Annual Report for Period: 03/2005 - 02/2006 **Submitted on:** 12/29/2005

Principal Investigator: Prescott, William H. **Award ID:** 0453975

Organization: UNAVCO, Inc.

Title:

PBO Nucleus: Support for an Integrated Existing Geodetic Network in the Western U.S.

Project Participants

Senior Personnel

Name: Prescott, William

Worked for more than 160 Hours: No

Contribution to Project:

Name: Blume, Frederick

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Blume is the project manager and receives 20% FTE support from this grant.

Post-doc

Graduate Student

Undergraduate Student

Technician, Programmer

Name: Feldl, Nicole

Worked for more than 160 Hours: Yes

Contribution to Project:

Ms. Feldl was hired in June 2005 as Project Engineer and receives 100% FTE support from the grant. She is involved in all aspects of the project, including performing station upgrades and maintenance in the field, configuration and testing of equipment, monitoring of data flow, and project documentation.

Other Participant

Name: Walker, Rebecca

Worked for more than 160 Hours: Yes

Contribution to Project:

Ms. Walker was hired in September 2005 as Education Specialist and receives 100% FTE support from the grant. Her responsibilities include development of educational modules for undergraduate general education and middle school Earth science classrooms, conducting professional development workshops for educators, and general outreach related to project activities.

Research Experience for Undergraduates

Organizational Partners

University of Utah

This institution is a subawardee of this grant. In addition to salaried staff and field expenses partially supported by project funds, the University provides vehicles, office space, and computer and communication hardware used for data flow and network operations.

Central Washington University

This institution is a subawardee of this grant. In addition to salaried staff and field expenses partially supported by project funds, the University provides vehicles, office space, internet support, and computer and communication hardware used for data flow and network operations.

University of Southern California

This institution is a subawardee of this grant. The University provides staff who's salaries are supported by project funds, as well as financial oversight through other institutional employess.

California Institute of Technology

This institution is a subawardee of this grant. In addition to salaried staff and field expenses partially supported by project funds, the University provides vehicles, office space, and computer and communication hardware used for data flow and network operations.

University of California-Berkeley

This institution is a subawardee of this grant. In addition to salaried staff and field expenses partially supported by project funds, the University provides vehicles, office space, and computer and communication hardware used for data flow and network operations.

University of California-San Diego Scripps Inst of Oceanography

This institution is a subawardee of this grant. In addition to salaried staff and field expenses partially supported by project funds, the University provides vehicles, office space, and computer and communication hardware used for data flow and network operations.

United States Geological Survey

The USGS provides office space, vehicle support, computers, and organizational staff to the project. PBO Nucleus stations in Parkfield are primarily maintained by USGS staff using USGS resources, with hardware support provided by Nucleus.

USGS staff in southern California regularly perform maintenance on PBO Nucleus stations, and Nucleus staff (employed by USC) do so on USGS-operated stations. The USGS provides a dedicated vehicle to the Nucleus project as well as office space and supplies to Nucleus project staff in Pasadena.

The USGS Golden office provides the project access to their NSN satellite network which allows access and control of GPS stations at remote locations free of charge. USGS staff have worked extensively on development of a secure network in order to satisfy USGS and UNAVCO IT policy requirements.

Harvard Smithsonian Ctr for Astrophysics

The University provides computer and communication hardware used for data flow and network operations.

University of Alaska Geophysical Institute

University provides staff, vehicles, office space, and computer and communication hardware used for data flow and network operations, and station maintenance.

Other Collaborators or Contacts

Plate Boundary Observatory, UNAVCO Inc.: In addition to staff and activities of the PBO Permitting and Data Managemement and Information Technology (DMIT) groups that are funded directly by this grant, staff and resources from PBO Boulder and regional offices have been extensively involved in PBO Nucleus project activities. PBO staff have performed maintenance on Nucleus stations, provided vehicles and other resrouces to Nucleus staff, and been involved in the design and implementation of communication networks that are shared between Nucleus and PBO GPS stations.

UNAVCO Facility, UNAVCO Inc.: Staff from the UNAVCO Facilities Engineering and Data Management and Archive (DMAG) groups have provided extensive support to the PBO Nucleus project under core funding from NSF I&F. DMAG staff has primary responisibily for archiving data from non-upgraded GPS stations, and Engineering group staff have assisted with data flow and field maintenance activities.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Findings:

Research findings resulting from PBO Nucleus activities are publications and discoveries that are presented by users of raw data produced by this project. While full-scale journal publications using data collected during the first year of this project will follow in the near future, abstracts from presentations at professional meetings are a preliminary indicator of the number and nature of the results that will ensue.

