earthscope

FACILITY OPERATION & MAINTENANCE

OCTOBER 1, 2008 – SEPTEMBER 30, 2018

Proposal to the National Science Foundation

March 2007

EarthScope Facility Operation and Maintenance

October 1, 2008–September 30, 2018

A Collaborative Proposal from:

the IRIS Consortium—for USArray

David Simpson, PI

Thorne Lay, University of California, Santa Cruz representing the IRIS Board of Directors

UNAVCO Inc—for Plate Boundary Observatory

Mike Jackson, PI

Charles Meertens, co-PI

Eric Calais, Purdue University representing the UNAVCO Board of Directors

Stanford University—for SAFOD

Mark Zoback, PI

Steven Hickman, USGS, co-PI

William Ellsworth, USGS, co- PI

Submitted to the

National Science Foundation

Division of Earth Sciences

EarthScope Program

March 2007

Project Summary

EarthScope is a broad-based earth science initiative that is taking a multidisciplinary approach to studying the structure and evolution of the North American continent and the physical processes responsible for earthquakes and volcanic eruptions. The integrated observing systems that comprise the EarthScope Facility can be used to address fundamental questions at all scales—from the active nucleation zone of earthquakes, to individual faults and volcanoes, to the deformation along the plate boundary, to the structure of the continent and planet. EarthScope data will be openly available to maximize participation from the national and international scientific community and to provide ongoing educational outreach to students and the public.

The **intellectual merit** of the EarthScope Facility is derived from its link to the support of fundamental research throughout the earth sciences. Through an ambitious data collection scheme and broad geographic coverage, the EarthScope Facility will provide the observational resources to encourage cross-disciplinary investigations and stimulate the next generation of research scientists. The design and implementation plan for EarthScope was developed through extensive, decade-long engagement with the scientific and educational communities. Through numerous workshops and working groups, the research community, along with federal and state partners, defined the data and tools required for geoscience to take the next step in exploring the fundamental processes that shape the structure and evolution of our continents. As the MREFC-supported construction stage for the EarthScope Facility nears completion, exciting results are already emerging from the analysis of new EarthScope data, confirming the enhanced resolution provided by this powerful new suite of observational tools.

The **broader impacts** of EarthScope will be achieved through an integrated education and outreach program and applications in hazard assessment, land use, and resource management. While EarthScope is a national program, it is being operated and maintained at local levels through interactions with hundreds of universities, schools, and organizations across the nation. As EarthScope collects data and makes it available, students and the public will be introduced to key unanswered scientific questions and the role that their region or discipline plays in understanding the evolution of the North American continent and the active processes driving deformation and volcanic activity. Improved understanding of the natural environment is the first step toward improved land use, environmentally sound development, and resiliency to natural hazards. With over 3,000 geographical locations, the broad distribution of EarthScope facilities will engage traditionally under-represented groups, particularly students in rural areas that have under-resourced schools and Native Americans on tribal lands (where some of the EarthScope stations will be installed). EarthScope will provide a unique opportunity for students and the public to observe geological processes in real time and to measure geological change within the time frame of an academic school year. EarthScope is providing the public with practical examples of how science advances, as they see new data being collected and watch new theories being formulated and tested.

Volume I

1. Executive Summary

EarthScope is a national science initiative to explore the structure and evolution of the North American continent and the physical processes controlling earthquakes and volcanoes. Unprecedented in both scope and ambition, EarthScope is taking an integrated, interdisciplinary approach to study the active nucleation zone of earthquakes, individual faults and volcanoes, deformation along plate boundaries, continental geodynamics and plate tectonic motion, fluids in the crust, and volcanic and seismic hazards. It will image Earth structure and measure deformation across the contiguous United States and Alaska with a level of detail and data accessibility never seen before. A clearer understanding of the forces that shape the environment will translate into better assessment of earthquake and volcanic hazards and improved knowledge of the country's natural resources.

The North American continent is an ideal location for EarthScope, as few places on Earth offer such a rich set of ancient and active geological processes so accessible for study. The full spectrum of ongoing plate boundary processes is represented, ranging from plate convergence in the subduction zones of Cascadia and the Aleutians, to transform motion along the San Andreas Fault, to intraplate extension of the Basin and Range. North America also contains active intraplate volcanic hotspots and seismic zones as well as a 3.5-billion-year record of continental evolution, which includes ancestral rifts and orogenic belts. EarthScope facilities have begun collecting multiple data sets that will enable integrated studies over a broad range of spatial and temporal scales, from the physics of individual faults and volcanoes to tectonic-plate interactions.

EarthScope facilities are providing state-of-the-art seismic and geodetic observational systems that serve multidisciplinary research on the structure and evolution of the North American continent at all scales. The National Science Foundation (NSF) will have invested approximately $200M from the Major Research Equipment and Facility Construction (MREFC) account to construct EarthScope facilities with a completion date of September 30, 2008.

EarthScope facilities (Figure 1.1) include the following components:

- **The Plate Boundary Observatory (PBO)** is a network of 1100 continuously operating Global Positioning System (GPS) receivers, 103 borehole strainmeters and borehole seismic stations, and six long baseline strainmeters installed along the western United States plate boundary, as well as a pool of 100 transportable GPS sensors for focused temporary deployments.
- **The USArray** consists of a Transportable Array of 400 broadband seismographic stations to be sequentially deployed at 2000 sites in a 70-km grid across the United States, a Flexible Array of hundreds of seismic and magnetotelluric instruments for high-resolution investigations of targeted regions, and a Reference Network of fixed, fiducial seismic and magnetotelluric network installations.
- **The San Andreas Fault Observatory at Depth (SAFOD)** is a three-kilometer-deep observatory emplaced directly within the San Andreas Fault near Parkfield, CA. Downhole sampling, measurements, and instrumentation during the MREFC phase of EarthScope provide the first opportunity to observe directly the conditions under which earthquakes occur, and under the O&M phase will offer the first possibility ever to directly monitor the physical processes associated with earthquake nucleation, propagation, and rupture.

The data collected from the EarthScope facilities are being made openly available to the scientific and educational communities with minimal delay to ensure optimal use. Associated data centers and data-distribution capacity are to be supported by this proposal, along with the operations and maintenance of EarthScope instrumentation. This proposal does not include funding for integrated EarthScope science research or education and outreach beyond that associated with sustaining the facilities, nor does it include support for the EarthScope National Office, which is separately funded. Operations and maintenance support is only for the facilities constructed under the MREFC phase; no support for enhancements, new facilities development, or associated long-term support is included here.

The proposal budget target of $23.4M for the first year and its partitioning across the facilities (58% USArray, 40% PBO, and 2% SAFOD) directly reflects NSF guidance. An Independent Cost Review was commissioned by NSF to review the costs of individual EarthScope operational tasks as included in an earlier version of this proposal reviewed in 2005. The results of that review, which substantiated the basis for the earlier costs estimates, have been used in the development of this proposal. Recognizing the budgetary constraints under which NSF earth sciences research is conducted, every effort has been made by the EarthScope facilities operators to keep costs as low as viable while sustaining the facilities and services essential to achieving EarthScope scientific goals and supporting research applications.

EarthScope facilities derive their primary support from the NSF, but include key partnership arrangements with the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), along with a host of federal and private property owners. This proposal does not include operations and maintenance support for EarthScope activities conducted by agencies other than NSF.

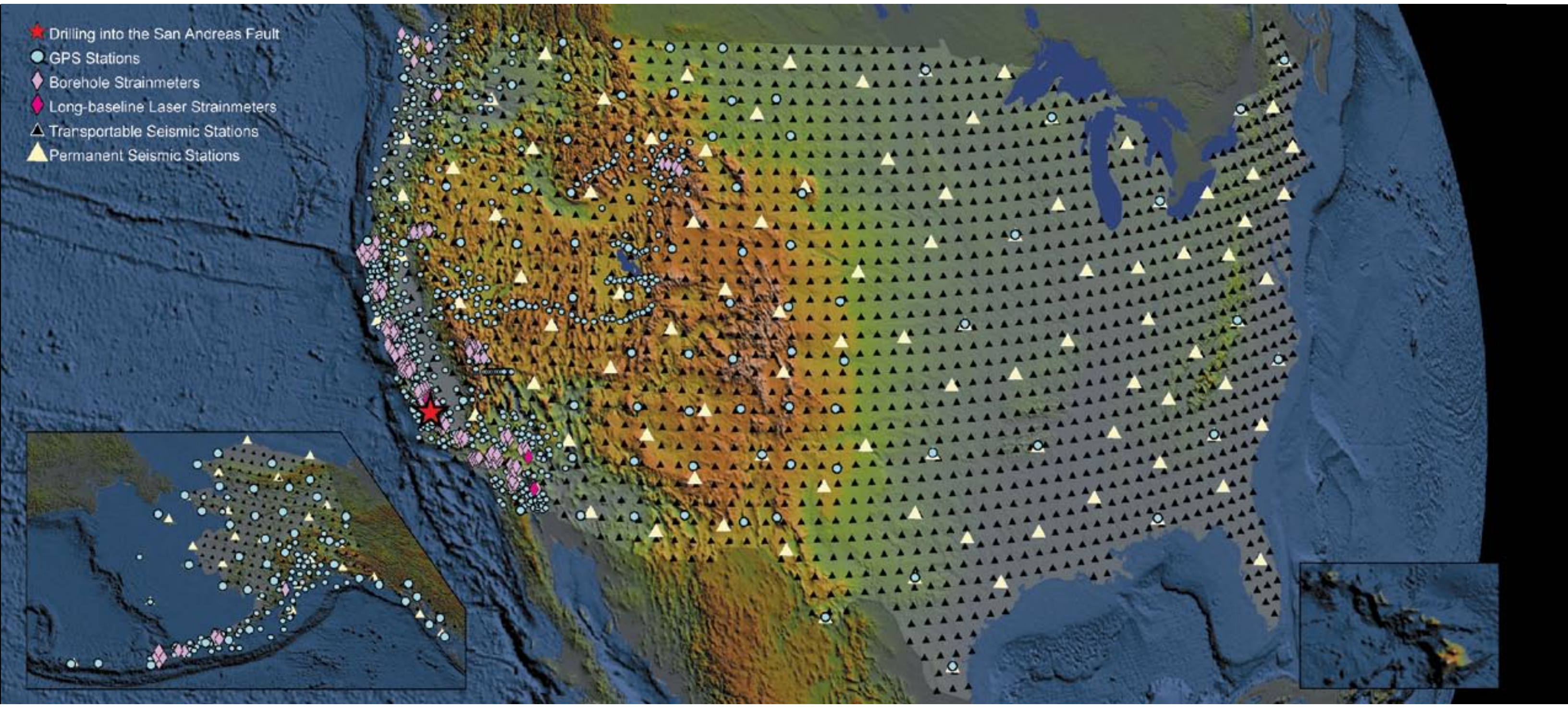


Figure 1.1. Construction of the EarthScope facility was initiated in 2003 with funding from the NSF Major Research Equipment and Facility Construction (MREFC) program. The facility is now over 65% complete and expected to be finished on-time and on-budget by October 2008. The scientific promise of EarthScope is already being demonstrated, as described in contributed scientific results in Volume III of this proposal.

In addition, the facilities operations derive great benefits from the existing organizational and facilities infrastructures of the Incorporated Research Institutions for Seismology (IRIS) and UNAVCO, which are separately funded. A subset of separately funded GPS instruments, called the PBO Nucleus, is being merged with the PBO GPS network built under the MREFC for long-term operations and maintenance. The original MREFC proposal included an Interferometric Synthetic Aperture Radar (InSAR) component to be supported by NASA. This support has not yet materialized (beyond the MREFC-funded acquisition of InSAR data conducted under GeoEarthScope), and there is no support for the InSAR component in this proposal.

The EarthScope Management Team (EMT), comprised of two representatives from each facility component and the NSF EarthScope Program Director, collectively manages the EarthScope facilities. The IRIS President and IRIS Chair of the Board of Directors represent USArray; the PBO Director and Chair of the UNAVCO Board of Directors represent PBO; the Stanford principal investigator (PI) and a USGS co-PI represent SAFOD. The EMT works collaboratively to address pan-EarthScope technical and funding issues, and to digest extensive input from the component advisory committees (USArray Advisory Committee, PBO Standing Committee, SAFOD Advisory Committee) and existing advisory and community oversight committees of IRIS and UNAVCO. The non-NSF members of the EMT are the leaders on the development of this proposal. The PIs from IRIS, UNAVCO, and Stanford are co-investigators and are responsible for conducting the NSF-supported operations and maintenance activities. The EMT will continue to draw extensive input and advice from the broad community representation and engagement enabled by the IRIS and UNAVCO consortia.

EarthScope facilities supported by this proposal will provide data for research on scientific topics in a number of critical, active research areas with fundamental outstanding questions to be resolved:

- **Fault properties and the earthquake process.** How do earthquakes start, propagate, and stop? How does strain accumulate and how is it released along the boundaries and within the North American plate? What structural and geological factors control earthquake generation along plate boundaries such as the San Andreas Fault and Cascadia and give rise to intraplate regions of seismic hazard such as the New Madrid zone?
- **Magma migration and volcanic hazard.** How can better methods be developed for the prediction of volcanic eruptions and hazard mitigation? How does magma originate and how is it transported in the subsurface?
- **Crustal strain transfer.** What kinds of transient movements occur at depth? How do crust and mantle rheology

vary with depth or with distance from an active fault? What influence does this have on seismic and aseismic deformation? How does it vary near active fault zones and affect the earthquake process? How do faults interact with one another? What is the state of stress in the lithosphere?

- **Convergent margin processes and volatile cycling.** What is the nature of the plate boundary megathrusts in the Pacific Northwest and Alaska and how does it affect the seismic cycle? What is the structure of the deeper slab and how does it affect earthquakes and the overall subduction process? How is strain partitioning accomplished in the forearc and what controls it? What are the distributions and effects of subducted volatiles?
- **Continental structure and evolution.** What is a continent? How does continental lithosphere form and evolve? How are continental structure and deformation related? What is the lithospheric strength profile and what controls it? What is the composition of the lithosphere and how are fluids distributed through it?
- **Continental deformation and asthenospheric structure.** What are the spatial and temporal scales of intraplate deformation? What are the forces driving continental deformation? How is the evolution of continental lithosphere related to upper mantle processes? How and where are forces generated in the upper mantle and how and where are they transferred to the crust?
- **Deep Earth structure.** What is the nature of the lowermost mantle? What are the heat budgets of the core, deep mantle, and lithosphere?

The successful deployment of the EarthScope facilities, on budget and on schedule, has greatly improved the prospect of making major advances in understanding these fundamental issues. This proposal focuses on successful operations and maintenance of these facilities for a sufficient time period to provide the data necessary to answer these important scientific questions.

This proposal seeks NSF support for operation and maintenance of EarthScope facilities for the first five years (FY09–14) beyond the MREFC phase, as the second stage of the planned 15-year operational lifetime of the facilities. Estimates are also provided for the third phase (FY14–18). The proposal is structured in three volumes:

- Volume I is the core content of the proposal, including the project description and budget information. A broad outline of MREFC-funded EarthScope facilities is presented in the following section. Highlights the scientific opportunities enabled by these facilities are included in Section 3. The specific tasks to be carried out by each of the EarthScope components during the O&M phase are included in Section 4. An overview of the budget plan and the year-by-year budgets for each component are presented in Section 5, followed by a brief summary statement in Section 6. The full budgets, presented in the required NSF budget tables, along with CVs for key personnel and other NSF-required materials are in Section 7. Additional budget information in the form of a "work breakdown dictionary" is also included in Section 7. To aid in cross-referencing, the materials in Sections 4, 5, and 7 are all identified by a numbered "work breakdown structure," the elements of which are linked to the tasks described in Section 4.
- Volume II describes each of the EarthScope facilities in more detail, including information of the organizational structure, underlying technology, and technical aspects of instrumentation.
- Volume III provides additional materials revealing the science enabled by the EarthScope facilities, including short summaries of thematic areas and numerous one-page articles contributed by the scientific community.

2. EarthScope Facilities

The facilities component of the EarthScope project is a set of integrated and distributed multi-purpose geophysical instruments that will provide observational data to significantly enhance our knowledge of the structure and dynamics of North America. The EarthScope facilities are being implemented through the parallel construction of multiple observational systems aimed at investigating scientific questions at all scales.

The San Andreas Fault Observatory at Depth (SAFOD) is a three-kilometer-deep hole drilled directly into the San Andreas Fault midway between San Francisco and Los Angeles near Parkfield, CA. Located in an area that has ruptured seven times since 1857, the hole is providing the first opportunity to observe directly the conditions under which earthquakes occur, to collect rocks and fluids from the fault zone for laboratory study, and to continuously monitor the physical conditions within an active earthquake nucleation zone.

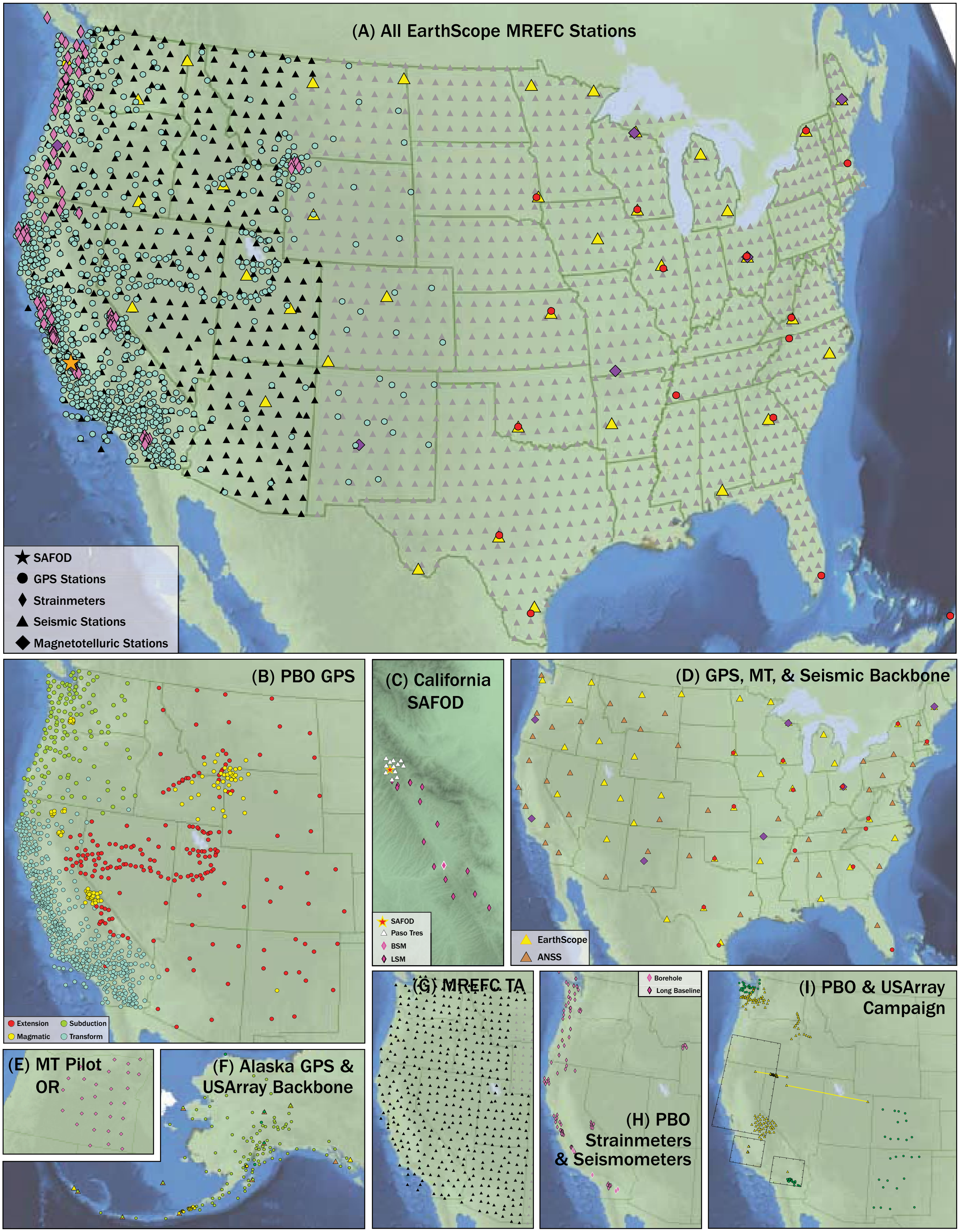
The Plate Boundary Observatory (PBO), with observational periods from fractions of seconds to decades, is an array of geodetic and strain instrumentation that will image both fast and slow deformation in the lithosphere along the western United States and Alaska. A network of permanent, continuously operating Global Positioning System (CGPS) receivers and borehole strainmeters and seismometers is measuring strain on Earth's surface in key tectonic targets, from the edge of the Pacific Coast to the Rocky Mountains, from Washington to Mexico, and across Alaska. A backbone network of CGPS receivers with a spacing of about 200 km in the western United States and 400 km in the eastern United States provides a reference deformation grid and establishes a stable reference frame away from the actively deforming plate boundary.

