# University NAVSTAR Consortium (UNAVCO)

# Annual Progress Report for Support to the NASA Global Positioning System Global Network and Solid Earth and Natural Hazards Research and Applications Program

UCAR Proposal No. 2000-175

Submitted to:

Dr. David Lambert
Dr. Russ Kelz
National Science Foundation
Division of Earth Sciences

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Submitted by:

Dr. Charles Meertens
Manager, UNAVCO Boulder Facility
(303) 497-8011
chuckm@unavco.ucar.edu

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University Corporation for Atmospheric Research (UCAR)
3340 Mitchell Lane
Boulder, CO 80301

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## 1.0 Executive Summary

UNAVCO, Inc. is a non-profit membership-governed consortium that supports and promotes Earth science by advancing high-precision geodetic and strain techniques such as the Global Positioning System (GPS). UNAVCO Inc, through its Boulder Facility supports over 35 institutions in the use of the Global Positioning System for high accuracy geoscience research. As part of this mandate, the UNAVCO Boulder Facility, currently operated by UCAR, provides GPS project support to investigators funded by the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA), including the NASA Solid Earth and Natural Hazards (SENH) Research and Applications Program. In addition, support is provided to the NASA Jet Propulsion Laboratory (JPL) in their management of the NASA GPS Global Network (GGN) and to the International GPS Service (IGS) Central Bureau (CB), also located at JPL.

The issue of synergy between NASA and NSF in applications of precise GPS technologies is an important one to emphasize. NASA, for a variety of programmatic reasons, has chosen to emphasize support for the global infrastructure critical for all precise GPS applications. The availability of increasingly accurate precise GPS orbits, better predicted orbits, and real time data is making improvement possible in existing applications, as well as development of new one's. NSF, on the other hand, continues its critical support for PI-level research where GPS is an effective tool leading to improved fundamental understanding of Earth dynamics. NASA also supports basic research, but with more of a focus on natural hazards studies and fusion of technologies such as GPS and InSAR.

The importance of the NASA GPS Global Network has grown in the last several years from supporting primarily geodetic studies to applications as broad as real time ionospheric scintillation monitoring, Low Earth Orbit (LEO) occultation mission support, and real-time global, differential corrections for dynamic positioning. The need for global coverage and increased data reliability, redundancy, and rates has driven the technical requirements and complexity of the network. In addition to this growth in applications, there have been pressures leading to real increased costs for the GGN such as the growing number of stations supported, the higher costs of real time data communications, equipment purchases and testing needed for station upgrades and high data rate applications, especially new receivers and download computers, and the greater difficulty of the remote stations being planned and installed to fill holes in the network (e.g., Africa, South America, and Pacific islands). In the face of these more demanding and complex requirements for the GGN, the effective funds available for support have shrunk. The net effect of several years of cuts in both the JPL and UNAVCO budgets, along with inflationary effects on salary and overheads have resulted in significantly fewer real resources being available to support the GGN than were available three years ago. Given the critical role of the GGN in many high priority NASA science and technology initiatives, finding the means to maintain and expand the capability of the network is essential.

A major issue for UNAVCO is continued NASA support for GPS-based geophysical research. The SENH Program has funded numerous GPS projects in the past and a new Request for Proposals has been issued. The criteria for NASA support have shifted from GPS techniques development and basic data collection in the late phase of the Dynamics of the Solid Earth (DOSE) Program to development and application of new technologies such as lower cost systems and hazards-specific research and applications such as real time volcano monitoring under the SENH Program. Continued NASA support for research applications of GPS remains very important to the UNAVCO community and Facility and both look forward to future research and support opportunities as outlined in upcoming SENH Program research announcements.

By all measures, the nine-year relationship between NASA and UNAVCO has been successful. The purpose of the enclosed report is to define and extend the benefits of the NASA-JPL-UNAVCO relationship into the future. The report is broken into three major elements including UNAVCO support to JPL and the GGN, PI-level projects under the SENH Program, and other more general support activities responding to NASA requirements.

## 2.0 Introduction

The current working relationship between JPL and UNAVCO is collaborative, with JPL defining multi-support requirements for the GGN, and UNAVCO responding at a variety of levels from field support to associated technology development and equipment configuration. A secondary benefit of the NASA-UNAVCO relationship is that it allows investigators funded under the NASA SENH Program to receive GPS facility support from the same organization supporting their associated NSF projects, e.g., Eastern Mediterranean Project. NSF and NASA also receive cost benefits from their joint funding of a facility with broad GPS capability. An example of this was the jointly funded maintenance trip to Greenland undertaken last fall. Three permanent GPS stations were serviced and upgraded by two UNAVCO engineers in the span of one week. Another example is the Sierra Negra L1 Project on the Galapagos which allowed for a maintenance and new monument installation at the GALA GGN station (Figure 1) while the engineers were on-site for an NSF project. While important in and of itself, this element of multi-agency support and capability becomes even more critical when the GPS community is faced with challenging opportunities such as the Plate Boundary Observatory (PBO). The need for in-depth technical, logistical, and management capability becomes paramount.

Figure 1. New GGN monument (GAL2) at the Darwin Station, Galapagos.

This report briefly summarizes UNAVCO's NASA-funded activities over the two year period of FY2001-02. GGN support during the current period included the installation of four new international stations (CHPI, MSKU, MBAR, KELY), one new domestic station (BREW), and reconnaissance for one station in Saudi Arabia targeted for installation in 2003. Another round of TurboRogue firmware upgrades were started with completion expected in early 2003. There are still 31 TurboRogue receivers in the GGN/SENH networks that require periodic firmware upgrades. The relatively smaller number compared to earlier years reflects equipment failures and an extensive equipment upgrade throughout the network. Two new permanent stations were installed in South Africa (SIMO) and Zambia (ZAMB) by local collaborators using TurboRogue receivers and communications equipment supplied by UNAVCO. In this performance period, four stations were also equipped with meteorological sensor instruments (MSKU, MBAR, GALA, GUAX).

One of the major success stories of last year was a collaboration with Centro de Investigacion Cientifica y de Educacion Superior de Ensenada (CICESE) in Mexico and the Southern California Integrated GPS Network (SCIGN) group, in which UNAVCO installed a permanent station on Guadalupe Island (GUAX) just west of the Baja Peninsula using the Nanometrics VSAT telemetry system. This station is currently producing 1 Hz real-time GPS data and will be included in the IGS in FY03. This last installation is a very good example of a multi-funded and multi-agency collaboration using new technology acquired, tested, and deployed by UNAVCO on behalf of our sponsors and the scientific community. One reason the GUAX station is critical is that it is the only permanently occupied GPS installation firmly on the Pacific Plate, but close to the Pacific-North American Plate boundary.

UNAVCO continues to provide data backup and distribution support to JPL for 50 GGN stations, a number expected to grow in 2003. Other essential work includes the maintenance and continued improvement of an interactive, password-protected database for storing permanent station information that provides a single-user point of reference for critical, site-specific information. Work is ongoing to add capability to automatically generate and submit new IGS site logs whenever station information changes. New satellite-based data communications techniques to support a global real time GPS network were also evaluated and installed at selected stations. For example, the Facility is currently operating four GGN stations using VSAT telemetry (MSKU, MBAR, GALA, GUAX), with one more coming online in the fall of 2003 (EISL). These installations provide essential data from otherwise Internet inaccesible locations (two in Africa, Galapagos, Guadalupe Island, and Easter Island, respectively) that greately enhance the GGN network. Facility support to the NASA GGN is further detailed in section 3.0 of the report.

Another effort in support of the GGN is the replacement and continued maintenance of network download computers including keeping up to date on LINUX remote systems administration and security tasks.

Highlights of UNAVCO support to SENH projects include the installation of new permanent stations in Syria, Morocco, Turkey, and (two in) Saudi Arabia (Figure 2). The L1 volcano monitoring networks on Taal in the Philippines, Popocatepetl in Mexico, Mt. Erebus in Antarctica, and Kilauea and Mauna Loa in Hawaii, have been maintained and new L1 networks have been installed along the Hayward Fault in California, on the Galapagos Islands, and on the Cotopaxi Volcano in Ecuador. The total number of L1 systems operated by the Facility now stands at 42. L1 system networks require the same level of monitoring, troubleshooting, data management, and archive support as dual-frequency permanent stations. Finally, the Facility

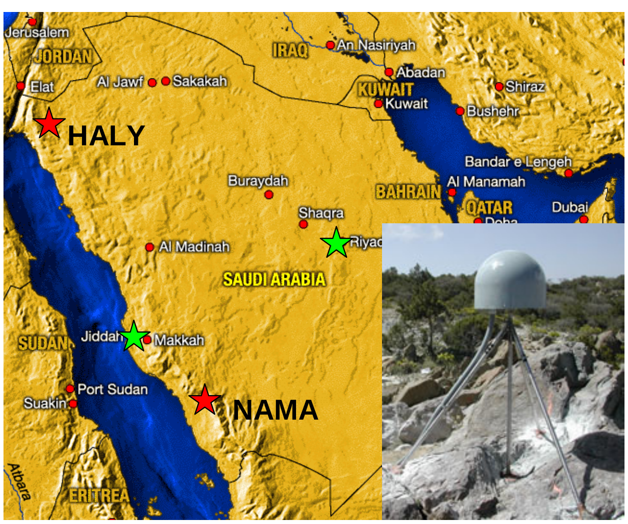



Figure 2. SENH/GGN work in Saudi Arabia. Red stars show new SENH site installations. Green stars show GGN reconnaissance sites. Inset shows new SENH station at NAMA.

continued to provide daily monitoring of data flow, in-field station support, maintenance, and troubleshooting for the 22 permanent GPS stations previously installed under specific SENH investigator projects. A full description of Facility support to SENH projects is contained in section 4.0. Other related efforts that support the GGN, SENH projects, and the IGS include NASA-specific enhancements to UNAVCO's translation, editing and quality check software (TEQC), continued development of a binary exchange (BINEX) data format, development of new data streaming software (EGADS), testing, evaluation and installation of the IEEE standard 802.11b wireless Internet system, commercial satellite based communication systems (Starband and Optistream), continuation of small-board (PC-104) computer developement, and receiver testing and evaluation. UNAVCO also provides data processing support for newly installed stations using the Massachusetts Institute of Technology (MIT) developed software package, GAMIT. This allows the Facility to produce GPS time-series to provide initial short-term monument stability and data quality assurances to investigators. The Facility Engineers also expanded their monument installation capabilities by aquiring equipment and training to install short drill-braced monuments. This is discussed in detail in section 5.

