbo.unavco.org in order to bring its content and applications into the www.unavco.org namespace in a virtual manner. We migrated our Knowledge Base into a new Knowledge Base platform accessible at www.unavco.org/kb that will soon run completely under the www.unavco.org namespace. With this major migration, facility.unavco.org can be retired from public view. Some internal applications, that are not publicly available, remain to be refactored.

We monitor user activity of the new integrated site to measure the usage and understanding of our new information architecture and to track broken links from outside parties. These insights enable us to provide iterative improvements to promote better site accessibility for all users. We are focusing on modernizing our Web Infrastructure, including IT infrastructure, server and application software, and reviewing best practices for building and maintaining this infrastructure with an eye towards virtualization and standardization.

The UNAVCO websites are a key resource for both the UNAVCO community and as a tool to reach beyond to educators and the general public (Table 1-2A). The GAGE Facility also provides infrastructure and maintenance support to websites for the Research Experiences in Solid Earth Science for Students (RESESS) and Continuously Operating Caribbean GPS Observational Network (COCONet) programs. A new TLALOCNet site is also under development. TABLE 1-2B shows the activity for individual domains UNAVCO is responsible for maintaining.

Table 1-2A. Quarterly activity for the primary UNAVCO websites. Number of users: quantifies the number of different site visitors. Session: the period time a user is actively engaged with our website. Users are those that have had at least one session within the past quarter (includes both new and returning users). Pageviews: the total number of pages viewed; repeated views of a single page are counted.

<table>
<thead>
<tr>
<th>WEBSITE IMPACTS</th>
<th>GAGE Y3Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Users</td>
<td>66,004</td>
</tr>
<tr>
<td>Number of Sessions</td>
<td>105,566</td>
</tr>
<tr>
<td>Page Views</td>
<td>251,332</td>
</tr>
</tbody>
</table>
Table 1-2B. Breakdown of Table 1-2A by third order domain. Note that these metrics will change in future reports with the reconfiguration of the web site.

<table>
<thead>
<tr>
<th>WEBSITE</th>
<th>NUMBER OF USERS</th>
<th>NUMBER OF SESSIONS</th>
<th>PAGE VIEWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y3Q2 <a href="http://www.unavco.org">www.unavco.org</a></td>
<td>60,781</td>
<td>97,772</td>
<td>235,740</td>
</tr>
<tr>
<td>Y3Q2 pbo.unavco.org</td>
<td>1,346</td>
<td>2,241</td>
<td>3,882</td>
</tr>
<tr>
<td>Y3Q2 reseas.unavco.org</td>
<td>3,109</td>
<td>4,317</td>
<td>9,472</td>
</tr>
<tr>
<td>Y3Q2 coonet.unavco.org</td>
<td>768</td>
<td>1,236</td>
<td>2,238</td>
</tr>
</tbody>
</table>

**UNAVCO Outreach and Broader Impacts.** Outreach activities are conducted by staff throughout the entire UNAVCO organization including Geodetic Infrastructure (GI) and Geodetic Data Services (GDS). This quarter multiple field engineers conducted visits to K-12 schools and several colleges. These visits focused on the science of the Plate Boundary Observatory in the local region as well as an overview of geodesy and UNAVCO. Through their personal experiences, the field engineers are able to share detailed information about what is involved in supporting scientific research. After these visits, the faculty tell the engineers that their anecdotal stories and pictures have made a lasting impression on the students who participated in these visits. The engineering staff are able to incorporate these visits into their travel when conducting standard operations and maintenance, bringing added value to their primary scope of work.

This quarter UNAVCO staff directly impacted 21,588 individuals (Table 1-4) through formal and informal interactions, reaching a diverse audience. As expected, the largest individual impact continues to be through the PBO-GPS museum exhibit at Hatfield Marine Science Center in Newport Oregon.

Table 1-3. Metrics for activities led and products produced by all UNAVCO Programs (GI, GDS, ECE).

<table>
<thead>
<tr>
<th>OUTREACH: ACTIVITIES (QTY)</th>
<th>GAGE Y3Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Courses</td>
<td>3</td>
</tr>
<tr>
<td>Education Workshops and Outreach Events</td>
<td>16</td>
</tr>
<tr>
<td>Internship Programs</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1-4. Number of people reached through the activities identified in Table 1-3, organized by audience. Researchers and research faculty include non-teaching faculty and researchers; college and university faculty include tenure and non-tenure track faculty. Other Professionals include anyone participating in activities for professional growth and development, who do not fall into one of the other professional categories. Examples of Other Professionals include Emergency Managers, Park Interpreters, Federal Agency staff, and Sponsors, among others. Large event visitors are individuals visiting museum displays and conference exhibit booths.

<table>
<thead>
<tr>
<th>OUTREACH: INDIVIDUALS REACHED (QTY)</th>
<th>GAGE Y3Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Researchers + Research Faculty</td>
<td>78</td>
</tr>
<tr>
<td>University + College Faculty</td>
<td>144</td>
</tr>
<tr>
<td>Post-docs</td>
<td>90</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>99</td>
</tr>
<tr>
<td>Undergraduate Students</td>
<td>73</td>
</tr>
<tr>
<td>Public / K-12 Students</td>
<td>187</td>
</tr>
<tr>
<td>K-12 Faculty</td>
<td>0</td>
</tr>
<tr>
<td>Other Professionals</td>
<td>49</td>
</tr>
<tr>
<td>Large Event visitors</td>
<td>20,868</td>
</tr>
</tbody>
</table>
2. Geodetic Infrastructure Program

2.1 OVERVIEW

This UNAVCO program integrates all geodetic infrastructure and data acquisition capabilities for continuously operating observational networks and shorter-term deployments. Supported activities include development and testing, advanced systems engineering, the construction, operation, and maintenance of permanent geodetic instrument networks around the globe, and engineering services tailored to PI project requirements. The GI program coordinates closely with Geodetic Data Services program (Section 3) to assure the highest standards of data quality control, integrity of metadata, ease and transparency of data access for the UNAVCO user community, and to provide appropriate and timely metrics on data usage for sponsors. Major projects currently supported by the GI program include the 1,132 station Plate Boundary Observatory (PBO) core and affiliated stations, Polar networks in Greenland and Antarctica (GNET and ANET, together known as POLenet), COCONet spanning the Caribbean plate boundary, the multi-disciplinary AfricaArray, and several other smaller continuously observing geodetic networks. One important milestone this quarter was that UNAVCO operations and management (O&M) support surpassed support of 900 cGPS stations globally in 63 different networks installed in support of PI projects.

The GI program provides engineering services to individual PIs for shorter-term GPS and TLS projects, and other investigator-led data acquisition that had been previously managed by the UNAVCO Facility. While a large share of GI resources in GAGE are tied to ongoing O&M of the PBO, GGN, and POLenet continuous GPS (cGPS) networks and ongoing support to PI projects, two key areas for enhancement were identified through community input and delineated in the GAGE proposal:

- The continued upgrade of PBO to high-rate (>1 Hz), low-latency (<1 s), well-hardened sites in order to support research activities related to dynamic fault rupture and volcanic eruption processes and for early detection of earthquake and volcano hazards and risk mitigation.
- Continued evaluation and upgrade of all GPS receiver pools for implementation of full GNSS capability.

Both of these tasks build on the specific recommendations of the Committee on National Requirements for Precision Geodetic Infrastructure [NRC, 2010]. Based on evaluation and selection of a new GNSS preferred acquisition of the new multi-constellation GNSS instrument was completed during GAGE YR2.

Several proposals were developed by GI staff, submitted, or remained pending during GAGE Y3Q2, including two Community Workshop proposals: 1) Community Workshop: COCONet – Results, Sustainability, and Capacity Building, submitted to NSF on February 10, 2016; and 2) Community Workshop: International Workshop on Borehole Strain and Borehole Strain Instrumentation, submitted to NSF on February 18, 2016. The first was recommended, for the planned workshop dates of May 2-6, 2016 in Punta Cana, Dominican Republic. GI staff participated in the organizing committee for the COCONet 4th workshop. The second proposal to support a strainmeter workshop was withdrawn from submission to NSF on March 24, 2016, after it became clear that supporting this workshop was not a priority for the IF program at this time.

In addition to these two workshop proposals, the GI Director prepared a proposal for a community workshop on the future of research and research facilities at Mt. Erebus together with Dr. Peter LaFemina, who served as Co-PI on this proposal. A proposal entitled “Community Workshop: Scientific Drivers and Future of Mount Erebus Volcano Observatory (MEVO)” for $30K to support community members and several invited speakers was submitted on December 24, 2015 and funded on February 23, 2016. The workshop occurred on February 22 to 24, 2016 at UNAVCO HQ in Boulder, CO. Completion of the workshop was a top priority for the GI Director during GAGE YR3Q2. The final workshop report was submitted to NSF on April 25, 2016.
The GI Director was also a member of the organizing and writing committee for the NASA Challenges and Opportunities for Research in ESI (CORE) Report from the NASA Earth Surface and Interior (ESI) Focus Area Workshop, November 2–3, 2015, Arlington, Virginia. He participated in weekly telecons, an all-day writing workshop at the NASA Jet Propulsion Lab in Pasadena, CA on February 4, 2016, and contributed substantially to the final written report, which is currently in review.

The first Septentrio PolaRx5 production instruments (n=70 out of 100 ordered) were received by UNAVCO in GAGE Y3Q2 for testing by prior to deployment. PBO GPS Ops staff met several times to refine the station plan for deployment of the new PolaRx5 instruments. The initial plan has been guided by feedback from the GI Director and the GI AC recommendations and will focus on installing the new multi-constellation GNSS instruments at PBO stations that already have broadband GNSS LNA and elements in existing choke ring antennas. The goal is to deploy all 100 new instruments by the close of GAGE YR3. Final technical specifications and requirements for the PolaRx5 initial firmware release as well as the initial implementation of BINEX streaming data packages was cooperatively developed through several telecons and document exchanges continued in Y3Q2.

At the close of Y3Q2, the GI group headcount is at 42 with 40.75 FTE. The PBO engineering position that was vacant last quarter was filled in GAGE Y3Q2.

A summary of the important support GI metrics for the quarter is shown below in Table 2-1.

<table>
<thead>
<tr>
<th>NO DATA</th>
</tr>
</thead>
</table>

**Table 2-1. Geodetic infrastructure metrics for GAGE.**

<table>
<thead>
<tr>
<th>GEODECTIC INFRASTRUCTURE METRICS: SUMMARY OF KEY METRICS</th>
<th>GAGE Y3Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI Projects &amp; Proposals Supported: NSF-EAR, NSF-Other (Qty)</td>
<td>19</td>
</tr>
<tr>
<td>PI Projects &amp; Proposals Supported: NSF-PLR (Qty)</td>
<td>13</td>
</tr>
<tr>
<td>PI Projects &amp; Proposals Supported: Other Community (Qty)</td>
<td>15</td>
</tr>
<tr>
<td>Permanent Stations Supported: NSF-EAR and Community, PBO and Related (Qty)</td>
<td>2249</td>
</tr>
<tr>
<td>Permanent Stations Supported: NSF-PLR (Qty)</td>
<td>133</td>
</tr>
<tr>
<td>Permanent Stations Supported: NASA GGN (Qty)</td>
<td>59</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PI PROJECTS SUPPORTED (QTY)</th>
<th>GAGE Y3Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS NSF-EAR</td>
<td>7</td>
</tr>
<tr>
<td>GPS NSF-Other</td>
<td>4</td>
</tr>
<tr>
<td>GPS Other Community</td>
<td>11</td>
</tr>
<tr>
<td>GPS NSF-PLR Arctic</td>
<td>5</td>
</tr>
<tr>
<td>GPS NSF-PLR Antarctic</td>
<td>3</td>
</tr>
<tr>
<td>TLS NSF-EAR</td>
<td>2</td>
</tr>
<tr>
<td>TLS NSF-Other</td>
<td>0</td>
</tr>
<tr>
<td>TLS Other Community</td>
<td>4</td>
</tr>
<tr>
<td>TLS NSF-PLR Arctic</td>
<td>0</td>
</tr>
<tr>
<td>TLS NSF-PLR Antarctic</td>
<td>2</td>
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</table>

<table>
<thead>
<tr>
<th>PI PROPOSALS SUPPORTED (QTY)</th>
<th>GAGE Y3Q2</th>
</tr>
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<tbody>
<tr>
<td>GPS NSF-EAR</td>
<td>1</td>
</tr>
<tr>
<td>GPS NSF-Other</td>
<td>4</td>
</tr>
<tr>
<td>GPS Other Community</td>
<td>0</td>
</tr>
<tr>
<td>GPS NSF-PLR Arctic</td>
<td>1</td>
</tr>
<tr>
<td>GPS NSF-PLR Antarctic</td>
<td>1</td>
</tr>
<tr>
<td>TLS NSF-EAR</td>
<td>1</td>
</tr>
<tr>
<td>TLS NSF-Other</td>
<td>0</td>
</tr>
<tr>
<td>TLS Other Community</td>
<td>0</td>
</tr>
<tr>
<td>TLS NSF-PLR Arctic</td>
<td>0</td>
</tr>
<tr>
<td>TLS NSF-PLR Antarctic</td>
<td>1</td>
</tr>
</tbody>
</table>
2.2 COMMUNITY AND CONTINUOUSLY OBSERVING NETWORKS

2.2.1 Plate Boundary Observatory and Related Projects

UNAVCO operated and maintained the following instruments this period as part of the PBO network:

- 1132 permanent GPS stations (1,100 PBO core, 32 affiliated)
- 75 borehole strainmeters (74 PBO core, 1 NSF Continental Dynamics)
- 79 borehole seismometers (78 PBO core, 1 NSF Continental Dynamics)
- 23 borehole pore pressure sensors
- 26 shallow borehole tiltmeters
- 6 long baseline laser strainmeters
- 145 meteorological stations (118 core, 27 NOAA)
• 484 real-time streaming GPS stations (approximate total including ~425 PBO Core/Cascadia, 13 TLALOCNet, 45 COCONet, 1 in Nepal)

2.2.1.1 cGPS Network
During GAGE Y3Q2, the PBO GPS and Related Networks Group completed a number of tasks in support of the primary goal of maintaining the PBO GPS network at a high level of performance. The work involved upgrading radio networks to provide high rate, real-time, multi-constellation data streams. The work within the group did not slow down for the winter; there were maintenance trips to Mt St Helens and Yellowstone National Park. Lastly, the TLALOCNet project also made progress this quarter, with engineers finishing all but one of the GPS-Met station installations scheduled for the construction phase of the project.