A sampling of presentation and posters from the 2005 AGU Fall Meeting, detailed in the 'Publications and Products' section of this report, shows the variety and importance of the applications of PBO Nucleus data by the geodetic community. Results from studies of the 2005 Cascadia Episodic Tremor and Slip (ETS) event, magmatic-induced transient motion in Nevada, viscoelastic strain in the Wasatch mountains, post-glacial isostatic rebound in Alaska, and joint LIDAR/GPS imaging, among others.

Training and Development:

Outreach Activities:

We have developed project plans for each of our PBO Nucleus education and outreach projects, and work is underway on developing educational modules (including lecture materials, photographs, illustrations, graphs, lab and homework exercises, GPS data sets, instructorsÆ manuals, and internet resources) for undergraduate general education and middle school Earth science classrooms. The modules will involve students using GPS data and will provide educators at the secondary and post-secondary levels with problem-based ways to teach their students how Earth scientists measure plate tectonics using GPS, illustrate how these measurements are important to hazard prediction, and convey the excitement of new discoveries yielded by high-precision GPS. The modules are being explicitly designed to accommodate a wide variety of class sizes, learning styles, and student populations. We presented our project plan at a poster session at the Coalition for Earth Science Education meeting in September 2005 and at the UNAVCO education and outreach standing committee meeting in October 2005. UNAVCO education and outreach personnel also staffed the UNAVCO booth at the 2005 GSA and AGU meetings, during which we promoted our educational projects and internship opportunities for underrepresented students.

We have taken several steps to assess the needs of prospective module users. For the undergraduate general education module, we are conducting telephone interviews with over twenty faculty members to elicit their opinions on the module content. Of the interviews that we have completed, we have gained valuable feedback and found three volunteers to pilot test the module. The first iteration of the module will be completed by April 2006, followed by individual pilot testing, revision, and classroom pilot testing beginning during the fall 2006 semester. With regard to the middle school Earth science module, we created two handouts for teachers presenting an overview of high-precision GPS and how GPS data are used to measure crustal deformation. We also developed an agenda and supporting materials in preparation for middle school teacher focus groups, which we will conduct in early 2006 to obtain feedback from teachers on the types of materials that they wish to incorporate into their curricula. In addition, we are working with an external evaluator to develop an evaluation plan for the modules.

We have built a timeline for regional and national workshops for professional development and dissemination. We recently submitted a proposal for a half-day workshop at the 2006 Geological Society of America meeting in Philadelphia and anticipate recruiting faculty from liberal arts colleges, community colleges, tribal colleges, historically black colleges and universities, comprehensive universities, and research I universities to participate. The workshop will prepare faculty to use the undergraduate general education module in their teaching. A series of local professional development workshops for middle school Earth science teachers will be convened in 2006, and we plan to submit a proposal for a workshop at the April 2007 NSTA meeting in New Orleans.

Finally, a major part of our work involves creating an interactive education and outreach webpage for faculty, teachers, scientists, and students. Currently, we have created a detailed outline of the webpage elements and are in the process of assembling and uploading content material for the webpage.

Journal Publications

Melbourne, T, R Flake, M Santillan, M M Miller, W Szeliga, R Bilham, N Suszek, "High-resolution imaging of the anticipated 2005 Cascadia ETS slip transient", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Miller, M M, T Melbourne, M Santillan, W Szeliga, "Kinematics and temporal evoluation of silent earthquakes along the Cascadia convergent margin", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Johnson, D, K Creager, A Wech, R Bennett, S THompson, F Blume, N Feldl, "Stalking the September 2005 Cascadia Episodic Tremor and Slip event: Results from a
Dense GPS Deployment", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Davis, J, B Wernicke, S Bisnath, N Neimi, "Time-Dependent Motion of Slide Mountain, Western Nevada, 1997-2005", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Larsen, C F, R Moytka, J Freymueller, K Echelmeyer, E Ivins, "Glacial isostatic rebound, ongoing glacial wastage, and geoid change in southern Alaska", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Chang, W, R B Smith, R Harris, "Elastic and viscoelastic strain loading models of the Wasatch fault, Utah, from GPS measurements and comparisons with geological observations", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Herring, T A, R King, S McClusky, M Murray, M Santillan, T Melbourne, G Anderson, "Plate Boundary Observatory GPS Data Analysis", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Liu, Z, and P Segall, "Detecting and Imaging Aseismic Transient Deformation in Southern California", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Bevis, M, and 21 others, "The B4 Project: Scanning the San Andreas and San Jacinto Fault Zones", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Smith, RB, W Chang, C Puskas, and J Farrell, "Tectonic and magmatic stress interaction of the Yellowstone volcanic system", Eos Trans. AGU, p. , vol. 86(52), (2005). Abstract