# 3.0 Support of the GPS Global Network (GGN)

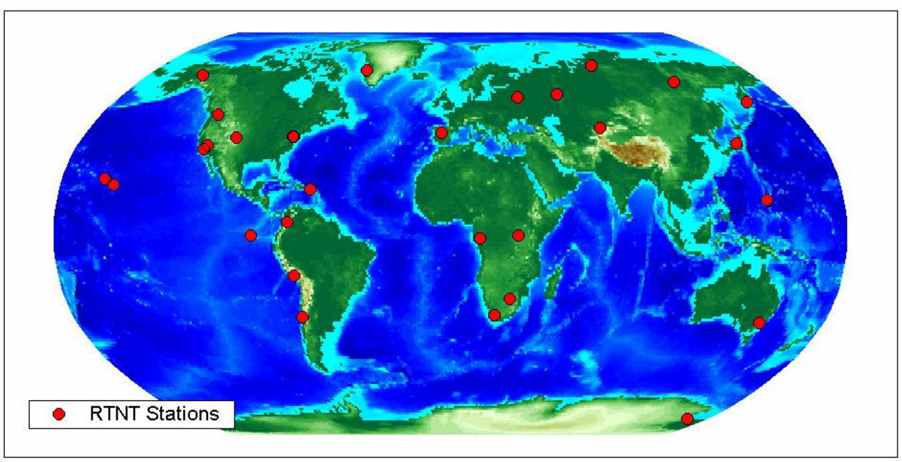



Figure 3. Stations in the JPL/NASA RTNT network.

Crucial to many state-of-the-art GPS scientific research investigations are continuously operating GPS stations - also called permanent stations. On a global scale, these stations contribute to IGS data and precise products, help realize an International Terrestrial Reference Frame (ITRF), determine station velocities for global tectonic models, and provide atmospheric, ionospheric, and essential ground network data for applications such as space weather forecasting and Low Earth Orbit (LEO) occultation missions. Increasingly important for the IGS community, is providing 1Hz data products for real-time global, differential corrections for dynamic positioning. JPL is currently receiving 1Hz data, in real-time, from 30 global stations (Figure 3), and UNAVCO's responsibility has increased to include operational and backup functions for these important real-time installations. NASA provides support for this GPS infrastructure through a network of permanent GPS stations called the GPS Global Network (GGN) which represents 25% of the 236 stations that make up the IGS permanent station global network. Also, GGN stations represent approximately 50% of IGS hourly stations.

The primary components of UNAVCO support to the GGN include:

- installation and initial operational capability for new stations
- daily monitoring, troubleshooting and maintenance of existing stations
- development and evaluation of potential new technologies to enhance performance and capability of the GGN
- database development and maintenance of key station information
- back-up of JPL GGN data collection and data management

## 3.1 GGN Permanent Installations

The Facility participates in site reconnaissance, site selection, monumentation, and establishing local infrastructure such as power and communications. Other activities include development of local support along with subsequent training and technology transfer, site documentation and configuration management, integration with other data systems, and control and automation of station operations. The goals include successful implementation of initial capability at the stations, collection of data indefinitely or during the period of planned experiments, maintenance of valuable collaborations, and contributing to the long term future of the global GPS infrastructure. Over the period of the current award, UNAVCO has performed site reconnaissance for one GGN station at BREW (Brewster, WA), maintenance at seven GGN stations; THU1 (Thule, Greenland), QUIN (Quincy, CA), GALA (Galapagos Island, Ecuador), CORD (Cordoba, Argentina), PIE1 (Pie Town, NM), BOGT (Bogota, Colombia), and PHLW (Helwan, Egypt), and supported the installation of five new GGN stations at CHPI (Sao Paulo, Brazil), MSKU

(Franceville, Gabon), MBAR (Mbarara, Uganda), BREW (Brewster, WA), and KELY (Kellyville, Greenland) (Figure 4). One new additional short drill-braced monument was also installed at GAL2 (Galapagos Island, Ecuador). UNAVCO engineers also coordinated the installation of Very Small Aperture Terminal (VSAT) satellite communications at GALA (Galapagos Island, Ecuador), MSKU (Franceville, Gabon), MBAR (Mbarara, Uganda), and GUAX (Guadalupe Island, Mexico).

Figure 4. Site at Kellyville, Greenland upgraded to a GGN/RTNT capable site.

**Daily GGN Monitoring and Upgrades**

UNAVCO provided daily monitoring support for 67 NASA permanent GPS stations during this report period, nine of which are part of the LEO sub-network, three are part of the Deep Space Network (DSN), and five are stations supporting Scintillation projects, and 21 sites are real-time 1Hz (RTNT offloaded) global stations. JPL delegated first response authority to UNAVCO for ensuring successful data offload operations and communications at these stations, including data flow to JPL on a daily basis. Each morning the UNAVCO-NASA network engineer checks data volumes for all stations for which UNAVCO has primary oversight responsibility. If a station shows low or no data, the engineer logs onto the data server at JPL and checks station log and tracking files for the problem station. Poor tracking or low data volumes could indicate a receiver or communications failure. The engineer troubleshoots the problem, determines the cause of data loss, and corrects the problem to restore normal data flow from the station to JPL. Corrective actions include logging on to remote site computers and receivers, contacting local site representatives, exchanging equipment, and making engineering site visits when required. Once the problem is resolved a status report is logged into the GGN operations database at UNAVCO and a report is forwarded to the GGN Program Element Manager (PEM) at JPL. The network monitoring responsibility has required 1456 individual troubleshooting tasks at GGN stations around the world, as logged since October 2000. (Table 1).

In addition to the 12 Ashtech Z-XII3 receivers deployed in FY1998-2000 primary in support of the LEO ground network (CRO1 (Christiansted, US Virgin Islands), FAIR (Fairbanks, Alaska), GALA (Galapagos Island, Ecuador), GODE (Greenbelt, Maryland), GOL2 (San Bernardino, California), GUAM (Dededo, Guam), HRAO (Krugersdorp, South Africa), KOKB (Kokee Park, Hawaii), MAD2 (Robledo, Spain), MCM4 (McMurdo, Antarctica), MKEA (Mauna Kea, Hawaii), and TID2 (Tidbinbilla, Australia)), another six Z-XII3 and three MicroZ receivers were deployed to upgrade existing stations in this award period (in addition to the new installations mentioned earlier). Seven more are scheduled for FY03, bringng the total number of Ashtech receivers in the GGN network to 28. This upgrade supports both the existing LEO missions (CHAMP, SAC-C, JASON, GRACE, FEDSAT and ICESAT), and also the community's demand for high frequency (1Hz) real-time data.

**Table 1. GGN Troubleshooting Summary.**

| Site | # of actions | Summary of actions |
|---|---|---|
| AREQ | 94 | New wireless Internet, new Ashtech equipment, connection problems. 1 Hz rtnt offload. |
| BOGT | 70 | New Ashtech equipment, moved Scintillation experiment, connection and I-net problems. 1 Hz rtnt offload |
| BREW | 18 | New installation, 1Hz rtnt offload |
| CHPI | 36 | New installation, broken equipment, planned upgrade and customs negotiations. |
| CORD | 43 | ppp connection problems, Internet connection problmes, planning upgrade to wireless link. |
| DGAR | 24 | Phone dial-up problems, new TurboRogue equipment, tracking problems. |
| EISL | 47 | Numerous connection problems, planning VSAT integration installation with new Ashtech equipment. |
| GALA | 56 | VSAT connection problems, new secondary monument, site visit, 1 Hz rtnt offload. |
| GODE | 18 | Numerous Internet connection problems, tracking problems. |
| GUAM | 33 | Numerous power and Internet outages |
| IISC | 67 | Numerous power and connection outages, new Ashtech equipment, 1 Hz rtnt offload. |
| IRZU | 23 | Mostly Internet outages. |
| KELY | 27 | New installation, 1 Hz rtnt offload. |
| KOKB | 32 | Tracking problems, new Ashtech equipment. |
| MBAR | 32 | New installation, VSAT, solar powered, new PC-104 computer, 1 Hz rtnt offload. |
| MCM4 | 29 | Internet changes, some outages. |
| MDO1 | 33 | TurboRogue equipment problems, swapped receiver, power supply, and laptop power problems. |
| MERS | 22 | TurboRouge tracking and offload problems, computer partitions filling up. |
| MSKU | 38 | New installation, VSAT, 1 Hz rtnt offload, some VSAT outages. |
| NSSP | 71 | Generally communications problems on local link, new Ashtech equipment, planning wireless upgrade. |
| PIE1 | 21 | Some connection problems. |
| PIMO | 70 | Numerous Internet outages, computer died, new equipment shipped |
| POL2 | 38 | Upgraded with new Ashtech equipment, 1 Hz rtnt offload, major Russian Internet (satellite) outage |
| QUIN | 52 | Numerous satellite communication outages, receiver problems, tracking problems. |
| RABT | 18 | Numerous connection outages, and computer access problems. |
| RBAY | 23 | Internet outages, computer firewall and security upgrades. |
| RIOP | 30 | TurboRogue equipment problems, dial-up connection problems, planning site upgrade. |
| SEY1 | 44 | Numerous local ppp dial-up problems, some equipment problems |
| SHAO | 17 | Mostly Internet outages, and computer hacked into, taken offline |
| SUTH | 35 | Upgraded to 1 Hz rtnt offload, some Internet and firewall problems. |
| THU1 | 20 | Tracking problems, site visit, some connection problems for download to Denmark. |
| YKRO | 22 | Internet problems, political unrest, new fiber connection planned locally. |
| **Total** | **1203** | |
| **Others(1)** | **253** | |
| **Total** | **1456** | |