With instruments extending completely across the United States, USArray is a nested array of permanent, transportable, and temporary seismographic stations and magnetotelluric instruments designed to capture high-resolution images of the structure of the continental lithosphere and deeper mantle at a continuous range of scales, from global to continental, regional, and local scales. At the continental scale, EarthScope, in cooperation with the United States Geological Survey's (USGS's) Advanced National Seismic System (ANSS), has contributed to the establishment of a permanent network of seismic stations that serve as fiducial points linking the seismic observations in space and time (Reference Network). At the regional scale, a an array of seismic instruments will eventually roll across the entire continental United States and Alaska in a leapfrog fashion to produce a synoptic sampling of the continent at 70-km spacing. At the local scale, this Transportable Array can be supplemented by a separate set of portable seismometers (Flexible Array) available to individual investigators to provide dense coverage in areas of special interest (Figure 2.1).

The EarthScope facilities are being constructed under NSF's Major Research Equipment and Facilities Construction (MREFC) account. As of the writing of this proposal, the facilities are on schedule and on budget for completion of the construction phase by October 2008. When the construction phase is complete, the SAFOD borehole will have been drilled and sampled and observational equipment installed; all permanent PBO geodetic, seismic, and strain instruments will be operational; the permanent stations of USArray will be fully integrated with the ANSS; the first deployment of the USArray's 465 transportable stations (400 new and 65 upgraded) will have been completed; portable GPS and seismic equipment will have been acquired and will be in use in NSF-funded experiments; and data from all EarthScope instrumentation will be fully documented and openly available, with most data being collected and distributed continuously and without delay.

This proposal requests support for the EarthScope facilities beyond the construction phase for operations and maintenance. During the Operations and Maintenance (O&M) phase, we request support to continue operation of EarthScope installed instrumentation, ongoing field installations, and data distribution from more than 1100 permanent CGPS stations, 103 borehole strainmeters and borehole seismic stations, six long baseline laser strainmeters, 100 campaign GPS receivers, and the instrumented SAFOD borehole; continue deployment of 400 transportable broadband seismometers as they complete their transit across the contiguous United States and prepare for deployment in Alaska; continue support for the deployment of approximately 2000 portable seismometers; and continue to provide SAFOD core, cuttings, and fluid samples to scientists.

Figure 2.1 (opposite page). The EarthScope facilities. All facilities in the lower 48 states are shown in the upper map A. Dark symbols are those expected to be installed by the end of the MREFC phase in October 2008. The lighter triangles in map A show the Transportable Array sites to be occupied during the O&M phase. Permanent MREFC installations in Alaska are shown in map F. The Reference Array, including both EarthScope and ANSS backbone seismic stations, is shown in map D, along with MT stations and backbone GPS stations in the eastern US. Maps B and H show GPS, strainmeter and seismic stations installed by PBO in the western US. Installations of permanent and campaign instruments around the SAFOD site are shown in map C. Current, past and planned (boxes) seismic and GPS campaign installations are shown in Map I. Map E shows the locations of the pilot MT campaign in Oregon in 2006.


(A) All EarthScope MREFC Stations
SAFOD
GPS Stations
Strainmeters
Seismic Stations
Magnetotelluric Stations
(B) PBO GPS
Extension
Subduction
Magmatic
Transform
(C) California SAFOD
SAFOD
Paso Tres
BSM
LSM
(D) GPS, MT, & Seismic Backbone
EarthScope
ANSS
(E) MT Pilot OR
(F) Alaska GPS & USArray Backbone
(G) MREFC TA
(H) PBO Strainmeters & Seismometers
Borehole
Long Baseline
(I) PBO & USArray Campaign

Current and Projected MREFC Status

As of March 2007, construction of the MREFC EarthScope facilities is more than 65% complete. In this section, we provide a snapshot of the current MREFC status and a description of the individual facilities as they are anticipated to exist at the start of the O&M phase.

Permanent Installations

A significant part of the O&M activities will be to maintain a diverse network of geophysical observatories distributed throughout the United States, but concentrated along the western margin of the continent and in Alaska. This permanent network includes GPS, strain, and seismic instruments installed as part of PBO; seismic and magnetotelluric instruments installed as part of USArray; and a complex of in situ sensors installed within the SAFOD borehole.

GPS, Strain, and Seismic Instruments

The core of PBO is a permanent geodetic observatory that consists of an integrated network of GPS stations and borehole and long baseline strainmeters constructed under the EarthScope MREFC project. Borehole seismic and strain instruments are well suited for capturing short-term transient deformation (from seconds to a month) and, consequently, will play a central role in observing phenomena that occur in the seconds before, during, and after earthquakes, as well as slow fault-slip events and volcanic eruptions. GPS is particularly well suited for time scales greater than a month, thus covering long-period transients, such as those associated with viscoelastic relaxation following earthquakes, and decadal estimates of strain accumulation and plate motion and their spatial variations. By using this suite of complementary techniques, PBO will provide unprecedented spatial and temporal coverage of time-dependent deformation signals essential to understanding the fundamental physics that govern deformation, faulting, and fluid transport in Earth's lithosphere.

When completed, the PBO component of the EarthScope MREFC facility will operate and maintain 1100 permanently installed CGPS stations. Of these 1100 stations, 875 are located throughout the contiguous western United States and Alaska, 16 are permanently installed in the eastern United States, and 209 are existing stations upgraded to PBO standards as part of a separate proposal (PBO Nucleus). PBO will also operate and maintain 103 borehole strainmeter and seismometer stations and six long baseline laser strainmeters (LSM) in the western United States. Other equipment purchased under the MREFC that will require O&M funds includes a pool of 100 portable GPS receivers for temporary ("campaign") deployments and rapid-response activities. As of March 2007, PBO has installed 533 CGPS stations, upgraded 165 Nucleus CGPS stations, installed 28 borehole strainmeters and 27 borehole seismometers, and installed three LSMs.

Seismic and Magnetotelluric Instruments

A key element of the EarthScope seismic observation system is a dispersed permanent network that provides a long-term reference frame for comparison of observations made with the denser, but transient, Transportable Array as it crosses the country. This Reference Network was developed in close collaboration with the USGS as an augmentation to the backbone component of the ANSS. EarthScope contributed the installation and upgrading of 39 stations to the ANSS Backbone, which now consists of more than 70 stations, at approximately 300-km spacing, across the conterminous United States and 10 stations in Alaska. EarthScope and IRIS will continue to explore ways to work with regional operators and the USGS to fill some gaps in coverage that continue to exist, especially in the north-central United States.

Each of the reference stations includes broadband sensors capable of recording seismic waveforms, from long-period surface waves to high-frequency body phases, for use in studies of structure from the lithosphere to the core. A subset of the stations are equipped with ultra-long-period sensors, extending instrument response to thousands of seconds, making them capable of capturing Earth's free oscillations excited by the largest earthquakes. Data from these stations are transmitted in real time to the USGS National Earthquake Information Center in Golden, CO to support their mission of national and global earthquake monitoring. These data, along with those from all other ANSS Backbone stations, are then transmitted to the IRIS Data Management Center (DMC) for archiving and distribution. To ensure that the reference framework was available early in the development of EarthScope, installation of the USArray permanent stations was completed in September 2006. O&M responsibility for these permanent stations has been transferred to the USGS and, while the data from this network remain critical to EarthScope scientific goals, support for the continued operation of this EarthScope component is not included in this proposal.

The magnetotelluric (MT) facility consists of both permanent and portable elements. The backbone component, consisting of seven permanent MT stations installed across the United States as a reference network, will measure naturally occurring electric and magnetic fields. These data will be integrated with other geophysical data to identify Earth's thermal structure and study the significance of fluids in the crust. To date, four of the seven permanent backbone MT sites have been constructed and are awaiting instrument installation. The remaining three stations will be constructed and installed by September 2008.

Figure 2.2. Top Row. (Left) Installing antenna for GPS station RG20 in the Rio Grande Rift. (Center) Core retrieved from SAFOD drill hole. (Right) Installing seismometer and supporting electronics for a typical Transportable Array station. MIddle Row. (Left) Vault and site construction for Transportable Array station I05A near Bend, OR. (Center) Transportable Array station C08A near Almira, WA. (Right) Drilling of SAFOD observatory. Bottom Row. (Left) Installing PBO strainmeters near Parkfield, CA. (Center) Installing electronics for a typical GPS station. (Right) SAFOD drill rig.

In Situ Borehole Sensors

Under the MREFC, the 3.2-km-deep SAFOD borehole was drilled through the San Andreas Fault just north of the rupture zone of the 1966 and 2004 magnitude 6 Parkfield earthquakes, at the transition between the creeping and locked sections of the fault. In the summers of 2004 and 2005 during the rotary-drilling phases of SAFOD, the borehole passed through the entire San Andreas Fault Zone at seismogenic depths while acquiring a comprehensive suite of downhole measurements and obtaining 60 m of 2.5-in- and 4-in-diameter spot cores, fluid samples, and continuous drill cuttings. Lateral coring scheduled for the summer of 2007 will produce an additional 600 m of 2.5-in-diamater continuous core from within the active fault zone. Samples already collected are currently being analyzed by over 30 principal investigators (PIs) from the United States and abroad to obtain information about fault behavior and the composition and physical properties of fault-zone materials at depth. Seismometers and tiltmeters have already been deployed multiple times in the SAFOD borehole at seismogenic depths and will be augmented with accelerometers and a fluid-pressure sensor (to monitor pressure variations directly within the fault zone) before the conclusion of the MREFC phase. All of these downhole instruments will continue to provide data during the O&M phase.

Campaign Instruments

EarthScope has acquired a pool of portable seismic and geodetic instruments that are available to investigators who receive separate funding under the NSF EarthScope program to study specific areas of interest.

One hundred campaign GPS receivers were purchased and configured for focused temporary deployments within the EarthScope footprint as part of the EarthScope MREFC. The UNAVCO Facility configures and deploys the instruments, provides pre-proposal budget and equipment planning and training to funded PIs, and archives the data at project completion. Equipment is installed for a few weeks to a few years, depending on the nature of the event to be studied. PBO has supported both long- and short-term projects with the campaign pool. For instance, PBO supported short-term campaign observations associated with the 2005 and 2006 Cascadia episodic tremor and slip (ETS) events (Figure 2.3), which require a few weeks of continuous operation at a time. PBO is also supporting the Rio Grande Rift project with a long-term campaign deployment to determine the present-day kinematics of lithospheric extension across the rift and how extension is related to lithospheric heterogeneity.

A pool of portable seismic instruments, referred to as the Flexible Array, is supported out of the USArray Array Operations Facility (AOF), collocated with the PASSCAL Instrument Center in Socorro, NM. In addition to acquisition and maintenance of the equipment for the Flexible Array, the AOF also supports PIs by training them in instrument operation, helping in the field, and collecting data.

As of March 2007, 120 broadband, 120 short-period, and 1200 active-source instruments are available. The broadband instruments are used primarily in long-term, multi-year deployments to record earthquake sources and provide higher-resolution images within the footprint of the Transportable

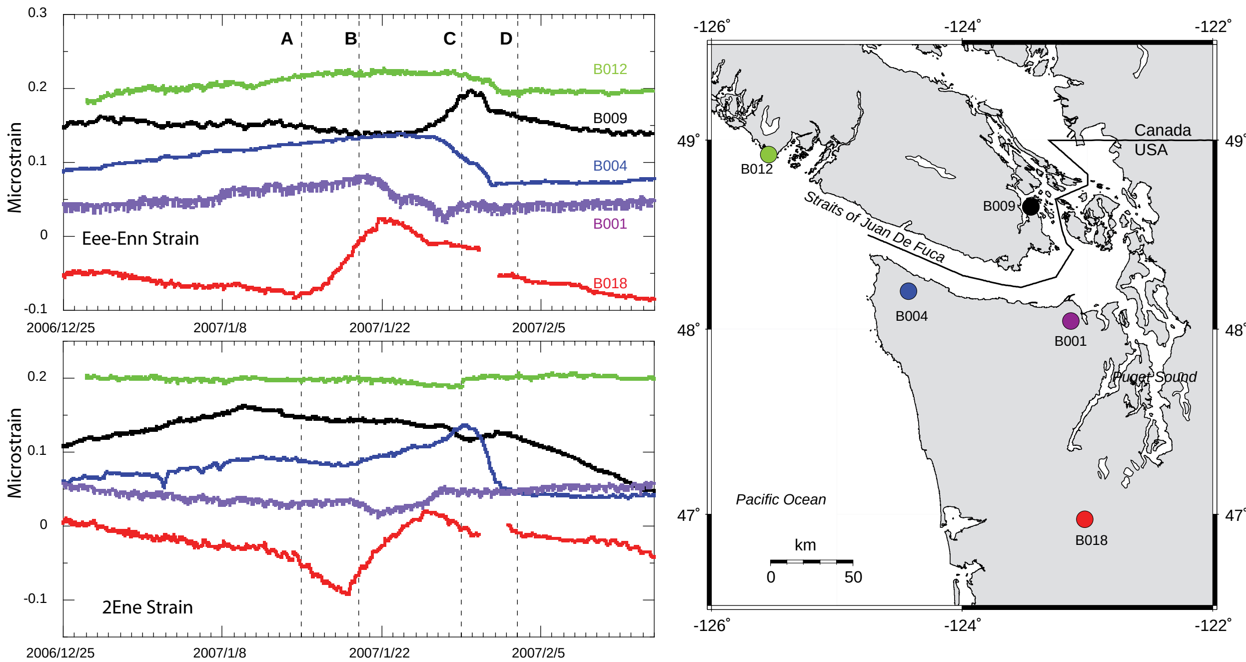


Figure 2.3. A strain transient moves from north to south through the PBO strainmeter network due to propagating transient slip along the Cascadia subduction zone. Left subfigures show shear strain recorded by PBO borehole strainmeters located in the Pacific Northwest (see map at right), from December 25, 2006 to February 20, 2007. Data have been detrended and tides and atmospheric pressure have been removed. Dotted lines show the stages of the 2007 ETS tremor. (A) tremor is detected in central Puget Sound. (B) tremor is detected in the northern Puget Sound. (C) tremor migrates across the Straits of Juan de Fuca. (D) tremor ceases.

Array. The short-period instruments are intended for shorter-term deployments in high-resolution investigations of smaller targets, such as fault zones and magmatic centers. The active-source instruments are used to record explosive or vibratory sources in dense arrays for high-resolution reflection and refraction studies of the crust. EarthScope plans to acquire at least 171 additional broadband instruments and 500 active-source instruments as part of the MREFC acquisition.

All data from Flexible Array experiments are archived at the IRIS DMC. Currently active experiments using these instruments include the Sierra Nevada EarthScope Project (SNEP), Cascadia Arrays for EarthScope (CAFÉ), and the Wallowa experiment in eastern Oregon. The data-collection phase of three other campaign experiments—Fault Zone Guided Waves and Paso Tres at SAFOD and Tremor in Washington—has already concluded. Information on the preliminary results from these experiments is included in Volume III of this proposal. Preparation for the use of broadband instruments in new experiments in 2007 is underway.

Transportable Seismic and Magnetotelluric Arrays

To provide increased resolution of lithospheric and deep Earth structure, the Transportable Array of 400 broadband seismometers will gradually cross the United States and Alaska, occupying sites for about two years on a 70-km grid. Under the MREFC funding, all 400 systems are being acquired and, by October 2007, the first footprint will have been established from north to south along the westernmost quarter of the United States (Figure 2.4). In the O&M phase, the Transportable Array will be rolling, and over the next six years will complete an additional three full deployments to cover the conterminous United States with over 1600 observation points before moving to Alaska.

Each of the Transportable Array stations consists of a three-component broadband seismometer with associated signal processing, power, and communications equipment. In the early phase of the MREFC, significant effort was devoted to the design of the temporary vaults to house the instruments, which resulted in a configuration that provides both high-quality data and a data return of greater than 90%. Data from each station are continuously transmitted to the Array Network Facility at the University of California, San Diego, where initial operational and quality checks are performed, and then sent to the IRIS DMC, where all data and associated metadata are archived.

As of March 2007, more than 325 Transportable Array stations are operating in California, Oregon, Washington, Idaho, Montana, Nevada, Arizona, and Utah. Of these, 255 are new installations, while the remaining stations are upgrades to existing seismic stations in regional, local, or university networks. Approximately 70% of the stations are located on private land and 30% are on public lands, including National

Park, National Forest, Native American, and Department of Defense lands. Stations are currently being constructed in southern Arizona and sensors, communications equipment, and power systems are being installed in vaults in Nevada and Idaho. Permits are already in hand for the remaining sites in Utah, Idaho, and Montana and construction activities will resume in these states when weather conditions improve. During the 2007 field season, about 250 sites for Transportable Array stations will be identified in central and eastern Montana, Wyoming, Colorado, and New Mexico and in the Big Bend area of Texas. For the third year in a row, university students will be engaged to conduct reconnaissance activities for a significant number of these sites. Beginning in August 2007, stations in California will be demobilized and then redeployed at a site in the second footprint.

Twenty transportable MT systems are being acquired with MREFC funding to complement the seven permanent MT stations. The transportable MT instruments will be used for deployments on a nominal 70-km grid spacing for imaging of crustal and lithospheric conductivity structure in areas of special interest as proposed by the MT community and approved by NSF. A pilot experiment operated 30 stations in Oregon in 2006. A preliminary three-dimensional inversion of the data highlighted NE-SW lineaments as major crustal conductors. Preparation for a 50–60 station deployment in 2007 in the Pacific Northwest is underway.

Data Management

At the heart of EarthScope are the data collected from each of the instruments. During the MREFC, servers and storage systems have been acquired to archive and distribute quality-controlled data and associated metadata. The IRIS DMC serves as the primary archive for seismic data from USArray and PBO. The Northern California Earthquake Data Center (NCEDC) is in charge of metadata, data conversion, and quality assurance/quality control (QA/QC) for SAFOD time-series data and is the primary archive for these data, with the IRIS DMC serving as a backup archive. The IRIS DMC is also a backup archive for EarthScope strainmeter, tiltmeter, and fluid-pressure data. PBO GPS data are archived at the UNAVCO Facility Archive; PBO strainmeter and SAFOD tiltmeter and fluid-pressure data are archived at the NCEDC. SAFOD data pertaining to drilling operations, downhole measurements, and samples are maintained as part of the International Continental Scientific Drilling Program, with the SAFOD samples themselves being curated at the Gulf Coast Repository of the Integrated Ocean Drilling Program. MREFC funds will be used to develop a central portal operated in conjunction with the EarthScope Web site that will allow integrated access to all EarthScope data. In the current model, the central portal will use Web services to connect information at the component data centers.

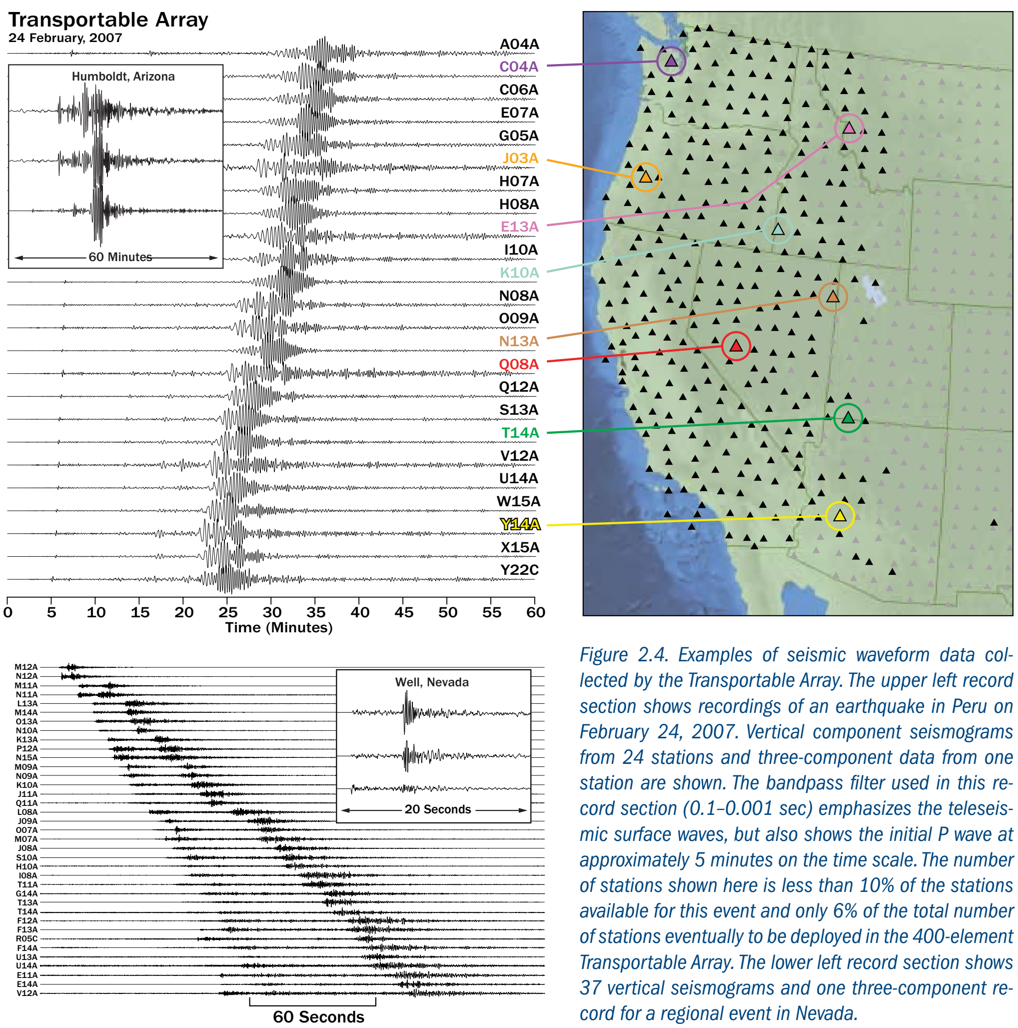


Figure 2.4. Examples of seismic waveform data collected by the Transportable Array. The upper left record section shows recordings of an earthquake in Peru on February 24, 2007. Vertical component seismograms from 24 stations and three-component data from one station are shown. The bandpass filter used in this record section (0.1–0.001 sec) emphasizes the teleseismic surface waves, but also shows the initial P wave at approximately 5 minutes on the time scale. The number of stations shown here is less than 10% of the stations available for this event and only 6% of the total number of stations eventually to be deployed in the 400-element Transportable Array. The lower left record section shows 37 vertical seismograms and one three-component record for a regional event in Nevada.