Books or Other One-time Publications

Web/Internet Site

URL(s):
http://www.unavco.org/exnet/exnet.html
Description:
The "PBO Nucleus Web Center" is continuously updated to provide comprehensive, up-to-date information relating to the project. Station status, data access, publication lists, and other important information is available here.

Other Specific Products

Contributions

Contributions within Discipline:

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Special Requirements

Special reporting requirements: None
Change in Objectives or Scope: None
Unobligated funds: $ 0.00

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Activities and Findings: Any Training and Development
Any Book
Any Product
Contributions: To Any within Discipline
Contributions: To Any Other Disciplines
Contributions: To Any Human Resource Development
Contributions: To Any Resources for Research and Education
Contributions: To Any Beyond Science and Engineering

PBO Nucleus: Support for an Integrated Existing Geodetic Network in the Western U.S. - Year 1 Project Activities

1. Overview

The PBO Nucleus project is designed to operate, maintain, upgrade and integrate 210 existing GPS stations and 1 long-baseline laser strainmeter into the Plate Boundary Observatory (PBO). Originally designed and constructed as six independent networks: the Alaska Deformation Array (AKDA), the Bay Area Deformation Array (BARD), the Basin and Range Geodetic Network (BARGEN), the Eastern Basin and Range and Yellowstone Network (EBRY), the Pacific Northwest Geodetic Array (PANGA), and the Southern California Integrated Geodetic Network (SCIGN), these stations from the Nucleus around which the PBO is based and built. It will increase the number of stations in the completed PBO and extend the time series back to the early 1990's when the first of the Nucleus stations were constructed.

During the first ten months of the project excellent progress has been made in transitioning the network from independent, region-specific operations to a centralized unified network. The UNAVCO Facility has been established as the primary data archive for the entire network, and data from all stations has been analyzed by the PBO Data Analysis Center since its inception in October, effectively doubling the volume of data available to PBO and its users during this early stage. Approximately 30% of the network has had its hardware upgraded to PBO standards and its data flow transferred to the PBO Data Management and Information Technology (DMIT) group. Transfers of site permits from original network operators to UNAVCO/PBO are well underway, and Education and Outreach activities related to the project are under active development. PBO Nucleus project personnel have also made many important contributions to the testing and development of the hardware and procedures used by both the PBO and Nucleus projects.

Fig. 1. EGAN, near Ely, NV. Upgraded 6/12/05

Fig. 2. SC01, near Socorro, NM. Upgraded 11/14/05

Most importantly, the network has been maintained in excellent health with a large volume of high-quality data having been made available to the scientific community. 93% of possible data have been returned by the stations to date, and 96% of stations in the network are currently healthy and producing data. These data have already been used by the community to produce many results, which are described in the Products and Publications section of this report.

2. Project Personnel

The PBO Nucleus project is managed by co-P.I. Dr. Frederick Blume (20% support), with oversight from P.I. Dr. William Prescott, who derives no support from the project. Project Engineer Nicole Feldl, hired in June 2005, is 100% supported by the project and is involved in all aspects of the project on a day-to-day basis. Education and Outreach activities are the responsibility of Education Specialist Rebecca Walker (100% support), hired in September 2005, with oversight by UNAVCO E & O Coordinator Dr. Susan Eriksson, who contributes 25% FTE to the project at no charge.