**(1) Total actions on stations not included in table**

## 3.2 GGN Technology Evaluation and Development

GGN-related development activities during the report period focused on software, hardware, and systems integration strategies to improve the latency and reliability of data flow. Software development included further enhancements to UNAVCO's Translate, Edit and Quality Check (TEQC) and data streaming software detailed in section 5.3. Hardware upgrades included improved computer operating system security, power management, clock synchronization (UNAVCO is managing its own timeserver for in-house and permanently installed field computers), and various communication methods, and low power DC computer configurations. Configuration management database software has been further improved to organize the meta-data for the GGN and SENH permanent stations. A Web access interface is available to JPL network support staff as discussed in section 3.5. The system was designed to also accommodate IGS station data flow information, on-line station reporting tools, and the automated creation of IGS site logs.

JPL's development of streaming software has been driven by a very specific need for high rate GPS data for global real time differential positioning capability. The Internet-based Global Differential GPS (IGDG) software package from JPL provides GPS-based real-time positioning and orbit determination. It's accuracy, global coverage and economic mode of operation (Internet) makes it a truly unique and powerful real-time differential system. In the IGDG endeavour, UNAVCO supports the JPL-developed streaming software called Real Time Net Transfer (RTNT) to include installation, configuration and troubleshooting of Ashtech- and TurboRogue-equipped LEO and GGN stations. RTNT creates 1 Hz data packets at a remote station and sends them in real time to JPL. In addition, 15 minute user configurable data files are created on the local computer which are subsequently transferred to JPL. RTNT is now installed on 30 sites providing researchers with worldwide real-time coverage. To learn more about IGDG and see live positioning demonstrations, please see: http://gipsy.jpl.nasa.gov/igdg/demo/index.html

Another area of technology evaluation is improved data telemetry for permanent GPS stations. Joint installations in the Galapagos Islands, Gabon, Uganda, Easter Island, and Guadalupe Island resulted from the technical and financial collaboration of JPL, IRIS, CICSES, SCIGN and UNAVCO. Collaborations included the VSAT telemetry and hardware components including GPS receivers, meteorological sensors, and improved frequency standards.

In the last award period UNAVCO installed, in collaboration with CICESE and SCIGN, as mentioned above, a new premanent station on Guadalupe Island (GUAX) outside Baja, Mexico (Include GUAX poster photo here and maybe a SOPAC timeseries). The installation is unique for several reasons. The location is firmly on the Pacific plate and well away from any North American – Pacific Plate boundary motions. Still, it is in much closer proximity to the North American Plate than existing installations in Hawaii. Due to the remote location of the island and the lack of commercial infrastructure (power, etc.), the Nanometrics VSAT system is ideal. It's low power requirements allowed for a manageable solar array to support both the GPS and VSAT equipment. Even though initial logistical hurdles had to be overcome, the station has performed well, and is currently producing 1Hz real-time GPS and meterological data which is streamed back to UNAVCO. Data is then forwarded to the SCIGN Group. The station will be included in the IGS network in FY03.

Figure 5. Joint GPS/Seismic site using VSAT telemetry at Socorro NM.

A second Nanometrics VSAT system (Figure 5) was installed in a joint effort with PASSCAL/IRIS in Socorro, NM. This system is also running off solar power, and features an integrated three component broadband seismic and GPS instrumentation in an effort to highlight and show the integration benefits of the system. Each data stream is separated upon arrival at the UNAVCO VSAT control computer and made available to users with only a few seconds delay. This installation is a testing ground for the integration of various GPS receivers, seismometers, and communication techniques to be used in future large scale deformation initiatives such as the Plate Boundary Observatory (PBO).

A third Nanometrics VSAT system is installed in Boulder, CO as a test site for the UNAVCO Facility. New technology and beta firmware tests are routinely performed to maintain operational control and to be prepared for new installation challenges. UNAVCO performed a complete upgrade of the Nanometrics system in the last year, adding new remote firmware to be compatible with new hardware and also to improve overall performance of the VSAT network. All upgrades were performed remotely over the VSAT link.

The Facility has also investigated the use of the IEEE 802.11b wireless Internet protocol for new installations and upgrade of existing stations to improve data reliability and facilitate high data throughput for real-time 1Hz data applications. The new 802.11b system will be deployed in the fall of 2002 in conjunction with the completed VSAT upgrade on Easter Island. This system configuration will replace an existing 9600 baud link and permit the streaming of 1Hz real-time data back to JPL, while at the same time allow the existing installation and GPS mark to remain undisturbed, perserving a long timeseries.

In conjunction with the ongoing VSAT work, UNAVCO has also invested in the Starband and Optistream commercial satelllite Internet based systems. These are commercial satellite TV systems, which also provide internet service. These systems are primaraly US based but are considerably less expensive and much smaller than a VSAT network based system (e.g., Nanometerics VSAT mentioned above). The systems are easily installed, low power consumption, but do require some periodic maintenance. The system is also less flexible than network based VSAT, and operations and maintenance is out of the facility’s control. However, in select locations beyond regular Internet service, the commercial satellite Internet systems have proved themselves as affordable and viable alternatives.

UNAVCO also continues to update and improve on the PC-104 (low DC-power, single board Linux computer) system (Figure 6). The PC-104 is a robust (no moving parts, including hard drive), low power, environmentally contained system suitable for extreme installations or certain low power installations. The PC-104 runs a stripped down version of the RedHat Linux Operating System. UNAVCO faces a multitude of installation challenges associated with power and space, and the PC-104 is a viable alternative to the less robust laptop and bulky desktop. There is currently one PC-104 installed at the VSAT station MBAR in Uganda. The system delivers 1Hz real-time data from an Ashtech Z-XII receiver and a MET-Pack, all powered by solar power.

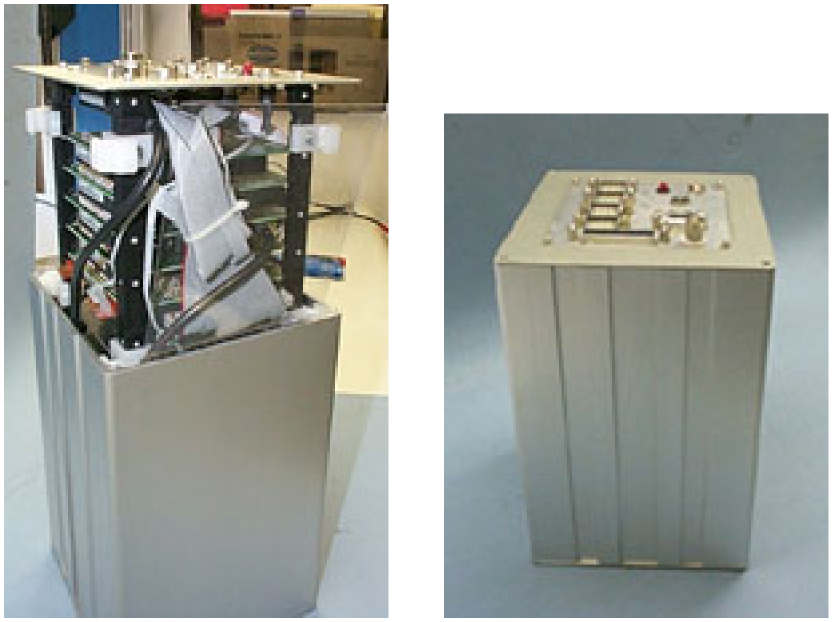


Figure 6. PC-104 computer design, showing individual cards and enclosure.