![GPS Network Status](image)

Figure 2-1. GPS uptime time series for PBO network from April 2009 through March 2016.

Other highlights from Y3Q2 include:

• The 1,100-station core PBO GPS network uptime percentage for the month of March was 90.8%. For Y3Q2, the network uptime percentage was 91.3% and for the project since inception is 94.7%. We note that there is now an indication that deferred O&M has started to negatively impact PBO uptime from a peak in 2012 (see figure above).

• In GAGE Facility Y3Q2, there were 97 PBO GPS site visits for PBO and 9 site visits for TLALOCNet, resolving 213 GPS maintenance issues for PBO and 16 maintenance issues for TLALOCNet during 131 engineer-days in the field. An additional 58 days of engineer travel
involved required meetings and training. Other PBO GPS Operations staff travel included activities related to Rio Grande Rift support (8 days), and TLALOCNet (27 days).
- In a continuing effort to modernize the PBO GPS network, PBO engineers reviewed data communications performance network-wide and configured equipment to stream 1Hz data from 192 additional stations. These data streams are currently being tested in the BKG real-time system and will be added to PIVOT in Y3Q3. This will bring the total count to 616 real-time sites (56% of the PBO network).
- Engineers from PBO-SW region upgraded and expanded radio networks along the San Andreas fault near Parkfield with high bandwidth 5.8GHz spectrum communications. Four cell modems were decommissioned and data transfer rates were in increased 5-10-fold for most stations. The GI and PBO Director participated in this fieldwork.
- PBO-NW engineering staff completed a day of helicopter work on Mt St Helens, resulting in the repair of a critical repeater and several stations were made operational.
- PBO engineering staff completed helicopter dunker training in Anchorage in preparation for the summer field season.
- PBO-AK staff participated in a joint operations meeting with the IRIS Transportable Array, AEC and USGS-AVO in preparation for the upcoming summer field season.
- PBO-East engineering staff completed a successful winter maintenance trip into Yellowstone National Park, including collaborative maintenance with borehole strain/seismic group.
- A returning PBO field engineer, Summer Rhodes, was hired at the Boulder office and has begun extensive training and cross training with different operations groups, including borehole strainmeters.
- With assistance from PBO staff, seven new stations were installed in the TLALOCNet network, bringing the total station count to 23. One older GPS-Met station (PENA) was retrofitted for improved data communications.
- TLALOCNet engineers responded to Hurricane Patricia by downloading high sample rate data from all stations in the network, and repairing damaged station TNCM.

2.2.1.2 Borehole Geophysics

The Borehole Geophysics group continued to maintain the borehole strainmeter sensors in PBO with an operational status of more than 93% (project to date), with an operational status of 90.9% in Y3Q2. Keeping the PBO BSM network running at a very high level was done while completing the first UNAVCO-led borehole installations outside the PBO footprint as part of the GeoGONAF project, which consists of 6 boreholes located proximal to the Sea of Marmara in Anatolia, near Istanbul, Turkey. In addition, development efforts continue for follow on strainmeter manufacturing capability within the UNAVCO community framework (discussion above in the GI Overview section above). The PBO borehole seismic network continues to see above metric uptime due to hardening and virtualization of internal dataflow systems with a statistic of 93.6% in the last quarter. Tiltmeters have fallen below the target uptime metric. This is primarily due to winter conditions in Alaska, Yellowstone and MSH and reduced field operations in these costly locations. We expect normal operations as soon as these sites are accessible by efficient means (i.e. vehicle).

<table>
<thead>
<tr>
<th>Table 2-2. PBO borehole geophysics network uptime over Y3Q2.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of stations</td>
</tr>
<tr>
<td>Number of stations</td>
</tr>
<tr>
<td>Uptime Jan 2016</td>
</tr>
<tr>
<td>Uptime Q2 FY2016</td>
</tr>
</tbody>
</table>
Figure 2-2. PBO seismic network uptime time series from April 2009 through March 2016.

Figure 2-3. PBO Borehole strainmeter network uptime time series from April 2009 through March 2016.
Figure 2-4. PBO tiltmeter network uptime time series from July 2012 through March 2016. Tiltmeter network status is tracked on a quarterly basis.

Other highlights from Y3Q2 include:

- BSM field engineers resolved 53 PBO BSM maintenance issues with 57 field days in Y3Q2.
- In addition, 19 field days were spent in Turkey on the GeoGONAF project. The enclosure was installed at HALK and equipment set up. Unfortunately a contractor trenched through the GTSM cable during follow up work, thus requiring repair work on the next trip to Turkey. Maintenance was also performed on the Izmit creepmeter.
- Continued preparations with partners for DOE installation of a GTSM in Oklahoma, which is expected to occur later this year.
- Mencin, Gottlieb, Johnson, van Boskirk, and Pyatt all attended a 2-day training with Septentrio on the new PolaRx5 in Boulder CO.
- Pyatt and van Boskirk attended Helicopter Underwater Escape Training in Anchorage AK in March 2016.
- Worked with ECE group on region specific mailers to be provided to landowners as part of our permitting agreements.
- Upgraded three additional VSATs to RV50 CDMAas in Q2, bringing the total number of VSATs in the BSM network down to 32. This is part of an ongoing effort to reduce ongoing communications costs.
- Conducted a week of BSM cross-training activities with Doerte Mann.
- Began working on a BSM-team instance of Nagios VM to track SOH data.
- Received estimates from two electricians for a planned upgrade to the power system at Bo03, which is expected to be completed in Q3.
- Continued efforts to diagnose reparability and improve data quality issues at BSM stations, including starting to deploy a new test procedure for the downhole GTSM instrument.

Planned activities include:

- Completion of uphole infrastructure at sites near Istanbul Turkey, closing out the GeoGONAF construction. Additional funds are required and we are negotiating with H. Ozner, Director of Kandilli Observatory to provide those funds to support UNAVCO BSM staff returning to Turkey.
• Continued efforts to improve data quality at poorly performing BSM sites. Currently working through a list of stations with potentially resolvable (electronic) issues.
• Improve/finalize list of sites by data quality and scientific priority, which will be used to focus maintenance efforts for increased cost-effectiveness.
• Electrical upgrade at Bo03.
• Continue preparations for DOE installation of Gladwin instrument in Spring/Summer 2016.

2.2.1.3 Long Baseline Laser Strainmeter Subaward: UC San Diego

Long baseline laser strainmeter (LSM) network performance and data quality were good overall this quarter due to considerable maintenance efforts on the part of UCSD. An unusually mild 2016 winter in southern/central California allowed preventative maintenance site visits in Y3Q2, resulting in high data-quality from the LSM network. An exception to the overall good network performance was a succession of laser troubles at SCS1 which resulted in a low value of 53% for this station in February. Problems with the laser outlined in the previous GAGE Y3Q1 report increased during Y3Q2. The laser manufacturer, MicroG-LaCoste continues to have problems producing systems that can be used for their absolute gravity meters. In February 2016, the reference-laser at SCS1 failed, and no back-up laser, which had been tested and was performing adequately, was available to serve as a replacement. Eight days after failure, a promising replacement laser was deployed at SCS1. Immediately, it also showed signs of problems of the sort that can only be recognized when employed in the unequal-arm interferometers. UCSD attempted to fix the laser problems from mid-February to late-March, when the first replacement laser was swapped out again. UCSD is returning the poorly performing lasers to MicroG and has also received additional lasers, which are being evaluated for their suitability for deployment at SCS1 and other long-baseline laser strainmeters. Efforts to maintain operations and performance in the face of these ongoing issues continue into next quarter. Data processing, products and interpretation are discussed in section 3.3.2.

<table>
<thead>
<tr>
<th>CHL1</th>
<th>CHL2</th>
<th>DHL1</th>
<th>DHL2</th>
<th>SCS1</th>
<th>SCS2</th>
<th>Network Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-01</td>
<td>99%</td>
<td>99%</td>
<td>99%</td>
<td>99%</td>
<td>99%</td>
<td>99%</td>
</tr>
<tr>
<td>2016-02</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>96%</td>
<td>53%</td>
<td>99%</td>
</tr>
<tr>
<td>2016-03</td>
<td>99%</td>
<td>99%</td>
<td>99%</td>
<td>99%</td>
<td>90%</td>
<td>100%</td>
</tr>
</tbody>
</table>

2.2.1.4 PBO Network Data Return and Data Quality

The PBO network data return target is 85% for all data types except tiltmeter, for which data return is on a best effort basis. The summary for all PBO sensor types is shown in Table 2-4. The time series for data return percentage during the GAGE period is shown in Figure 2-5. This period, all PBO data types met or exceeded the data return target except for tilt. Tiltmeter data return was lower this period compared to last quarter, or any previous GAGE quarter, due to severe winter weather.

<table>
<thead>
<tr>
<th>Period</th>
<th>Target</th>
<th>GPS</th>
<th>Seismic</th>
<th>Borehole Strainmeter</th>
<th>Laser Strainmeter</th>
<th>Tiltmeter</th>
<th>Pore Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAGE Y3Q2</td>
<td>85%</td>
<td>93%</td>
<td>96%</td>
<td>99%</td>
<td>100%</td>
<td>63%</td>
<td>97%</td>
</tr>
<tr>
<td>Cumulative since 2013-10</td>
<td>85%</td>
<td>96%</td>
<td>98%</td>
<td>99%</td>
<td>100%</td>
<td>90%</td>
<td>93%</td>
</tr>
</tbody>
</table>
PBO network data return percentage from 01 October 2013 through 31 March 2016.

Borehole Strain
- The strainmeter network passed the data quality metrics criteria during GAGE Y3Q2: 75% of the network strainmeters are recording compression, 76% were relatively free of problematic steps, 93% and record a strong M2 tide. Four sites now fail the requirement to record teleseismic shear: Bo06 in the Pacific Northwest, B076 and B078 in Parkfield, and B206 in Yellowstone.

Pore pressure
- The overall pass rate for the data quality metric of tracking changes in barometric pressure was 87% for Y3Q2. Bo82 usually fails this metric, a result of year-round hydrological pumping into a nearby lake. Bo81 failed as a result of a data outage and B010 which is installed a few hundred meters from the shoreline also failed.

Tilt
- The tiltmeter network cumulative data return percentage was 63% this quarter, compared to 82% in Y3Q1. The data quality pass rate for the tiltmeters decreased from 77% in Y3Q1 to 62% in Y3Q2. Several sites were offline for most or all of Y3Q2. Tiltmeters AV14, AV24, AV29 and AV36 were offline in Alaska. On Mt St Helens B202, P690, P691 and P693 were offline. Data may be retrieved when the sites become accessible again in the spring. Otherwise the data quality overall was quite good with an M2 tide identifiable in the power spectra at most sites for which there were data.

The number and type of data quality metrics vary by data type. The summary for all PBO sensor types is shown in Table 2-5. In this reporting period, all PBO data types exceeded data quality metric targets except for tiltmeter.
Table 2-5. Network performance metrics for PBO: data quality.

<table>
<thead>
<tr>
<th>PBO NETWORK PERFORMANCE: DATA QUALITY (Pass/Fail)</th>
<th>GAGE Y3Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBO GPS</td>
<td>PASS</td>
</tr>
<tr>
<td>PBO Borehole Strainmeters</td>
<td>PASS</td>
</tr>
<tr>
<td>PBO Shallow Borehole Tiltmeters</td>
<td>FAIL</td>
</tr>
<tr>
<td>PBO Pore Pressure Sensors</td>
<td>PASS</td>
</tr>
<tr>
<td>PBO Long Baseline Laser Strainmeters</td>
<td>PASS</td>
</tr>
</tbody>
</table>

2.2.1.5 Real-Time GPS Network Operations

The average completeness across the UNAVCO RT-GPS network was 77% for Y3Q2, meaning that 23% of the data did not make it to the Boulder data center via the RT system; this is slightly lower than Y3Q1 (79%). Average and median latencies were higher throughout Y3Q2 than previous quarters. It is possible that both latencies and completeness are affected by winter weather (Table 2-6, Figure 2-6A and B).

Table 2-6. Real-time GPS network completeness and latency for GAGE Y3Q2.

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of Sites</th>
<th>Network Completeness (%)</th>
<th>Average Latency* (ms)</th>
<th>Median Latency (ms)</th>
<th>25% (ms)</th>
<th>75% (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-01</td>
<td>480</td>
<td>71</td>
<td>789</td>
<td>296</td>
<td>196</td>
<td>607</td>
</tr>
<tr>
<td>2016-02</td>
<td>484</td>
<td>80</td>
<td>767</td>
<td>347</td>
<td>215</td>
<td>916</td>
</tr>
<tr>
<td>2016-03</td>
<td>484</td>
<td>80</td>
<td>695</td>
<td>299</td>
<td>197</td>
<td>589</td>
</tr>
</tbody>
</table>

* Latencies are based on sites online during the quarter.

Figure 2-6A. Real-time GPS latency during GAGE Y3Q2 plotted out to 1000 milliseconds.
2.2.2 Field Support for the NASA GGN

UNAVCO, in collaboration with JPL, is responsible for the operations and maintenance of the 59 permanent GNSS stations that comprise the NASA Global GNSS Network (GGN) (Figure 2-7). UNAVCO staff monitor station network connections, ship new equipment to site operators as necessary, and construct new permanent sites as directed by JPL. UNAVCO staff work closely with local collaborators at each station for the purposes of routine maintenance as well as troubleshooting when data flow is interrupted, and perform field maintenance and upgrades.

Eighty-eight receivers are monitored in the GGN as 20 stations have multiple receivers on the same antenna. Currently, 55 GGN stations are fully operational and provide daily files to the geodetic user community. One station that is offline has an issue with the station computer, which is soon to be replaced. An additional station has an issue with satellite communications, and the two remaining stations are offline due to local host network outages. UNAVCO personnel are working to troubleshoot these problems with local collaborators.
Figure 2-7. Operational state of the NASA GGN on January 1, 2016. Green indicates an operational station, orange indicates a one week or less interruption in computer connectivity, red indicates a 1-2 week interruption, and grey indicates a 3-week or longer interruption in data flow.

In GAGE Y3Q2, UNAVCO upgraded the communications link at station HARV on the Harvest Oil Platform, off of the coast of Santa Maria, CA. The station previously utilized a satellite link to transmit data from the station. The satellite infrastructure was mounted directly to the platform and had been in place prior to 2006. The quality of the link had historically been less than optimal, but had additionally been deteriorating steadily over the course of the past year and a half. UNAVCO engineering staff visited the platform in February of 2016 to decommission the satellite link, and to install a radio connection to a communication hub on the shore. The hub site is PBO GNSS station VNDP located on Vandenberg Air Force Base, at a distance of 7 miles from the platform. VNDP has a functional satellite communications system installed with a robust link that is able to accommodate the additional traffic from station HARV.
Figure 2–8a. The new radio antenna that was installed on the Harvest Oil Platform is visible behind the yellow railing, which it is attached to. The antenna points to PBO station VNDP, in direct line of sight from the platform.