Many other UNAVCO personnel are supported directly or otherwise by funding from the Nucleus project. The PBO DMIT group is funded on a per-station basis to monitor data flow, archive and analyze data from Nucleus stations. A 10% FTE from the PBO permitting group is supported to advise network operators and assist with the transfer of site permits to UNAVCO/PBO. Members of the UNAVCO Facility's Data Management and Archive Group (DMAGU) are supported through the PBO DMIT funding and NSF core funding to oversee data flow for non-upgraded stations and archiving for all stations. Additionally, many UNAVCO Facility and PBO employees from Boulder and regional offices have assisted with Nucleus project operations when practical at no cost; Nucleus personnel have assisted with PBO station installation and maintenance, and Facility supported projects as well.

Critical non-UNAVCO personnel are supported by the PBO Nucleus projects through 6 sub-awards. Dr. Blume and Ms. Feldl coordinate the operations, maintenance and permitting activities of network coordinators, technicians, and specialists at the University of Utah, U.C. Berkeley, U.C. San Diego, Central Washington University, Caltech, and the University of Southern California. Personnel at these institutions are responsible for station maintenance until an upgrade is performed, as well as many upgrades themselves.

Figure 3. Upgrading BURN, S.E. Oregon, 7/30/05

Figure 4. I40A, Mojave Desert, CA, upgraded 10/22/05

3. Project Operations

To date, 61 of the 210 GPS stations in the PBO nucleus network have been upgraded to PBO standards, as defined by having Trimble NetRS receivers, choke ring antennas, and IP-based data communications. 43 of these took place during the first 10 months of the Nucleus project, with 18 having been completed during the "Support for Western U.S. Existing Networks" project (NSF MREFC) prior to 1 March, 2005.

Upgrades have been performed primarily by Nucleus-supported personnel from UNAVCO and the sub-awardees; many have been done with assistance from PBO and UNAVCO Facility employees as well as contributions from various other institutions. The prioritization of upgrades as a function of station health, location, IP comm. availability and cost, and synergy with other projects has proven to be very effective. Figure 5 shows the current status of the network, with completed, imminent and planned upgrades highlighted. Future upgrade plans change rapidly and often as hardware failures and logistical opportunities are unpredictable, so flexibility is an important asset.