The Facility now provides Investigators and JPL with limited processing support with the MIT-developed GAMIT software. The goal is to quickly process and produce time-series of newly installed permanent stations to determine initial monument stability and investigate

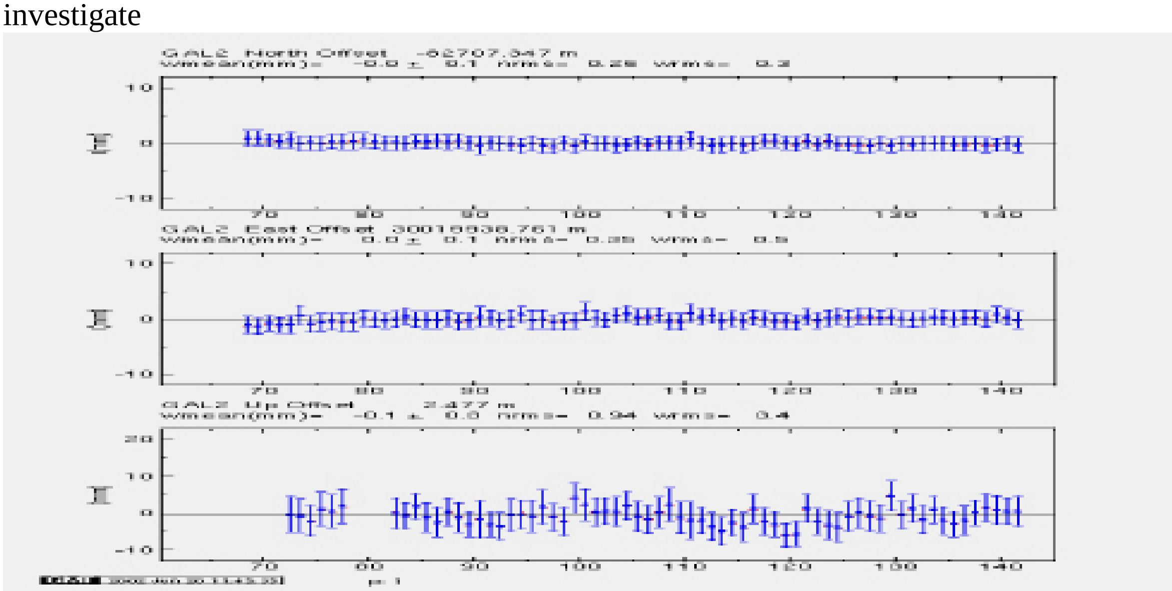
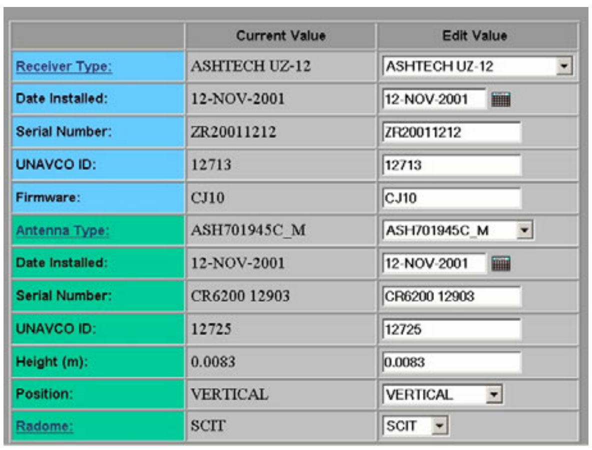


Figure 7. Timeseries from new monument (GAL2) on Galapagos from GAMIT processing software.

site specific problems (Example from Galapagos, Figure 7). A dedicated LINUX computer is configured for GAMIT use and work is underway to automate the processing efforts and disseminate the results within three months of monument installation.

## 3.3 Database Support

The Network Operations Group has made significant progress in the storage and organization of information related to Permanent Stations. UNAVCO has recently transitioned the existing Equipment Database from a MS-Access desktop application to a relational database server (SQL7). This new schema tracks all GPS equipment that goes through our facility by serial number, UNAVCO ID, and NASA ID where appropriate. In addition, each piece of equipment now has a history associated with it, thus users can see where and when it has been utilized. There is also a reporting feature that creates a custom spreadsheet for all of the NASA tagged equipment. In the near future UNAVCO hopes to present some of this information to Internet users with the proper credentials.



| | Current Value | Edit Value |
|---|---|---|
| Receiver Type: | ASHTECH UZ-12 | ASHTECH UZ-12 |
| Date Installed: | 12-NOV-2001 | 12-NOV-2001 |
| Serial Number: | ZR20011212 | ZR20011212 |
| UNAVCO ID: | 12713 | 12713 |
| Firmware: | CJ10 | CJ10 |
| Antenna Type: | ASH701945C_M | ASH701945C_M |
| Date Installed: | 12-NOV-2001 | 12-NOV-2001 |
| Serial Number: | CR6200 12903 | CR6200 12903 |
| UNAVCO ID: | 12725 | 12725 |
| Height (m): | 0.0083 | 0.0083 |
| Position: | VERTICAL | VERTICAL |
| Radome: | SCIT | SCIT |

Figure 8. Equipment database records for station PAS1.

The official Permanent Station Database, located at www.unavco.net, is continually improving. It now stores station metadata and equipment configuration information for over 360 permanent stations (Figure 8). The on-line relational database allows password-restricted users to add, remove or edit site information. One major enhancement has been the development of the Installation Reporting Tool. This customized online tool allows field engineers to dynamically create permanent station installation reports. Field engineers can also create IGS Reports for a given station based on the entered information. The Permanent Station Database provides a critical single source for station meta-data needed by JPL and UNAVCO to implement automated data management and GGN backup routines. The Facility is currently working on interfacing this database with an ESRI ARCIms map server. This new feature will allow mapping permanent stations with interactive details coming from the database.

## 3.4 GGN Back-up

Beginning in the last quarter of 1998, UNAVCO and JPL began working together to develop a method to enhance the reliability of data delivery from GGN stations to the broader GPS community via the Crustal Dynamics Data Information System (CDDIS). Toward that goal, UNAVCO and JPL collaborated to develop a backup/data offload capability that can be implemented in the event of a system failure at JPL.

During pre-planned test periods and in the event of an actual system failure at JPL, UNAVCO will assume responsibility for downloading raw data from a subset of the GGN stations, in addition to continuing management of all SENH permanent station data. This process includes retrieving raw data from remote stations, creating RINEX files, and pushing those files to CDDIS - all in near real time. UNAVCO also added the sftp (secure ftp) capability to its "puller" scripts to improve on computer security. Table 2 summarizes the initial backup effort.

Once the raw GPS data were transferred to the UNAVCO Facility Archive and quality-checked using TEQC, it was converted to RINEX and pushed to CDDIS in Hatanaka-compressed format. Raw data were also made available to JPL on the UNAVCO data management and archive server. In addition, new backup capabilities have been added in this performance period including data handling for 1Hz RTNT TurboRogue streaming data conversion to raw TurboBinary format, and data handling for 1Hz RTNT Ashtech data conversion to 1Hz RINEX files. These files were generated every 15 minutes and forwarded to the CDDIS as indicated by the sub-hourly station in Table 2. Future plans include biannual backup tests to test and verify data communications paths and IP address information to ensure the Facility is ready to respond to both planned and unexpected data outages at JPL. Table 2 shows the GGN stations for which UNAVCO has the capability to back up.

**Table 2. GGN Backup Summary.**

| SITE | Dial-up | Frequency | Format | Backup Date | Backup Status | Station Notes |
|---|---|---|---|---|---|---|
| amc2 | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| aoa1 | **YES** | hourly | tb | 7/20/2002 | SUCCESSFUL | pulled 3 files during 7/19-20/2002 |
| areq | NO | hourly | tb | 6/24/2000 | SKIPPED | STATION DOWN, during backup on 7/20/02 |
| asc1 | **YES** | daily | tb | 7/20/2002 | FAILED | No files pulled during backup |
| auck | NO | hourly/daily | RINEX | 7/20/2002 | SUCCESSFUL | pickup from epsilon.gns.cri.nz (131.203.5.237), forward RINEX only |
| bogt | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| brew | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | Works with SFTP only |
| casa | **YES** | daily | tb | 7/20/2002 | FAILED | No files pulled during backup |
| chat | NO | hourly/daily | RINEX | 7/20/2002 | SUCCESSFUL | pickup from epsilon.gns.cri.nz (131.203.5.237), forward RINEX only |
| cic1 | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| cord | NO | sub-hourly | RTNT | | SKIPPED | STATION DOWN, during backup on 7/20/02 |
| cro1 | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| dgar | **YES** | daily | tb | 7/20/2002 | FAILED | No files pulled during backup |
| eisl | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| fair | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| gala | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| gode | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| godf | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | DO NOT FORWARD RINEX TO CDDIS |
| guam | NO | sub-hourly | RTNT | 6/24/2002 | SKIPPED | STATION DOWN, during backup on 7/20/02 |
| guao | NO | daily | RINEX | 7/20/2002 | SUCCESSFUL | |
| hrao | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| iisc | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | Works with SFTP only |
| jplm | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| kely | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| kokb | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| krak | **YES** | daily | tb | | SKIPPED | STATION DOWN, during backup on 7/20/02 |
| kwj1 | **YES** | hourly | tb | 7/20/2002 | FAILED | No files pulled during backup |
| mbar | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| mcm4 | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| mcmz | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | DO NOT FORWARD RINEX TO CDDIS |
| mdo1 | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| mkea | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| msku | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| nlib | NO | hourly | cb | 7/20/2002 | SUCCESSFUL | |
| nssp | NO | | | | SKIPPED | STATION DOWN, during backup on 7/20/02 |
| pie1 | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| pimo | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| pol2 | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| quin | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | Data is pushed to JPL via script, cannot connect directly to download |
| sant | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| sey1 | NO | daily | tb | 7/20/2002 | SUCCESSFUL | online during 3,11,12,23 UTC hour |
| shao | NO | daily | cb | 6/24/2000 | SKIPPED | Never successfully pulled file from 6/24/00 backup, Computer is Linux 4.1 and doesn't work w/ puller. Skipped on 7/20/2002 backup |
| simo | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |
| suth | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | Must login to 192.96.109.250 which will re-direct to download computer. Only works with SFTP. |
| usn1 | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| usud | NO | sub-hourly | RTNT | 7/20/2002 | SUCCESSFUL | |
| xian | NO | | | | SKIPPED | XIAN data on SHAO computer. Telephone Problem to XIAN. Did not backup. |
| yar1 | **YES** | daily | tb | 5/22/2000 | SKIPPED | Never successfully pulled file from 5/22/00 backup. Skipped on 7/20/2002 backup. |
| ykro | | | | | SKIPPED | STATION DOWN, as of 7/20/02 |
| zamb | NO | hourly | tb | 7/20/2002 | SUCCESSFUL | |

**Summary:**

Number of Stations Skipped: 9
Number of Stations successfully backed-up: 37
Number of Stations that failed the backup: 4
Total Number of Stations: 50

In addition, UNAVCO and CDDIS continue to coordinate data flow for other GGN/SENH stations. In the past, CDDIS pulled RINEX files from UNAVCO on a daily basis for selected permanent stations. As part of the UNAVCO GGN backup requirements, UNAVCO implemented the ability to push sub-hourly, hourly, and daily RINEX files to CDDIS. Pushing data has the advantage of reducing the latency of data received by

CDDIS, allowing sub-hourly and hourly data, creating easily updated RINEX configuration files, and providing a consistent format for data whether received from JPL or UNAVCO. Data from the following mix of GGN and SENH stations are being pushed to CDDIS: CHUM (Chumysh, Kazakhstan), KAYT (Taal Volcano, Philippines), KAZA (Kazarman, Kyrgyzstan), KUNM (Kunming, China), PODG (Bishkek, Kyrgyzstan), RIOP (Riobamba, Ecuador), SELE (Almaty, Kazakhstan), SEY1 (La Misere, Seychelles), SHAS (Shamsi, Kyrgyzstan), SUMK (Khantau, Kazakhstan), TALA (Talas, Kyrgyzstan), and TVST (Taal Volcano, Philippines).