Figure 2–8b. Map showing location of the Harvest Oil Platform relative to PBO station VNDP. The distance between the two sites is approximately 7 miles.

Components for a solar/battery DC power supply were also shipped to station CGGN in Toro, Nigeria. The station’s uninterruptable power supply was broken in early 2015 and never repaired. Erratic power outages have been an issue at the station since.
UNAVCO worked with local collaborators to import the hardware for an autonomous DC system that will provide consistent power to the GNSS equipment. The on-site personnel will also be responsible for installing and maintaining the new power hardware.

Additionally, UNAVCO decommissioned the satellite communications system for the five receivers at the Marshall Field Test Site, in Boulder, CO (each receiver is on a separate antenna). One legacy GPS receiver was also replaced with a more modern receiver with embedded ethernet hardware. All five systems are now connected directly to the local network and are connected to UNAVCO’s virtual private network.

Finally, as part of regular station maintenance, UNAVCO ships computers into the network whenever old computers fail. Station CHPI in Cachoeira Paulista, Brazil, failed in late February of 2016 when the existing computer died. Customs delays caused a delay of one and a half months; however, the new machine was received at the station in late March 2016 and will be installed soon.

NASA GGN Performance Metrics: Stations Monitored: 59; Receivers Monitored: 88; Troubleshoots: 106.

2.2.3 Polar Projects: POLENET

POLENET support is a year-round effort of the UNAVCO Polar team. With telemetered cGPS networks in Greenland and Antarctica, the cycle of network monitoring, planning, preparation and fieldwork is continuous and ongoing. GAGE Y3Q2 GPS network activities for Polar Services were focused on field maintenance of the ANET network (Figure 2-9), as well as managing data flow and QC for both ANET and GNET sites.

![Polenet Station at Mt Howe, Antarctica. Photo by Nicolas Bayou, 2016.](https://example.com/polenet_station.jpg)

GNET support is given over to telemetry and data management during the boreal winter months. This network was visited during the last quarter and made ready for the upcoming winter months. As of the end of Y3Q2, 99% of the GNET network was telemetering data, which is exceptional and speaks to the resilience of the design. Overall GNET data recovery, measured by data that reaches the UNAVCO archive, is currently at 89.4%. For monthly averages, see Figure 2-10. Overall the network is performing quite well. The stations are at a technically mature state and are proving robust and reliable. A map of the sites making up the Greenland POLENET network can be seen in Figure 2-11.
Figure 2-10. POLENET/GNET network status since inception. Solid red area shows the number of stations operating through time (42 at close of Y3Q2). Blue line shows percentage cumulative monthly data return.

Figure 2-11. GNET continuously operating GPS stations in Greenland. Green: Operational, Red: No Ops.
Support efforts for ANET focused on station maintenance, repair, data retrieval and archiving in GAGE Y3Q2. By February 15, 2016, 21 ANET sites had been visited by UNAVCO, where repairs and preventive maintenance were performed. Currently 99% of the network is telemetering data as the ANET field team reached the sites that had failed over the austral winter. While the Antarctic environment is particularly hard on the installations, most data issues are related to communications, and the sites not telemetering are often still operational and logging data. The total number of core ANET sites is currently 45.

LARISSA (LARson Ice Shelf System), a sister network to POLENET, operating on the Antarctic Peninsula, maintains 10 additional stations. Through a cooperative effort with the British Antarctic Survey (BAS), two failed LARISSA sites were visited and repaired this quarter. These sites were located on the difficult to access eastern side of the Antarctic Peninsula.

The average cumulative ANET data recovery, measured by data that reaches the UNAVCO archive, is currently at 88.7%. For monthly trends see Figure 2-12. Figure 2-13 highlights the locations of the ANET network sites.

Figure 2-12. POLENET/ANET network status since inception. Solid red area shows the number of stations operating through time (45 at close of Y3Q2). Blue line shows monthly data return percentage.
Figure 2-13. Locations of ANET and LARISSA continuously operating GPS stations in Antarctica. Orange dots indicate the final sites installed during the 2014-2015 field season. Green: Operational, Red: No Ops.

Figure 2-14. Rime Ice and snow infiltration into the chokering antenna are among the challenges faced by the POLENET cGPS sites. Photo by Annie Zaino, 2016.
The Polar Network Science Committee (PNSC) has set June 28-29, 2016 to review the state of the POLENET network and to discuss the future of GNSS networks in Greenland and Antarctica. The effort to scope future science that may benefit from the now mature network is ongoing. One aspect of this next generation network involves procuring a very low power (less than 2 watts) GNSS receiver to work at the core of the remote systems.

GNET Stations receiving field maintenance visits this quarter: 0
ANET Stations receiving field maintenance visits this quarter: 14

2.2.4 Network Engineering Support for Other Community GPS Networks

UNAVCO provides operations and management (O&M) support at various levels. GAGE Y3Q2 activities included support to 908 continuously operating GPS stations in 63 different networks installed in support of PI projects. Many of these stations continue to operate beyond the original award period. The O&M support includes data downloads, state of health monitoring and reporting, resolving communications and equipment issues, shipping replacement equipment, and working with PIs and local contacts to resolve problems. UNAVCO, working closely with PIs and their collaborators, provides this O&M support at three broad levels:

- **High**: UNAVCO provides centralized O&M support that may include retrieving the data, monitoring station data flow, and proactively responding to problems with data flow or station hardware. Problems are fixed remotely working with collaborators if necessary. If maintenance trips or materials are required for O&M, these are funded by the PI project.
- **Medium**: PI or collaborators download the data from the stations, monitor station data flow, and handle most problems themselves. UNAVCO provides engineering and technical support on a request basis. Any UNAVCO Engineering maintenance trips and materials required for O&M are covered by the PI project.
- **Low**: UNAVCO provides only archiving support and a low-level of technical support. UNAVCO does not monitor or download data from the stations. UNAVCO provides engineering and technical support on a request basis.

The performance of each network varies greatly and primarily has to do with the method of data delivery and funding status or local support of the cGPS network. Networks with stations that are online, with data downloaded and archived by UNAVCO, service by engaged collaborators, typically show a higher data return than those that are manually downloaded. For instance, RAPID-Bolivia continues to deliver 91% expected data, COCONet (88%) and Caltech - Nepal (83%). In contrast, networks that are in remote areas, not online, and only downloaded periodically, yield lower percentage or no recent data returned for a particular quarter. During this reporting period there was about the same amount of data submitted to the archive from networks that require manual downloading, thus the average data return for all the stations remained the same at 64%.

2.3 PI PROJECT SUPPORT

2.3.1 EAR PI GPS Project Engineering and Equipment Support

UNAVCO provides state-of-the-art GNSS equipment and engineering services to PI projects. This includes project management (both GNSS and TLS), planning, installation, operations and maintenance of continuous, permanent GPS/GNSS station networks around the globe. Engineers and technicians also undertake technology development, testing, and systems integration to support new project demands.

2.3.1.1 GPS PI Project Support

In GAGE Y3Q2, 22 PI projects (7 NSF-EAR, 4 NSF-Other, and 11 Community) were supported by UNAVCO. UNAVCO staff was involved in proposal development, project planning, network design,
monument design, equipment preparation and installation, and establishing real-time data flow. Additionally, UNAVCO supported 5 new PI proposals (1 NSF-EAR, 4 NSF-Other, and 0 Community).

2.3.1.2 GPS Instrument Pool

The UNAVCO GAGE receiver pool consists of 670 GPS or GPS/GNSS-capable receivers (Figure 2-15). The receiver pool consists of Topcon GB1000, and Trimble NetR9, NetRS and R7 receivers purchased by UNAVCO for use as both campaign instruments and to support for specific NSF-EAR projects and thus are deployed in semi-permanent installations. An additional 20 Septentrio PolaRx5 were ordered and will be delivered in GAGE Y3Q3. These will be used to support campaign projects and long term loans for new projects. Additionally, NetRS receivers from upgraded PBO receivers are being used to support PI networks. This reporting period saw a continued high level of utilization of the UNAVCO receiver pool with an average of 79% and a peak of 82% (Figure 2-16).

Figure 2-15. UNAVCO NSF-EAR receiver pool inventory from 01 October 2003 through 31 March 2016. The metric reflects the number of receiver pool instruments. Note: the drop the number of units in 2006 is due the NSF-PLR pool no longer being included in the metric.

Figure 2-16. UNAVCO NSF-EAR receiver pool utilization from 01 October 2003 through 31 March 2016. The metric reflects the proportion of receiver pool instruments that are sourced out of the UNAVCO GeoLogistics Center and assigned to any project during any given week.
2.3.1.3 GPS Instrument Repairs

The GAGE Facility continues to be an authorized Trimble repair facility for the UNAVCO community. Since the introduction of the Trimble NetRS and now up to the recent release of their latest GNSS product, the NetR9, the UNAVCO community has purchased thousands of receivers through the UNAVCO Community purchase program. With this program new receivers come with a five-year warranty with the stipulation that repairs are handled by UNAVCO. This arrangement has brought the costs down for equipment purchases and further enables GPS instruments to be used for longer periods of time. During this reporting period, UNAVCO processed 39 Return Merchandise Authorizations (RMAs). This includes repairs for GPS receivers, antennas, and surface meteorological packages. The repairs ranged from handling RMA submissions to vendors to board level repairs. An offsite contractor is currently providing this PI-support service to UNAVCO. Additionally UNAVCO provides office support to collaborators who perform repairs to PI equipment in remote locations. These repairs usually consist of flashcard replacement n NetRS receivers and repairs to antennas.

2.3.2 Polar Services

Figure 2-17. Regular seasonal support is provided for teams studying one of the southernmost active volcanoes, Mount Erebus, Antarctica. UNAVCO support includes a telemetered network of cGPS stations capable of running continuously year round. Photo by Nicolas Bayou, 2014.

UNAVCO provides broad support to PIs working in the Arctic and the Antarctic. This support can require extensive field work, particularly in Antarctica, where travel is challenging. The Polar Services FTE count is currently seven, with five engineers, one technician and one project manager. All team members provide direct support of field projects and participate in various stages of project planning and preparation for the polar project loads. Planning and support activities for the Arctic and Antarctic are ongoing year round, with significant overlap. While the full force of the Antarctic field season doesn't get underway until the first quarter of the year, UNAVCO provides year round support to the LARISSA network located on the Antarctic Peninsula. Access to the Antarctic Peninsula is viable nearly continuously, so it is possible to work with PI projects in this region at almost any time. The limitation is transportation and sea ice coverage, which impact the eastern side of the peninsula more significantly. Early project starts are now more common for the Arctic and the Antarctic than even a few years ago. As projects grow larger and more complex, the Polar team at UNAVCO spends more time working on instrumentation preparation and PI planing for both hemispheres year round.
UNAVCO engineers provided Terrestrial Laser Scanning (TLS) support to two Antarctic projects in GAGE Y3Q2, for a total of four TLS projects this field season. New applications for the TLS technology continue to emerge, including this year an attempt to resolve volumetric estimates of meltwater lake cycles on the Ross Ice Shelf. TLS demand is generally steady, with an annual average of three or more scanning projects in each the Arctic and the Antarctic. We note that most TLS projects also have a GPS component, which results in the higher demand for GPS instruments. UNAVCO engineers employ both the longer-range Riegl VZ-2000 scanner and a shorter-range VZ-400 for polar field applications. This suite of scanners enables a broad range of uses, including small scale volumetric estimates and change detection. The Polar team supported 31 Antarctic campaign projects of varying complexity this Antarctic field season, including five this quarter. Support required UNAVCO engineers to travel into to remote locations across the Antarctic continent. UNAVCO polar supports a diverse science, including geodesy, geology, glaciology, volcanology and ocean-ice interfaces.

UNAVCO monitors and maintains several non-POLENET GPS networks in the Arctic and the Antarctic and also maintains GPS reference stations and forward-deployed equipment at multiple locations. In the Arctic, these can be found at Barrow, Atqasuk, Toolik camps in Alaska and Summit Station in Greenland. In Antarctica, these are found at three continuously operated US research stations: McMurdo Station, Palmer Station and the Amundsen-Scott South Pole Station. Currently there are 125 GPS systems in the Arctic pool and 208 systems in the Antarctic pool. Many of these are deployed year round in support of continuous stations in Greenland and Antarctica.

Figure 2-18. Geo-locating TLS target in the McMurdo Dry Valleys. Photo by Nicolas Bayou.

The Polar Projects Support manager provided supporting documents, including budgets and letters of support to three PIs submitting to the NSF solicitation for Arctic and Antarctic research opportunities.

2.3.3 Geodetic Imaging (TLS)

Geodetic Imaging TLS activities during the GAGE Y3Q2 period included engineering support for PI projects, planning support for PI proposals, education and outreach, and resource development. In GAGE Y3Q2 a total of 10 TLS projects and proposals (3 NSF-EAR, 4 Other Community, and 3 PLR-Antarctic) were supported by the Geodetic Imaging program (Figure 2-19).
Figure 2-19. Number of TLS projects and proposals supported by UNAVCO through March 31, 2016. 
Note: this plot shows the number of projects per program year or partial year, including a transition from December end to September end during 2013. The final bar in this figure shows metrics for the current program year to date only, from September 2015 through March 2016, which is only two quarters.

To meet the needs of a growing and diversifying TLS user community, UNAVCO is actively developing training resources and documentation to support Earth science TLS users. During the current reporting period, several new documents and entries were added to the TLS Knowledgebase with a focus on software tutorials and training resources: (http://facility.unavco.org/kb/categories/Geodetic+Imaging/Terrestrial+Laser+Scanning+(TLS)/). New documents on software license server access and TLS instrument service histories were also added to the internal UNAVCO wiki.

Also during the Y3Q2 period, activities were undertaken to maintain the TLS instrument pool. The VZ1000 underwent full Riegl factory service in Horn, Austria, while three other instruments were run through the UNAVCO TLS validation array to ensure they are operating within specifications. Three new Septentrio APS-3L “smart antenna” GPS systems were acquired during the reporting period using funds from NSF-EAR 1261653: Acquisition of Next Generation Terrestrial Laser Scanning Systems for Community Earth and Polar Science Research. These antennas will enable RTK and GPS-on-top TLS workflows, and can also be utilized for target-based georeferencing. They streamline TLS kit size and enable a variety of data collection capabilities.