3. Scientific Opportunities

The North American continent has been evolving for billions of years, repeatedly subjected to continental collisions and mountain building, rifting events, fluctuating sea levels, volcanic-arc development and extinction, underthrusting by oceanic lithosphere, delamination, magmatic upwellings, earthquake fracturing and faulting, meteorite impacts, massive erosion, and deposition. Unraveling the relic signatures of these dramatic events and understanding the processes that continue to occur and the hazards that accompany them qualifies as one of the grand intellectual undertakings in science. EarthScope facilities are designed to contribute fundamental observations for addressing this challenge.

USArray

Multi-scale imaging of crustal and upper mantle structure beneath North America is a primary objective of the EarthScope program, as this is a starting point for quantifying the dynamical processes and history of the continent and its plate tectonic context. Another major objective is to analyze seismic sources, from microearthquakes to large ruptures, in an effort to understand the fundamental nature of earthquakes and their relationship to volcanic and tectonic events. Seismology provides one of the most important geophysical tools for imaging subsurface structure and recording earthquake signals. All EarthScope components involve seismological data acquisition; however, USArray is the principal seismological effort.

The progressive deployment of the Transportable Array across the 48 contiguous states and Alaska, and the pool of deployable seismometers in the Flexible Array, are the key USArray activities and facilities to be supported by this proposal. They will directly provide or allow acquisition of the requisite seismic data for imaging subsurface structure at multiple scales and for studying earthquakes in many environments. USArray also consists of permanent broadband seismic stations (Reference Network) that provide a large-aperture, fixed grid of observing sites, essential for tying together the 70-km-spaced grid of sequential Transportable Array deployments. Transportable Array and Reference Network station distribution together provide unprecedented spatial coverage and uniformity of seismic wavefield sampling, enabling well-established and new seismological analyses to reveal deep Earth structure and to characterize earthquake sources throughout the continent. The scientific community will be able to conduct a host of research projects with Transportable Array data and with separately funded field deployments of Flexible Array sensors. In addition, USArray magnetotelluric (MT) instruments include a permanent network and a transportable array that will be systematically deployed in campaign mode with 70-km spacing.

USArray facilities will provide data for many scientific applications directed at the foremost problems in earth science. One of the most valuable attributes of seismic recordings is that any given seismic station can record signals useful for diverse applications in the study of seismic sources and Earth structure. The broadband recordings of the Transportable Array and Reference Network stations, along with those collected using Flexible Array broadband sensors deployed in field experiments, each yield myriad body wave and surface wave arrival times and waveforms that investigators can analyze for completely different objectives. For example, an isolated three-component recording can be processed to estimate the receiver function—the sequence of converted and reflected arrivals accompanying the direct P or S arrivals that reveals velocity

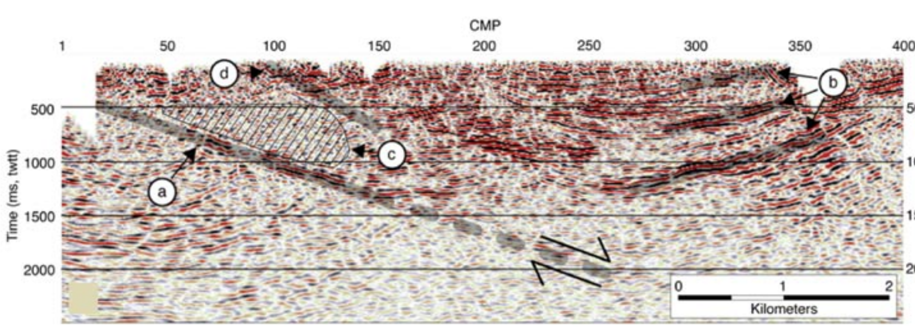


Figure 3.1. Example of high-resolution shallow crustal structure imaging achieved by active-source seismology using portable deployments of USArray Flexible Array and other instruments. This migrated image of the Surprise Valley basin near the NV-CA-OR border has no vertical exaggeration based on basin-fill Vp=2 km/s. Common mid-point spacing is 20 m. The Surprise Valley Fault (SVF) (a) forms a continuous, moderate-amplitude low-angle east-dipping reflection that bounds the western side of the basin. Prominent west-dipping reflections (b) on the eastern edge of Surprise Valley correspond to late Miocene to Pliocene (8–3 Ma) volcanic strata. The reflection-free region (c) immediately above the SVF is interpreted as alluvium deposited along the range-front during footwall exhumation. West-dipping reflections near CDP100 appear to be truncated by a fault splay (d) above the SVF. Courtesy of D.W. Lerch, S.L. Klemperer, A. Egger, and J.P Colgan.

contrasts at depth below the station—as well as the shear-wave splitting caused by elastic anisotropy on the path of a given arrival. The same signals can be analyzed to study the earthquake sources that generated the elastic waves. Multiple-station recordings can be migrated to resolve the three-dimensional configuration of subsurface velocity contrasts and anisotropic structures or to image earthquake sources. Dispersed surface wave signals at the same stations can be analyzed to build structural models along the path to a source or between recording stations; the regular grid distribution of the Transportable Array could enable reconstruction of the actual wavefield as it refracts through the network. Even the background vibrations recorded by the seismometers are now recognized to contain coherent information from which the fine-scale heterogeneity of the crust and uppermost mantle can be deduced. Seismic recordings can be analyzed to study a small nearby earthquake or the complex rupture process of a large earthquake located halfway around the world. While data accumulates for studying North American structure and sources, information simultaneously accumulates for analyses of structure near the base of the mantle or in Earth's core—making USArray a tool for truly global research applications.

Over the next decade, the Transportable Array will sweep eastward over the Rocky Mountains, the Great Plains, Appalachia, and the eastern seaboard, then up to the great expanse of Alaska. The data will progressively illuminate increasingly poorly known structures of the lithosphere and asthenosphere. The continent's hidden past will come increasingly into focus. Data collected from the eastward migration of the Transportable Array—densely sampled receiver functions, shear-wave-splitting measurements, and body and surface wave tomographic images of the lithosphere—will provide a widening window into the deep-mantle location of the Farallon slab and the relic structures from the early opening of the Atlantic Ocean. The successful migration of the Transportable Array across the continent, which is contingent upon the funding requested in this proposal, will provide a dramatic new framework of North American continental structure upon which integrative modeling and geological reconstructions can be built for decades to come.

With startling new revelations anticipated with every new seismic station, clear contributions to major problems in earth science are assured as the rolling deployment of the Transportable Array progresses. The broad structural constraints provided by multiple analyses of Transportable Array data will provide framework and context for high-resolution deployments of Flexible Array stations in targeted studies of key problems, typically as part of multidisciplinary efforts to resolve geological processes (Figure 3.1). The Transportable Array data and accompanying Flexible Array deployments will address problems such as:

- **Fate of the Farallon slab and history of subduction under North America.** Seismic tomography, receiver function, and shear-wave-splitting methods will image the deep structure of the oceanic slab currently descending beneath Cascadia, and its relationship to the much older, overrun Farallon slab that descended below the western United States. Tomography, migration, and scattering analyses will address the mechanism of slab flattening and descent of the younger portions of the Farallon slab and its connection to deep transition zone and lower mantle relics of the older portions of the slab. Large- and small-scale imaging efforts will address the influence of this subduction history on the continental lithosphere, delamination, and regional volcanism and crustal extension (Figure 3.2).
- **Configuration of the North American lithosphere and nature of the lithosphere-athenosphere boundary under the continent.** The deep crust and uppermost mantle of the western United States have been profoundly affected by the history of subduction, but the entire continental lithosphere and asthenosphere have also been affected by motion of the North American plate. Deter-

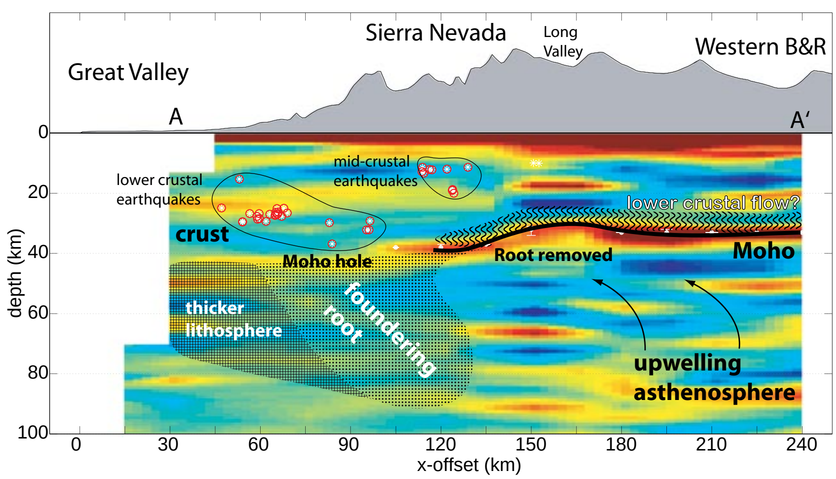


Figure 3.2. Example of deep crust and uppermost mantle imaging achieved by passive-source seismology using portable deployments of USArray Flexible Array instruments (SNEP project). This is a southwest-northeast oriented cross section across the Sierra Nevada with receiver functions and interpretations. Surface topography along this profile is plotted along the top of the cross section. Red colors correspond to positive polarity arrivals while blues mark negative polarities. Earthquakes located near this profile are plotted as white asterisks within red circles. An interpretation of flow within the lower crust is based on observations of anisotropy at the base ofthe crust towards the eastern part of the array (Frassetto et al., 2006). The lack of a Moho arrival along the southwestern portion of the cross section can be explained by a gradual increase in seismic velocities between the base of the crust and the still-intact portion of the batholithic root. The bright Moho present to the northeast marks the sharp contrast between the crust and inflowing asthenosphere that replaces the root following removal. Courtesy of H. Gilbert, C. Jones, and G. Zandt.

mining the broad-scale structure using tomography, receiver functions, shear wave splitting, surface wave polarization analyses, and scattering migrations will allow a comprehensive analysis of the process of continental and tectospheric drift—a key problem in plate tectonics. The interaction between ancient crustal provinces, rift zones, and the Atlantic margin with lithospheric and asthenospheric deformation will be ripe targets for exploration as the Transportable Array and Flexible Array deployments move eastward (Figure 3.3).

- **Continuity and undulations of upper mantle velocity contrasts and their relationship to melt, fluids, and dynamic shear flows.** The role of deformation, volatile enrichment and depletion, partial melting, and thermal history in the deep crust and upper mantle will be addressed using tomographic images of volumetric velocity heterogeneity, attenuation heterogeneity, and mapping of compositional and phase boundaries manifested as seismic discontinuities on the continental scale. The relationship of melting anomalies, volcanic lineaments, and tests of hotspot origins of Yellowstone, the Rio Grande Rift, and other regions will be explored using the Transportable Array and Flexible Array data deployments (Figure 3.4).
- **Detailed characteristics of transition-zone discontinuities near 410-km, 520-km, and 660-km depth and their relationship to sinking slabs, upwelling flows, and the continental keel.** Receiver functions, stacks of converted phases, surface-wave overtones, and triplication profiles will be provided by the Transportable Array and Flexible Array data, enabling comprehensive mapping of transition zone discontinuities beneath the North American continent. In combination with the history of subduction, the influence of sinking and rising mantle flows on the transition zone will be examined, and an understanding of the impact of cumulative subduction on the development of the Wilson cycle will be explored.
- **Deep structure of Proterozoic crust and upper mantle, and deep characteristics of ancient rift and mountain belts.** The lateral extent and configuration of the deep crustal and uppermost mantle structures under the stable portion of the North American continent will be revealed to an unprecedented level with Transportable Array and Flexible Array deployments, providing first-order discoveries about the historical assembling of

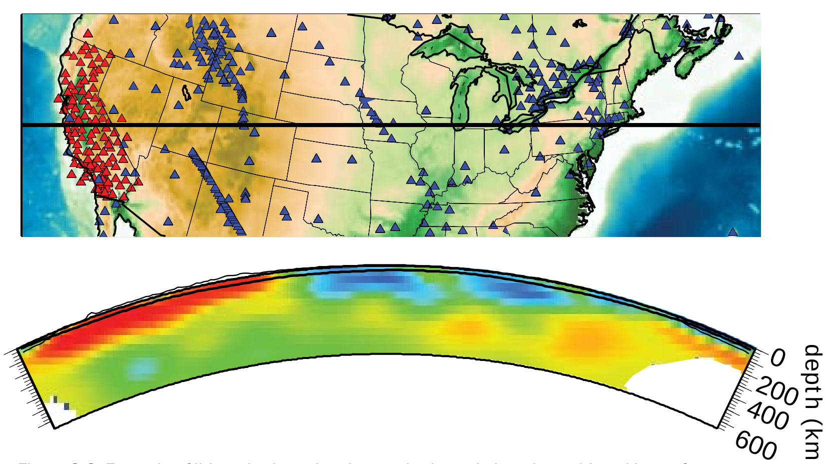


Figure 3.3. Example of lithospheric and asthenospheric scale imaging achieved by surface wave analysis using ANSS Backbone and USArray Transportable Array recordings. This is a cross section through a tomographic model for the North American upper mantle. The western United States is much better illuminated than the central and eastern United States because of data provided by USArray Transportable Array stations (red triangles). As the Transportable Array is fully deployed and migrates eastward, the entire lithosphere and asthenosphere under the contiguous United States will be imaged at high resolution. Courtesy of S. van der Lee.

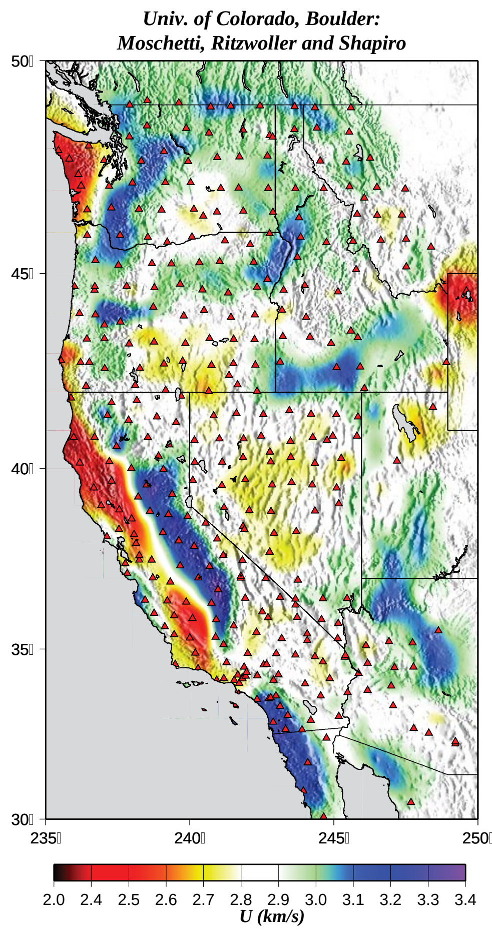


Figure 3.4. Example of crustal- and lithospheric-scale structure imaged by ambient noise tomography using USArray Transportable Array and ANSS Backbone recordings. This is a surface wave tomography map for 16-second-period Rayleigh wave group velocity, where warm shades are slow and cool shades are fast. More than two years of Transportable Array data (stations shown as red triangles) were used to construct this image. Courtesy of M.P. Moschetti, M.H. Ritzwoller, and N.M. Shapiro.

the continent and the overprinting effects of past collisions and mountain-building events.

- **Characteristics of earthquake ruptures in the crust and lithosphere across North America.** Transportable Array and Flexible Array data will enable research on earthquake-rupture processes and the earthquake cycle on faults distributed throughout the continent. Broadband recordings will reveal details of the ruptures, with deployments of Flexible Array instruments, analyzing structural and temporal variations of fault zones before and after earthquakes. Active and passive seismic imaging will reveal connectivity and geometric interactions between faults, allowing assessments of large rupture and future earthquake potential.

Detailed examples of these and many other research topics to which USArray data will contribute are described in the research overviews and community contributions assembled in Volume III of this proposal.

USArray data also may be applied to studies of earthquake-rupture processes and remote structures in the lower mantle and core (Figures 3.5 and 3.6). While these investigations may not directly impact understanding of North America, they will contribute to related issues, such as the ultimate fate of subducted lithosphere, the overall configuration of mantle convection, the thermal history of the mantle and how it influences the growth of the inner core, and generation of the dynamo. USArray data are already being incorporated into studies of large and small seismic events around the globe, exploiting the dense wavefield sampling in rupture-migration studies, or for detection of small events and triggered aftershocks. Sustaining real-time open access to the USArray data is imperative for maintaining these important dual-use applications of the USArray data and expanding the impact of EarthScope to a truly global context.

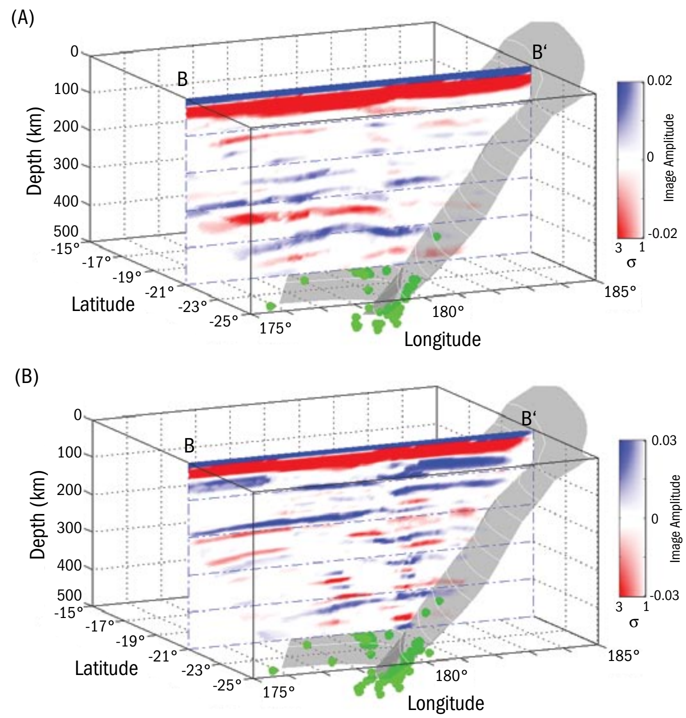


Figure 3.5. An example of use of USArray Transportable Array, ANSS Backbone, and broadband regional network data to study upper mantle structure far from North America. These are east-west vertical cross sections showing reflections in the upper mantle wedge above the Tonga Slab (gray facade). P wave reflectivity is shown in the upper panel, and SH reflectivity is shown in the lower panel. Deep focus events used as sources are shown as green dots. The arrivals are underside reflections observed at teleseismic distances as precursors to surface reflections pP and sS. These are imaged by migrating signals from North America and other global broadband stations. The blue stripes indicate reflections from impedance increases with depth, while red stripes are from impedance decreases with depth. The blue stripes at the surface are from the pP and sS reflections, which have a side-lobe giving the underlying red bands. Remarkable, unexpected reflectivity is observed in the mantle wedge. Courtesy of Y. Zheng, Y., T. Lay, M. P. Flanagan, and Q. Williams.