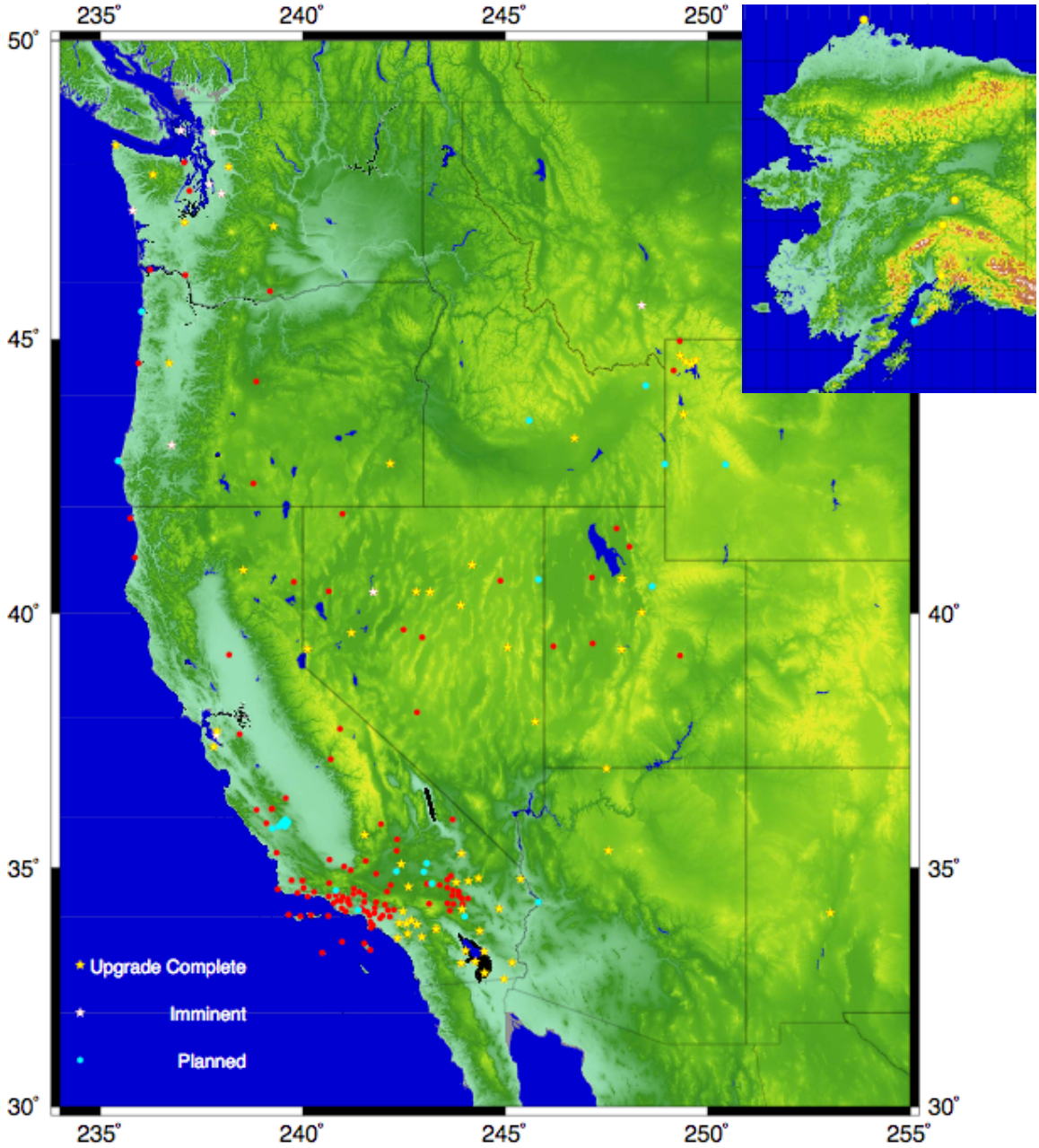

Figure 5. PBO Nucleus Network status, 12/2005. 61 upgrades have been completed with 8 expected to take place within the next 3 weeks and 30 more by Q1 2006.

The distribution of upgraded GPS stations throughout the six original existing networks is shown in Table 1. It's important to note that the pace of upgrades during the first six months of the project were greatly slowed by problems with first generation equipment that being used in Nucleus and new PBO installations. Hardware and firmware failures plagued the Trimble NetRS receivers and Proxicast cellular modems resulting in multiple station failures and equipment shortages through the third quarter of 2005. Nucleus project personnel made significant contributions in diagnosing and solving many of the problems. The resulting hardware configurations are now reliable, and 100% of the 61 upgraded stations are healthy. Overall station health is presently at 96% (202 of 210).

Existing Network (PBO Regions)	**Original Operating Institution**	**# Stations in Nucleus**	**Upgrades Complete**	**Upgrades since March 1, 2005**
AKDA (Alaska)	Univ. of Alaska	5	4	2
BARD (N. Ca.)	Univ. of California, Berkeley	12	3	3
BARGEN (Basin and Range, S. Ca.)	California Inst. of Technology	26	12	6
EBRY (Rocky Mtn., Basin and Range)	Univ. of Utah	16	7	2
PANGA (Pac. NW, N. Ca, Basin and Range)	Central Washington Univ.	26	7	2
SCIGN (S. Ca.), Parkfield (N. Ca.)	Univ. of Southern California	124	27	27
SuomiNet (Rocky Mtn.)	New Mexico Tech	1	1	1
Total:		**210**	**61**	**43**

Table 1. Distribution of upgraded stations in PBO Nucleus network.

Synergy with PBO and other projects has been a cost-effective method of maximizing productivity, with PBO, Facility, Nucleus, and subawardee personnel having combined forces several times on a variety of projects. Highlights include the design and construction of communication networks in Yellowstone, WY and Salton Sea, CA that are shared between Nucleus and PBO stations, and new Facility-supported station installations the Socorro, NM are that share communications with the newly added Nucleus station on M-mountain, SC01. This 210'th station was owned and operated by the New Mexico Institute of Technology under funding by the now-expired SuomiNet project, and was added to Nucleus for only the cost of a NetRS receiver, with no other costs necessary to integrate and operate the station. Nucleus station maintenance and upgrades in Nevada, Oregon, and Washington were timed to coincide with the deployment of the EarthScope-supported Cascadia ETS GPS campaign deployment in August, resulting in significant value added to both projects.

An important part of the successful operation of the Nucleus network is the continued maintenance of stations in their original configurations prior to upgrades, and a

great deal of resources and expertise have been devoted to this effort. Remote troubleshooting is routinely done by UNAVCO and network operators to monitor and maintain station health while minimizing travel expenses, and several site visits have been made to repair stations where upgrades are not currently practical.