Finally, UNAVCO updated its full suite of Riegl software licenses. The ability to loan software licenses to enable community data processing and analysis is a key support activity of the UNAVCO TLS program.

2.4 DEVELOPMENT AND TESTING

The GAGE Facility Development and Testing effort is staffed by 2.75 FTE at the Project Manager III, Engineer III and Engineer II levels, and now also incorporates the PBO strainmeter and GPS testing efforts. Ad hoc contributions to individual D&T projects from other UNAVCO groups have been critical to
the effort, with individuals participating in projects of direct interest to their operational efforts. The ongoing development of teqc software and implementation of server-based real-time GPS positioning capabilities in close collaboration with GDS are important ongoing projects undertaken by the D&T staff. Under guidance from the Development and Testing Product Council, the group's activities continue to be oriented toward three important strategic goals: development of battery monitoring tools, which can help realize economy and efficiency of field operations; evaluation of cellular data communications systems suitable for use anywhere in the world; and evaluation of real-time positioning methods, both receiver- and server-based, for use in earthquake early detection and other monitoring applications.

With basic testing and acceptance of the new UNAVCO GNSS receiver having concluded at the end of last quarter, the D&T group led the effort in Y3Q2 to begin the process of integrating the new PolaRx5 GNSS receiver into UNAVCO's existing data flow and command and control systems. We are continuing to optimize the receiver's configuration to achieve the best performance with all of UNAVCO's operations, including field hardware, data flow, archiving, and staff expertise. A two-day long training was held in Boulder on February 17th and 18th, led by Septentrio support staff and attended by over 40 UNAVCO staff from both the Geodetic Infrastructure and GDS directorates, to familiarize everyone with the intricacies of deployment and use of these complex instruments. Seventy PolaRx5 receivers were received during the quarter, and to date half have been tested and configured and are being readied for deployment at selected PBO stations in the Western U.S. The first PolaRx5 receiver was installed at Po41 at our Marshall test facility in late March, and data flow, archiving, and GAGE GPS Analysis Center testing of procedures is under way. The first general deployments are planned for late April. Ongoing collaboration with Septentrio on the prioritization and implementation of new features to the receiver's firmware and configuration software are resulting in the issue of new versions on a quarterly basis. The implementation of BINEX capability is expected at the end of Y3Q3, with archival quality streaming capability to follow in the months following.

We also began our evaluation of Septentrio's nascent receiver-based real-time kinematic PPP positioning system. A key feature of Trimble's NetR9 hardware is its RTX Positioning system, which we have extensively tested and shown to produce excellent results that are useful in Earthquake Early Warning and GPS Seismology applications. While the Septentrio PolaRx5 is technologically superior to the NetR9 in every way, Septentrio is only now beginning development of their own system; we completed our evaluation of their alpha-level product, which employs corrections received through the L-Band antenna from the Terrastar commercial satellite. Figures 2-20A and 2-20B show the comparative results from RTX and the Septentrio system from our UNAVCO-built positioning table. At higher frequencies the results are clearly unacceptable, with a high level of damping and smoothing being applied to carrier-phase positions that are determined without ambiguity resolution as is done in RTX. We have shared these results with Septentrio, who are revising their system accordingly. A beta version should be available for testing in Y3Q3.

The D&T Performance Metric for Y3Q2 included 9 Development and Testing Projects in progress, and 3 projects completed.
Figure 2-20A. Positions from Septentrio RT-PPP (red) compared with Trimble’s RTX (green) and the measured shake-table position (blue) at 0.5 Hz oscillation frequency. While RTX tracks the ground truth almost exactly, the Septentrio position shows some overshoot and phase lag even at this low frequency.

Figure 2-20B. Positions from Septentrio RT-PPP (red) compared with Trimble’s RTX (green) and the measured shake-table position (blue) at 4 Hz oscillation frequency. Septentrio positions are severely impacted by apparent smoothing of positions. Septentrio is revising its system to improve performance based on these results.
2.5 GI PROGRAM SUMMARY

This has been another busy quarter for the GI program. UNAVCO has now received ~70 of the 100 production Septentrio PolaRx5 instruments and completed a rigorous pre-deployment testing regime. Significant progress was made toward completing all upheole infrastructure for the 6 GeoGONAF BSM instrument packages in Turkey, although additional work remains to complete this network and move towards full operational capability as designed. COCONet and TLALOCNet construction continues to move forward. COCONet is currently in a 1-year, grantee-approved NCE. All sites were reviewed for data quality, ongoing technical issues; a final installation and site remediation plan was developed and approved by the COCONet Working Group. NSF provided support for a fourth COCONet Community Workshop that will occur in GAGE Y3Q3 (May 2-6, 2016 in Punta Cana, DR). We remain ahead of schedule for TLALOCNet installations. At the close of Y3Q2, the GI group headcount was 42 with 40.75 FTE with the hiring of the a new Engineer to fill the vacancy in the PBO Eastern Region.

3. Geodetic Data Services Program

3.1 OVERVIEW

The Geodetic Data Services (GDS) program manages a complex set of metadata and data flow operations providing a wide range of geodetic/geophysical observations to scientific and educational communities. Sensors currently include GPS (downloaded files and high-rate data streaming in real time (RT-GPS)), borehole geophysics instrumentation (strainmeters, tiltometers, seismometers, accelerometers, pore pressure and meteorological sensors), long baseline laser strainmeters, and terrestrial laser scanners. Field data are acquired either from continuously operating sites or episodic “campaign” surveys conducted by the community. UNAVCO also acquires and distributes satellite synthetic aperture radar (SAR) data from foreign space agencies. GDS services include data operations (managing metadata; data downloading, ingesting and preprocessing); data products and services (generating processed results and QA/QC and state-of-health monitoring); data management and archiving (distribution and curation); cyberinfrastructure; and information technology (systems and web administration). In order to perform this mission, GDS maintains a technical staff, onsite and offsite computer facilities with networking, servers and disc storage, and manages a number of subawards to university groups who provide additional products, software and training.

Some highlights of activities for the GAGE Y3Q2 quarter include:

- GDS staff led numerous activities at the 2016 UNAVCO Science workshop including Special Topics Sessions, training courses, PI support meetings and governance meetings.
- The total volume of data archived (all sensors) is now over 195 TB (including 9.8 TB of ALS data archived at OpenTopography/NCALM). The total volume of data archived this quarter, 19.1 TB, was 12.5 TB greater than last quarter, almost exclusively due to higher volumes of SAR data.
- The total volume of data delivered to users this quarter, 30.4 TB, was 6 TB greater than last quarter, again primarily due to SAR data.
- There were an estimated ~2,904 unique data users this quarter, ~260 more than last quarter.
- Six custom requests for high rate GPS data downloads were supported this period, including an event response following the 24 January M7.1 Old Iliamna, Alaska earthquake.
- Three fully processed high rate (1-sps) borehole strainmeter data sets were generated this period for the following earthquakes: 24 January M7.1 Old Iliamna, Alaska; 30 January M7.2 Yelizovo, Russia; 02 March M7.8 Sumatra, Indonesia.
- The GAGE GPS Analysis Centers (ACs) and Analysis Center Coordinator (ACC) processed data and provided products this quarter from 1,913 GPS stations this quarter.
- Eighteen new GPS stations, primarily from TLALOCNet, were added to the analysis stream this period.
• One of the new stations added to the GAGE analysis stream this quarter was the first Septentrio PolaRx5 receiver deployed at a PBO site: PRX5. The receiver was installed by D&T personnel at Po41 at Marshall, CO on a splitter with a Trimble NetR9 receiver. The ACC and ACs worked closely with D&T to examine the solutions from this new receiver and compare with the NetR9.

• Software development to support Septentrio PolaRx5 data flow on a production basis was initiated and completed this quarter. Data and products from PRX5 are now being archived and distributed to users.

• RINEX3 format data are being made available to the community as part of a pilot project. Data from four stations are now in production, with download of the RINEX3 format data (produced onboard the receivers), metadata extraction, archiving, and delivery to customers from a dedicated directory on the ftp server; data going back to January 1, 2016, are available.

• UNAVCO plans for formats and tools related to GNSS have been described in the white paper UNAVCO Geodetic Data Services Plan for GNSS Modernization – Data Formats and Preprocessing Tools that was released to the community on March 25 in coordination with the RINEX3 announcement.

• Fifty-nine new users requested access to the data streams in Y3Q2 bringing the total number of registered RT-GPS users to 508 (Figure 3-4), a 13% growth. The largest increase in user numbers was in the Commercial sector (42).

• Development of a new TLS data archive system is nearing completion and was showcased at the UNAVCO Science Workshop.

• As planned, in mid-January we took the existing TLS data archive offline and began the transition to the new data archive that is based on the software that underlies the WInsAR Portal system; development continues. The new archive was released in early February and was showcased at the UNAVCO Science Workshop in March. Data downloads for January and February are therefore very low, making the quarterly total abnormally low compared with previous quarters.

• The volume of SAR data archived in Y3Q2 was greatly increased due to data from ALOS-2/JAXA proposals. JAXA provides 50 scenes per year for PI proposals and there was a large surge in data ordered by PIs due to quotas expiring on March 31, 2016. Some ALOS-2 data files are 50-60GB each, which accounts for the large volume of data.

• The volume of SAR data deliveries was also large in Y3Q2 (10.0 TB), continuing the surge first noted in Y2Q3. These increased download volumes were associated with ALOS-2 and TSX data.

• As part of the Dataworks and GSAC projects UNAVCO provided a VM with the Dataworks Amazon Machine Image (AMI) installed for temporary exploration by partners from Mexico.

• Development to support the pulling of GPS daily position solutions from the University of Nevada-Reno (UNR) for UNAVCO GPS time series web service was completed this quarter as part of the NASA ROSES Plug & Play project.

• A significantly revised web service to return GPS time series data was developed this quarter and was demonstrated at the UNAVCO Science Workshop. This service supports the output of daily GPS time series position products from the GAGE Analysis Centers as well as from the University of Nevada-Reno (UNR) analysis center. Documentation for the service was greatly expanded.

• Initial development was started to begin loading all real time GPS, BSM, seismic, tilt, pore pressure and accelerometer data into an instance of Open Source software called Data Turbine that has been deployed at the UNAVCO site. Data Turbine is a ring buffer that will be used to hold recent data collected for a yet to be determined number of days and give users the ability to easily look at data in real time or collected during this past number of days.

• All UNAVCO users were migrated to Google calendars this quarter. Training by the IT group was provided to all employees.

• UNAVCO IT staff collaborated with personnel from the University of Alaska, Fairbanks to support feature enhancements to the Earthscope web site.

• GDS gathers and reports some 90+ performance metrics and is engaged in automating this
process. Support for SAR and pore pressure archival and delivery metrics were added this quarter, and backfill of metrics for previous periods for SAR and pore pressure data was also completed this quarter. We anticipate that the new automated metrics system will be in full production mode next quarter for borehole geophysics and SAR data and that Y3Q3 metrics will be based on automated report values. GPS usage metrics are now being gathered and stored into the metrics database. All web services will begin to collect delivery metrics.

GDS data metrics are summarized below in Tables 3-1 and 3-2.

**Table 3-1. Geodetic Data Services metrics for GAGE facility.**

<table>
<thead>
<tr>
<th>GEODETIC DATA METRICS: SUMMARY OF KEY METRICS</th>
<th>GAGE Y3Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campaigns Archived - All Sensors (Qty)</td>
<td>16</td>
</tr>
<tr>
<td>Permanent Stations Archived - All Sensors (Qty)</td>
<td>2,986</td>
</tr>
<tr>
<td>Data Volume Archived - All Products (GB)</td>
<td>19,097</td>
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<td>Data Volume Delivered - All Products (GB)</td>
<td>30,370</td>
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<tr>
<td>PBO Data Volume Archived - All Products (GB)</td>
<td>3,682</td>
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<tr>
<td>PBO Data Volume Delivered - All Products (GB)</td>
<td>14,979</td>
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<table>
<thead>
<tr>
<th>CAMPAIGNS ARCHIVED (QTY)</th>
<th>GAGE Y3Q2</th>
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<tbody>
<tr>
<td>GPS</td>
<td>4</td>
</tr>
<tr>
<td>TLS</td>
<td>12</td>
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<table>
<thead>
<tr>
<th>PERMANENT STATIONS ARCHIVED (QTY)</th>
<th>GAGE Y3Q2</th>
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<tbody>
<tr>
<td>GPS - All sample rates and delivery methods</td>
<td>2,765</td>
</tr>
<tr>
<td>GPS High Rate (1-Hz and Higher)</td>
<td>592</td>
</tr>
<tr>
<td>Delivered via Stream</td>
<td>417</td>
</tr>
<tr>
<td>Delivered via Download, Continuous</td>
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<tr>
<td>Delivered via Download, Intermittent</td>
<td>45</td>
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<tr>
<td>Seismic</td>
<td>83</td>
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<tr>
<td>BSM</td>
<td>83</td>
</tr>
<tr>
<td>Tilt</td>
<td>26</td>
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<tr>
<td>Pore Pressure</td>
<td>23</td>
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<td>LSM</td>
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<table>
<thead>
<tr>
<th>TOTAL STATIONS W/ DATA MAINTAINED IN ARCHIVE (QTY)</th>
<th>GAGE Y3Q2</th>
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</thead>
<tbody>
<tr>
<td>GPS - All Stations with Data</td>
<td>13,044</td>
</tr>
<tr>
<td>GPS - All Campaigns with Data</td>
<td>991</td>
</tr>
<tr>
<td>GPS - All Permanent Stations with Data</td>
<td>3,289</td>
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<tr>
<td>Seismic</td>
<td>84</td>
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<tr>
<td>BSM</td>
<td>84</td>
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<tr>
<td>Tilt</td>
<td>27</td>
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<td>Pore Pressure</td>
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<tr>
<td>LSM</td>
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<table>
<thead>
<tr>
<th>DATA VOLUME ARCHIVED (GB)</th>
<th>GAGE Y3Q2</th>
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<tbody>
<tr>
<td>GPS - All sample rates and delivery methods</td>
<td>4,048</td>
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<tr>
<td>GPS Standard Rate</td>
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<tr>
<td>GPS High Rate</td>
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<tr>
<td>GPS Data Products (Level 2 and higher)</td>
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<tr>
<td>Seismic</td>
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<tr>
<td>BSM Raw Data</td>
<td>103</td>
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<tr>
<td>BSM Data Products</td>
<td>1.5</td>
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<td>Tilt</td>
<td>1</td>
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<tr>
<td>Pore Pressure</td>
<td>2</td>
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<tr>
<td>LSM Raw Data</td>
<td>3</td>
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### DATA VOLUME DELIVERED (GB)