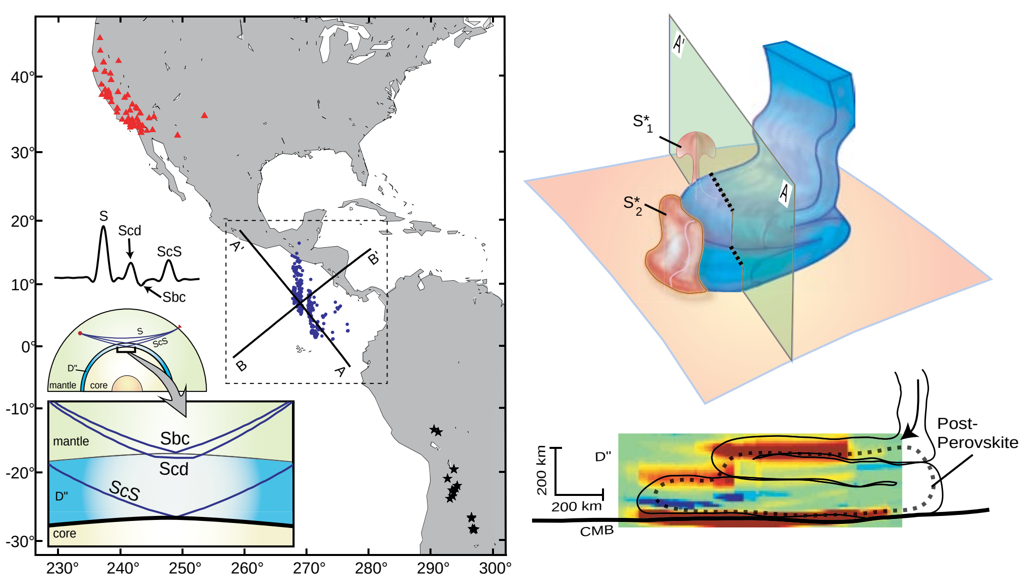


Figure 3.6. An example of use of USArray Transportable Array and broadband regional network data to study lowermost mantle structure below North America. The deep mantle corridor sampled by paths from deep South American events to the initial Transportable Array deployment in the western United States is shown on the left. S and ScS observations were migrated to form the image on the right along profile A'-A, which is interpreted as having a reflector above the core-mantle boundary caused by post-perovskite phase transition in a cold, folded and piled relic Farallon slab. From: Hutko, A. R., T. Lay, E. J. Garnero, and J. Revenaugh. 2006. Seismic detection of folded, subducted lithosphere at the core-mantle boundary. Nature 441:333–336.

Plate Boundary Observatory

Quantifying three-dimensional deformation and its temporal variability across the active boundary zone between the Pacific and North American plates is one of the core scientific objectives of EarthScope, with far-reaching implications to the dynamics of plate-boundary-zone deformation, earthquakes, and volcanic processes. In the last decade, declining cost of instrumentation and data communications, improved accuracy of instrumentation and data processing, increased data availability, enhanced computing power, and corresponding advances in model sophistication have allowed the scientific community to better address an array of critical scientific and societal problems thanks to geodetic data—in particular space geodesy.

The integrated Plate Boundary Observatory (PBO) builds on these advances by implementing the infrastructure necessary to provide high-accuracy and high-resolution data from a network of continuous Global Positioning System (CGPS) stations, borehole tensor strainmeters, borehole seismometers, long baseline laser strainmeters, and a pool of campaign GPS units. In addition, the GeoEarthScope component of EarthScope, managed under PBO, includes the acquisition of aerial and satellite imagery and geochronology to examine the strain field beyond the decadal time scale. This combination of instruments and techniques allows scientists to investigate the entire temporal spectrum of deformation processes, from seconds (borehole strainmeters and seismometers) to decades (GPS, Interferometric Synthetic Aperture RADAR [InSAR]), to a few million years (Light Detection and Ranging [LiDAR]-derived high-resolution topography, geochronology). Thanks to a footprint that encompasses the entire plate boundary zone and to continuous data collection, PBO is providing an unprecedented data set to address key questions on tectonic, seismogenic, and magmatic processes. Sustaining continuous operation of PBO and the delivery of data products to the scientific community is critical for achieving EarthScope scientific goals.

PBO provides raw and processed data products to users in the form of GPS velocities and time series of GPS positions and strain measurements (Figure 3.7). GPS results to date show a precision of 1.2 mm (horizontal) and 3.9 mm (vertical) similar to, or better than, other CGPS networks such as the Southern California Integrated GPS Network (SCIGN) or the Japanese GeoNet project. GPS velocities are expressed in the Stable North American Frame (SNARF), developed by a UNAVCO working group of community geodesists that relies on GPS stations in the central and eastern United States

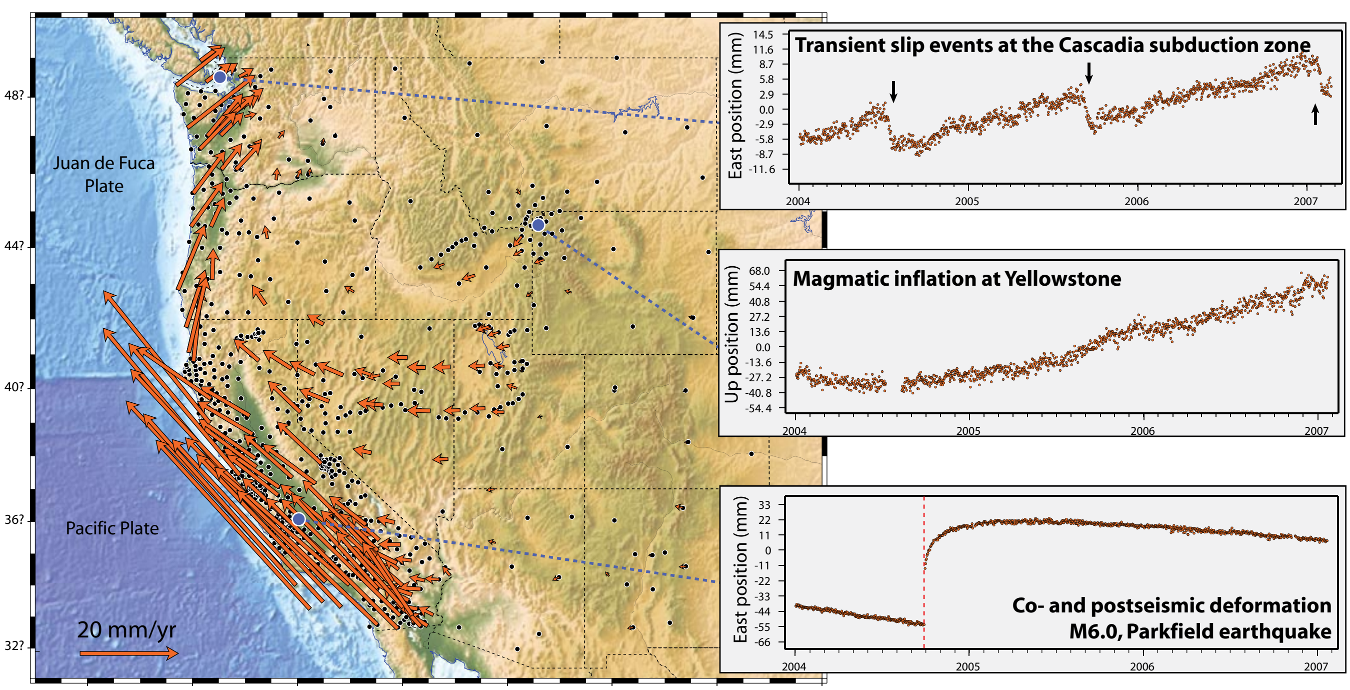


Figure 3.7: The PBO GPS network is already providing outstanding data to elucidate the dynamics of plate boundary zone, subduction, and earthquake and magmatic processes in the western United States and Alaska. Red arrows on the left panel show PBO site velocities with respect to stable North America (for a sake of readability, only a subset of the 708 sites currently processed by the analysis centers are shown). Block dots show the location of all PBO sites. Right panels are time series of daily position at three sites, illustrating transient signals. Top panel shows slow slip events on the Juan de Fuca/North America subduction in the Pacific Northwest ("ETS events"). Center panel shows recent uplift in the Yellowstone area due to magmatic activity. Bottom panel shows co- and postseismic deformation associated with the 2004, M6.0, Parkfield earthquake. Courtesy of Eric Calais.

(including 16 PBO stations) and Canada. The reference frame is obtained through a rigorous combination of independent solutions and accounts for glacial isostatic adjustments. The ability of PBO to address its scientific goals relies heavily on continuous instrument operation to obtain uninterrupted time series of positions and strain, which is critical for rigorously quantifying measurement errors and detecting transient deformation. When the construction phase—currently on schedule and on budget—is completed in October 2008, PBO will span the North American continent with instrumentation providing the detailed deformation data necessary to address a wide range of scientific goals at the forefront of tectonics and earthquake science, including:

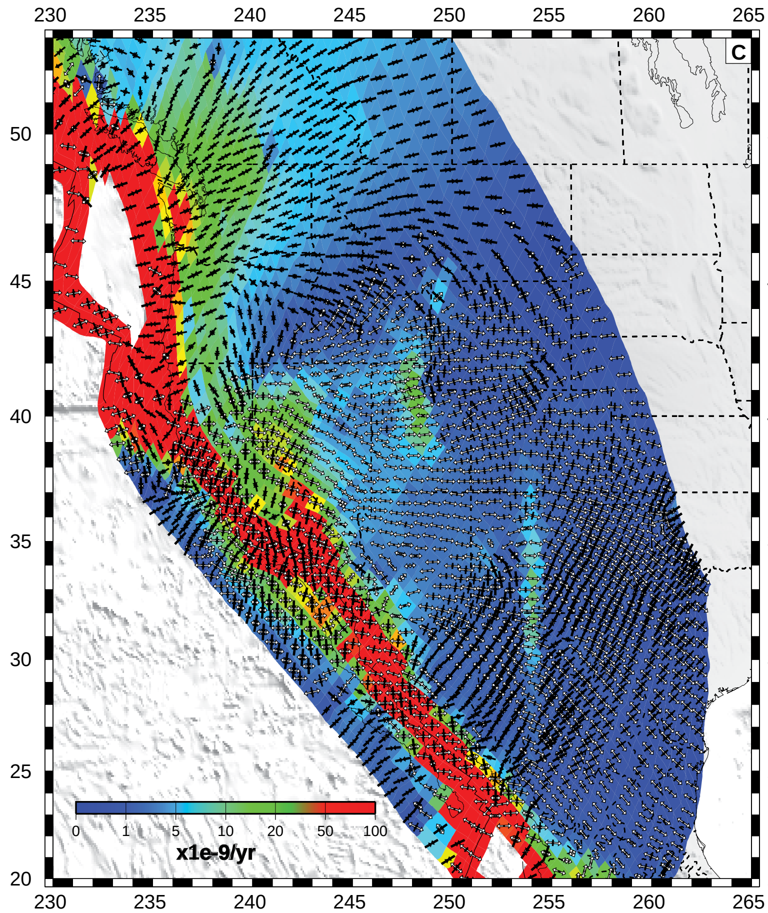


Figure 3.8: Strain rate field in the western United States derived from existing GPS velocities. Background color shows strain rate magnitude, solid and white bars show extensional and compressional principal axis, respectively. This preliminary description of the strain rate field across the western United States will be greatly improved as PBO delivers reliable GPS velocities at more sites, allowing researchers to investigate the mode of deformation of continents and the forces driving plate-boundary-zone deformation. Courtesy of Lucy Flesch.

- **Mode and driving forces of distributed plate boundary deformation.** The wide aperture, high-density, and high-precision velocity field provided by PBO will help solve one of the outstanding problems in tectonics—the mode of deformation of broad plate boundary zones, and the relative importance of various driving forces. Is deformation in such a context localized on a limited number of major faults bounding non-deforming lithospheric blocks and driven solely by boundary stresses due to the motion of neighboring plates? Or, is deformation quasi-continuous and better described by viscous flow of a continuously deforming solid in which faults play a secondary role? Do buoyancy forces resulting from gravitational potential energy gradients play a significant role in the force balance driving deformation? Is plate-boundary-zone deformation essentially "self-driving," with a lithosphere decoupled from the mantle through a mechanically weak asthenosphere? Or, are plates strongly coupled to a mantle flow field driven by sources of buoyancy in the mantle? Discriminating between competing models to solve the long-standing issue of the dynamics of plate-boundary-zone deformation requires highly accurate and spatially dense measurements of lithospheric strain rates covering the whole deforming area. Thanks to a footprint encompassing the entire Pacific-North America plate boundary zone, to continuous measurements ensuring optimal precision, and to a rigorous reference frame, PBO data will bring our understanding of plate-boundary-zone deformation to a new level (Figure 3.8).
- **Time-dependent deformation and rheology of the lithosphere.** Since the investigation of postseismic deformation following the 1906 San Francisco earthquake, we have known that moderate to large earthquakes are followed by years to decades of accelerated strain detectable using surface measurements. We now understand that earthquakes signal the beginning of lithosphere-scale rock mechanics experiments, where geodetic data can be used to infer the mechanical properties of faults and the rheology of the lower crust and upper mantle. Assessing these properties and the role they play in controlling the temporal and spatial distribution of surface strain at all scales is one of the current challenges in continental dynamics. Continuous measurements of surface strain of the kind provided by PBO are ideally suited to identify and quantify transient deformation and, in turn, address the rheology of major strike-slip faults and of the lithosphere. Do the aseismic roots of brittle strike-

slip faults represent a zone of broadly distributed ductile flow? Alternatively, do they extend through much of the crust and possibly the upper mantle as narrow shear zones? Or, do they experience both localized faulting well below the seismogenic zone along with distributed ductile shear in the surrounding host rock at different times during the earthquake cycle? Is the traditional "jelly sandwich" model, where a weak lower crust overlies a strong upper mantle, an accurate description of lithospheric rheology? Or, is the upper mantle—at least in some regions—more ductile than the lower crust, as suggested by several studies constrained in particular by geodetic measurements of postseismic transients? Is the viscosity of the upper mantle (and possibly lower crust) stress-dependent (power law), as suggested by laboratory experiments and recent postseismic studies in the western United States and Alaska? Power-law rheology serves to focus high strain rates under faults early on, a characteristic that may play an important role in the perseverance of major faults. Most recent major earthquakes have been the targets of intensified postseismic

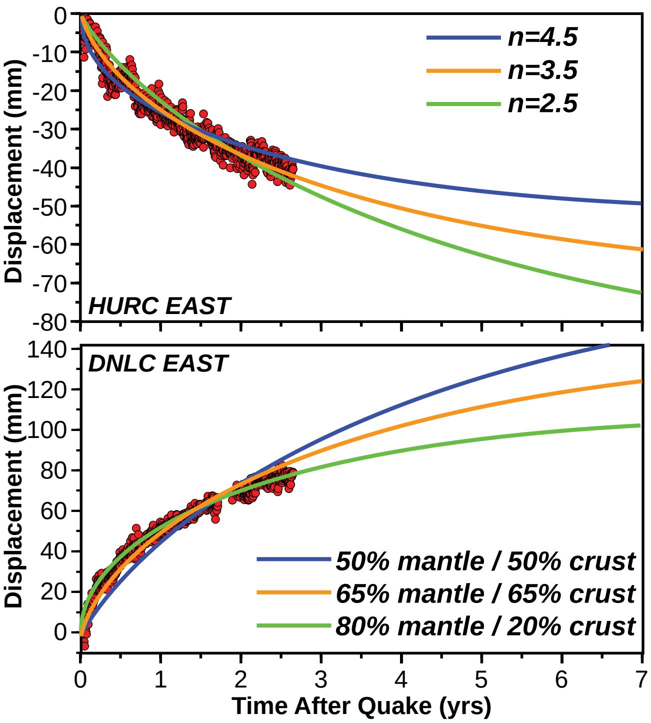


Figure 3.9. Red dots show position time series (east component) for two continuous GPS stations installed in Alaska after the Mw7.9, 2002, Denali earthquake, now part of PBO. Solid lines show fit and predicted continuation of a postseismic relaxation signal for ranges of models that acceptably fit the existing data. Upper panel illustrates the role of power-law parameter n, which controls the time dependence of viscoelastic relaxation assuming a stress-dependent rheology. Lower panel shows the contribution of upper mantle vs. lower crust to the relaxation signal. All models show that the Denali postseismic signal is likely to last for years into the Earthscope O&M phase. The next few years of data at PBO sites in Alaska will greatly constrain the range of possible models.

geodetic monitoring, revealing aseismic fault slip, fluid redistribution in the crust, and viscous crustal and mantle flow. Until recently, geodetic data in the western United States had insufficient spatial resolution and duration to differentiate between competing hypotheses. Through CGPS stations and targeted campaign GPS deployments, PBO is poised to provide the strain history necessary to resolve these issues (Figure 3.9).

- **Episodic tremor and slip.** One of the most exciting recent scientific developments from CGPS measurements has been the discovery of episodic tremor and slip (ETS) at subduction plate boundaries. In the Pacific Northwest, these events are characterized by a reversal of the strain accumulation signal, with up to 5 mm of seaward displacement. In Cascadia, ETS transients typically last for about two weeks, repeat every 10 to 18 months, and are always accompanied by seismic tremors. Although the source mechanism of ETS events is not yet fully understood, they likely indicate transient creep below the locked portion of the subduction interface. ETS, therefore, appears to be a fundamental stress-release process, with key implications on the dynamics and earthquake potential of subduction zones, the processes of stress transfer, and possible earthquake triggering. It is of critical importance to understand how ETS events affect the strain and stress budgets at subduction zones. These phenomena would have gone unnoticed for much longer without precise and continuous GPS observations. Because of the implications of ETS events on stress transfer and possible earthquake triggering, it is of critical importance to understand how they affect the strain and stress budget at subduction zones. The last three ETS events have now been captured by PBO CGPS instruments (Figure 3.10), USArray seismometers, and by newly installed borehole strainmeters. In addition, deployment of the PBO campaign GPS pool and USArray Flexible Array seismometers is increasing the spatial density of measurements in key areas, such as the Olympic Peninsula. In the long run, the density of PBO GPS and strainmeter instruments in the Pacific Northwest, together with the long-term commitment of operating these stations, will provide critical data for the scientific community to address a number of key questions: Does ETS occur along the entire length of the Cascadia Margin? What controls the migration pattern and recurrence intervals of ETS? Can surface ETS displacements be attributed to either distributed shear or planar slip? Does the spatial and temporal distribution of ETS imply structural and stress variation controls? What are the necessary and sufficient conditions for ETS? Does ETS influence the location and timing of earthquakes? Data provided by PBO will be critical for answering these questions about this new and poorly understood phenomena of plate boundary dynamics.

Other types of slow deformation events are starting to be identified in the western United States. For instance, a large-scale slow transient was recently identified in the Basin and Range Province, possibly caused by creep on a ~ 500-km-wide detachment horizon at or near the base of the crust. At the other end of the spectrum, PBO GPS and strainmeter data are now being used to investigate the dynamics of coseismic rupture and postseismic afterslip, for example, associated with the 2004 Parkfield earthquake (Figure 3.7), thanks in particular to high-rate data and data processing. Continued operation of PBO instrumentation will provide the crucial data sets to quantify transient deformation at a wide range of spatial and temporal scales, eventually leading to the seamless integration of coseismic, postseismic, and interseismic deformation with longer-term tectonic processes (Figure 3.10).

PBO is also improving our understanding of magmatic systems. By their very nature, the magmatic reservoirs and conduits that underlie active volcanic systems are elusive. How can we detect the magmatic processes that occur beneath active volcanoes? What are the physical characteristics of this “plumbing system”? What are the dynamics of magma transport? What controls when a volcano erupts? These questions comprise some of the most fundamental, recurring themes of modern volcanology. PBO is playing a critical role by providing surface strain and displacement measurements on and around some of the most spectacular volcanic provinces in the United States, such as the Aleutian, Cascadia, Long Valley, and Yellowstone areas. PBO instruments have already captured the details of deformation associated with major eruptions at Mount St. Helens, WA (2004–2007), Augustine, AK (2005–2006), and the recent revival of activity at Yellowstone (Figure 3.7). The long-term maintenance of PBO instrumentation will allow scientists to benefit from a wealth of surface deformation data associated with magmatic processes at active volcanic provinces of the western United States and contribute to a better understanding of the associated hazard.

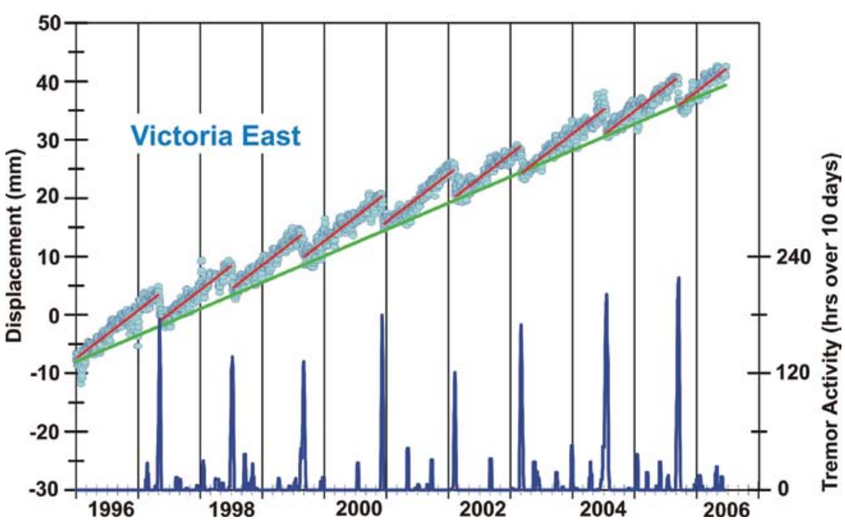


Figure 3.10. Summary of geodetic and seismic observations that characterize episodic tremor and slip in the Pacific Northwest. Blue circles show daily changes in the east component of the position of the CGPS station ALBH (Victoria, B.C.) The green line indicates the long-term eastward linear trend of motion (~ 4 mm/yr) due to margin deformation caused by the locked portion of the subduction interface. The red line segments show the average linear motion (~ 8 mm/yr) over ~ 15-month segments due to temporary additional plate coupling on a deeper portion of the plate interface. This deeper coupling is released over periods of weeks every 15 months, resulting in repeated temporary westward motion and the characteristic sloped sawtooth time series. The bottom graph shows the total number of hours of tremor activity in a sliding 10-day period. With a high density of CGPS stations and strainmeters in the Pacific Northwest, PBO will provide critical data to elucidate the mechanism of ETS and understand its implications on seismic potential at subduction zones. Courtesy of Herb Dragert.