# 4.0 SENH Project Support

SENH PI research projects investigating geophysical hazards, and engineering problems using GPS continued to receive technical, logistical and equipment support from UNAVCO during the period of this report. Support tasks included installation and upgrade of permanent stations, the design and installation of single frequency (L1) GPS networks, data management and archiving of data, and support for campaign measurements. These projects were investigating new ways to study scientific problems including volcano deformation, fault motion, and plate tectonics requiring the highest levels of GPS precision.

Technical developments to improve GPS accuracy, stability, and installation reliability, and to reduce data latency, were so successful that some SENH stations are now important contributors to the global network and will in the future move under the GGN maintenance umbrella. Other regional networks, however, have not achieved operational status and will require upgrades and ongoing support to maintain reliable data collection during their project lifetime. Several of the single frequency network installations were accomplished under the technology demonstration umbrella and will require future upgrades and investments for reliable, longer-term operations.

## 4.1 Campaigns and Agent Projects

Early in the previous award period (1998-2000), a programmatic decision was made by NASA Headquarters that GPS campaign support would be phased out under the SENH Program. UNAVCO did not support any campaigns under the SENH program over the last two years, but did support a campaign in Bolivia for a survey of paleolake shoreline elevations for geodynamic investigation of isostatic rebound last year. This summer a team of scientists from the Scripps Institution of Oceanography is planning a

GPS survey of the Salar de Uyuni in Bolivia, an 80km x 40km salt flat in the central Andes. This surface will be used as a calibration target for NASA's Geoscience Laser Altimeter System (GLAS). The survey is part of calibration/validation operations for NASA's IceSat mission and is funded under the Geoscience Laser Altimeter System (GLAS) budget. Also, 23 campaigns received archive support from the Facility, see Campaign Archiving in section 4.4.

## 4.2 Dual Frequency Permanent Stations

Support for SENH dual frequency permanent station installation, maintenance, and/or upgrades was provided for eight projects during FY2000-2001. The Central Asia Project received equipment upgrades including two download computers, ongoing technical support, and funds via a subcontract to in-country collaborators for installation of two new permanent stations (KMTR and KRTV) and maintenance of a nine station permanent network. One station (POL2) has been upgraded with an Ashtech Z-XII receiver and supported with JPL’s RTNT streaming data offload software including this station in the NASA global real-time network. Four stations in the Central Asia Project are currently picked up by JPL for distribution to the CDDIS. The Eastern Mediterranean Project saw three new permanent stations installed, in Damaskus, Syria (UDMC), Mersen, Turkey (MERS), and one in Ifran, Morocco (IFRN). All three stations were installed and configured by UNAVCO engineers, bringing the total number of permanent stations in the Eastern Mediterranean Project to ten. The existing stations have been maintained and two have been upgraded to GGN status (RABT and NSSP). Preparations have been ongoing to further upgrade the communication configuration at NSSP in Armenia with 802.11b wireless Ethernet extension to allow for real-time RTNT offloads. This work is expected to be finished in FY03. In addition, a UNAVCO engineer visited Saudi Arabia and installed two SENH stations (HALY and NAMA) and did reconnaissance for one new proposed GGN installation. Both installations feature solar powered equipment, and new Ashtech MicroZ receivers. This project was logistically difficult comprising of two short-braced monument installations, GSM (cellular) phone-modem data offloading configuration, and unfamiliar working conditions. The proposed GGN installation will include an Ashtech MicroZ receiver and real-time data streaming back to JPL.

Maintenance has been ongoing for the two dual-frequency stations and the four L1 stations on the Popocatepetl Volcano outside Mexico City. The permanent dual-frequency station on the Irazu Volcano in Costa Rica continues to deliver data. This station is powered with solar panels and connected to the OVSICORI download computer with a FreeWave spread spectrum radio link.

Permanent stations installed under SENH support were monitored on a daily basis similar to GGN stations. Many of the permanent GPS stations installed under SENH regional projects have good monument stability (e.g., not located near an active volcano) and low data latency, and are becoming important additions to the GGN. These include stations in Morocco and Armenia for the Eastern Mediterranean Project, and Kyrgyzstan and Kazakhstan for the Central Asia Project.

## 4.3 Single Frequency GPS Installations

The development of the single frequency (L1) system under the first round of SENH awards (1998-2000) was funded by a grant to Dr. Charles Meertens via the University Corporation for Atmospheric Research (UCAR). The UNAVCO Facility contributed engineering and technical support to the development activity, as well as field engineering time, data management, and archiving support for a number of NASA PI projects funded under the SENH awards. NASA's motivation was to extend the application of low cost GPS techniques to as wide a range of engineering and science disciplines as possible.

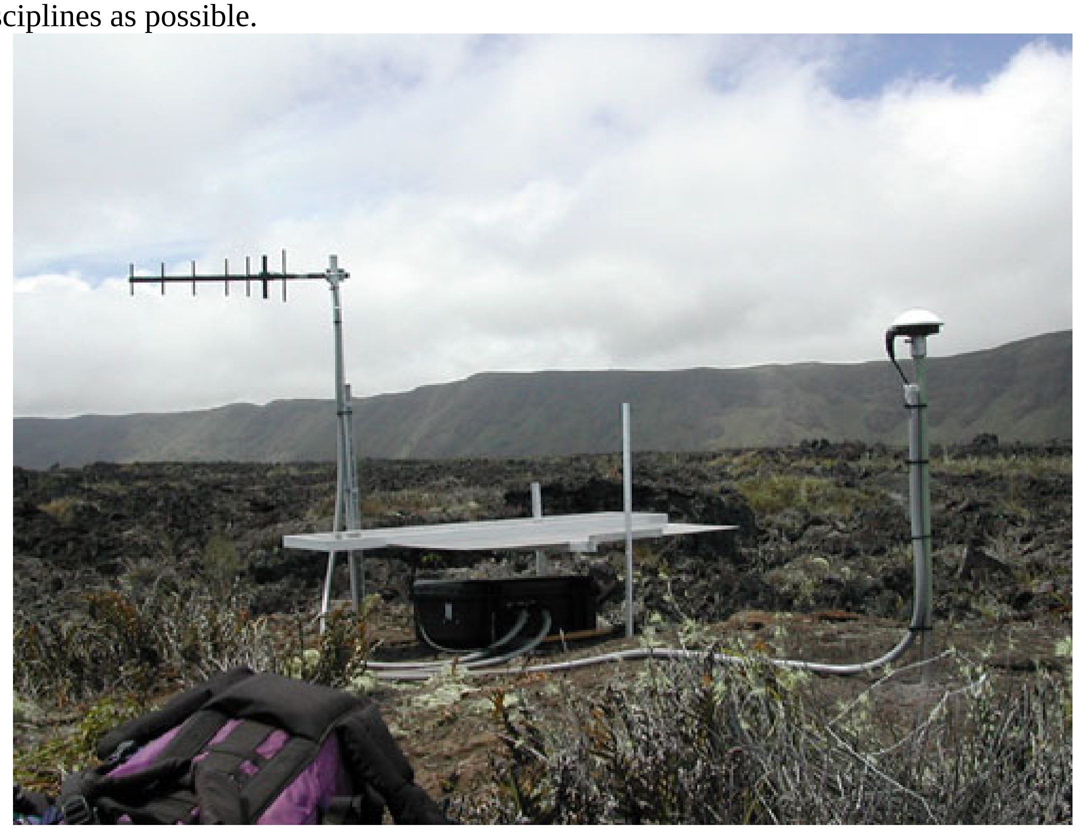


Figure 9. L1 system installed in the Sierra Negra caldera on Isabella Island, Galapagos.

The status of these L1 networks are presented in short summaries below.

1. **Taal Volcano, Philippines:** Eleven Time Domain Multiple Access (TDMA) L1 systems, one serial L1, and three dual-frequency systems are in operation on Taal Volcano as part of the evaluation of a real time volcano monitoring capability. A new computer for processing the data was purchased by Indiana University and has been configured with the Bernese processing package.

2. **Hayward Fault, California:** The two L1 systems deployed in January 1999 along the Hayward fault were augmented with four more L1 systems and software for TDMA operation in this award period. The six permanent single frequency GPS systems along the Hayward Fault will attempt to resolve the spatial and temporal distribution of interseismic slip on the fault. Complicated radio telemetry links are relaying the data back to the seismological lab at UC Berkeley. The data collection software installation was a challenge as well because the data collection computer, provided by UC Berkeley, was a non-standard configuration Solaris machine (UNAVCO uses LINUX OS).