<table>
<thead>
<tr>
<th>Data Product</th>
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<tr>
<td>LSM Data Products</td>
<td>0.018</td>
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<tr>
<td>SAR</td>
<td>14,460</td>
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<tr>
<td>TLS</td>
<td>211</td>
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### DATA USERS (MONTHLY AVERAGE, QTY)

<table>
<thead>
<tr>
<th>Data Product</th>
<th>QTY</th>
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<tbody>
<tr>
<td>GPS Standard Rate (unique IP’s)</td>
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</tr>
<tr>
<td>GPS High Rate (unique IP’s)</td>
<td>55</td>
</tr>
<tr>
<td>GPS Data Products (unique IP’s)</td>
<td>276</td>
</tr>
<tr>
<td>GPS Real Time Streams (active registered users)</td>
<td>93</td>
</tr>
<tr>
<td>Seismic (2nd level domains)</td>
<td>112</td>
</tr>
<tr>
<td>BSM Raw Data (2nd level domains)</td>
<td>51</td>
</tr>
<tr>
<td>BSM Data Products (2nd level domains)</td>
<td>51</td>
</tr>
<tr>
<td>Tilt (2nd level domains)</td>
<td>18</td>
</tr>
<tr>
<td>Pore Pressure (2nd level domains)</td>
<td>32</td>
</tr>
<tr>
<td>LSM Raw Data (2nd level domains)</td>
<td>7</td>
</tr>
<tr>
<td>LSM Data Products (2nd level domains)</td>
<td>4</td>
</tr>
<tr>
<td>ALS (unique users reported by OpenTopography)</td>
<td>103</td>
</tr>
<tr>
<td>SAR (active registered users)</td>
<td>24</td>
</tr>
<tr>
<td>TLS (unique IP’s)</td>
<td>2</td>
</tr>
</tbody>
</table>

### CUSTOM HIGH RATE GPS DATA REQUESTS THIS PERIOD (QTY)

<table>
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<th>Request Type</th>
<th>QTY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event response</td>
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</tr>
<tr>
<td>Total</td>
<td>6</td>
</tr>
</tbody>
</table>

### NSF & NASA COMMUNITY SOFTWARE (QTY)

<table>
<thead>
<tr>
<th>Software</th>
<th>QTY</th>
</tr>
</thead>
<tbody>
<tr>
<td>teqc downloads</td>
<td>7,543</td>
</tr>
<tr>
<td>teqc information requests</td>
<td>130</td>
</tr>
<tr>
<td>ISCE downloads</td>
<td>286</td>
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Table 3.2. Geodetic data metrics for PBO network.
<table>
<thead>
<tr>
<th>PBO BSM Data Products (Level 2 and higher)</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBO Tilt</td>
<td>1</td>
</tr>
<tr>
<td>PBO Pore Pressure</td>
<td>2</td>
</tr>
<tr>
<td>PBO LSM</td>
<td>3.1</td>
</tr>
<tr>
<td>PBO LSM Data Products (Level 2 and higher)</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>PBO DATA VOLUME DELIVERED (GB)</strong></td>
<td><strong>GAGE Y3Q2</strong></td>
</tr>
<tr>
<td>PBO GPS</td>
<td>11,472</td>
</tr>
<tr>
<td>PBO GPS Standard Rate</td>
<td>3,967</td>
</tr>
<tr>
<td>PBO GPS High Rate</td>
<td>960</td>
</tr>
<tr>
<td>PBO GPS Data Products (Level 2 and higher)</td>
<td>500</td>
</tr>
<tr>
<td>PBO GPS Real Time Streams</td>
<td>6,045</td>
</tr>
<tr>
<td>PBO Seismic</td>
<td>3,187</td>
</tr>
<tr>
<td>PBO BSM Raw Data</td>
<td>87</td>
</tr>
<tr>
<td>PBO BSM Data Products (Level 2 and higher)</td>
<td>82</td>
</tr>
<tr>
<td>PBO Met</td>
<td>3.9</td>
</tr>
<tr>
<td>PBO Tilt</td>
<td>3.2</td>
</tr>
<tr>
<td>PBO Pore Pressure</td>
<td>144</td>
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<tr>
<td>PBO LSM Raw Data</td>
<td>0.4</td>
</tr>
<tr>
<td>PBO LSM Data Products (Level 2 and higher)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Figure 3-1. Cumulative total UNAVCO data volume archived from 01 January 2004 through 31 March 2016. More than 195 TB of data have been archived including 19+ TB in Y3Q2 and 94+ TB since the beginning of GAGE.
Figure 3-2. Cumulative PBO data delivered from 01 October 2004 through 31 March 2016. More than 270 TB of PBO data were delivered to users during this time, including 15+ TB in Y3Q2 and 126+ TB since the beginning of GAGE.

Figure 3-3A. Number of UNAVCO data users by quarter from 01 January 2009 through 31 March 2016, including 2,900+ users this quarter. The method of counting users varies by data product, for example by unique IP address, second level domain or active registered user. Values in this figure are consistent with the user count method given in the Data Users section of Table 3-1.
3.2 DATA OPERATIONS AND MANAGEMENT

3.2.1 Network Data Flow

Network data flow includes data and metadata management from the field to the Boulder operations center, a critical activity in support of data archiving and distribution (for related performance metrics, see Table 3-1). Staff with responsibilities for data and metadata flow focus on timely handling of operational flow and any issues as they arise.

The GI directorate informed the GDS development team that they wished to begin deployment of Septentrio receivers near the beginning of March. To support these deployments, modifications were made to dataflow software, the POD and the MetaData Manager (MDM). Dataflow developers collaborated with the data archive development team on the development changes and testing to insure end to end support for this new receiver. These changes were delivered to production before the end of March.

Last quarter, the accelerometer data arriving at UNAVCO was greater in volume than the volume of data that could be sent to IRIS. This meant that data being sent to IRIS were delayed. The amount of data held in queues at UNAVCO but not sent to IRIS was growing and anyone using IRIS for retrieval of this data was seeing large delays. To overcome this growing problem, the accelerometer software was modified to send larger packets when the backlog reached a certain configurable queue size. These modifications resolved this issue and the delays were eliminated.

Comparison of accelerometer data stored at IRIS and San Diego revealed discrepancies in the accelerometer data stored at IRIS. As a result, software defects were uncovered in the software running at UNAVCO and San Diego. The software development team at UNAVCO made modifications to the software executing at UNAVCO to correct these issues. In addition, all accelerometer data previously archived at IRIS were retrieved, corrected for the issues identified, and updated at IRIS.
In the previous quarter, work had been completed to change how tilt data were archived, requiring changes to the structure used to store the data. This quarter, data from earlier dates were reloaded and reprocessed to fit into this new structure. The reprocessing made the retrieval of tilt data consistent across all UNAVCO systems and allowed the development team to free up space in the POD database that previously was used to store tilt data.

Improvements to the Iridium-based polar data download software and systems reported last quarter were completed after several more weeks of testing and final bug fixes. Extensive documentation of the improvements was completed in the internal software and operations WIKI. One task remains: completion of the configuration of the failover server to handle Iridium-based data flow, in case of an outage of the primary server.

### 3.2.2 Campaign Data Flow

Four GPS campaigns and 12 TLS campaigns were archived this period (Table 3-1). While completion of campaign archiving was low, we note that there are nineteen GPS campaigns in varying states of completion, all of which are stalled due to missing data or information from the contributors. There were no maintenance activities or improvements to GPS campaign data flow for the quarter.

### 3.3 DATA PRODUCTS

#### 3.3.1 GPS/GNSS Data Processing and Products

The GAGE GPS Analysis Centers (ACs) and Analysis Center Coordinator (ACC) processed data and provided products this quarter from 1,913 GPS stations in the PBO, COCONet, GAMA and SCIGN networks as well as NGS CORS and other regional stations in middle and eastern North America. Eighteen new GPS stations, primarily from TLALOCNet, were added to the processing stream this period. One of the new stations was the first installed Septentrio PolaRx5 receiver added to the GAGE analysis stream; the Septentrio receiver was added to existing PBO station P041 on a splitter with a Trimble NetR9 receiver. Routine data processing and product operations were stable this period. In addition to regular monthly analysis operations conference calls attended by UNAVCO and AC/ACC personnel, the GAGE GPS analysis paper writing team participated in daily conference calls for much of February and March in order to finalize the manuscript. This group also met in person at a face to face GAGE GPS analysis meeting during the UNAVCO Science Workshop on 30 March 2016. The manuscript is on track to be completed and submitted to a peer reviewed journal next quarter.

High rate (1-Hz and 5-Hz) GPS data were provided in response to events and custom requests described in section 3.3.1.5. New and updated resources were added to the GPS data products web page, the GAGE GPS AC Products Log, and the Google+ web page focusing on GAGE GPS data products. Data Products Project Manager D. A. Phillips attended the 2-day Septentrio PolaRx5 receiver training held in Boulder on February 17th and 18th.

#### 3.3.1.1 GPS Analysis Center Subaward: Central Washington University

- Generation of rapid and final products was stable with no delays or issues.
- Metadata updates were made.
- Several new stations were added to the processing stream.
- A systematic, network-wide ~3-6 mm average height difference between the CWU and NMT position solutions has finally been resolved as described in the MIT section below. Significant effort was expended verifying methodology and no errors were found with CWU’s contributions.
- Changes to narrow the window of acceptable phase post-fit residuals resolved the poor positioning performance in processing of station ATW2 and COCONet sites, which was identified during the Seattle writing workshop in Y3Q1. Detailed analysis will occur in the future.
• T. Melbourne and W. Szeliga contributed to development of the processing paper draft.
• W. Szeliga attended the GAGE GPS analysis face-to-face meeting on 30 March during the UNAVCO Science Workshop. T. Melbourne participated remotely.

3.3.1.2 GPS Analysis Center Subaward: New Mexico Tech

• Generation of rapid and final products was stable with no delays or issues.
• Metadata updates were made.
• Several new stations were added to the processing stream.
• Updated GAMIT/GLOBK analysis package (version 10.6) to account for reassignment of satellite numbers, and beta-tested modifications to better handle duplicated epochs in RINEX files.
• Systematically examined phase residuals at each station to help identify problematic station antennas, high multipath environments, and changing conditions at sites. No significant change in phase residuals was detected at OLVM after the addition of an antenna dome at an unknown date. Examined anomalous changes in horizontal positions at AB33 during several recent seasons, which are similar to changes at AC61 where photographs suggest rime ice to be the cause.
• Reprocessed GPS weeks 1138-1139 without VMF1 atmospheric models, without second-order ionospheric modeling, and without both to investigate the network scale differences between the CWU and NMT solutions.
• Investigated poor phase ambiguity resolution in subnets in the Los Angeles basin with many Topcon NET-G3A receivers. Subsequent improvement in ambiguity resolutions is highly correlated with receiver firmware upgrades from version 4.0 to 4.5.
• M. Murray contributed to development of the processing paper draft.
• M. Murray attended the GAGE GPS analysis face-to-face meeting on 30 March during the UNAVCO Science Workshop.

3.3.1.3 GPS Analysis Center Coordinator Subaward: Massachusetts Institute of Technology

Level 2 Products. Routine combination of final and rapid level 2a products was stable, including 12- and 26-week supplemental solutions. During this quarter 1,913 sites were processed (compared to 1,918 last quarter; even though stations were added this quarter the total number is lower because some stations were offline/unreachable or not processed for various reasons). Statistics reported cover the period from 15 December 2015 to 12 March 2016.

Analysis of Final Products. For the three months of the final position time series generated by NMT, CWU and combination of the two, MIT fit linear trends and annual signals and compute the RMS scatters of the position residuals in north, east and up for each site in the analysis. The median horizontal RMS scatter is 1.0 mm or less for all centers, and as low as 0.8 mm for the NMT analysis of PBO north and east components. The vertical RMS scatter is less than or equal to 5.5 mm and as low as 4.7 mm. Seasonal changes in atmospheric delay properties will introduce small variations in these values quarter to quarter with this quarter being slightly worse than last quarter. In the NAMO8 frame realization, scale changes are not estimated.

Height Differences Between NMT and CWU Solutions. In Y2Q1 the ACC identified systematic height differences between NMT and CWU solutions as described in the Fall 2014 AGU presentation by Herring et al. (http://www.unavco.org/data/gps-gnss/derived-products/docs/AGU14_G13A-0511_GAGE.pdf). At that time it was stated that “the reason for the PBO scale tracking the CWU scale is not clear but it may be related to inter-site correlations in the NMT solutions where the satellite clocks are effectively estimated versus the CWU solution where they are fixed in the precise-point-positioning (PPP)”. Since then the ACC and ACs have dedicated considerable time and effort to identify the cause in order to resolve this difference. On June 14, 2015, the GAGE ACs implemented 2nd order ionospheric corrections into the
routine GAGE processing to ensure that the CWU PPP GIPSY processing would stay consistent with the models used by JPL to generate the orbit and clock products. Prior to the adoption of this model, both ACs generated test solutions that applied this model for GPS weeks 1800 and 1801 (July 2014). These weeks were chosen because this was the maximum in the solar cycle and the impact of applying the model was expected to be greatest at this time. The test runs showed changes in height estimates with average values between 0.8 and 1.5 mm for CWU with the RMS of the changes (about the mean) of 0.25 mm for 1850 stations. For NMT, the mean of the changes varied between -0.6 and 1.2 mm with RMS changes of 0.5 mm for similar numbers of stations. The mean difference between the NMT and CWU solutions was 0.7 mm, which was of the same level seen in earlier NMT/CWU height comparisons. After the 2nd ionospheric corrections started to be routinely applied to the non-rapid GAGE analyses, the ACC noticed that the average height differences at the reference frame stations (~550 stations) appeared to be showing systematic differences between NMT and CWU that increased to 5-6 mm (with CWU heights being greater than NMT height estimates). The ACC asked both NMT and CWU to recheck their implementations of the 2nd ionospheric corrections to see if any errors could be found. The ACs were asked to process data from 2001 during the previous solar maximum where the effects of applying the 2nd order ionospheric corrections are expected to be largest. The 2001 test runs did reveal large differences between the CWU and NMT solutions with average differences at the reference frame sites (~100 sites at that time) of 10 mm.