Other operational highlights include the development a USGS-UNAVCO Virtual Private Network agreement that will allow cost-free Nucleus and USArray GPS station operations through the USGS satellite network, and the execution of a high-level Memorandum of Understanding between UNAVCO and the Stanford Linear Accelerator Center providing for the joint operation of a Nucleus station at their facility.

The purchase of new hardware that replaces existing equipment has created a pool of surplus equipment that has been used to support other projects, as well as to maintain other Nucleus stations prior to upgrade. Working receivers removed from Nucleus stations are being used to measure subsidence in the Tucson Basin by P.I. Rick Bennett of the University of Arizona, and surplus Zephyr antennas will be used to increase the accuracy of the EarthScope-funded Rio Grande Rift project to be deployed by the Universities of Colorado and New Mexico in 2006.

4. Data Management

The continuous acquisition and distribution of high-quality geodetic data to the research community is the top priority of the PBO Nucleus project. On spite of the abovementioned issues with hardware and communications failures, Nucleus attained a 93% rate of data return for the network during the first ten months of the project. It is anticipated that a data rate of 95% or higher will be maintained through the duration of the project.

At the beginning of the Nucleus project, the UNAVCO Facility archive was the primary wholesaler for data from 5 of the 6 existing networks, and the transition of the SCIGN archiving responsibilities to UNAVCO was completed by June 1. Data flow responsibilities for all previously upgraded stations were transferred to the PBO DMIT group on July 1, and since then at the time of upgrades for individual stations. At the time of upgrades Nucleus stations are renamed to comply with PBO's 16 character ID

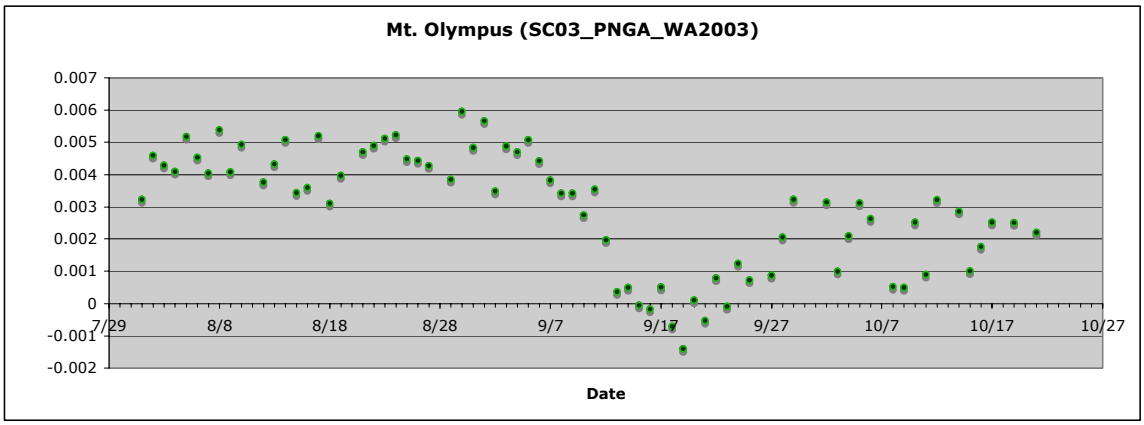

Figure 6. Time series from Nucleus station SC03, Mt. Olympus, WA generated by the PBO Analysis Center. The station shows 5 mm of westward movement between 9/7 and 9/17 caused by the 2005 Cascadia ETS event.

standards using a convention that was developed in order to preserve the original identities that have been in use by community data users. The transitions in data flow and responsibility have been seamless and invisible to the end users while greatly increasing efficiency and monitoring capabilities on the operational end. During this transition process meta-data are routinely verified and corrections to historic and present data made as necessary, resulting in a more reliable data set.

Data from all 210 PBO Nucleus stations have been analyzed by the PBO Data Analysis Centers since their inception, both during testing and operation phases. At the outset this data comprised 60% of the volume analyzed, although the percentage naturally decreases as more new PBO stations come on line. The AC director routinely communicates with Nucleus project personnel when data quality or meta-data issues arise. Level 2 data products are generated for all Nucleus stations as the example in Figure 6 shows.