3. **Differential Vertical Motion Estimation (DiVE) Project:** The goal of this project was to install and evaluate an absolute tide station, including assessment of the L1 system's ability to provide sufficient precision for such an application. There are two combined single and dual-frequency stations, one at Scripps and the other at Astoria, Washington. Two additional L1-only sites were installed in Oregon and Washington in summer 2000. The two sites are also being downloaded via phone modems from the UNAVCO Facility. Field engineering support after the initial installation phase includes receiver and antenna replacements and site maintenance.

4. **Popocatepetl Volcano, Mexico:** Four L1 systems were installed on Popocateptl and a nearby glacier in April 1999 to complement two dual frequency systems previously installed under DOSE/NASA support. The L1 equipment was funded through NSF, with Facility technical and field engineer support jointly funded by NASA. The network was upgraded to newer firmware in summer 2000. A new Linux computer and auxilliary equipment is being configured and scheduled for deployment in the fall of 2002. The dual-frequency stations are also in need of upgrade and maintenance, and efforts are underway to have the Popocatepetl network operational again in the beginning of FY03.

5. **Kilauea and Mauna Loa Volcanoes, Hawaii:** A 12-station network was installed in July 1999, covering a large portion of the East Rift of Kilauea. The success of the system

was demonstrated when L1 measurements confirmed a small dike intrusion on September 12, 1999. Although ionospheric effects can be quite significant across this 50 km long network, combination with dual-frequency data solutions using SINEX files and evaluation of shorter baseline sub-networks help to mitigate these effects. Overall, the addition of the L1 network has given investigators an unprecedented view of the deformation associated with a dike intrusion, while keeping the equipment cost low. The reliability of the network has been good with support service being provided by the USGS. In March of 2001 the network was upgraded with new L1 antennas and L1 receiver firmware.

6. **Erebus Volcano, Ross Island Antarctica:** In addition to the episodic campaign survey, maintenance was performed on the dual-frequency permanent GPS station at Truncated Cones (CONZ, Figure 10) and the L1 network stations at the side crater (E1GP), Hooper's Shoulder (HOOZ), and Nausea Knob (NAUS). Data from these permanent stations are downloaded daily to McMurdo Station, and transferred to the UNAVCO archive where they are on-line and publicly available. A second continuously operating dual-frequency receiver was installed on the deformation network monument (ELHT) at the Erebus Lower Hut. This receiver is one of the new low power/high

Figure 10. Continuous GPS and seismic station CONZ on Mount Erebus

memory Trimble 5700 receivers with capacity to log data throughout the winter. The receiver is powered by the wind and solar electric system at Lower Erebus Hut, and it will be downloaded at the beginning of the 2002-2003 field season.

7. **Sierra Negra Volcano, Galapagos Islands:** Jointly funded by the National Science Foundation-EAR and NASA-SENH, this project is a collaboration between the University of Idaho, Darwin Research Station, Galapagos National Park, and UNAVCO. The project is unique in the way that data from two different receiver types, single- and dual-frequency units, are being streamed via 900 MHz spread spectrum transceivers using the TDMA (Time Division Multiple Access) protocol. This is the first time the UNAVCO Facility has incorporated multiple receiver types into a TDMA data stream. Secondly, the direct (no-repeater) 90 km RF link between the volcano rim on Isabella Island and the Darwin Research Station on Santa Cruz Island, is the first permanent, direct, RF data link between these two islands. Lastly, the remoteness, difficult terrain, and harsh weather conditions of the Sierra Negra caldera combined for an exceptionally challenging deployment (Figure 9).

8. **Cotopaxi Volcano, Ecuador:** In June 2002, a network of two L1 receivers was installed on the Cotopaxi Volcano near Quito, Ecuador. This collaboration between UNAVCO and the Instituto Geofisica (IG) in Quito is intended to lay the groundwork for future collaborative work between UNAVCO and the IG. In FY03 it is expected that the IG will play a key role in the upgrade of the SENH Riobamba permanent station (RIOP) by providing critical infrastructure necessary for downloading and data transfer.

In summary, the precision of the low cost single frequency GPS system has met or exceeded design expectations while the design cost goal of <$3,500 for the entire system has been met. The precision of single frequency solutions depends on the level of local ionospheric activity, ability to model the ionospheric effect, baseline length, quality of data, and resolving the clock biases for processing. The system clearly has the capability to measure both the very small motions that are expected during the long intervals prior to volcanic eruptions and larger, more rapid motions associated with episodic events such as intrusions and eruptions. The rapid growth of L1 networks for volcano, earthquake fault, engineering, and tide gauge investigations and the large quantity of associated high rate GPS data have generated a significant increase in data management responsibilities at the UNAVCO Facility. The typical L1 network installation has a Linux computer and input from up to 17 remote L1 systems communicating locally via TDMA radio modems.

## 4.4 Data Management

**Data Management and Archiving**

Internally, UNAVCO Data Management and Archiving has been migrating off a single Solaris micro-Sparc workstation, which two years ago preformed all data management processing and connectivity to its Oracle archive database, to a distributed set of workstations and servers. This has required an increased role in data manangement personel in system administative tasks. The benefit is that the DMAG system is more stable and personel are better able to quickly respond to system problems or changes, as sometimes is required during GGN backup roles.

UNAVCO provides data management and archiving support for NASA-funded campaigns and permanent stations. All metadata for permanent stations and campaigns are managed in an Oracle relational database that is accessible to the user through the Internet.

**Campaign Archiving**

Approximately 20% of the 419 campaigns currently held in the UNAVCO Archive received NASA funding at the data collection stage. During FY2001 and FY2002, 23 campaigns with NASA support were added to the Archive (Table 3). When data are requested, RINEX is created (if raw files were archived) and provided to the requestor. In FY2002, UNAVCO developed a mechanism for distribution of campaign data via web pages with links allowing the user to pick up the the data from the anonymous ftp campaign pickup area. Principal investigators for these exported campaigns are asked to provide release notes, links to html or pdf reports, and any references that should be cited by users of the data. The references and release notes are incorporated as header comment lines of the RINEX files.

## Table 3. NASA Campaigns Archived by UNAVCO in FY2001-02

| ID | Campaign Name | PI |
|---|---|---|
| 2188 | Baja California 1996 | Miller |
| 2191 | Baja California 1998 | Miller |
| 2201 | Brewster Tie 2001 | Stowers |
| 1923 | Central Asia 1999 | Herring |
| 2157 | Garlock 1997 | Miller |
| 2159 | Garlock 1998 06 (Jun) | Miller |
| 2137 | Garlock 1998/1999 | Miller |
| 2162 | Garlock 2000 | Miller |
| 2164 | Garlock 2001 03 (Mar) | Miller |
| 2166 | Garlock 2001 06 (Jun) | Miller |
| 2151 | Goldstone 1999 | Miller |
| 2153 | Goldstone 2000 | Miller |
| 2155 | Goldstone 2001 | Miller |
| 2221 | Katmai 2000 | Freymueller |
| 1693 | Mammoth 1992 | Dixon |
| 1695 | Mojave/Mammoth 1993 | Dixon |
| 2133 | Mojave 1997 | Miller |
| 2135 | Mojave 1998 06 (Jun) | Miller |
| 2144 | Mojave 1998 12 (Dec) | Miller |
| 2139 | Mojave 1999 | Miller |
| 2142 | Mojave 2000 | Miller |
| 2146 | Mojave 2001 03 (Mar) | Miller |
| 2148 | Mojave 2001 06 (Jun) | Miller |

### Permanent Station Archiving

Data from 63 permanent stations supported by NASA funding arrives at UNAVCO via LDM-IDD, scp, ftp pull, and ftp-push on a daily basis (for most sites). Automated data handling ensures that files are archived within a few minutes of arrival. All data are RINEXed at the time of archiving and made available in the anonymous ftp pickup area. Table 4 shows NASA supported L1 and dual frequency permanent station networks archived at UNAVCO. Of the 63 sites archived, 42 are L1-only sites and 21 are dual frequency sites.