Analysis of these solutions by the ACC, with explicit estimates of scale changes included in the alignment, showed that the standard deviation of the NMT GAMIT estimates of scale changes were several times larger than for the CWU GIPSY estimates. (Scale estimates are effectively the average change in height across the network divided by the radius of the Earth). The GIPSY solution, computed with clock estimates from a global network of sites and with no site-to-site correlations has smaller scale uncertainty than the double difference regional GAMIT solution. No errors in the 2nd order ionospheric delay implementations were found by either CWU or NMT and it was the concluded that the differences in the height estimates after June 2015 reflected the noise in the NMT GAMIT solution due to its higher uncertainty. The GAGE combined solution is a weighted average of the CWU and NMT solution and hence is dominated by the CWU scale estimate. The combined solution is not affected by the NMT solution.

The height differences between the two solutions are reduced when the NMT regional double-differenced solution is combined with a global network double-differenced solution in GAMIT. Adding the MIT global solution to the NMT regional one transfers the scale inherent in the global network to the NMT regional solution. However, even with this addition, the CWU solution still tends to control the scale estimates of the combined PBO solution because the satellite clocks are fixed in the PPP solution whereas in the GAMIT double difference solutions they retain their implicit uncertainty.

**Snapshot Velocity Field Analysis.** MIT generates monthly and quarterly “snapshot” velocity fields in the NAM08 reference frame based on the time series analysis of all data processed to that time. These are distributed as official products from the UNAVCO website in the form of snapshot fields (SNAPS) and the significant updates to the standard PBO velocity file (SNIPS file) in standard PBO velocity field format. This quarter there were 2,156 sites, the same number as last quarter, in these analyses. Offsets are estimated for antenna changes and earthquakes. Annual signals are estimated and for some earthquakes, logarithmic post-seismic signals are also estimated. A direct comparison of the NMT and CWU solutions shows the weighted root-mean-squared (WRMS) difference between the two velocity fields is 0.08 mm/yr horizontal and 0.73 mm/yr vertical in direct difference of all sites with in 0.5 meters of each other (2,178 comparisons). Detailed presentation and discussion of these and other statistics are provided in the full MIT quarterly report available from the UNAVCO website.

**Earthquake Analyses.** The NEIC catalog was used to search for earthquakes that could cause coseismic offsets. Twenty-four earthquakes in the period from 2015-12-15 to 2016-03-15 were analyzed. Only one earthquake, the 2016-01-24 M7.1 Old Iliamna, AK event, generated measurable coseismic offsets. Rapid and final event files were generated for this earthquake and made available from the UNAVCO ftp site.
**PBO Data Processing Publication.** T. Herring continued to provide the bulk of new and updated content for the GAGE GPS analysis paper this quarter. Contributions were also made by M. Floyd and R. King. T. Herring and M. Floyd attended the UNAVCO Science Workshop and the face to face GAGE GPS Analysis Center meeting on 30 March during the Science Workshop.

### 3.3.1.4 GAMIT/GLOBK Community Support Subaward: Massachusetts Institute of Technology

During this quarter MIT continued work on modifications to GAMIT to allow processing of two-frequency observations from satellites of any single GNSS constellation. The development version of the software can now handle smoothly GPS, Beidou, and Galileo observations and orbits in RINEX 2 or RINEX 3 formats. Still to be completed are the modifications for Glonass, a particular complication for our double-difference algorithms because each satellite transmits on a different frequency. There is work to be done also in testing the yaw models for systems other than GPS. MIT continued to spend 5-10 hours per week in email support of users. During the quarter MIT issued 29 royalty-free licenses to educational and research institutions.

### 3.3.1.5 Custom GPS Data Product Requests

UNAVCO supported six PI custom requests for high rate (1-Hz or greater) GPS data downloads this period, including one event response following the M7.1 Old Iliamna, AK earthquake on 2016-01-24. High rate data from 60 PBO stations were downloaded as part this event response. Non-event requests were related to airborne lidar surveys, including two projects flown by NCALM, a SCEC GPS survey near Mexicali, and commercial survey projects including CALTRANS and private surveyor projects. A Special Topics Session (STS) covering event response was held during the UNAVCO Science Workshop.

### 3.3.2 Strain, Seismic and Tiltmeter Data Processing and Products

UNAVCO processes data and provides products for borehole strainmeters, seismometers and tiltmeters in the PBO network. Routine data processing and product operations were stable this period. Three fully processed high rate (1-sps) borehole strainmeter data sets were generated this period for the following earthquakes: 24 January M7.1 Old Iliamna, Alaska; 30 January M7.2 Yelizovo, Russia; 02 March M7.8 Sumatra, Indonesia. These data were made available within 48 hours of the event and were posted on the Geophysical Event page. A strainmeter Short Course was held March 28th 2016. The course included analysis of strainmeter data and the processing steps involved in generating Level 2 data.

UCSD, through a subaward managed by UNAVCO, processes data and provides products from the long baseline laser strainmeter (LSM) network described in section 2.2.1.3. Routine data acquisition, editing, and archiving operations were good this period. The evolution of a number of transient earth-deformation signals reported previously continued to be recorded this period.

### 3.3.3 Meteorological and Hydrologic Data Products

Meteorological data are collected together with GPS/GNSS and other geophysical data in order to enhance the datasets, improve network monitoring, and provide additional information for interpretation of deformation signals. Temperature, humidity and barometric pressure data collected at GPS stations are available directly from the GPS RINEX files. Routine product operations were stable. Documentation and metrics related to new hydrologic loading data products continue to be developed. Development activities continued this quarter on precise hydrologic data products based on NLDAS in addition to GLDAS.

### 3.3.4 Lidar – Terrestrial and Airborne Laser Scanning

UNAVCO provides TLS data services and products including basic data processing, data management and data archiving. The standard UNAVCO TLS deliverable is a merged, aligned, georeferenced point cloud,
which is accompanied by pertinent metadata products such as site photos, meteorological information, field notes and other ancillary project information. TLS data support is further described in section 3.4.4, LiDAR data management and archiving. EarthScope ALS data products are supported by OpenTopography; metrics are reported to UNAVCO. No new ALS data product activities have been performed to date under the GAGE Cooperative Agreement.

Development of a new TLS data archive system is nearing completion and was showcased at the UNAVCO Science Workshop. The system enables archiving and sharing of higher-level data products generated from UNAVCO collected TLS data. We anticipate community members uploading derived products such as DEMs to the archive so that they receive a DOI for citation, and are properly archived.

3.4 DATA MANAGEMENT AND ARCHIVING

3.4.1 GPS/GNSS

The Data Center provides a secure long-term archive for data, data products, and metadata from GNSS instrumentation, and makes data available to the scientific community and the public. User interfaces, APIs, and software tools that facilitate data search and access, data handling, and visualization are provided to support full utilization of the data assets. Data publication with digital object identifiers (DOIs) is routine for most data sets.

Two staff departures occurred in Y3Q2. Because the second position was funded from a project that is coming to a close, only one position has been posted.

Data archiving and distribution is an operational activity that continues to grow, with a total of 33 stations added for archiving from HOPRnet (HOluhraun Post Rifting network, Iceland), TLAOCNet (Mexico), COCONet (Caribbean), Nepal, Hastings, IGS, Antarctica Infrastructure, INL (Idaho National Laboratory), SCIGN, USGS Volcano, and Soil Moisture networks. The first deployment of a Septentrio PolaRX5 receiver, at the PBO Marshall site (four char ID PRX5), began delivering data for archiving and distribution. There was continued data archiving in support of the Gorkha earthquake response; one station was added.

To prepare for archiving activities related to the deployment of the Septentrio PolaRX5 receiver, three staff members attended the Septentrio training provided by the GI program. Software development in coordination with the data flow team was required to ensure readiness for handling the latest Septentrio SBF file format from receipt of data and metadata, through metadata harvesting, archiving, data translation to RINEX 2.11, QC, and distribution via the archive ftp server. All of the required software development was completed this quarter.

RINEX3 format data are being made available to the community as part of a pilot project. Handling of this data from four stations is now in production, with download of the RINEX3 format data (produced onboard on the receivers), metadata extraction, archiving, and delivery to customers from a dedicated directory on the ftp server; data going back to January 1, 2016, are available. UNAVCO is using the RINEX3 file naming guidelines from the International GNSS service. The receiver on-board RINEX3 file format includes mixed GNSS observation files and ephemeris files. Aspects of file management, such as file naming, relies on the GeoForschungZentrum’s gfzrnx open source software tool. In order to deliver quality checking (QC) for this data, the gfzrnx tool is used to reformat RINEX3 to RINEX 2.11, followed by QC from UNAVCO’s teqc software. A task remaining for this pilot project is developing the capability to use the G-NUT/Anubis software from the University of Pecny to run QC directly on the RINEX3 files. Another task for the next quarter will be translation of data from Septentrio’s PolaRX5 receiver to RINEX3. Availability of the RINEX3 format data was announced with a message to the unav_all mailing list and a web site news item on 25 March.
UNAVCO plans for handling formats and tools related to GNSS have been described in the white paper *UNAVCO Geodetic Data Services Plan for GNSS Modernization – Data Formats and Preprocessing Tools* that was released to the community on March 25 in coordination with the RINEX3 announcement. This white paper summarizes the landscape ahead for UNAVCO and the community to manage the increasing complexity of GNSS when resources are flat or declining. Both the RINEX3 pilot project and the white paper were topics of a special topics session at the UNAVCO Science Workshop.

We continue to investigate ways to utilize commercial cloud services to create cost-effective, efficient solutions for data & metadata management and archiving activities. Using Amazon resources provided to UNAVCO for data related cloud application pilot projects, we are continuing an information gathering experiment on scaling of Amazon services for handling thousands of stations’ data and metadata. We are using GSAC on an Amazon VM to mirror the ftp holdings and metadata for UNAVCO’s 2700-plus live stations, while gathering cost information for storage, access, and processing power. This experiment will be ongoing for the next several months.

In our role in support of IGS operations, staff attended the IGS Workshop in Sydney Australia in February. D. Maggert and F. Boler are members of the IGS Governing Board (F. Boler as elected Data Center Representative, and D. Maggert as Network Coordinator) and attended Governing Board meetings in Sydney. IGS operations support included guiding the station managers for tens of new stations and ongoing facilitation of the IGS RINEX3 transition.

Coding to support a new release of UNAVCO’s teqc software for GNSS data preprocessing was nearly complete at the end of Y3Q2. Most critically, this release will fix a bug causing a segmentation fault encountered when large magnitude phase values occur; in addition several translation related issues for Topcon receivers are addressed.

In the previous quarter we initiated work on a replacement tool for UNAVCO’s Velocity Viewer web application, which at a basic level allows map-based visual exploration of GPS station velocities, and which includes additional flexible display capabilities such as faults, earthquakes, selection of reference frame and/or plate fixed, is used by research scientists, teachers, and students alike. Progress was made this quarter with the new technology, but staff departures have caused a temporary suspension of work on this project.

Oracle is used for the Archive’s Database Management System (DBMS). As related last quarter, Oracle is making changes to its licensing model that would impact both costs and performance. The conclusion of our analysis of DBMS options this quarter is that the most prudent plan is to migrate from Oracle. PostgreSQL will be the future DBMS for archive operations, though migration will require many months to plan and carry out. In order to maintain stability during planning and carrying out the migration, a two-year license was purchased under special pricing that delays the higher anticipated Oracle costs in the future.

The metrics in Table 3-1 document the data volumes archived and delivered. Metrics notes for Y3Q2:

- The archived volume for high rate GPS data for the quarter was 1.98 TB, about the same as last quarter. High rate event response for the Old Iliamna Alaska earthquake, along with the Antarctic season data needs, and an added set of streaming stations, account for the volume.
- The delivered volume of high rate data was 0.96 TB, which is lower than observed for almost all quarters of GAGE. The number of distinct IPs accessing high rate data did not change.
- The archived volume of data products was lower than recent quarters at 0.8 TB; this represents the baseline level of products archiving, with no added reprocessing included. Delivery of products, at 0.5 TB, was neither high nor low compared to recent quarters. However, the number of distinct IPs accessing products jumped during the quarter. The additional customers likely picked up just a few products each.
- The unusual pickup activity by the domain seti.org in previous quarters diminished in Y3Q2 and
by March several other domains were accessing greater overall volume.

- The archived volume for standard rate GPS data for the quarter was 1.27 TB. The delivered volume of standard rate data was 9.19 TB. Over the GAGE award through Y3Q1 the average monthly standard rate pickup volume has been 2.13 TB, while this quarter the monthly average was 3.06 TB.

3.4.2 Real-time GPS Data Flow and Management

UNAVCO provides high-rate (1 Hz), low-latency (<1 s) GPS data streams (RT-GPS) from approximately 484 stations including 425 PBO (Core and Cascadia), 13 TLALOCNet, 45 COCONet stations plus one station in Nepal.

Fifty-nine new users requested access to the data streams in Y3Q2 bringing the total number of registered RT-GPS users to 508 (Figure 3-4), an increase of 13%. The largest growth in user numbers was in the Commercial group (42), compared to 10 and 7 in the Academic and Government categories respectively. Figure 3-5 shows the percentage of active data users in terms of user group. Commercial users form the largest active group (56%) followed by Government (25%) and then Academic (19%). Government agencies were responsible for 61% of all data downloaded through Y3Q2 (Figure 3-6).

The Institute of Communications and Navigation of the Federal Republic of Germany (DLR), who are using the data to generate maps of the Total Electron Content of the ionosphere, account for ~25% of all data downloaded. The second largest data user was a commercial company (15%) followed by the USGS at Menlo Park at 14%. Similar to Y3Q2 40% of all data downloads are made by federally funded agencies. The largest academic users were Central Washington University (11%), the fourth largest user overall and UCSD Scripps (8%).

The five sites with the greatest volumes of data downloaded were P475 at Point Loma, CA (30.9 GB), P395, Rose Lodge, OR (30.1 GB), P534 Davenport, CA (27.9 GB), P733 Gold Beach, OR (27.1), and P174 King City, CA (26.9 GB). Across the network, 456 sites were accessed by the academic community, 445 by commercial entities and 458 by government and nonprofit consortia. 445 sites were accessed by all three user groups; academic, commercial and government plus nonprofit consortia (Figure 3-8).
Figures 3-4 through 3-6. Real-time GPS data users. Registered data users are all of the users who have been given access to RT-GPS data streams since inception. Active data users are those who actually accessed data streams this quarter.
Figure 3-7. Cumulative volume western US RT-GPS data downloaded through GAGE Y3 Q2.