San Andreas Fault Observatory at Depth

By making direct measurements of the physical conditions under which earthquakes occur, by studying core and fluid samples from the San Andreas Fault Zone, and by directly monitoring earthquake nucleation, propagation, and arrest with near-field instruments, SAFOD will address myriad untested and unconstrained hypotheses that fill the geophysical literature based on inferences from laboratory and theoretical studies. Indeed, despite decades of progress in earthquake science, we still know virtually nothing about the composition of the San Andreas Fault at seismogenic depth, its constitutive properties, the origin of fault-zone pore fluids (and their role in faulting and earthquake generation), or the nature and significance of time-dependent fault-zone processes.

The central scientific objective of SAFOD is to study the physical and chemical processes that control deformation and earthquake generation within an active plate-bounding fault zone. Hence, the principal reasons for drilling into the San Andreas Fault have been to conduct extensive investigations in situ and on exhumed materials that are representative of the fault at the pressures, temperatures, and conditions at which earthquakes nucleate. In particular, through an integrated program of downhole sampling, measurements, and long-term monitoring, SAFOD was designed to (1) measure stress, permeability, and pore pressure conditions in situ, (2) determine frictional behavior, physical properties, and chemical processes controlling faulting through laboratory analyses of fault rocks and fluids, (3) characterize the three-dimensional volume of crust containing the fault, (4) directly monitor strain, pore pressure, and near-field seismic radiation during the cycle of repeating microearthquakes, and (5) observe

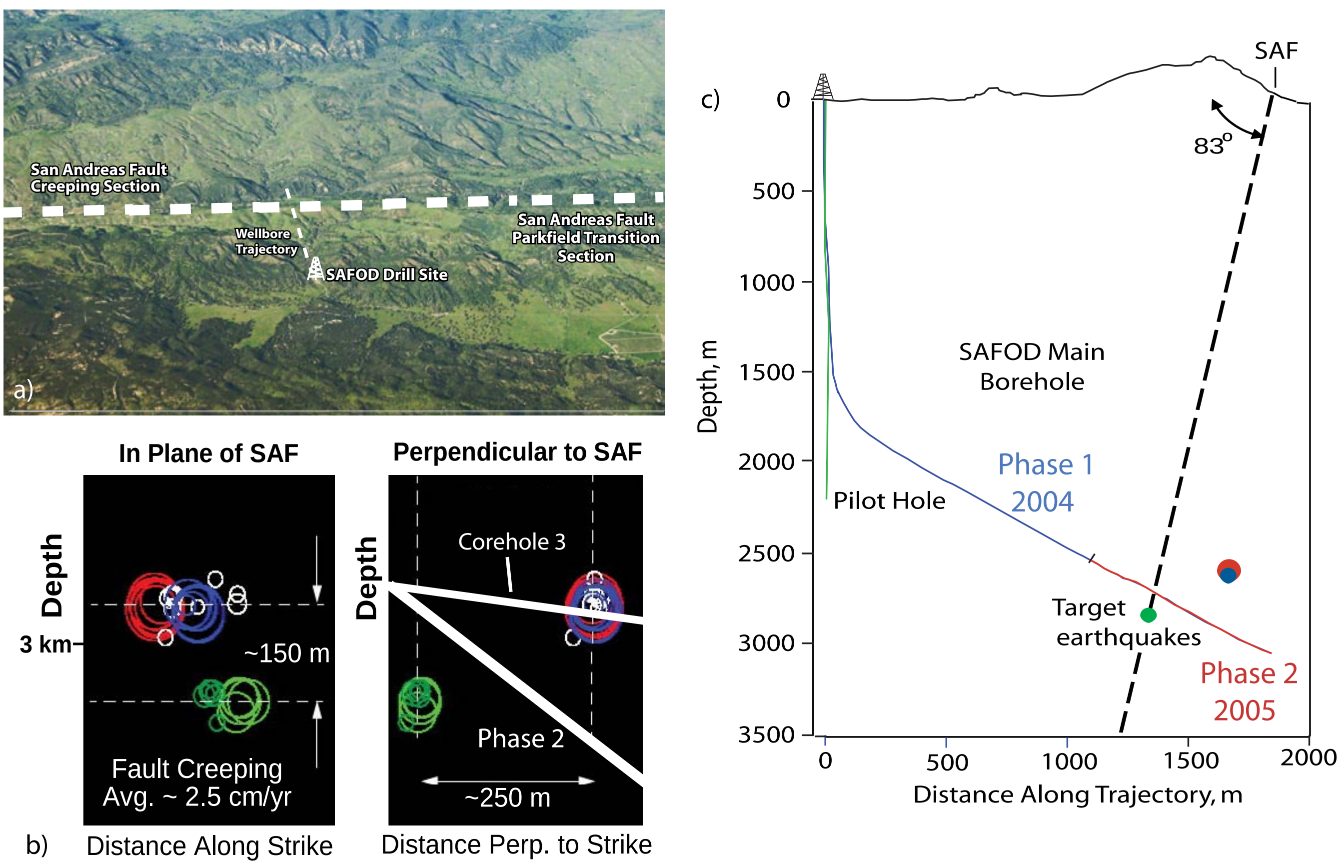


Figure 3.11. (a) SAFOD is located in central California where slip on the San Andreas Fault occurs mostly by fault creep with isolated, small "fault patches" produce repeating microearthquakes. The drill site is located at the southeastern end of the creeping section of the San Andreas, where the surface creep rate begins to gradually decrease in the Parkfield section of the fault. (b) The targets for SAFOD drilling are repeating microearthquakes at ~ 3 km depth. As can be seen in the figure, there are three groups of repeaters in the target area. As shown in the cross section in a plane parallel to the San Andreas, the groups of repeaters shown in red, blue, and green correspond to M~2 earthquakes that recur every ~ 2.5 years. As shown in the cross section perpendicular to the fault, the red and blue repeaters occur on a different strand of the fault than the green repeaters. Hence, there are multiple active fault traces at depth. The white lines schematically illustrate the location of the SAFOD main borehole—drilled in the summers of 2004 and 2005—and a corehole targeting the microearthquakes to be drilled in 2007. (c) Trajectories of the SAFOD pilot hole, drilled in 2002, and the SAFOD main hole. The microearthquake locations are to the southwest of the surface trace of the San Andreas Fault.

earthquake nucleation and rupture processes in the near field. A detailed discussion of the key scientific issues that can be addressed by SAFOD data and samples (including some early results from the SAFOD science team) can be found in Volume III of this proposal.

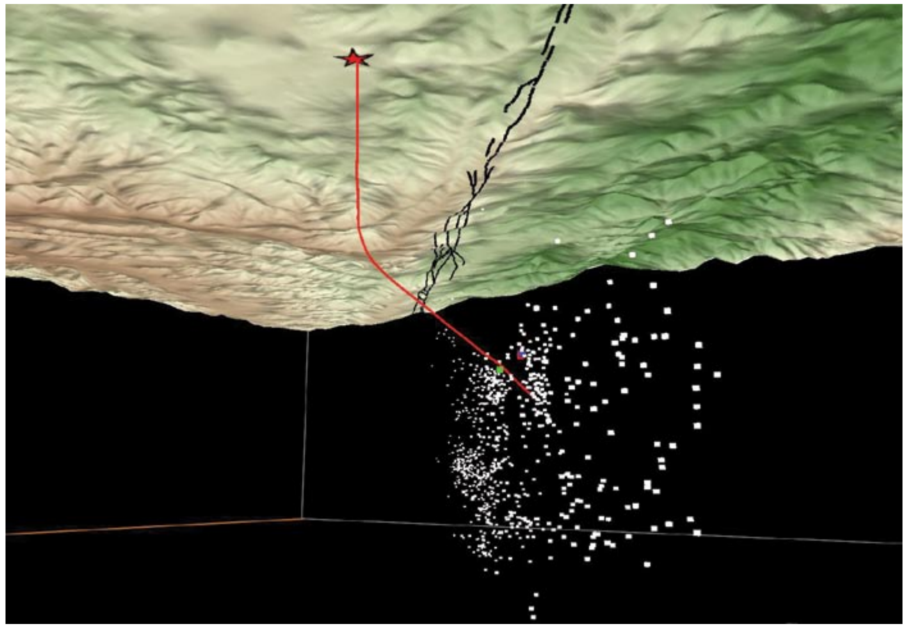


Figure 3.12. Seismicity of the San Andreas Fault as seen from a vantage point in the earth looking to the northwest. Hypocenters were determined by the Parkfield Area Seismic Observatory (PASO) UNO, PASO DOS, and EarthScope Flexible Array (PASO TRES) experiments, courtesy of Steve Roecker (RPI) and Cliff Thurber (University of Wisconsin). The San Andreas Fault is made visible by more than 1000 microearthquakes observed by the PASO networks. The SAFOD main hole is shown in red, extending downward from the surface facility (star). The surface trace of the fault is shown in black draped over the topography. The absolute locations of the SAFOD target earthquakes (red, blue and green symbols) were determined using travel time observations from instruments in the SAFOD main hole; PASO TRES, U.C. Berkeley HRSN and USGS NCSN network data; and active-source seismic experiments (recorded downhole and on the surface networks) conducted in 2004, 2005, and 2006.

SAFOD is located in central California, just north of the rupture zone of the 1966 and 2004 magnitude 6 Parkfield earthquakes, where the San Andreas Fault is moving through a combination of aseismic creep and repeating microearthquakes (Figure 3.11). SAFOD is designed to intersect the rupture patches of magnitude 2 earthquakes that have been observed to recur approximately every 2.5 years on the San Andreas Fault at a depth of about 3 km.

The San Andreas Fault displays a range of behaviors at the SAFOD site. At the surface, the fault is creeping at a rate of 1.8 cm/yr, with most of the fault displacement localized to a zone no more than 10-m wide. Numerous earthquakes occur directly on the San Andreas Fault in the depth interval from about 3–12 km. The seismicity at Parkfield occurs in tight clusters that have remained spatially stationary for at least the past 20 years. As illustrated in Figure 3.11, a 2-km-deep pilot hole was drilled at the SAFOD site in 2002 (funded by the International Continental Scientific Drilling Program), 1.8 km to the southwest of the surface trace of the San Andreas Fault. During Phases 1 and 2 in summers of 2004 and 2005, the SAFOD main hole was rotary drilled across the entire San Andreas Fault Zone through the zone of the repeating microearthquakes. Note that in the subsurface, the position of the fault is to the southwest of the surface trace.

A high-resolution image of the seismicity beneath SAFOD has been obtained from data collected by the Parkfield Area Seismic Observatory (PASO) network over the past five years (Figure 3.12). The PASO data reveal the seismically active San Andreas Fault to be a narrow, near-vertical zone of earthquakes with its top at about 3-km depth. An important feature of the microearthquakes beneath SAFOD is that they occur in families of repeating events. Individual earthquakes have been observed to recur numerous times at precisely the same location and with the same magnitude. Repeating sources of up to magnitude 2 are located at drillable depths beneath the SAFOD drill site. These events play a critical role in guiding core drilling through the active fault segments during Phase 3. From its inception, a major goal of this experiment has been to drill as close as possible to one or more of these sources (green, red, and blue earthquakes in Figure 3.12) and to follow the buildup of strain and its release through multiple earthquake cycles during the monitoring phase of the experiment.

Four major geologic units were encountered along the trajectory of the SAFOD main hole. In the vertical section of the wellbore, the near-surface Quaternary and Tertiary sediments were found to be underlain by Salinian granite at a depth of ~ 700 m. After deviating the borehole toward the fault, arkosic sediments (most likely locally derived from Salinian granite) were encountered about 300 m northeast of the drill site, perhaps after crossing the Buzzard Canyon Fault, a northwest-trending fault exposed at the surface that trends sub-parallel to the San Andreas. Approximately 1200 m northeast of the drill site, a possibly ancestral trace of the San Andreas was crossed as the lithology changed abruptly to claystones and siltstones of the Great Valley Formation, found throughout central California on the east side of the San Andreas.

Geophysical well logs and cuttings analyses indicate that the San Andreas Fault is a zone of anomalously low P- and

S-wave velocity and resistivity that define a relatively broad damage zone (Figure 3.13). Casing deformation (indicated by the red line in Figure 3.13) and the projection of the target earthquakes onto the borehole at 3300 m and ~ 3650 m reveal the locations of active fault traces. Note that the casing deformation is associated with a narrower, more highly localized zone of low P- and S-wave velocity and resistivity embedded within the broader damage zone. During Phase 3 of SAFOD in the summer of 2007, continuous coring will be conducted in multi-lateral holes branching off of the main SAFOD borehole to directly sample the damage zone and both creeping and seismically active fault traces at depth. Preliminary results from Phases 1 and 2 of SAFOD were presented in two special sessions of the December 2005 American Geophysical Union meeting and numerous publications are in print or under review detailing early results from SAFOD.

During the O&M phase of SAFOD, the scientific problems to be addressed by studying exhumed core and fluids in the laboratory are far-reaching and include determination of (1) the frictional strength and deformational behavior of fault zone materials, (2) how strain is localized within the fault zone and what factors control the temporal migration of fault slip, (3) how physical properties relate to fault-zone fabric, (4) the origin of low-velocity/low-resistivity zones associated with the fault, and (5) the composition, mineralogy, and deformation mechanisms of fault-zone materials at multiple scales (e.g., active slip surfaces, adjacent damage zones, relatively undeformed country rock). In addition, a number of studies to be carried out on physical samples obtained from SAFOD are specifically related to the role of fluids in faulting, including determining: (1) the extent of vertical and lateral fluid migration within the fault zone, (2) the permeabilities of fault-zone materials and country rock, (3) fluid transport mechanisms in and adjacent to fault zones, and (4) the interplay between water-rock interaction and rheology.

During the O&M phase, SAFOD downhole monitoring instrumentation will offer the unique opportunity to observe variations in deformation, fluid pressure, microseismicity and radiated seismic energy within and adjacent to recurring earthquake rupture patches over multiple earthquake cycles. Acting in concert with studies on recovered samples, SAFOD monitoring will thus make it possible to observe directly a number of time-dependant processes related to earthquake nucleation, propagation, and arrest, including: (1) the possible role of temporal variations in fluid pressure within the fault zone in controlling earthquake periodicity and rupture propagation and arrest, (2) the interplay between aseismic and seismic fault slip in the nucleation process for repeating microearthquakes, (3) the time scales and physical processes through which stress and strain interactions occur between nearby earthquakes, and (4) the manner in which earthquake energy is partitioned among seismic radiation, frictional dissipation, grain-size reduction, and chemical reactions.

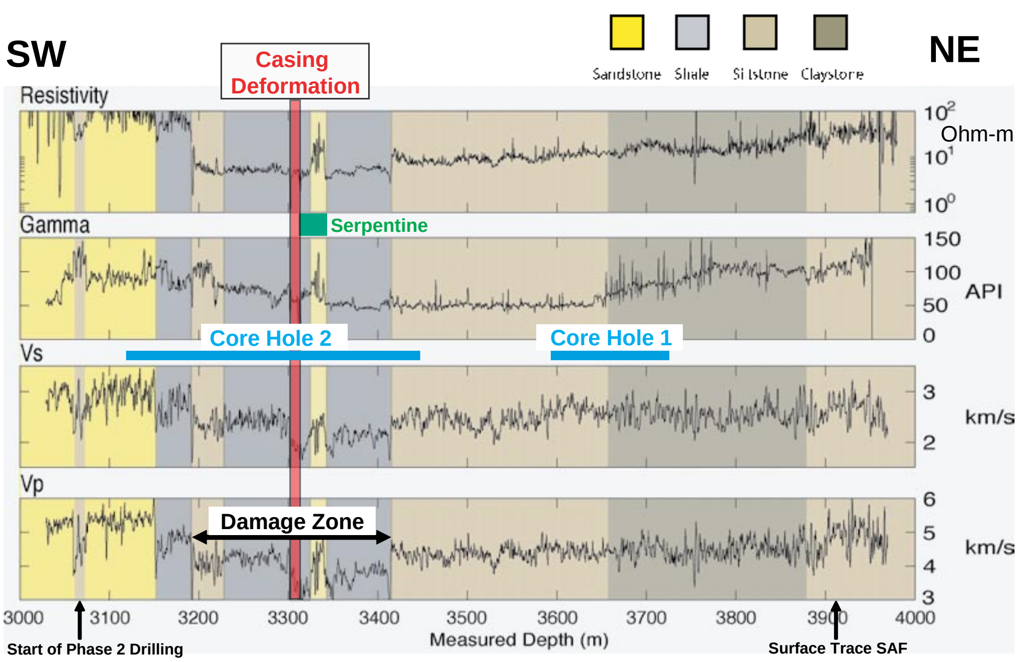


Figure 3.13. Geophysical well logs acquired across the San Andreas Fault Zone during SAFOD Phase 2, superimposed on major lithologies derived from cuttings analysis. Depths are as measured along the borehole, which is inclined at an angle of 54-60° from the vertical (see Figure 3.11c for reference). Also shown are zones of casing deformation revealed by repeat multi-finger caliper logging (corresponding to an active trace of the San Andreas Fault at a measured depth of ~3300 m) and an ~200-m-wide damage zone defined by anomalously low P- and S-wave velocities and resistivity. X-ray diffraction analyses on cuttings reveal the occurrence of serpentine (shown in green) and talc just to the northeast of the casing deformation zone, which is perhaps responsible for the low strength and predominately creeping behavior of the fault at this location. The approximate locations of two out of the three multilateral core holes planned for SAFOD Phase 3 are shown in blue. These core holes will be placed as close as possible to the trajectory of the Phase 2 borehole to sample two major faults identified from well logs, casing deformation, cuttings analysis, fault-zone guided waves and microearthquake relocations. A third core hole (not shown) will be steered away from the main SAFOD borehole to obtain core samples from directly within one of the rupture zones of the M~2 earthquakes shown in Figure 3.11.

EarthScope-Wide Integrative Research

The research topics described above are at the frontiers of disciplinary-based efforts. Addressing many of these and other research themes, from earthquake processes, to the nature of faulting, to continental deformation, require data captured by the panoply of EarthScope facilities. Indeed, a primary strength of EarthScope resides in the complementary nature of the instrumentation deployed to tackle some of the fundamental issues in solid earth geophysics.

All EarthScope components address earthquake processes. Progress in understanding the physics of earthquakes will require integrative research efforts. Seismic data provided by SAFOD, PBO, and USArray provide complementary spatial sampling, bandwidth, and array configurations essential for probing earthquakes at many scales. High-frequency seismic measurements provided by downhole PBO and SAFOD sensors allow ultra-precise locations of tiny events and determination of radiated-wave spectra free of contamination from strong, near-surface effects. This will enable more complete characterization of small earthquake recurrence intervals, the nature of seismicity streaks and repeating earthquakes, and examination of differences in the nature of rupture between large and small earthquakes. Distributed deployments of broadband sensors of USArray's Transportable Array and Flexible Array, and GPS observations from PBO, will provide improved focal-mechanism determinations and finite-rupture models for intermediate and large events in the North American lithosphere. Analysis of strainmeter recordings from PBO sites and SAFOD will provide a hitherto neglected characterization of crustal strains associated with pre-, co-, and post-seismic phenomena. GPS observations will reveal the spatial distribution of crustal strain accumulation and its relationship to earthquakes. Geodetic and seismic observations from PBO and USArray will be combined to examine ETS events, the relationship between slow earthquakes and strain accumulation, and the complexity of earthquakes in volcanic environments. Collectively, EarthScope facilities provide a broad observational basis for addressing fundamental issues in earthquake science.

Earthquakes are an important process in fault zones, but it is now recognized that investigations of fault zones should extend well beyond characterization of their seismic failures. Deformation in the fault zone for both locked and creeping fault segments can be observed from the surface by PBO CGPS and strainmeter facilities and within the fault zone at depth with SAFOD. PBO borehole seismometers, USArray Transportable Array and Flexible Array stations, and SAFOD seismometers can record spatiotemporal distributions of harmonic tremor and slow slip events on faults, fault-zone guided waves that can characterize the in situ low-seismic-velocity channels that develop along faults, and temporal fluctuations in these channels before and after large earthquake ruptures. SAFOD downhole measurements and portable MT deployments can address the fluid conditions in faults and surrounding environments. Core samples recovered from SAFOD will provide in situ fault-zone properties of creeping and seismogenic regions of faults for comparison and provide crucial calibrations of inferences on fault-zone properties derived from surface geophysical observations. Again, the collective EarthScope facilities will provide the suite of observations that will underlie major advances in understanding of fault-zone environments and their overall deformation processes.