**Table 4. Status of NASA-Funded Permanent Station Data Archived at UNAVCO**

| ID | Network Name | Number of Stations | Station Name | Institution | Funding |
|---|---|---|---|---|---|
| G1891 | Antarctica L1 | 3 operating<br>1 retired<br>2 planned | E1GP, HOOZ, NAUS | UNAVCO | |
| G1369 | Arenal | 2 operating | AROL, LOLA | UCSC,<br>U. Miami | NSF-EAR<br>NASA-SENH |
| G1594 | Central Asia | 4 operating<br>4 retired | CHUM, KMTR, KRTV, SELE | MIT | NASA |
| G1934 | Costa Rica | 1 operating | IRZU | | NASA-SENH |
| G2274 | Cotopaxi L1 | 2 operating | CX01, CX02 | UNAVCO | |
| G1857 | DIVE | 2 operating | SPW2,TPW2 | Central Washington U. | NASA-SENH |
| G1888 | DIVE L1 | 4 operating | CCW1, NPW1, SPW1, TPW1 | Central Washington U. | NASA-SENH |
| G2269 | Galapagos | 2 operating | GV01, GV02 | U. Idaho,<br>UNAVCO | NSF-EAR,<br>NASA |
| G2272 | Galapagos L1 | 4 operating | GV03, GV04, GV05, GV06 | U. Idaho,<br>UNAVCO | NSF-EAR,<br>NASA |
| G1895 | GGN- UNAVCO | 3 operating<br>4 retired | CHPI, KUNM, RIOP | JPL | NASA |
| G1606 | Greenland | 1 operating | KULU | U. Colorado | NASA/NOAA |
| G1826 | Hawaii L1 | 13 operating | HV01-HV12, HV14 | UNAVCO | NASA/SENH |
| T1469 | Hayward Fault L1 | 4 operating | BDAM, GRIZ, VOLM, WLDC | U. Calif. Berkeley | NASA/SENH |
| G1596 | Mediterranean | 4 operating<br>4 retired<br>2 planned | CRAO, DYR2, MERS, RABT | MIT | NASA, NASA-SENH |
| G1495 | Popocatapetl | 2 operating<br>1 retired | POSW, POPN | | NASA |
| G1893 | Popocatapetl L1 | 1 operating<br>4 retired | PP02 | U. Miami,<br>UNAM | NSF, NASA |
| G1828 | Taal L1 | 11 operating<br>4 retired | TV01, TV03, TV05-TV08, TV10-TV12, TV14 | Indiana U. | NSF-EAR,<br>NASA/ SENH |

**Data Management Software Development**

UNAVCO continues to develop and support the teqc (GPS and GLONASS Translation, Editing and Quality Checking) software package that remains the foundation of data input and output for the Boulder Facility data archive and is extensively used by the GPS community. In early 2002, teqc entered its fifth year of availability, and is now used worldwide, by investigators with GPS projects, for major networks like NASA's Global GPS Network (GGN), at many sites for the IGS global network, as well as at the SOPAC facility, SCIGN, BARGEN, BARD, PANGA, and new networks like SuomiNet. A major release of teqc occurred in March 2002, the first comprehensive release replacing all previous versions since February 2000. Associated with teqc is BINEX, the data format adopted for the Trimble 4700 receiver for SuomiNet and for the Ashtech micro-Z receiver currently deployed on UNAVCO projects. The BINEX format (see website: http://www.unavco.ucar.edu/data_support/software/binex/binex.html) was easily integrated into existing firmware by two GPS receiver manufacturers, Ashtech and Trimble. UNAVCO has developed BINEX in an effort to promote a robust binary standard. It can be implemented at the receiver level to facilitate data streaming, and to simplify data handling and integration of GPS with other systems such as seismic data loggers. BINEX is being proposed as a requirement for EarthScope/PBO GPS receivers.

# 5.0 Other Support Activities

## 5.1 Support to the IGS Central Bureau (CB)

UNAVCO support to the IGS Central Bureau included providing technical and logistical support for the various IGS CB responsibilities and functions as defined in the IGS Terms of Reference, primarily for the day-to-day coordination of the service. The key activity for UNAVCO was to implement the full back-up website for the IGS information system (http://igscb.jpl.nasa.gov). This is viewed by the IGS, JPL, and UNAVCO as a critical support effort, due to the importance of the system to all internal IGS contributors and external users. The IGS CB Web Mirror (igsws) maintenance includes installing Web server software, operating system patches, and security fixes. The IGSCB web mirror keeps a daily backup of the IGSCB Web site which consists of approximately 3GB of web pages, mail forums, and ftp files. This Web mirror has been implimented to provide a persistent IGSCB Web presence in the event of a system failure at JPL.

UNAVCO personnel also contributed to the greater IGS community through participation in meetings and workshops and through the development of tools that are useful to the IGS. The availability of programs like TEQC, a widely used translator and quality checking program developed and maintained by UNAVCO, and promotion of a binary exchange format, such as the BINEX developed at UNAVCO, are key activities. UNAVCO participates in an IGS international working group for the definition of a standard exchange format for high rate, low latency data. This will become the global standard supported by the IGS and must meet the requirements for such data and be acceptable to the community.

## 5.2 GPS Receiver and Antenna Testing

During the performance period, the UNAVCO Facility conducted numerous receiver, antenna, data communications, and power tests that directly and indirectly benefit the NASA GGN network.

AMCS – A project designed to develop an in-situ multipath calibration system. The Facilities role in this project is detailed at http://www.unavco.ucar.edu/science_tech/dev_test/antennas/amcs.html .

Antenna Rotation Test - conducted at UNAVCO in order to determine the effect of antenna rotation on carrier phase observations. Results of this test can be found at http://www.unavco.ucar.edu/science_tech/dev_test/antennas/amcs.html.

GPS Receiver Mixing Tests – This test was performed to analyze the effect of receiver replacement at a GPS site. The results of this study can be found at http://www.unavco.ucar.edu/science_tech/dev_test/testing/mixed.html

SuomiNet Receiver Testing – The UNAVCO Facility tested 4 new GPS receivers for the large SuomiNet atmospheric GPS initiative. A testing report can be found at http://www.unavco.ucar.edu/science_tech/dev_test/publications/publications.html

SCIGN Radome Testing - The purpose of this test was to see the affects on station coordinates when a short SCIGN radome is installed on a choke ring antenna. Contact victoria@unavco.ucar.edu for a copy of the results.

Ashtech MicroZ / Z-XII and Geodetic IV / Choke Ring Antenna testing – This test was performed primarily to analyze the performance of the Ashtech Geodetic IV antenna. Contact victoria@unavco.ucar.edu for a copy of the results.

Ashtech and Trimble Choke Ring Power and SNR Analysis – This test was performed to see if the less expensive Ashtech Choke Ring was compatible with Trimble GPS receivers. A preliminary report can be found at http://www.unavco.ucar.edu/~mikej/POWER/5700Ashtech.pdf

New generation receiver power specifications – This test was performed to analyze the power requirements from new generation receivers. A report detailing this effort can be found at http://www.unavco.ucar.edu/~mikej/POWER/ReceiverPower.pdf .

Serial to Ethernet device testing – A number of serial-to-Ethernet devices were tested for power consumption, usability, performance, and security. A report can be found at http://www.unavco.ucar.edu/science_tech/dev_test/communications/serial_ether.html

Short and medium distance 802.11b wireless Internet communications testing – testing is ongoing at the UNAVCO Facility to analyze the performance of the 802.11b based data communications. A report of these activities will be available soon. For more information contact ruud@unavco.ucar.edu.

VSAT data communications testing – The Facility has been testing both dedicated bandwidth (Nanometrics) and single user (Starband, Hughes) VSAT data communications systems. A report of these activities can be found at http://www.unavco.ucar.edu/science_tech/dev_test/communications/vsat.html .

Wind Power – The Facility is testing wind power as a complimentary DC power source at remote permanent stations. A preliminary report can be found at http://www.unavco.ucar.edu/science_tech/dev_test/power/wind/wind.html

## 5.3 Support Software Development

Three major software packages were developed or enhanced and supported from FY2000-2001. The primary package is TEQC, a tool for translating, editing, and quality checking GPS data. TEQC is now widely used by institutions and investigators around the world including JPL and CDDIS. Embedded in TEQC is a UNAVCO-developed binary exchange (BINEX) format software which is being promoted to make raw data streams more robust and compact. These software tools are briefly discussed below. Lastly, a new receiver offload software has been developed and tested over the last year. This new software called EGADS/SHARC, allows for control and download capabilities of Ashtech Z-XII3 and MicroZ receivers.

### Translate, Edit and Quality Check Software (TEQC)

NASA funding, along with NSF Facility support, has contributed significantly to the development and support of TEQC, a software tool which provides a simple and unified approach to the translation of raw GPS data to RINEX exchange format, editing of data files, and quality checking of the data. These primary functions can be done separately, or in combination, with the goal of making user applications of GPS data much easier. Freeware executables are available via anonymous ftp for a wide variety of computer platforms and operating systems at http://www.unavco.ucar.edu/teqc and have received widespread use.

### BINEX Initiative

In an effort to address the increasing data volumes associated with the LEO high rate fiducial sub-network, the Facility initiated an effort to define a new compact, machine-independent, binary exchange format called BINEX. BINEX was also designed to address and correct several deficiencies of the current ASCII data exchange formats, such as RINEX and SINEX. Most importantly, the format has to be receiver independent, compact, robust, and easily extendable. BINEX and its related software tools have been tested, are well documented, and are being made available to the wider GPS community. More information, including software independent source code for reading and writing BINEX, is available at http://www.unavco.ucar.edu/binex.

More recently, UNAVCO has negotiated with Ashtech Magellan and Trimble Navigation to directly stream BINEX GPS observables out of their GPS receivers. This will standardize the data communications interface to these systems, improve the precision of the observables, and possibly eliminate the need for an on-site data download computer. The BINEX standard has also been adopted by COSMIC for data storage in the COSMIC Data Analysis and Archival Center (CDDAC). UNAVCO will be a major participant in the IGS working group developing standards for a community-wide binary, streaming format.

**EGADS/SHARC Software Development**

The EGADS/SHARC software is user configurable allowing for a multitude of data offload options inluding data streaming at up to 10Hz frequency and binning the data into separate files at 10Hz, 5Hz, 2Hz, 1Hz, 5 sec, and 30sec. EGADS can be completely automated and has the capability download receivers over various modem and radio links. Multiple configurations have been tested such as direct, wireless, phone modem, streaming at 10Hz directly to download computer, streaming through a VSAT system, and through a serial to Ethernet device. UNAVCO has worked closely with the software developer to make the EGADS as robust and user friendly as possible. UNAVCO wrote all documentation pertaining to installation and configuration of this software. EGADS is an excellent compliment in places where RTNT can not be used due to phone line connections or slow communications.