Many PBO Nucleus stations have historically produced other data streams, such as high-rate real time GPS and meteorological data. Users from the geodetic and atmospheric research, surveying, and other communities rely on these data for ongoing operations, and care has been taken to preserve these capabilities while ensuring compliance with the PBO/EarthScope Data Management Plan (http://pboweb.unavco.org/dmsdocs/Root%20Folder/Data%20Management/Planning/Data%20Management%20Plan/pbo_dataplan.pdf). These auxiliary functions are provided as a courtesy only and are not supported by the Nucleus proposal.

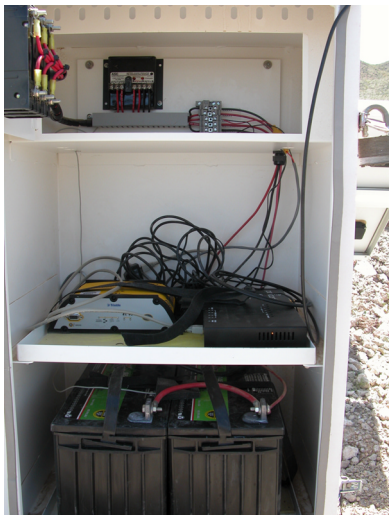

Figure 7. BKAP, Baker, CA Upgraded 4/20/05 NetRS receiver and CDMA modem shown in the center shelf.

Figure 8. MEE1, overlooking the San Andreas Fault north of Parkfield. An upgrade, including complete remonumentation, is planned for early 2006.

5. Station Permit Transfers

When the PBO Nucleus network is fully integrated into PBO in October 2008 it is important that station permits as well as the hardware and data conform to PBO standards. Station permits negotiated by the original networks must be transferred to UNAVCO/PBO and renegotiated where possible to minimize recurring payments and extend the terms through 2017. This process is well underway, with the official transfer of 10 stations throughout the network having been finalized, and 40 others in progress.

The process is being coordinated by the PBO Nucleus project manager, PBO Permitting office and various network coordinators or their designees.

6. Education and Outreach

Rebecca Walker joined UNAVCO in September as Education Specialist for the PBO Nucleus Project. Major accomplishments during the project period included: setting goals and a timeline for the next year of the project, interviewing college and university faculty who teach general education courses in geoscience as to their interest in GPS related materials for their courses, designing an evaluation plan, and scheduling workshops for faculty and teachers during 2006. We are engaging "GPS scientists" in the design and implementation of this project. Jessica Murray of the USGS Menlo Park and Tim Melbourne of Central Washington University have contributed in recent months. Further details are discussed in the Outreach Activities section of this report.

7. Project Information Dissemination

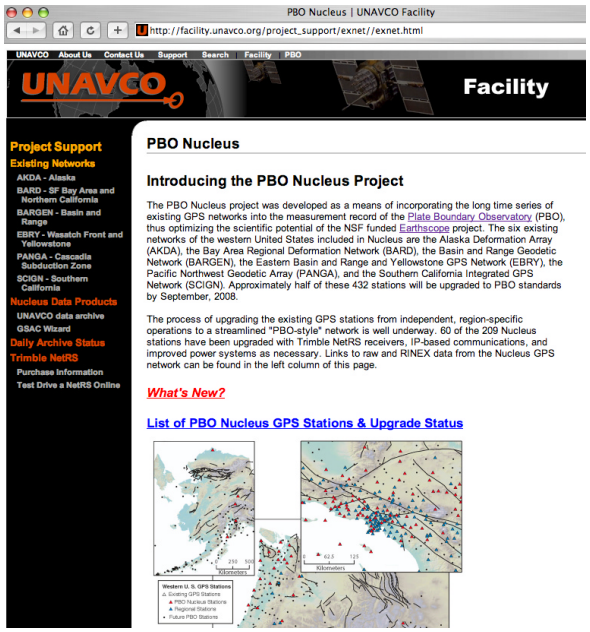

Figure 9. The PBO Nucleus Project web page

The PBO Nucleus Web Center (http://www.unavco.org/exnet/exnet.html) is continuously updated with information about project operations and network status as well as other important information. This page also contains links to data archives and data products, interactive mapping tools, and affiliated projects. PBO Nucleus project updates will also occasionally posted on the EarthScope web page (http://www.earthscope.org), and up-to-date network status is also available on the PBO Internet Map server (http://pboarcims.unavco.org).