At a broader scale, the integration of EarthScope geodetic and seismic data will be essential to understand the nature and driving forces of continental deformation across a broad and complex plate boundary zone. The joint interpretation of GPS and seismic observations will help quantify the state of stress in the western American lithosphere. New generations of deformation models will be served by EarthScope data; seismic observations will provide improved images of lithospheric and upper mantle structures, while GPS velocities and strain-rate fields will provide boundary conditions and constraints on internal deformation. Thanks to a higher resolution and spatial density of observations of structures and surface kinematics, researchers will be able to incorporate stresses and rheology into models addressing the dynamics of plate-boundary-zone processes. The integrated use of seismic and geodetic observations will help researchers better understand the Yellowstone mantle anomaly, its impact on lithospheric deformation, and its connection with shallow, intracrustal, magmatic processes. Geodetic data associated with seismic tomography, anisotropy, and receiver-function analyses will be crucial to understand the delamination of mantle lithosphere (e.g., Sierra Nevada) and its impact on extensional processes in the Basin and Range Province. It is now recognized that seismic anisotropy data can be an indicator of the upper mantle flow field. Comparisons between seismic anisotropy data derived from USArray and surface strain rates from PBO will help us quantify the degree of coupling between mantle flow and lithospheric deformation, furthering our understanding of the forces driving plate boundary zones and continental deformation. The integration of seismic and geodetic data provided by EarthScope facilities will be key to solving some of the outstanding unknowns in the geodynamics of plate boundary and continental deformation.

4. O&M Activities

This section describes the tasks to be performed by each of the EarthScope components to continue to operate and maintain the facilities described in Section 2. The structure of the presentation and the numbering of the task elements follow the work breakdown structure developed for project management during the MREFC phase. The summary level of this work breakdown structure is shown in Figure 4.1. Note that although the structure and numbering system retains elements 2.1 (EarthScope Management) and 2.4.2 (USArray Reference Network), neither of these elements is included in the funding request in this proposal. The EarthScope Facility Office was closed during the transition to the O&M phase and partial responsibility for overall EarthScope coordination will be under the separately funded EarthScope National Office. The tasks under the USArray Reference Network were completed during the MREFC phase and operational responsibility has transferred to the USGS. The order and number of this work breakdown structure is continued in the Budget Plan (Section 5) and in the detailed budget information (Work Breakdown Structure Dictionary) in Section 7.

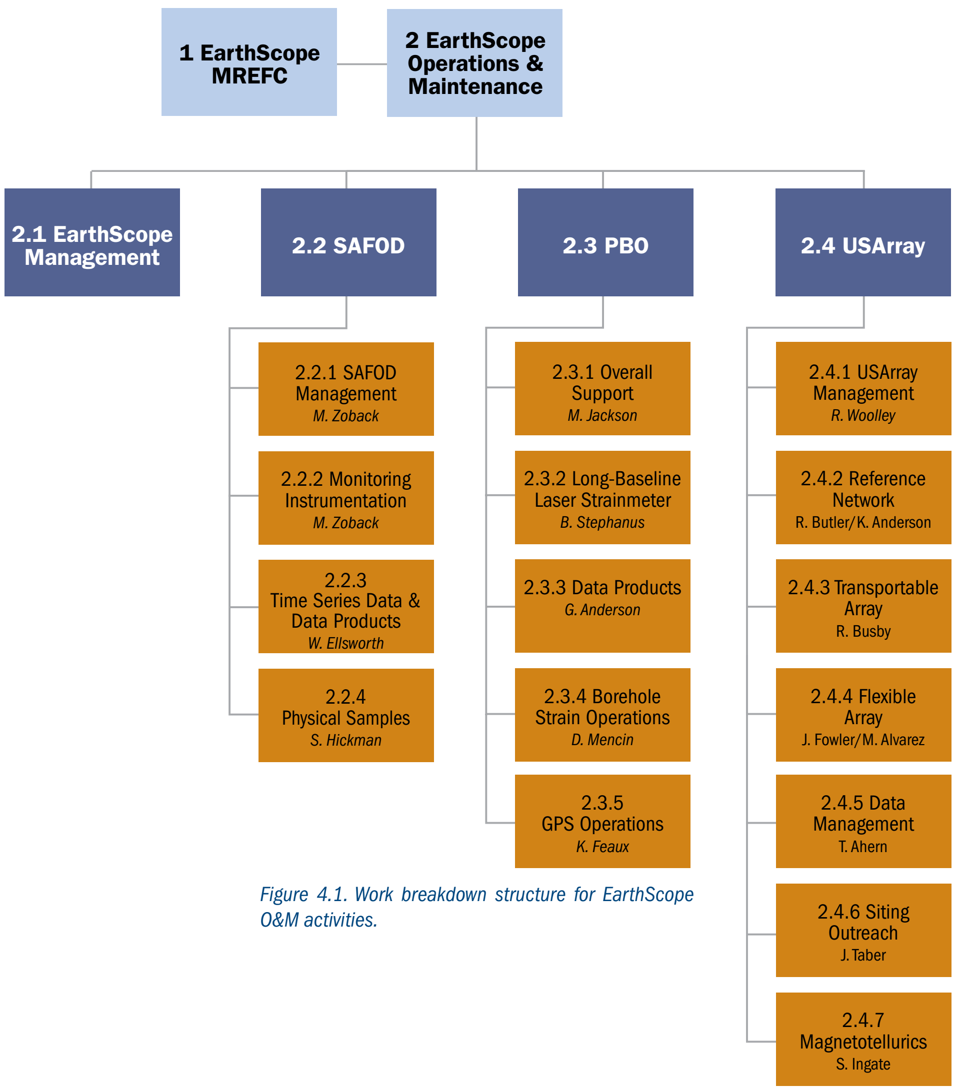


Figure 4.1. Work breakdown structure for EarthScope O&M activities.

San Andreas Fault Observatory at Depth (2.2)

During the O&M phase described in this proposal, the San Andreas Fault Observatory at Depth (SAFOD) requires support for the following four activities:

- Management of SAFOD operations, including outreach to the scientific community and the public.
- Operation of a suite of geophysical instruments in the SAFOD main hole to monitor, in the very near field, active processes associated with nucleation, propagation, and arrest of earthquakes on the San Andreas Fault.
- Deliver geophysical monitoring data to the scientific community through a series of data products optimized for geophysical research, store the geophysical monitoring data in the Northern California Earthquake Data Center (NCEDC) at the University of California, Berkeley and the IRIS Data Management Center (DMC) in Seattle, and carry out quality assurance/quality control (QA/QC).
- Safely store, sub-sample, and distribute physical samples (cores, cuttings, and fluids) from the SAFOD borehole to the scientific community.

SAFOD Management and Overall Support (2.2.1)

As shown in Figure 4.2, each of the co-PIs has primary responsibility for one or more activities during the operations and maintenance (O&M) period. Mark Zoback's responsibilities include overall SAFOD management, continued involvement as a member of EarthScope Management Team (EMT), and negotiating and managing the subcontracts for SAFOD O&M administered through Stanford University. Mark Zoback is also responsible for managing the downhole instrumentation to be deployed in SAFOD for near-field monitoring of earthquake sources. Bill Ellsworth is responsible for operation and maintenance of surface instrumentation at the SAFOD site and the telemetry systems that transmit the data from the site to data-analysis centers and repositories. Bill Ellsworth is also responsible for development of SAFOD data products. Steve Hickman is responsible for managing the physical samples obtained during all three SAFOD phases and supervising the storage and retrieval of such samples from the Gulf Coast Repository (GCR) of the Integrated Ocean Drilling Program (IODP) located at Texas A&M University. Working in close collaboration with the National Science Foundation (NSF) and the SAFOD Sample Committee, he will manage the process by which scientists request samples for study, how such samples are provided by the GCR, and then returned to GCR at the completion of study.

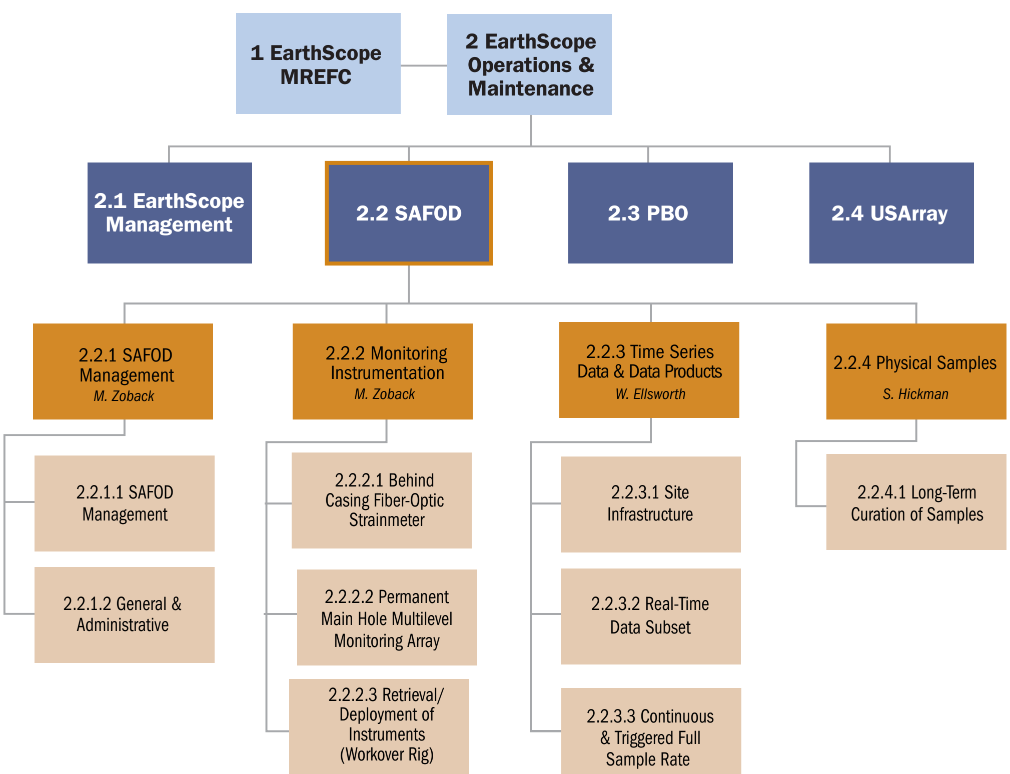


Figure 4.2. Schematic illustration of the activities to be carried out during the O&M phase of SAFOD with the co-PI that has primary responsibility for managing the tasks associated with each activity as indicated. The number in each box refers to the work breakdown structure (WBS) elements that are discussed in more detail in Section 7.

In addition to the management activities of the three co-PIs, another important SAFOD management component during the O&M phase will be the SAFOD Advisory Board and the Downhole Monitoring Instrumentation Technical Panel, both of which proved to be extremely valuable during the three SAFOD MREFC phases. The SAFOD Advisory Board is a group of leading scientists from government, academia, and industry. It will meet annually during the O&M phase to advise the PIs on overarching scientific issues confronting SAFOD. The Downhole Monitoring Instrumentation Technical Panel will also meet annually to provide SAFOD the benefit of their experience on technical issues regarding instrumentation and performance. It should be noted that the members of these committees that come from private industry come from oil companies, which, like SAFOD, are technology consumers. None is a member of oil-field service companies, as that would constitute a conflict of interest.

Monitoring Instrumentation (2.2.2)

For the time period covered in this proposal, SAFOD will have two independent borehole instrumentation systems to maintain and operate: an interferometric strainmeter cemented behind the casing in the main hole (described in Section 5) and a multi-level sensor package deployed near the bottom of the main hole (Figure 4.3). In the sections below we describe the instruments, budgets, and maintenance requirements for these two systems in detail. Because all the instruments will be operating at high pressure and temperature conditions using specialized surface instrumentation, they will need continual maintenance and replacement.

The maintenance and replacement program for SAFOD downhole monitoring sensors and electronics has been designed around the significant technical challenges of operating high-sensitivity, low-noise instruments in a hostile environment deep underground. Our goal is to have instrumentation operating at depth for 95% of the time. Consequently, we have developed a regular instrument-replacement program (described in Section 5) to ensure the continuity of data throughout the lifetime of the experiment. This program includes the replacement of components on a scheduled basis that will take advantage of advances in both sensors and high-temperature electronics as they mature. Because there are substantial lead times associated with the construction and refurbishment of the main hole instrumentation system, a multi-year plan is required to operate a degraded instrument or to pull it for repair. Decisions regarding when to pull an instrument and what repairs or replacements are necessary rest with the SAFOD management team in consultation with the SAFOD Advisory Board and Downhole Monitoring Instrumentation Technical Panel.

Surface facilities are an integral part of SAFOD monitoring instrumentation, and include an instrumentation building, UPS electrical power system, wellheads, conduits for instrumentation cables, telemetry systems, security equipment, and leases and permitting. The temperature-regulated instrumentation building houses multiple computer systems that control, record, archive, and telemeter data from the SAFOD site to the USGS in Menlo Park, CA and the NCEDC. The building also houses a frequency-stabilized laser and other electronics associated with the fiber-optic strainmeter. Scheduled maintenance of back-up electrical generators, collection of back-up tapes of full-sample-rate continuous data, mailing of data to the NCEDC, maintaining landowner relations, and other chores are conducted by a USGS employee stationed at Parkfield, CA. When problems arise at the surface facility that cannot be fixed remotely, the USGS assumes responsibility for first response, troubleshooting, and repair. Because respon-

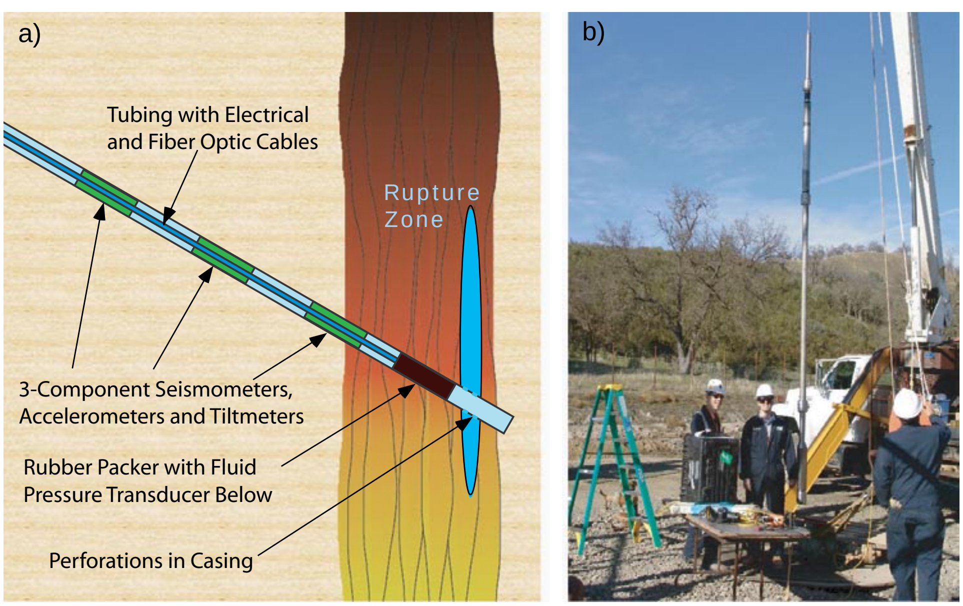


Figure 4.3. (a) Schematic of the long-term monitoring array for SAFOD. After casing is cemented in place from the bottom of corehole 3 to the surface (see Figure 3.11b), the casing is perforated in the fault zone and the array is emplaced on rigid tubing close to the target earthquake rupture zone. This array is designed so that it can be periodically removed for maintenance and repair. Unidirectional bow-springs (not shown) decentralize the seismic sensors to insure good coupling with the casing, and a rubber packer is inflated just above the perforations to monitor variations in fluid pressure during the earthquake cycle. (b) Photograph of engineers from Pinnacle Technologies testing a prototype for the seismic and tilt sensors in the SAFOD borehole following Phase 2 drilling.

sibility for operation and maintenance of SAFOD surface facilities lies with the USGS, no funds for these activities are being requested in this proposal.

Long-term operation of sensors and electronics at pressures of up to 30 MPa and temperatures of 135°C (as required in SAFOD) stretches the limits of proven technology. The Geothermal Research Instrumentation group at Sandia National Laboratory comprehensively analyzed borehole geophysical instrumentation operating under similar pressure and temperature around the world. These analyses have led to the conclusion that the effective operational lifetime of the instrumentation to be deployed is approximately three years. Hence, it is now clear that the borehole instrumentation will have to be periodically replaced. This additional cost represents a significant departure from O&M costs estimated at time that the MREFC proposal was originally submitted in January 2003. At that time, the SAFOD co-PIs had thought that it would be possible to maintain the instrumentation through the lifetime of the observatory.

Time-Series Data and Data Products (2.2.3)

The challenge of delivering the very high volumes of seismic data produced at SAFOD to the scientific community will be met by a comprehensive data management plan. This plan takes maximum advantage of the limited Internet bandwidth available coming out of SAFOD to provide rapid turn around of the most important data products while ensuring the reliable delivery and archiving of the full data set in a timely manner. The plan also makes extensive use of USGS-supported resources for the rapid collection of selected real-time data and production of an initial earthquake catalog, with support requested for the NCEDC for metadata, data conversion, and QA/QC, and for serving as the primary archive for SAFOD seismic and strain data. The NCEDC is well qualified to process and archive SAFOD time-series data because the NCEDC archives and distributes the most comprehensive set of northern California seismic and geophysical data available and has extensive experience processing borehole data from its Parkfield High Resolution Seismic Network (HRSN), Northern Hayward Fault Network (NHFN), and Mini-PBO borehole networks.

The SAFOD co-PIs will ensure coordination among all personnel (USGS, NCEDC, other sub-awardees) involved in instrument deployments and/or operation of data loggers and telemetry at SAFOD, such that any change that may affect data processing is communicated to all parties. Extensive use of USGS-supported resources will be required for the rapid collection of selected real-time data, creation of spectrograms, production of an initial earthquake catalog, and for support of field operations.

SAFOD monitoring data products will focus on geophysical events occurring in the vicinity of the borehole and earthquake activity along the Parkfield segment of the San Andreas Fault. Monitoring data streams include time series from three-component seismic sensors (velocity and acceleration), pore pressure, strain, and tilt. Elements of the SAFOD seismic data will be directly incorporated into real-time monitoring and cataloging operations of the Northern California Seismic System (NCSS), operated jointly by the USGS and the University of California, Berkeley.

The high sensitivity of some of the seismic sensors and low-noise conditions in the borehole will produce a data stream rich in regional and teleseismic data that will be of value to researchers with interests far removed from SAFOD. Moreover, as the sensors will be within tens of meters of the target earthquakes, we will have an unprecedented opportunity to record very-high-frequency, near-field seismic signals. We anticipate recording 10,000 or more earthquakes each year with instrumentation at the SAFOD site. This opportunity, however, comes with the burden of producing 10 TB of raw data per year. Our intention is to manage the data in ways that minimize storage costs and promote easy data access without jeopardizing the science that can be done with it.

The pathways for SAFOD seismic data are shown graphically in Figure 4.4, and seismic data products from SAFOD are listed in Table 4.1. The primary seismic monitoring data are recorded on tape at SAFOD. The raw data are in SEG2 format. To make the SAFOD data products discoverable and accessible to the broadest community, it is vitally important to convert the seismic data into the Standard for the Exchange of Earthquake Data (SEED) format, which is the international standard for the exchange of digital seismological data.

The seismic monitoring data stream from SAFOD is recorded at 4000 samples/sec, producing approximately one gigabyte of data per hour (10 TB/yr). At this sample rate, the data volumes are too large to transmit to the NCEDC in real time over the very limited Internet bandwidth coming out of SAFOD. The only cost-effective way to capture these data at full sample rate is to write them to tape at SAFOD, which will be delivered to the NCEDC on a monthly basis for processing. These files will be converted to miniSEED and the NCEDC will maintain the most recent continuous data (e.g., at least the previous 12 months) in an online disk buffer. These data shall be made accessible to all users through the NCEDC, which will provide online access to this unique seismic data set.

To facilitate more rapid data access, several additional data products that are essentially derivatives of the full data set will be created and made available to the research community in near real time. These derivative data products are described below.