Figure 3-8. RT-GPS sites in the western US from which data were accessed by all user types GAGE Y3Q2.
3.4.3 Strain, Seismic, Tilt, Pore Pressure Data

Metrics for data archiving and delivery volumes this period, as well as unique users, are summarized in Table 3-1. No unusual trends in LSM data metrics were observed this quarter compared to previous GAGE quarters. There was an unusual increase in the number of users accessing seismic, BSM, tilt and pore pressure data in January. Investigation of user domains suggests that this may be an artifact of an internet service provider in Europe and not a real increase in the number of unique users that month. There was a moderate increase in the volume of pore pressure data deliveries in March. The trend of increased BSM data users and tilt data volume deliveries seen in previous quarters appears to be leveling out. Similar to previous quarters, the cause and primary users driving these trends and variations are not clearly known. Work to fully automate metrics tracking and reporting is nearly complete and in the final stages of testing. Most fully automated metrics from this quarter agreed with traditionally compiled metrics to within a 95% confidence level. We anticipate that all metrics from these datasets reported next quarter will be based on a completely automated system.

3.4.4 Lidar – Terrestrial and Airborne Laser Scanning Data

Data from TLS PI projects continue to be added to the archive as projects are completed, with approximately 211 GB of TLS data added this quarter. Approximately 205 MB of data have been downloaded from the TLS archive by 5 unique users.

As planned, in mid-January 2016 we took the existing TLS data archive offline and began a transition to the new data archive, which is based on the software that underlies the WInSAR Portal system and continues to be developed by Data Engineer (M. Okal), Geodetic Imaging Project Manager (C. Crosby) and Software Engineer (S. Baker). The new archive was released in early February 2016, and showcased at the UNAVCO Science Workshop in March. Data downloads for the months of January and February are therefore very low, making the quarterly total abnormally low compared with previous quarters.

The new archive, which is based on Django, the open source software that underlies the WInSAR Portal system, provides a more structured and dynamic representation of project information and allows the archive to function better internally when queries are made by users and visitors. A new user interface includes an improved data discovery interface, a publication submission tool and user authentication. While all archive materials remain visible to the public, the new archive requires user accounts (authentication) for all downloads. User authentication not only provides users with personalized pages allowing them direct access to their projects, but it also eliminates bot downloads and allows usage metrics to be automated.

The new archive software development effort continues in Y3Q3 with the development of a data upload or submission interface, creation of automated usage metrics, and DOI minting for all existing data sets. In an effort to align TLS data archive with UNAVCO best practices, we are maintaining an offsite backup of the TLS archive using Amazon’s Glacier cloud storage service.

Another area of focus for TLS data support is improved access to software required by community members to process and analyze TLS data. Data Engineer M. Okal, with support from UNAVCO System Administrators, maintains a software license server and is working to improve documentation on accessing and using these software packages. Available software includes four seats of Leica Cyclone, 20 seats of Riegls RiScan Pro and 10 seats of RiSolve, ten seats of Blue Marble’s Geographic Calculator, 10 seats of ArcGIS, three seats of Quick Terrain Modeler, 10 seats of Polyworks, and five seats of Trimble Business Center. During this period software maintenance on two of these software packages were updated. Software maintenance for the RiScan Pro licenses was extended in this quarter.

OpenTopography is the official archive and access point for EarthScope ALS data. Metrics provided by OpenTopography this quarter indicate 103 unique users accessed point cloud and raster terrain products, running 206 jobs to gain that access.
3.4.5 SAR Data

UNAVCO manages two tasks in support of SAR Data: the archive and GEO SuperSites.

3.4.5.1 SAR Archive

UNAVCO has managed the SAR Archive since 2005. Under GAGE, UNAVCO orders European Space Agency (ESA) and DLR scenes in response to WInSAR user requests. In addition, the WInSAR Executive Committee and UNAVCO arranged for a tasking quota with DLR for use by WInSAR. WInSAR user requested tasking orders for the TerraSAR-X mission have been placed on a regular basis. UNAVCO archives WInSAR community TSX and ALOS-2 data in the UNAVCO SAR Archive. UNAVCO also manages access to the ISCE SAR data processing software package for all members of the WInSAR Consortium.

SAR data metrics are shown in Table 3-1. The volume of SAR data archived in Y3Q2 was greatly increased due to data from ALO2-2/JAXA proposals. JAXA provides 50 scenes per year for PI proposals and there was a large surge in data ordered by PIs due to quotas expiring on March 31, 2016. Some ALO2-2 data files are 50-60GB each, which accounts for the large volume of data.

WInSAR scenes from ESA are available without cost under their open data policy. TSX and ALO2-2 data access is restricted to Co-PIs associated with a specific science proposal approved by DLR or JAXA, respectively. The volume of SAR data deliveries was also large in Y3Q2 (10.0 TB), continuing the surge first noted in Y2Q3. These increased volumes were associated with ALO2-2 and TSX data downloads.

UNAVCO continues to maintain the core SAR archive infrastructure, including hardware, database, software, and web presence. Data ingest capabilities have been developed to allow UNAVCO to host data from newer satellite platforms such as COSMO-SkyMed, ALO2-2, RADARSAT-2, and Sentinel which WInSAR community users are beginning to utilize. Search and discovery for these hosted data is possible through the UNAVCO SAR Archive GUI and API interfaces. Access to data from COSMO-SkyMed, RADARSAT-2, ALO2-1/ALO2-2, and TSX are restricted to collaborators on proposals, and the WInSAR Portal interface permits role-based access to groups of users.

ESA is the primary archive for ERS-1, ERS-2, and Envisat, while the Alaska Satellite Facility (ASF) is primary archive for RADARSAT-1. For all data not archived in ESA’s Archive4 system or at ASF, UNAVCO is now backing data up to Amazon Glacier, a commercial cloud storage system. This ensures a complete offsite backup of the full UNAVCO SAR archive while minimizing redundancy, beyond duplication.

3.4.5.2 GEO SuperSites

For the GEO Supersites and Natural Laboratories initiative, UNAVCO provides data ordering (from the European Space Agency), together with data management (download and repackaging) of the orders received, and upload of the orders to the ESA supported cloud storage (Level 4 archive). In addition to this operational data management activity, UNAVCO provides some website content management and hosting for the Supersites but it is the intention to migrate all content to the new GEO website over the coming quarters.

As noted above, UNAVCO now supports TSX, COSMO-SkyMed, RADARSAT-2, and ALO2-2 data collected under the Supersites initiative. For these datasets, the list of PIs with access to the data include international collaborators as well as WInSAR community members. To address this expanded community of users and associated access constraints, we’ve made several modifications to the WInSAR Portal system to allow registration by international partners.

Building on the successes of UNAVCO’s ongoing NASA ROSES ACCESS-funded work to develop a Seamless SAR Archive (SSARA), UNAVCO staff members have been engaged in joint planning with the European SAR community (DLR, ESA, CEOS, etc.) regarding federated access to data, data processing
environments, and metadata and product formats. The goal is to leverage the SSARA work to build federated access to data hosted by the space agencies that participate in Supersites. Federated query of Supersites SAR data (ESA’s Virtual Archive 4 and DLR’s TerraSAR-X Archive) along with data archived at the Alaska Satellite Facility and UNAVCO is now available due to SSARA efforts (http://web-services.unavco.org/brokered/ssara/).

Following the release of the InSAR product archive (developed under the SSARA project) in GAGE Y3Q1, UNAVCO continues efforts on the adoption of the HDF-EOS5 standard product format for contributed InSAR products. This format is now fully documented and available for comment here: https://winsar.unavco.org/portal/media/insar/InSARProductArchive-ProductFormatSpecification_draft-20151118.pdf. Associated with this product format, we also produced scripts/converters to generate HDF5 format InSAR products from GMTSAR and ISCE, to enable users of these software packages to quickly generate compliant product - a new GitHub provides access to available tools: https://github.com/bakunavco/ProductArchive.

The archive supports user controlled DOI assignment for products uploaded to the InSAR archive at UNAVCO (https://winsar.unavco.org/portal/insar/). InSAR products are uploaded via the API (https://winsar.unavco.org/portal/insar/api/interferometry/), and users are now able to request a DOI from UNAVCO, making the products persistent and citable. This functionality was fast-tracked in Y2Q3 in response to community demand as InSAR products from the April 2015 Nepal earthquake were being generated. More recently, JPL-Caltech ARIA project has used the InSAR product archive to publish a coseismic interferogram for the 16 August 2015 Mw 8.3 Illapel Earthquake in Chile processed from Copernicus Sentinel-1 data (https://winsar.unavco.org/portal/insar/19/).

### 3.4.6 Pore Pressure and Temperature Data

All of UNAVCO’s pore pressure data have been forwarded and stored at IRIS for years. IRIS provides access to these data through a variety of web services and archival services. IRIS provides UNAVCO with monthly metrics on storage and retrieval information. In the future, UNAVCO will announce that it will be eliminating the storage of pore pressure data at the UNAVCO data center and all users wanting the data will need to go the the IRIS archives to retrieve it. All UNAVCO pore pressure web services will continue to be supported after this announcement and were rewritten this quarter to support the retrieval of data from the IRIS archives. Initially, not all the pore pressure data stored at UNAVCO were available from IRIS. To resolve this, the development team at UNAVCO uploaded previously archived data from UNAVCO that were not available at IRIS. Once this was complete, the pore pressure data archives at both IRIS and UNAVCO matched and all pore pressure data requests can now be fulfilled by IRIS.

### 3.5 CYBERINFRASTRUCTURE

Several projects are in progress to expand the cyberinfrastructure capabilities of UNAVCO GDS.

We are collaborating on the NCAR-led EarthCube Building Blocks award “Enabling Scientific Collaboration and Discovery through Semantic Connections” (EarthCollab) based on the Cornell-developed “VIVO” semantic web ontology and web presentation software. Members of the community in attendance at the UNAVCO Science Workshop were able to interact with the publicly available prototype, Connect UNAVCO (connect.unavco.org). The site provides connections, linkages and visualizations of people, publications, data, tools, techniques and other events related to research, development and applications of geodesy through the UNAVCO facility and community. Technical work continued on developing cross-site compatibility for EarthCollab and affiliated University VIVO sites.

UNAVCO Dataworks and GSAC projects are resources for partners and interested groups to accelerate their participation in multi-institutional data sharing technologies. A working Dataworks instance on an Amazon virtual machine (VM) was tested last quarter. This capability provides an easy option for groups desiring to run Dataworks with minimal investment in infrastructure and IT support. UNAVCO provided
a VM with the Dataworks Amazon Machine Image (AMI) installed for temporary investigation by partners from Mexico.

Dataworks, and the related topics of data attribution, open data and data DOIs was the subject of a lunchtime mini-special topic session at the UNAVCO Science Workshop. Dataworks as a way to manage data and metadata for our community investigators was discussed.

The European Plate Observing System (EPOS) is expanding their use of the GSAC code as they move into the implementation phase of their data and metadata infrastructure development. UNAVCO is offering advice on their proposed utilization, though we do not currently have resources or any internal requirement to expand GSAC. UNAVCO staff met with EPOS representatives at the IGS workshop to continue our interactions on this effort.

UNAVCO is continuing to facilitate expansion of use of GSAC within the US. To allow evaluation by NASA's Crustal Dynamics Data Information Systems, UNAVCO has deployed an instance of the earlier-generation flat-file based GSAC containing CDDIS's records of the monument catalog and datafile holdings information harvested from their published flat files.

The IGS Site Log XML metadata exchange effort progressed during the quarter through discussions at the IGS Workshop. The wider IGS community was introduced to the plans of the Data Centers Working Group. Plans include further fleshing out of use cases and building the required systems for machine-to-machine interactions with GeodesyML and a Site Log XML application schema.

One of the server platforms that UNAVCO is using as a back end for its web services will no longer be supported in the future by the vendor currently supporting it. As a result, the development team has started to move all web services over to a new Python based platform. Through some initial development, the team has demonstrated that development time on this new platform is significantly less. All current web services will or are being rewritten to run in this new environment.

Development to pull GPS time series data from the University of Nevada-Reno (UNR) for UNAVCO GPS time series web service was completed this quarter as part of NASA ROSES ACCESS “Plug and Play GPS” developments. The service now supports final and rapid station position solutions from any of the GAGE Analysis Centers or UNR. Rapids are returned for those epochs where finals are not yet available. Data is pulled as X/Y/Z, then converted to lat/long/height and NEU and delivered in the response to the requester. Related to this effort, a significantly revised web service to return GPS time series data was developed this quarter and was demonstrated at the UNAVCO Science Workshop. This service supports the output of daily GPS time series position products from the GAGE Analysis Centers as well as from the University of Nevada-Reno (UNR) analysis center. Documentation for the service was greatly expanded. Going forward and as service are moved to the new platform, additional documentation will be added.

Initial development was started to begin loading all real-time GPS, BSM, seismic, tilt, pore pressure and accelerometer data into an instance of Open Source software called Data Turbine that has been deployed at the UNAVCO site. Data Turbine is a ring buffer that will be used to hold recent data collected for a yet to be determined number of days and give researchers the ability to easily look at data in real time or collected during this past number of days. New tools are also being developed to display and extract the data form Data Turbine. The development team is currently working on software to support the loading of all real-time GPS stations using data from one of the castors distributing real-time data. Strain, pore, accelerometer and some tilt data will be retrieved from Antelope and seismic data/remaining tilt data will be delivered hourly by dataflow.

3.6 Internal Computing Initiatives and Support

3.6.1 IT Highlights
Migration of all users to Google Gmail was completed last quarter. After looking more closely through the logs generated by Google, it was discovered that not all messages had been migrated for some users due to timeouts experienced during the initial migrations. To migrate all messages possible, Google provided a tool that allows one to run migrations again for those mailboxes where timeouts were experienced and only migrate those messages that had not been previously migrated. These migrations had to be run multiple times for some users as timeouts re-occurred each time the tool was run and migrating more messages each time until all possible messages had been migrated.

All UNAVCO users were migrated to Google calendars this quarter. All prior calendar information from the in house Kerio server over to Google. Training by the IT group was provided to all employees. This included training for Apple iCal and Outlook calendar users.

Comcast has received approval for the permit from the City of Boulder to run fiber to the UNAVCO location. Since March, the IT group has been working with Comcast engineers and technicians to get it installed in the building. Splicing into the main feeder circuit along with installation of a switch within the building is all that is remaining before service can be turned up. Current project plans have the turn up date at the end of May, however they are hoping to bring this in. This will initially provide the building with a redundant 100Megabit connection and can be quickly expanded to 1 Gigabit should the need arise. The connection will be used at all times for carrying traffic along with the 1 gigabit connection that we currently have in place with Level 3/FRGP.