## Appendix 1. NASA Station List

| Station Type | Site | City | Country |
|---|---|---|---|
| GGN | aoa1 | Passadena, CA | USA |
| GGN | areq | Arequipa | Peru |
| GGN | asc1 | Ascension Island | Ascension Island |
| GGN | auck | Whangaparaoa Peninsula | New Zealand |
| GGN | bogt | Bogata | Columbia |
| GGN | brew | Brewster, WA | USA |
| GGN | casa | Mammoth Lakes, CA | USA |
| GGN | chat | Waitangi | New Zealand |
| GGN | chpi | Sao Paulo | Brazil |
| GGN | cic1 | Ensenada | Mexico |
| GGN | cord | Cordoba | Argentina |
| GGN | cro1 | Christianhead | US Virgin Islands |
| GGN | dgar | Diego Garcia | Diego Garcia |
| GGN | dubo | Lac Dubonnet, Manitoba | Canada |
| GGN | eisl | Easter Island | Chile |
| GGN | fair | Fairbanks, AK | USA |
| GGN | flin | Flin Flon, Manitoba | Canada |
| GGN | gala | Galapagos Island | Ecuador |
| GGN | gode | Greenbelt, MD | USA |
| GGN | guam | Dededo | Guam |
| GGN | guao | Urumqi | PRC |
| GGN | harv | Harvest, CA | USA |
| GGN | hrao | Krugersdorp | South Africa |
| GGN | iisc | Bangalore | India |
| GGN | jplm | Pasadena, CA | USA |
| GGN | kely | Kangerlussuaq | Greenland |
| GGN | kokb | Kokee Park, HI | USA |
| GGN | kunm | Kunming | PRC |
| GGN | kwj1 | Kwajalein Atoll | Kwajalein Atoll |
| GGN | mbar | Mbarara | Uganda |
| GGN | mcm4 | Ross Island | Antarctica |
| GGN | mcm5 | Ross Island | Antarctica |
| GGN | mcmz | Ross Island | Antarctica |
| GGN | mdo1 | Fort Davis, TX | USA |
| GGN | mkea | Mauna Kea | USA |
| GGN | msku | Franceville | Gabon |
| GGN | moin | Heredia | Costa Rica |
| GGN | nlib | North Liberty, IA | USA |
| GGN | nril | Norilsk | Russian Federation |
| GGN | nssp | Yerevan | Republic of Armenia |
| GGN | okc2 | Lamont, OK | USA |
| GGN | pie1 | Pie Town, NM | USA |
| GGN | pimo | Quezon City | Philippines |
| GGN | pol2 | Bishkek | Kyrgyzstan |

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|---|---|---|---|
| GGN | quin | Quincy, CA | USA |
| GGN | rbay | Richards Bay | South Africa |
| GGN | riop | Riobamba | Ecuador |
| GGN | sant | Santiago | Chile |
| GGN | sele | Almaty | Kazakhstan |
| GGN | sey1 | La Misere | Seychelles |
| GGN | shao | Sheshan | PRC |
| GGN | simo | Simonstown | South Africa |
| GGN | suth | Sutherland | South Africa |
| GGN | thu1 | Thule | Greenland |
| GGN | usn1 | USNO, MD | USA |
| GGN | usud | Usuda | Japan |
| GGN | xian | Lintong, Xi'an | PRC |
| GGN | yar1 | Yaragadee | Australia |
| GGN | ykro | Yamsukro | Ivory Coast |
| GGN | yssk | Yuzhno-Sakhalinsk | Russian Federation |
| GGN | zamb | Lusaka | Zambia |
| DSN/Other | gol2 | Goldstone, CA | USA |
| DSN/Other | gold | Goldstone, CA | USA |
| DSN/Other | mad2 | Robledo | Spain |
| DSN/Other | madr | Robledo | Spain |
| DSN/Other | mag0 | Magadan | Russian Federation |
| DSN/Other | petp | Petropavlovsk-Kamchatka | Russian Federation |
| DSN/Other | tid2 | Tidbinbilla | Australia |
| DSN/Other | tidb | Tidbinbilla | Australia |
| DSN/Other | tixi | Tixi | Russian Federation |
| DSN/Other | yakz | Yakutsk | Russian Federation |
| Scintillation/Other | are2 | Arequipa | Peru |
| Scintillation/Other | bog2 | Bogata | Columbia |
| Scintillation/Other | fai2 | Fairbanks, AK | USA |
| Scintillation/Other | san2 | Santiago | Chile |
| Other | carr | Parkfield, CA | USA |
| Other | irkt | Irkutsk | Russian Federation |
| Other | guax | Isla de Guadalupe | Mexico |
| SENH | crao | Crimea | Ukraine |
| SENH | chum | Chumysh | Kazakstan |
| SENH | dyr2 | Diyarbakir | Turkey |
| SENH | haly | Halat Ammar | Saudi Arabia |
| SENH | ifrn | Ifrane | Morocco |
| SENH | indi | Punto Indio | Costa Rica |
| SENH | irzu | Irazu Volcano | Costa Rica |
| SENH | kayt | Taal Volcano | Philippines |
| SENH | kaza | Kazarman | Kyrgyzstan |
| SENH | kmtr | Kumtor | Kyrgyzstan |
| SENH | krtv | Kumtor | Kyrgyzstan |
| SENH | mers | Erdemli | Turkey |
| SENH | nama | Namas | Saudi Arabia |
| SENH | phlw | Helwan | Egypt |

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|---|---|---|---|
| SENH | podg | Bishkek | Kyrgyzstan |
| SENH | popn | Popocatepetl | Mexico |
| SENH | posw | Popocatepetl | Mexico |
| SENH | ppyn | Popayan | Columbia |
| SENH | rabt | Rabat | Morocco |
| SENH | spw2 | La Jolla, CA | USA |
| SENH | sumk | Khantau | Kyrgyzstan |
| SENH | tala | Bishkek | Kyrgyzstan |
| SENH | talg | Talgar | Kyrgyzstan |
| SENH | tetn | Tetouan | Morocco |
| SENH | tgyt | Taal Volcano | Philippines |
| SENH | tubi | Gebze | Turkey |
| SENH | tvst | Taal Volcano | Philippines |
| SENH | tpw2 | Astoria, OR | USA |
| SENH | udmc | Damascus | Syria |
| L1-Antarctica | e1gp | Mt. Erebus | Antarctica |
| L1-Antarctica | hooz | Mt. Erebus | Antarctica |
| L1-Antarctica | naus | Mt. Erebus | Antarctica |
| L1-Cotopaxi | cx01 | Cotopaxi Volcano | Ecuador |
| L1-Cotopaxi | cx02 | Cotopaxi Volcano | Ecuador |
| L1-Galapagos | gv03 | Sierra Negra Volcano | Galapagos |
| L1-Galapagos | gv04 | Sierra Negra Volcano | Galapagos |
| L1-Galapagos | gv05 | Sierra Negra Volcano | Galapagos |
| L1-Galapagos | gv06 | Sierra Negra Volcano | Galapagos |
| L1-Hayward Fault | HF01 | Hayward, CA | USA |
| L1-Hayward Fault | HF02 | Hayward, CA | USA |
| L1-Hayward Fault | bdam | Hayward, CA | USA |
| L1-Hayward Fault | griz | Hayward, CA | USA |
| L1-Hayward Fault | volm | Hayward, CA | USA |
| L1-Hayward Fault | wldc | Hayward, CA | USA |
| L1-Hawaii | HV01 | Devil’s Throat | Hawaii, USA |
| L1-Hawaii | HV02 | Halemaumau | Hawaii, USA |
| L1-Hawaii | HV03 | Keauhou | Hawaii, USA |
| L1-Hawaii | HV04 | Kilauea Iki | Hawaii, USA |
| L1-Hawaii | HV05 | Keanakakoi | Hawaii, USA |
| L1-Hawaii | HV06 | Mauna Ulu | Hawaii, USA |
| L1-Hawaii | HV07 | Mauka Makaopuhi | Hawaii, USA |
| L1-Hawaii | HV08 | Makai Makaopuhi | Hawaii, USA |
| L1-Hawaii | HV09 | Pu’u Kamoamoa | Hawaii, USA |
| L1-Hawaii | HV10 | Pu’u O’o | Hawaii, USA |
| L1-Hawaii | HV11 | Pu’u Ulaula | Hawaii, USA |
| L1-Hawaii | HV12 | Po’omoku | Hawaii, USA |
| L1-Hawaii | HV14 | Kilauea Iki | Hawaii, USA |
| L1-Popo | pp01 | Popocatepetl | Mexico |
| L1-Popo | pp02 | Popocatepetl | Mexico |
| L1-Popo | pp03 | Popocatepetl | Mexico |
| L1-Popo | pp04 | Popocatepetl | Mexico |
| L1-DiVE | ccw1 | Crescent City,WA | USA |

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|---|---|---|---|
| L1-DiVE | npw1 | Newport, OR | USA |
| L1-DiVE | SPW1 | La Jolla, CA | USA |
| L1-DiVE | TPW1 | Astoria, OR | USA |
| L1-Taal | TV01 | Crater Rim | Philippines |
| L1-Taal | TV02 | Balantoc | Philippines |
| L1-Taal | TV03 | Alas-as | Philippines |
| L1-Taal | TV04 | Binitang-maliaki | Philippines |
| L1-Taal | TV05 | Pirapiraso Point | Philippines |
| L1-Taal | TV06 | Caluit | Philippines |
| L1-Taal | TV07 | Pinabulabuan | Philippines |
| L1-Taal | TV08 | Barigon | Philippines |
| L1-Taal | TV10 | Maria Paz | Philippines |
| L1-Taal | TV11 | Buco | Philippines |
| L1-Taal | TV12 | Main Crater | Philippines |
| L1-Taal | TV13 | Tagaytay | Philippines |