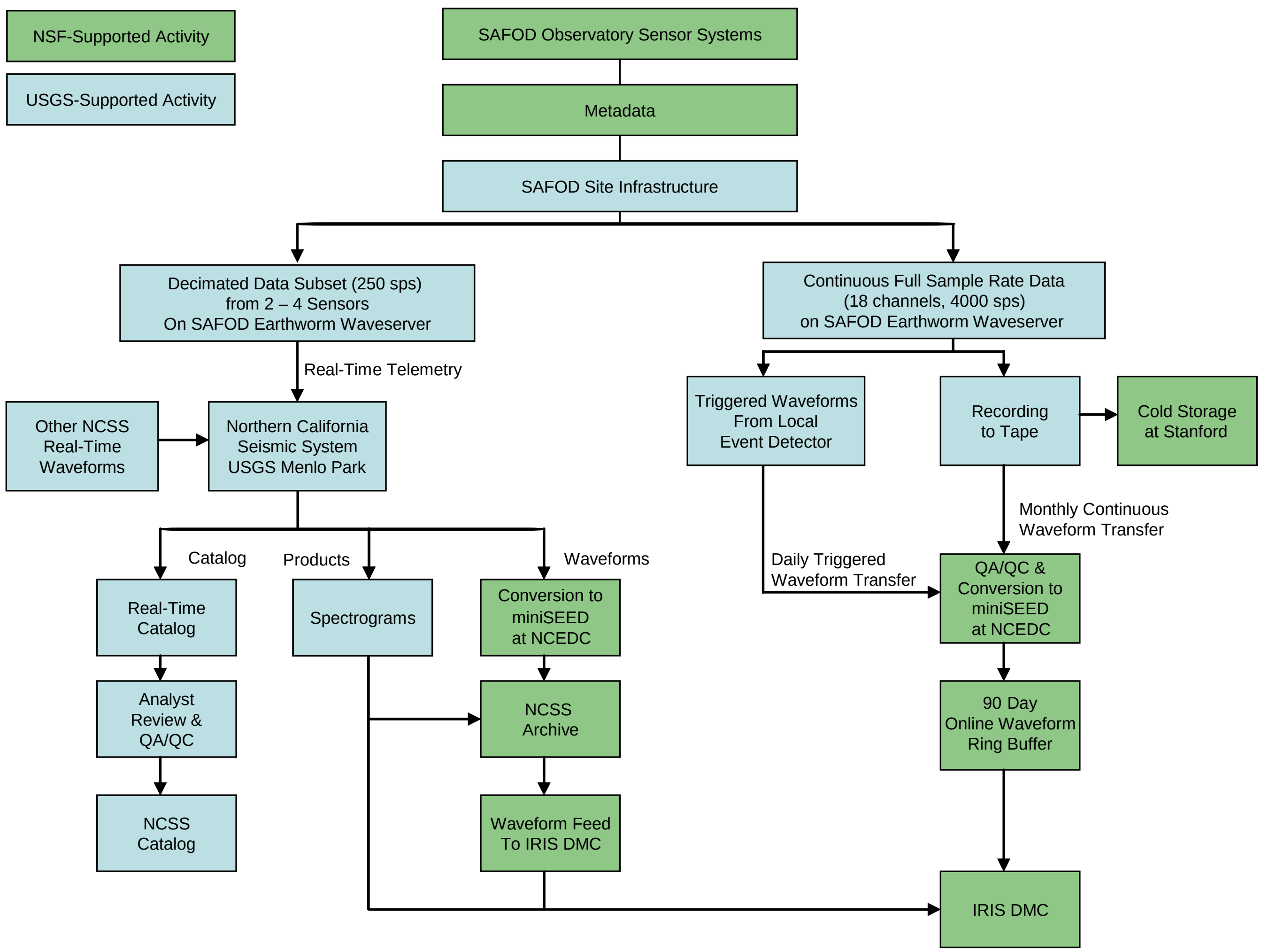


Figure 4.4. Data pathways for SAFOD seismic data. Boxes with a green background are to be supported by the EarthScope O&M budget from NSF (this proposal). Boxes with a blue background are to be supported by the USGS. The left branch of the tree follows the decimated subset of data, branching off into sections for the earthquake catalog, spectrograms, and waveforms. The catalog is a USGS product. The waveforms and spectrograms are EarthScope data products hosted at the NCEDC, which are also copied to the IRIS DMC. The right branch follows the full sample rate data through the NCEDC to the IRIS DMC. A "Local Event Detector" collects ~ 10-sec windows of full-sample-rate data, and sends those to the NCEDC on a daily basis. These files are converted to miniSEED and stored online. The tapes containing the continuous recordings are delivered to NCEDC monthly. The tapes are read and converted to miniSEED. After processing, the data are available for 90 or more days in the online ring buffer at the NCEDC and indefinitely from tape at the IRIS DMC. The field tapes are kept in storage at Stanford.

Real-Time Seismic Data for Seismic Monitoring

One data product is a downsampled, or decimated, version of the continuous data. (Figure 4.4, left). The effort and materials for the acquisition of this data stream will be supported by the USGS, which already operates seismic networks in the Parkfield area. Waveforms from events M1 and greater from a few selected sensors will flow into the real-time NCSS. The waveforms will be converted to miniSEED and archived with the other NCSS data at the NCEDC. The waveforms and associated parametric data will be accessible with the current tools for searching the catalogs and retrieving SEED waveform data. The data management infrastructure is well established at the NCEDC and thus requires minimal NSF support. These real-time data will also be relayed to the IRIS DMC for archiving.

By lowering the data sample rate for selected channels, this data set is compact enough to be transmitted over the Internet in real time. These data will be used to create a visual guide to earthquake activity on a minute-to-minute basis in the form of spectrograms generated at the USGS that will be available and updated within minutes on the NCEDC and USGS Web sites. Additionally, by transmitting these data in real time, the SAFOD instruments can be integrated with the entire NCSS, increasing its utility to Parkfield researchers and lowering the reporting threshold of the NCSS network near SAFOD.

TABLE 4.1. SAFOD MONITORING DATA PRODUCTS

DATA PRODUCT	LEVEL	COMMENTS	AVAILABILITY
Seismic Waveforms in SEG2 format	Level 0	The raw data will only be available on the field-recorded tapes.	Available on tape by request only
Seismic Waveforms in SEED format, full sample rate	Level 1	The conversion from SEG2 to SEED involves quality control as well as conversion from floating point to integer.	Available online from NCEDC for at least 90 days. After that, available offline from IRIS DMS. Field tapes read monthly.
Seismic Waveforms in SEED format, decimated sample rate	Level 1	Downsampled to 250 samples/second, for selected channels from the array	Available in near real-time from NCEDC, may have up to 24 hour latency before becoming available at IRIS DMC
Trigger-associated waveforms, full sample rate.	level 1	Waveforms in a ~10 second window triggered by a local event detector at SAFOD.	Available online at NCEDC for more than 90 days. Then available offline from IRIS DMC. Will be available within 1 day.
List of Triggers	Level 2	A local event detector will create a list of triggers. These triggers will not be verified.	Available within 1 day.
Contribution to the NCSS catalog	Level 2	Several channels of decimated SAFOD data will flow into the NCSS real-time network analysis system.	The NCSS catalog is produced in real-time. Hypocenter review occurs within 1 week.
Spectrograms	Level 1	The spectrograms will be based on the decimated real-time channels and will provide a visual guide to the data.	Available in near real time from USGS, and within 1 day from the NCEDC and IRIS data centers.
Tiltmeter data	Level 0,1	Daily tiltmeter files will be converted to SEED format	Available within 1 day from NCEDC. Will also be available from IRIS DMC
Strainmeter data	Level 0,1	Strain data will be streamed to the IDA seismic array system and stored in CSS format	Available within 1 day from IDA and NCEDC

Triggered Waveforms from Local Event Detectors

Another data product that will greatly increase the utility of the seismic data is short (approximately 10-sec) segments of the full-sample-rate waveforms for all channels following event triggers (Figure 4.4, right). The sensors in SAFOD will be the closest sensors to an active fault zone anywhere in the world. As such, there will be dozens of events (or more) each day at SAFOD that are not in the existing catalogs. We estimate that there may be on the order of 10,000 triggers per year (25–30 events per day). A subset of the events, those generally M1 and larger, will also be in the NCSS catalog (as mentioned above). The triggers will be created at SAFOD and an automatic process will extract short sections of the data and transmit them over the Internet to the NCEDC where they will be converted to miniSEED and made available to the community. SAFOD will not have the personnel to verify whether the triggers are events, but the list of trigger times and windowed waveforms will help direct researchers to the data of interest rather than having to begin by scanning the voluminous continuous data files.

The SAFOD team has set the following performance goals for SAFOD seismic data: (1) 99% of the data from real-time telemetered channels will be accessible through the NCEDC within seconds of transmission, (2) 95% of triggered-event data files will be accessible through the NCEDC within one work day of occurrence and all files will be available within one month (to accommodate seismic crises such as the Parkfield or San Simeon earthquakes, which would overwhelm the telemetry bandwidth), (3) 95% of continuous, full-sample-rate data will be available on a ring buffer at the NCEDC within one month of collection, and (4) 100% of archived data will be available with zero loss due to catastrophic infrastructure failure.

IRIS Seismic Data Archiving

Along with the NCEDC, the IRIS DMC will also be a data archive for the SAFOD seismic data products. The triggered and decimated data products will be transmitted to IRIS as the data products are generated at NCEDC. The DMC will be the primary long-term archive for the continuous high-rate seismic data. IRIS has mass storage systems that can incorporate all the anticipated SAFOD data, accessible through a tape robot. This will ensure that all SAFOD seismic data will always be available to the community. By converting the data to miniSEED at the NCEDC, we ensure that the metadata are captured and the best tools for the discovery of the data are available.

SAFOD Tilt and Pore Pressure Data

SAFOD will acquire four channels of tilt data at low sample rate (≤ 1 sample/second) and one channel of pore pressure data at the same rate. The NCEDC will receive these data over the network on a regular basis from SAFOD, convert the raw tilt data to miniSEED, archive and distribute the miniSEED data, and generate the dataless SEED metadata for these data channels from the information provided by the SAFOD PIs.

Metadata

The responsibility for all metadata related to SAFOD instrumentation will be shared among the SAFOD PIs and the NCEDC. The NCEDC will work closely with the SAFOD PIs to ensure that the metadata can be quickly and accurately cataloged and integrated with the data. The NCEDC will be responsible for the generation and distribution of metadata for the SAFOD data channels in the form of dataless SEED volumes, which will also be provided to the IRIS DMC.

Physical Samples (2.2.4)

Some of the most important products coming from SAFOD will be the physical samples exhumed from the San Andreas Fault Zone and country rock. These samples include core, cuttings, and fluids retrieved directly within and adjacent to the seismogenic zone. Because of the importance of these samples, we will describe sample-handling operations in this section separately from the SAFOD digital data.

The samples being acquired by SAFOD are described in detail on the International Continental Scientific Drilling Program (ICDP) Web site for SAFOD (http://www.icdp-online.de/contenido/icdp/front_content.php?idart=1037) and are as follows:

- Cores are being collected during all three phases of SAFOD drilling, and are the most voluminous and scientifically valuable sample type to be acquired during this project. Approximately 60 m of 2.5–4-in diameter spot cores were acquired during drilling Phases 1 and 2, whereas approximately 600 m of 2.5-in-diameter continuous core will be acquired from the three multilaterals to be drilled during SAFOD Phase 3 in the summer of 2007.
- Multiple sets of washed and unwashed drill cuttings were collected at 10-ft intervals during Phases 1 and 2, with large-volume cuttings samples acquired every 100 and 300 ft. These were supplemented by drilling mud samples (with and without cuttings) collected every 100 ft, and more frequently inside the fault zone.
- Borehole and formation-fluid samples were acquired following Phases 1 and 2 using downhole fluid samplers deployed either on wireline or on the drill pipe. These samples were relatively few in number (~ 20 samples) and small in volume (~ 1 liter per sample).

Curation and Distribution of SAFOD Samples

Sampling handling operations involve two major components: on-site sample handling at the SAFOD drill site and curation and distribution of samples stored at the IODP Gulf Coast Repository at Texas A&M University in College Station, TX. Because on-site sample handling is already funded by the MREFC program, only activities associated with curation and distribution of SAFOD samples at the GCR are described in this proposal.

After extensively evaluating a number of options for curation of SAFOD core, cuttings, and fluid samples, we selected the GCR as the long-term storage facility for all SAFOD samples for a variety of reasons:

- The GCR has the facilities to store SAFOD core samples in their original fluid saturation state and under constant refrigeration. The GCR will hermetically seal the SAFOD cores in heat-shrink plastic and then store these cores—as well as the SAFOD cuttings and fluid samples—in refrigerated core storage lockers at 4°C. This is essential for preserving the in situ physical and mechanical properties of clays and other hydrous minerals thought to be very important in the rheology of the San Andreas Fault, while at the same time minimizing the geochemical and physical alteration of mineral phases through oxidation reactions, low-temperature weathering reactions, or microbial growth on samples stored wet.
- The GCR has a state-of-the-art facility for sample examination, preparation, and distribution, as well as excellent record-keeping practices pertaining to sampling history, sample maintenance, and repository environmental conditions. This has allowed us to meet the high demand for SAFOD core and other samples acquired to date, which is expected to become more intense for continuous core to be obtained during Phase 3 in and near the San Andreas Fault Zone.
- The technical staff and management of the GCR have several decades of experience in handling rock and sediment core samples acquired through the IODP and previous, closely related academic ocean drilling programs. This experience is already proving invaluable in designing safe and effective procedures for handling of SAFOD core, cuttings, and fluid samples, both in the repository and at the drill site.

Thus, although use of the GCR for long-term curation of SAFOD samples does incur a modest cost of about $27,000/year, this cost is justified by the safe storage and reliable distribution of precious SAFOD core, cuttings, and fluid samples that is made possible by the GCR.

The primary tasks to be undertaken at the GCR during the time period covered by this O&M proposal are as follows:

- Receive shipments of core, cuttings, and fluid samples from the SAFOD drill site as they come available.
- Verify that all samples are properly packaged and sealed, and replace packaging damaged during shipment when needed.
- Triple-seal all core pieces in high-grade plastic laminate using an automated heat-shrink machine at the GCR.

- Store all SAFOD core, cuttings, and fluid samples in refrigerated storage lockers at 4°C. Samples will be maintained in this condition indefinitely, until otherwise instructed by NSF management in consultation with the SAFOD Sample Committee.
- Prepare and distribute core, cuttings and fluid subsamples to PIs in the United States and abroad in response to approved sample requests (see SAFOD Sample Policy, below).
- When necessary, assist PIs with specialized sampling needs using equipment available in the GCR or provided to the repository by SAFOD staff or by the PIs themselves. This includes obtaining oriented sub-cores, deriving mineral separates from cuttings, and extracting borehole fluid sub-samples from pressurized and non-pressurized sample containers.
- Receive samples returned to the GCR for restocking. This includes noting the condition of the samples, cleaning them where needed, and repackaging and returning the samples to the archives,
- Maintain records of core, cuttings, and fluid sample requests filled; to whom these samples were provided and on what dates; the preparation steps and analysis procedures applied to these samples; and the condition of these samples when returned to the GCR.

SAFOD Sample Policy

Evaluation and prioritization of requests from the earth science community for SAFOD cores, cuttings, and fluid samples are being handled in accord with the EarthScope Data and Sample Policy, through a process that starts with the annual NSF EarthScope Program Announcement. Decisions regarding sample dispensation are reached through procedures that differ somewhat for the cuttings, fluid, and spot cores acquired during Phases 1 and 2 and the continuous core to be acquired during Phase 3. For Phases 1 and 2, following initial approval of a sample request by the NSF Program Director (either as part of an official NSF EarthScope Program proposal or through stand-alone requests), samples are allocated through a consensus process involving the researchers requesting samples, the Superintendent of the GCR, and the SAFOD Sample Manager. Although this process has worked very well to date, we anticipate a much greater demand for the continuous core from Phase 3, in particular for samples obtained from within and adjacent to the actively deforming traces of the San Andreas Fault. This concern was also raised at the November 2006 EarthScope Baseline Review, which recommended that a more formal, independent process be set up for allocating the Phase 3 core samples. Accordingly, following initial approval by the NSF EarthScope Program Director, all requests for Phase 3 core samples will be passed on to an independent SAFOD Sample Committee. The SAFOD Sample Committee will then decide how the Phase 3 core samples are used, who gets these samples, and in what order (i.e., when sequential measurements are to be made on the same samples by different researchers). In addition, the SAFOD Sample Committee makes recommendations to NSF and the SAFOD Management Team on: (1) the balance between obtaining immediate scientific results and preserving samples for future study, (2) collection, documentation, and curation procedures, and (3) other sample-related matters as requested by NSF or the SAFOD Management Team. Although the SAFOD Sample Committee may seek advice from outside scientists or other experts, neither the SAFOD Sample Manager nor other members of the SAFOD Management Team will play a formal (i.e., voting) role on this committee.

Core Orientation

Josep Pares (University of Michigan) successfully tested paleomagnetic core orientation techniques on spot core from the bottom of the Phase 2 drillhole. Because this Phase 2 core sampled the same siltstones and shaley sandstones anticipated during the Phase 3 continuous coring, we have decided to use this same paleomagnetic core reorientation technique to orient about half the core to be acquired from the Phase 3. This technique will allow structures seen in the Phase 3 core to be oriented with respect to the overall San Andreas Fault System. Costs associated with this activity will be covered out of the MREFC budget for SAFOD, and thus have no financial impact on the EarthScope O&M budget presented here.

Plate Boundary Observatory (2.3)

The Plate Boundary Observatory (PBO) is a geographically distributed and networked machine that takes as input raw data from Global Positioning System (GPS) and strainmeter instruments and produces as output high-quality data products for the EarthScope scientific and educational communities. The machine will require maintenance in the form of engineering, data management, and project management staff to keep stations running and data products flowing, and to keep our sponsors and our community up to date.

PBO will address O&M activities with a dedicated staff of GPS and strainmeter network engineers for monitoring station health, troubleshooting, and formulating and executing a response plan, and data-management professionals to ensure data product generation, quality control, flow, archiving, and distribution. A small management team composed of the PBO Director, Operations Manager, Data Products Manager, Senior Engineer, Cost Schedule Coordinator, and an administrative assistant will oversee the management of O&M activities. Focused Education and Outreach (E&O) activities, including summer intern programs and core classes devoted to GPS, strainmeter, and imagery data processing and modeling, will be performed by a PBO E&O specialist and managed by the UNAVCO E&O Director. In the following sections, we describe each major element of the operations and maintenance activity by Work Breakdown Structure (WBS) (Figure 4.5); for a more complete discussion of position descriptions, tasks, and the budget justification, see Section 7.

Over the next five years, the primary tasks to be undertaken by the PBO to support EarthScope's scientific goals are to:

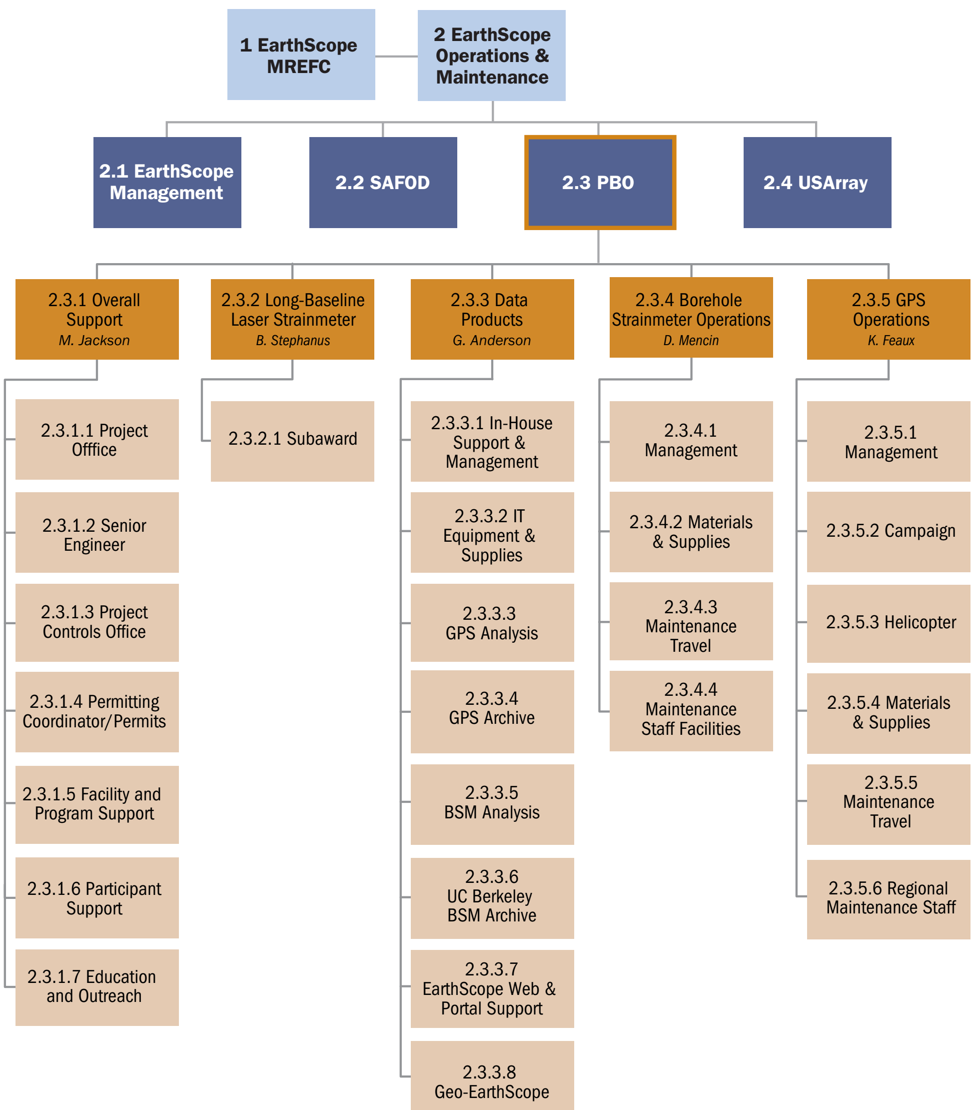


Figure 4.5. Schematic illustration of the activities to be carried out during the O&M phase of PBO with the co-PI that has primary responsibility for managing the tasks associated with each activity as indicated. The number in each box refers to the work breakdown structure (WBS) elements that are discussed in more detail in Section 7.