A front end product for the open source Git version control system from Atlassian was installed and tested in a test environment during the month of March. It has been configured and tested along with single sign-on software from Atlassian. The plan is to deploy both products into production next quarter which will allow users to have a single sign-on for all these products. With single sign-on, IT will be able to provide users with an automated process to reset their passwords for all applications that use Active Directory for authentication.

The hardware previously used to support the DNS systems was old and were dedicated hardware platforms. During this past quarter, one of the servers was replaced and the remaining server will be replaced next quarter. The change out of the first server caused issues with GPS receivers that connect using VPN. The new server has a different version of the software and responds differently to certain queries. This different response created timeout scenarios and data from 234 stations was delayed by approximately five days until a temporary workaround was deployed. Upon deployment, the dataflow software was able to retrieve all prior data and resume pulling data on the schedule defined for each of these receivers. A long term solution was deployed a few days later and the issue resolved.

Prior to the DNS deployment new NTP servers were installed and deployed to replace servers running on older hardware. In addition, a 3rd server was installed so the it could be used as a moderator when two of the servers disagreed on the correct time. At the same it was discovered that some of the systems within the data center had not been setup to use these NTP servers. This has been corrected and all servers now point to these servers for time.

### 3.6.2 Internal Software Developments

Software development continued in support of automated metrics collection, specifically for data usage from UNAVCO archives. Support for SAR and pore pressure archival and delivery metrics were added. Pore pressure data archival metrics are compiled using information supplied from the IRIS repository. Backfill of metrics for previous periods for SAR and pore pressure data was also completed during the quarter. Development work was initiated to gather active station counts for all existing metrics categories. The counting and definition of an active (data available for 85% of days within period selected) is being made consistent across all categories. All web services will begin to collect delivery metrics as well.
To support the metrics streamlining effort, archive software staff continued the software development activities from prior quarters. The focus this quarter has been on finalizing code to facilitate use of the archive database to update the metrics database nightly with archived and delivered data volume metrics. Database queries identify active stations based on data newly archived, to support metrics collection. MongoDB supports acquiring data delivery metrics; a new release of the MongoDB was installed on the metrics Mongo server. Some java code supporting metrics required reworking after the update.

To support the ongoing renewal of station permits, the development team worked on a mailing page that will support landowner outreach. The mailing will contain information on the local GPS site including site motions with a comparison of other sites close by. This information is gathered from several sources at UNAVCO and put together to create a site specific custom 2-page mailing. A prototype for the mailing has been developed and waiting for feedback from stakeholders.

The GI and Business Administration directorates asked GDS development to investigate the tracking of SIM cards used in cell modems to improve the tracking of cell data charges for field installations. Initial software development work has started within MDM to track the modem SIM cards that enable the use of cellular data. Cell providers use SIM numbers to identify individual cell accounts. MDM will provide several tools to support entering of these numbers, activation and deactivation of cards, and association of a specific card with a specific modem in the field, for storage in the POD. This information will be used in custom reports to better and more efficiently validate and track cellular data charges.

More GI field engineers are starting to use Nagios as a tool to monitor deployed instrument performance. To improve monitoring, developers have built and modified plug-ins that can be used with Nagios to customize monitoring. These included plugins to monitor receiver temperature and voltage; a configurable plugin will send an alert when a file has not been delivered in a specified period of time.

### 3.6.3 Web Software Development

Development efforts to move the UNAVCO website to a Linux based system continued in Y3Q2. A new version of the Knowledge Base software was deployed to production. Some minor issues continue to arise and get resolved, which includes resolution of links from the old software that community members still use. UNAVCO staff collaborated with personnel at the University of Alaska, Fairbanks to support feature enhancements of the Earthscope web site; the enhancements were related to the part of the website that was previously developed at UNAVCO.

### 3.7 GDS PROGRAM SUMMARY

The Geodetic Data Services program continues to provide a growing body of diverse data sets and derived products for a wide range of observing systems to the community of contributors and users. GDS collects and monitors 90 detailed and six key summary metrics (Tables 3-1 and 3-2). These metrics include numbers of stations, data, and derived data product volumes archived and delivered, user metrics, and software downloads for data from all of the data different sensor types managed by UNAVCO. The six key summary metrics for Y3Q2 campaigns and permanent stations archived, data volumes archived and delivered are similar to prior quarters. The total volume of data archived this quarter, 19.1 TB, was 12.5 TB greater than last quarter, almost exclusively due to higher volumes of SAR data archived. The total volume of data archived (all sensors) is now over 195 TB (including 9.8 TB of ALS data archived at OpenTopography/NCALM) as shown in Figure 3-1. The total volume of data delivered to users this quarter, 30.4 TB, was 6 TB greater than last quarter, again primarily due to SAR data deliveries. The estimate of the number of unique users this quarter was 2,904, about 260 more than last quarter. As part of ongoing efforts to provide the most accurate metrics possible, slight changes to some previously reported metric values were made this quarter based on new information and/or refinements to our metrics tracking/reporting process. These metrics are one representation of core operations. Behind these numbers are a wide range of activities and projects, funded through core and multiple ancillary awards
that fund the large breadth of scope developed, operated and maintained by the GDS program. The focus of ongoing development continues to be upon enhancing services and building capacity to manage data from new systems. For GNSS this effort is moving from GPS to full GNSS and expanding real-time data acquisition and processing to include hundreds of new sites. For TLS the activity has been to completely revamp the archive architecture and to ingest legacy data. With SAR the challenge is handling and processing data from new satellites from ESA and JAXA and preparing for NiSAR. The theme of overall cyberinfrastructure developments is to develop web services across all data systems with consistency that will facilitate integrative access and broader utilization of data and services both within and external to GAGE.

4. Education and Community Engagement

4.1 OVERVIEW

The Education and Community Engagement (ECE) program has four strategic areas of focus: provide professional development activities for community scientists and teachers, develop and disseminates geodesy-focused education materials, support geo-workforce development, and provide communications and other support to the UNAVCO community. The ECE team actively participates in UNAVCO website updates, leads the organization-wide social media effort, works with UNAVCO staff to develop UNAVCO Program Highlights, and collaborates with external partners to develop interactive displays for exploring Earth science content. Whenever possible, ECE efforts closely coordinate with those of partner organizations including the EarthScope National Office, Geological Society of America, the American Geophysical Union, UCAR, and IRIS, among others.

4.2 PROFESSIONAL DEVELOPMENT

Professional development activities include technical short courses, education-focused workshops, and training sessions. March 9-11, UNAVCO participated in the UCAR-organized workshop “A Career Development Workshop for NSF Geosciences Postdoctoral Researchers”. Over 70 postdoctoral researchers participation. S. Olds led a session highlighting geodesy-focused resources available through UNAVCO. Materials feature include: GETSI educational materials, and animations of applications of geodesy data, online support for early career professionals (http://www.unavco.org/education/advancing-geodetic-skills/early-career-professionals/early-career-professionals.html), data and data products available for research, and how to request UNAVCO support.

4.3 EDUCATION RESOURCES

GEodesy Tools for Societal Issues (GETSI) (NSF DUE TUES 1245025), continues development and dissemination of curricular modules that feature geodesy data applied to critical societal issues. In total, seven modules are in various stages of development and publication. Finalized modules (NSF TUES-funded) are available online (http://serc.carleton.edu/getsi/index.html). Figure 4-1 shows the access page for the published modules. During this quarter preparation, development, testing, and/or revisions went forward on five other modules: *GPS, Strain and Earthquakes, *Measuring Water Resources with GPS, Gravity, and Traditional Methods, Surface Process Hazards, *Analyzing High Resolution Topography with TLS and SfM, and High Precision Positioning with GPS. The first three were funded by NSF TUES award and the last two (related to field geodesy) have been supported through primary and supplementary GAGE support and will be furthered by NSF EHR IUSE if the pending “Exploratory-level” proposal is awarded. It is anticipated that three of of the five (marked with *) will be complete and published this summer. GETSI materials were disseminated via a webinar by the Science Education Resource Center (SERC) “Using Data to Teach About Societally Important Questions” (47 participants) and UNAVCO short course “Geodesy Data Teaching Modules: GETSI Short Course” (10 participants).
Figure 4-1. Published and beta-version modules featured in the March 2016 “Geodesy Data Teaching Modules” short course offered in conjunction with the UNAVCO Science Workshop.

In order to support further development and dissemination efforts, a GETSI Phase 2 proposal was submitted January 13, 2016 to NSF EHR:IUSE. The proposal would fund an additional 7 modules on topics ranging from volcanic hazards to environmental change; professional development and dissemination to 400 faculty members in the geoscience, civil engineering, and ecology/forestry fields; and include educational research into the implementation practices of faculty.

4.4 COMMUNITY COMMUNICATIONS

ECE leads efforts related to communication, collaboration, access, and dissemination of UNAVCO science and education to both the UNAVCO and broader communities. UNAVCO joined over 40 organizations as members of the Portal to the Public Network (PoPNet) managed by the Pacific Science Center in Seattle Washington Portal to the Public is an approach focused on providing training opportunities to scientists so they can more effectively interact with the public in informal settings. UNAVCO will modify the model to facilitate connecting our community of scientists with their local informal science centers and provide professional development for the scientists.

The ECE program was key in organizing and execution of the EnGAGE Interactive Space and “community self-station” at the UNAVCO Science Workshop. The EnGAGE space showcased hands-on learning demonstrations, new geodetic instruments, and community & UNAVCO web tools. Demonstrations included an inflating sand volcano, an isostatically adjusting bowl of “flubber,” an augmented reality sandbox with flowing lava (Figure 4-2), a TLS instrument, the UNAVCO TLS Data Archive, the Plug-and-Play automated global GNSS processing platform, and Connect UNAVCO. The EnGAGE Interactive Space was co-located with the workshop posters allowing community members to interact with each other.
4.5 GEO-WORKFORCE DEVELOPMENT

UNAVCO is committed to broadening and increasing the geodesy community and geoscience workforce. Efforts focus on providing opportunity in various stages of the geoscience academic/career pipeline including internships, mentoring, and online resources.

RESESS (GAGE ARRG Supplement): Research Experiences in Solid Earth Science for Students (RESESS) is an internship that includes an 11-week summer research experience, support during the academic year, and science conference travel. The 2016 RESESS cohort was identified completed in GAGE Y3Q2. A total of 164 applications were received (4 for returning interns, 160 for first-year interns). A. Morris interviewed 16 finalists by telephone, and the RESESS selection panel reviewed the finalist applications. The six-member selection panel included five UNAVCO staff and one CU graduate student who served as the 2015 RESESS Graduate Assistant. Two interns were selected to return to RESESS, and six first-year interns were selected. An NSF EHR IUSE proposal was submitted January 2016 to continue the RESESS program and expand the professional development program to other universities via an online collaboration with Colorado State University, University of Northern Colorado, and the American Geophysical Union.

Geo-Launchpad (NSF ICER 1540524): The Geo-Launchpad internship provides an 8-week summer work experience for two-year college (2YC) students from Colorado. Interns work on UNAVCO GAGE-related projects under the mentorship of UNAVCO GI and GDS staff, and receive professional development throughout the summer program. Students apply to the program with a faculty mentor from their home
institution. The faculty member provides local support and will travel to UNAVCO for a mentoring workshop in late July. The UNAVCO project leadership team includes the PI (Charlevoix), Co-PI (Morris), Project Assistant (K. Russo-Nixon), and external evaluator (H. Thiry, CU-Boulder).

Students applied to the program through the UNAVCO employment portal. Sixteen completed applications were received (included student application, transcript, and faculty mentor application) and reviewed by a selection panel that included a representative of each intern project team (F. Boler, M. Okal, A. Morris) and the Geo-Launchpad Project Assistant (K. Russo-Nixon). Offers were made to six students (4 students from Larimer campus, 1 student from Westminster campus, and 1 student from Boulder campus). The Geo-Launchpad interns will work in pairs on projects developed with UNAVCO staff, and the interns will present their summer work at the end of summer poster session in conjunction with the RESESS interns and our partner internship programs in the Foothills region.

USIP: The UNAVCO Student Internship Program (USIP) is a summer internship for graduate students and advanced undergraduate students focused on gaining real-world work experience in a professional setting. One hundred ninety completed applications were received for seven intern positions. The 2016 interns will be supervised by UNAVCO staff: Crosby, Mencin, Olds, Bartel, and Austin. USIP interns work on projects of UNAVCO GAGE scope, collaborate with teams toward a common mission, and contribute their knowledge, skills, and abilities to the UNAVCO community. Interns spend eight weeks at UNAVCO, under the guidance of a staff supervisor, culminating in a short presentation to UNAVCO staff.

E-Net: Expanding Networks Through Mentoring (E-Net) is a mentoring program during the UNAVCO Science Workshop. The program invites students and early career professionals to connect with established members of the UNAVCO science community through both facilitated and free form mentoring interactions. The 2016 E-Net program involved 14 mentors and 28 mentees from a diversity of national and international organizations. Interested participants are invited to sign up during the workshop registration process, and indicate whether they are interested in participating as a mentor or mentee. Participants are matched in a way to best mix discipline and institution, and each mentor typically hosts two mentees. The goals of the program for mentees are to develop professional savvy and expand their professional network. The goals of the program for mentors are to expand their professional network and provide guidance to mentees on career pathways.

4.6 ECE PROGRAM SUMMARY

The first quarter of the calendar year for ECE is largely focused on preparations for summer activities and travel to conferences and workshops to strengthen existing and develop new collaborations and partnerships. UNAVCO staff participated in the 3-day training in Seattle for the Portal to the Public Network, participated in governance meetings of IRIS EPO, attended the National Alliance for Broader Impacts Summit (an NSF RCN), and the NSF-wide IUSE PI meeting. Ongoing activities taking place during planning include a focused social media campaign, distribution of posters and playing cards, and publishing registration materials for summer technical short courses. Efforts of ECE staff continue to engage all spectrum of the community - from students through early career and into professionals.

5. Summary

GAGE Y3Q2 was a busy and productive quarter, with strong engagement of governance and community. The biennial Science Workshop is always a highlight, and this year was no exception. All three programs made key advances on a number of technical and community support initiatives. Highlights include intake, testing and training for the new GNSS receiver, a number of software and IT advances that will realize important organizational efficiencies, and the delivery of new curriculum modules that feature geodesy. Staffing continues to be stable and forward looking, and focused on advancing key community initiatives across the organization.