- Operate and maintain 1100 permanent CGPS stations with critical station maintenance activities set by scientific priority and maintaining the data return from these stations at 80% or above.
- Operate and maintain 103 borehole strainmeter/ seismometers critical station maintenance activities set by scientific priority and maintaining the data return from these stations at 80% or above.
- Operate and maintain six long baseline laser strainmeters and maintain the data return from these stations at 80% or above.
- Maintain 100 portable GPS systems for rapid deployment and PI-funded projects.
- Continue to make available all GeoEarthScope imagery and geochronology data.
- Manage all of EarthScope's geodetic data and derived products and distribute the data quickly and easily via the Internet to all interested parties.

Overall Support (2.3.1)

The Plate Boundary Observatory has a team-based organizational structure led by the PBO Director, who reports to the UNAVCO President and is assisted by a small management team. During the O&M period, the PBO management team will comprise:

- *PBO Director (20 years of relevant experience)*
  Plans, coordinates, and directs PBO all operations and maintenance activities and ensures coordination and execution of PBO data collection, analysis, archiving, and distribution schemes.
- *GPS Operations Manager (15 years)*
  Oversees all regional offices and coordinate all station maintenance activities.
- *Data Products Manager (15 years)*
  Oversees all data management activities, including data flow, quality control, processing, archiving, and distribution.
- *Cost Schedule Coordinator (25 years)*
  Manages all PBO budgets, project forecasts, and corrective-action management support for O&M, and tracks performance schedules and NSF-required performance and reporting metrics.
- *Strainmeter Operations Manager and Senior Network Engineer (15 years)*
  Oversees all strainmeter operations and maintenance activities. Coordinates all testing and acceptance of all data communications and GPS receiver hardware, firmware, and software updates; coordinates and disseminates engineering reports and procedures to remote offices; assists with field repairs as needed; and acts as an engineering liaison to the Data Management staff.
- *Permitting Coordinator (10 years)*
  Ensures all fees for land use are paid in a timely manner; takes care of permits requiring no-cost renewals, insurance certificates, and other administrative activities; and ensures compliance with all National Park Service and other agency's requirements for annual reporting. Other administrative tasks, such as updating contact information in databases, maintaining hard-copy and soft-copy file folders with check stubs, insurance certificates, and other documentation, are performed concurrently with the aforementioned tasks. These tasks are all critical for maintaining the "permanence" of the EarthScope installations.
- *Systems Administrator (7 years)*
  Maintains critical IT infrastructure and supports all PBO IT users.

All senior management team members are cross-trained so there is no single point of failure in PBO leadership.

PBO Project Support activities include salary and travel support for the PBO Director (1 FTE), Cost Schedule Coordinator (1 FTE), Senior Network Engineer (0.5 FTE), Permitting Coordinator (0.5 FTE), and the Systems Administrator (1 FTE). Salary and travel support for the Data Products Manager (1 FTE), Borehole Strainmeter Operations Manager (0.5 FTE), and Operations Manager (1 FTE) are provided by WBS elements 2.3.3.1, 2.3.4.1, and 2.3.5.1, respectively.

PBO Project Support also supports PBO IT systems (2.3.5.1), including computers, software, and cellular telephones, and modems for PBO staff (2.3.5,2). It also includes a prorated share of the UNAVCO facilities costs (Facility Costs, 2.3.1.4) and includes the lease costs of UNAVCO's Boulder, CO office and warehouse space, associated utilities, taxes, building maintenance, and telecommunications (non-cellular) costs. This pool of costs is allocated to the various UNAVCO projects based on the square footage the project occupies. This indirect rate is part of an indirect pricing proposal that is submitted to the NSF.

The PBO Standing Committee (PBOSC) is an essential component of PBO management and oversight. The PBOSC is charged with ensuring the project meets and exceeds science and management goals. As the project transitions to O&M, the PBOSC will take on the additional tasks of scientifically prioritizing stations for acceptable downtime and ensuring that data products and software tools meet the user community's needs. Participant-support costs for PBO include travel for PBOSC members to attend one annual program review; these are included in this WBS element.

During the O&M phase, PBO E&O activities will focus on serving the communities in which PBO equipment is based, including producing curricular modules that use PBO data and highlight the scientific discoveries made from PBO data. The PBO E&O staff will work closely with the new EarthScope National Office to bring EarthScope scientific discoveries to local venues in areas throughout the EarthScope footprint. One focus of the E&O effort will be to continue the successful short-course series. This series was developed during the construction phase of the project and is key to integrating the EarthScope user community and increasing the diversity of EarthScope data users. Short courses proposed for the O&M period include "Using Strainmeter Data," "Using EarthScope Data," and "Integration of Seismic and Geodetic Data." Requested funds cover expenses for the instructors, and scholarships for students.

Long Baseline Laser Strainmeters (2.3.2)

PBO, through a subaward to the University of California, San Diego (UCSD), will maintain six long baseline laser strainmeters (LSM) in southern and central California, including:

- the existing Glendale-Verdugo Strainmeter (GVS) instrument installed in the densest part of the Southern California Integrated GPS Network (SCIGN), next to the San Gabriel Mountains and near Los Angeles basin blind-thrust faults
- one new instrument (DHL2) at Durmid Hill, CA, adjacent to an existing component on the eastern side of the Salton Sea and within 2 km of the southeastern terminus of the San Andreas Fault
- two new orthogonal instruments (SCS1 and SCS2) located on the western side of the Salton Sea near the historically seismogenic San Jacinto Fault
- two new orthogonal instruments near Cholame, CA, near the initiation point of the 1857 Fort Tejon earthquake along the San Andreas Fault

For periods of months or more, these instruments have stability comparable to GPS, while for shorter periods they are much quieter than GPS—quiet enough to easily resolve the solid earth tides. For periods of a few days, LSMs observe strain changes as small as 0.1% of the GPS resolution. The scientific benefit of long baseline strain records is greatest when the instrument is run continuously, but because the long baseline strainmeter includes several subsystems that are both exposed to the elements and accessible to people, such operation requires considerably more attention than do many other geophysical instruments. Continuous operation requires that close attention is paid to the performance of the equipment, through regular review of the data, allowing prompt response to any problems.

This proposal includes the operations of these six instruments, including funding for UCSD support personnel, replacement of necessary equipment, materials, and supplies, and necessary travel expenses to the sites. The costs also support data transmission to the PBO strainmeter archive and the generation of strainmeter data products.

PBO Data Management System (2.3.3)

PBO has been providing a variety of high-quality geodetic data products, outlined in Table 4.2, since October 2005. To date, PBO has collected nearly 350 GB of raw GPS, strain, and seismic data, and has delivered almost 1.4 TB of data to over 80 different educational institutions, government agencies, and commercial organizations across the United States and nine foreign countries. PBO provides everything from raw data (Level 0) to fundamental derived products (Level 2), which allows us to serve the range of users from experts in raw data analysis to those whose research requires reliable geodetic time series. In just the past 16 months, these products have been used to study such diverse phenomena as episodic tremor and slip along the Cascadia subduction zone, transient deformation in southern California, and magmatic deformation at Mount St. Helens, Yellowstone, and Augustine Volcano. During EarthScope's O&M phase, PBO's primary technical mission will be to continue to generate, archive, and distribute these products to support EarthScope community research; we anticipate that PBO will generate more than 30 TB of data products by the end of the first five years of the O&M phase (Figure 4.6). As with all geodetic series, the value of these products will only grow over time, and thus continued support of the PBO data management system is critical to the long-term scientific viability of EarthScope.

This WBS element provides support for the continued operation and maintenance of the distributed PBO Data Management System (Figure 4.7), comprised of software systems that collect raw data from remote stations; the PBO Boulder Network Operations Center (NOC), where network operations are monitored and controlled; the PBO analysis centers that generate higher-level derived products (Level 2); and the PBO archives that archive and distribute all PBO GPS data products. This task includes salary and travel support for a staff of 7.5 FTEs (Table 4.3), continued funding of subawards for the analysis centers and archives, and minimal ongoing support for PBO's critical information technology infrastructure.

GPS Data Management

PBO GPS stations currently record raw observations once every 15 seconds (15-sec) and 5 times per second (5-sps). PBO downloads the 15-sec data automatically at least once per day, while the 5-sps data are downloaded by request. Once they have arrived in Boulder, GPS data flow to the UNAVCO Facility, where they undergo automated quality checking and archiving procedures, creating Level 1 GPS products in RINEX format.

Analysis Centers at Central Washington University and the New Mexico Institute of Mining and Technology use different GPS analysis software packages to process all PBO RINEX data into initial Level 2 products, which the Analysis Center Coordinator at MIT then merges into a unified set

TABLE 4.2. PBO DATA PRODUCTS SUMMARY

INSTRUMENT	LEVEL	PRODUCT	FORMAT	GENERATED...
GPS	0	15-sec raw data	T00	Daily
		5-sps raw data	T00	Hourly*
		Survey-mode raw data	Varies	Varies
		Station metadata	Database	Varies
	1	15-sec quality checked data	RINEX	Daily
		5 sample/sec quality checked data	RINEX	Varies
	2	Station position and velocity solutions	SINEX	1-day, 15-day, and 3-month latencies
		Position time series	ASCII	1-day, 15-day, and 3-month latencies
		Station velocity estimates	ASCII	Varies
		Coseismic offsets for significant events	ASCII	Varies
BSM	0	20-sps, 1-sps, 10-min raw strain series	Bottle, SEED	Hourly, daily
		1-sps, 30-min instrument health series	Bottle, SEED	Hourly, daily
		1-sps, 30-min environmental series	Bottle, SEED	Hourly, daily
		Borehole geophysical logs, samples	Varies	During installation
		Station metadata	Database	Varies
	2	Corrected and scaled strain and environmental series	XML, ASCII	2-week, 4-month latencies
		Station notebooks	PDF	Varies
LSM	0	1-sps raw strain, instrument health, and environmental series	Ice-9, SEED	Daily
		Station metadata	Database	Varies
	2	Corrected and scaled strain and environmental series	XML, ASCII	2-week, 4-month latencies
		Station notebooks	PDF	Varies
Seismic	0	100-sps raw data	SEED	Streaming
		200-sps raw data	SEED	Streaming**
Pore pressure	0	10-sec raw	BINEX, ASCII	Hourly
Tiltmeter	0	1-min raw	BINEX, ASCII	Hourly

*Downloaded only when necessary
**Some stations

of high-quality combined products (Table 4.2). PBO based this structure on the experiences of the International Global Navigation Satellite System Service (IGS) and SCIGN, which have shown conclusively that having multiple independent processing centers that are coordinated through another center produces the highest quality GPS solutions. Such experience suggests that GPS position estimates produced in this exacting manner should be accurate to 2 mm horizontally and 5 mm vertically after two to three years; as shown in Figure 4.8, PBO exceeds this high standard, with median uncertainties of under 1.5 mm horizontally and under 4 mm vertically.

The UNAVCO Facility archives and distributes all PBO GPS data products using its Boulder archive and an off-site center operated by UNAVCO. PBO requires two archives to mitigate the risk to data product delivery and availability resulting from system failure at any one archive. These two facilities will also distribute these data to EarthScope users through a variety of command line- and Web-based mechanisms and the EarthScope Portal.

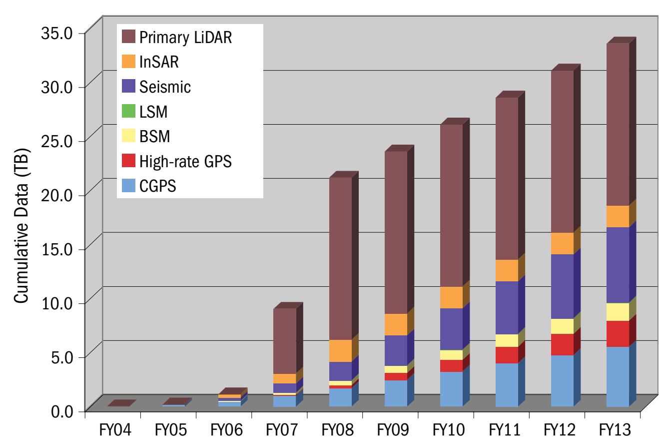


Figure 4.6. Anticipated growth in PBO and GeoEarthScope Level 0 and 1 data product volume, in terabytes. CGPS, high-rate GPS, BSM, LSM, seismic, InSAR, primary LiDAR: cumulative total of estimated volumes of standard continuously operating GPS data, triggered downloads of 5-sps GPS data, borehole strainmeter data not counting seismic data, long baseline strainmeter data, seismic data from PBO borehole stations, GeoEarthScope InSAR data, and laser point cloud and control information from GeoEarthScope LiDAR surveys, respectively. LSM cumulative data volume is 0.1% of the total data volume, so it appears as a single thin line in each of these bars.

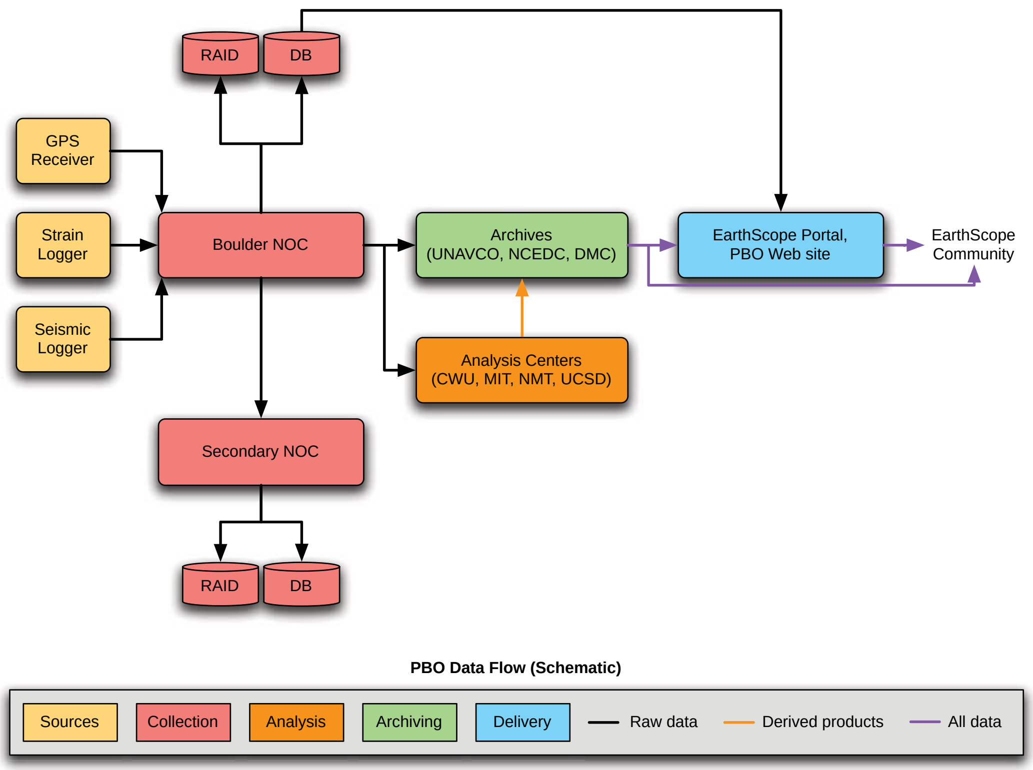


Figure 4.7. Flow of data through PBO Data Management System. The Boulder Network Operations Center (NOC) downloads PBO data, mirrors them to a secondary offsite NOC, and transmits them to archives and analysis centers. PBO analysis centers analyze raw data and produce a variety of Level 2 data products (Table 4.2). PBO archives archive and distribute PBO data products to end users directly and via the PBO Web site and EarthScope Portal. Either NOC can provide critical data flow control functions; either archive can receive, archive, and distribute data products; and analysis can be done with only one operational Analysis Center. Redundant, geographically distributed data collection centers and archives ensure high reliability and availability of data products despite possible system failures at any one center.

Strain Data Management

Digital Time Series Data

PBO borehole strainmeter stations record four components of strain data at each of three sampling rates, along with environmental and instrument health data, all in bottle format. PBO laser strainmeter stations record at least twelve channels of laser fringe count, environmental, and instrument diagnostic data once every second and once every five minutes, both in Ice-9 format.

At least once per day, PBO downloads raw strain data automatically to the Boulder NOC, where they undergo initial quality checks and conversion to SEED format, which improves usability for the broad EarthScope community. PBO then transmits all of these data to the strainmeter archives at the NCEDC and IRIS DMC for archiving and distribution.

The Borehole Strain Analysis Center in Socorro, NM, and the Laser Strain Analysis Center at UCSD process PBO strain data into Level 2 products, which they then deliver to the NCEDC and IRIS DMC, which archive all PBO strain products and make them available to the community through a variety of client-, command line-, and Web-based mechanisms. In addition, all strain products will be available via the EarthScope Portal.

Physical Samples and Geophysical Logs

During the installation of PBO borehole strainmeter stations, crews collect physical samples (e.g., cores, cuttings) and conduct geophysical logging of the borehole environment. These products will be curated at the Houston Research Center (HRC), a repository funded by NSF to hold physical samples and logs from all NSF-funded terrestrial coring projects in perpetuity, without cost to the investigator who collects and submits the samples to HRC. The HRC then makes samples and logs available to users. By using this facility, PBO leverages existing NSF-

TABLE 4.3. PBO DATA MANAGEMENT STAFF DURING O&M

LOCATION	POSITION	RESPONSIBILITIES	FTES
Boulder	Data Products Manager	Oversee all data management activities	1.0
	Data Engineer	Operate GPS data flow system	0.5
	DBA Programmer	Operate key PBO software systems and database	1.0
	Senior Web Administrator	Operate PBO and EarthScope Web presence	1.0
	Portal Software Engineer	Operate PBO Web services for EarthScope Portal	0.5
	PBO Archive Data Engineer	Operate PBO GPS archiving systems	1.0
	Geo-EarthScope Coordinator	Operate GeoEarthScope data management systems	0.5
Socorro	Strainmeter Data Manager	Oversees generation of all PBO strainmeter products	1.0
	Strainmeter Data Technician	Routine strainmeter data product generation	1.0

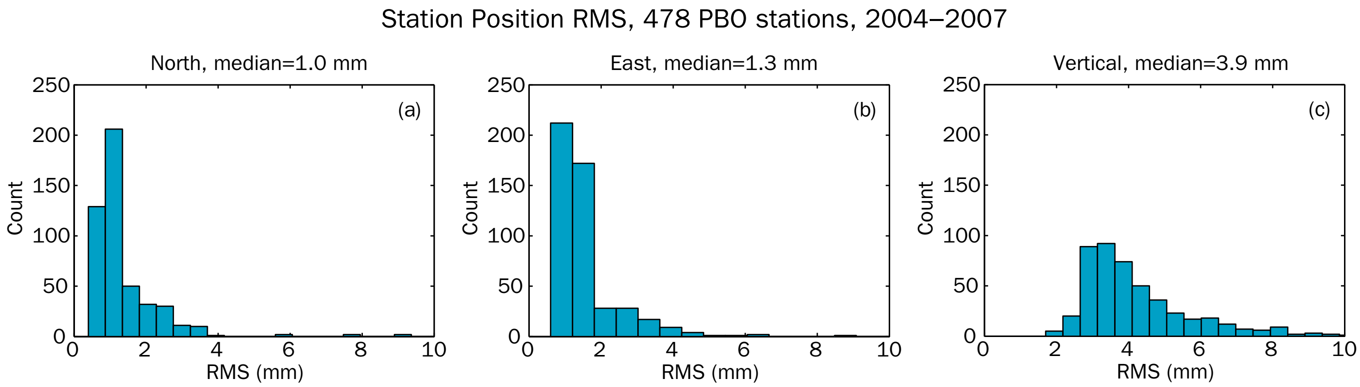


Figure 4.8. One key PBO GPS data quality metric is the RMS noise level in each station's position time series. (a) shows a histogram of the RMS noise level in the north component of the position time series for all PBO stations with at least 60 days of data through the end of January 2007; (b) shows the same, but for the east component; (c) shows the same, but for the vertical component. Median values for each are shown in the titles for each subplot. PBO is well within the range of uncertainty, less than 2 mm horizontally and 5 mm vertically, that would be expected from three years of high-quality GPS processing.

funded facilities and ensures that physical samples and logs collected during the installation of the PBO borehole instruments can be made available to the EarthScope community at no cost to EarthScope and very nominal cost to EarthScope users. No funding is requested for this activity.

Seismic Data Management

PBO borehole seismic stations collect three components of continuous 100-sps data; some stations may also collect 200-sps data where communications systems will support that data rate. All PBO seismic data flow in real time to the Boulder NOC, and from there to the IRIS DMC, via the Antelope Environmental Data Collection system; each station also has a local buffer in the event of temporary communications failures. UNAVCO staff monitor the network health and data quality using the Antelope system, and the DMC archive provides data to EarthScope users.

PBO also uses the Antelope system to provide seismic data directly to regional seismic network operators. This benefits the community by improving the quality of regional earthquake catalogs and by providing rapid access to PBO data for hazard monitoring and mitigation activities, at no additional cost to NSF. Direct use of PBO seismic data in regional networks also helps UNAVCO improve the quality of seismic data because network operators report back on timing quality and noise levels, which helps UNAVCO identify and correct possible problems more rapidly than would otherwise be possible.

Critical Hardware and Software Systems

The overall PBO Data Management System has been developed to be fault tolerant and to provide high-quality data in a timely fashion. All critical functions operate on enterprise-class servers and disk-based mass storage systems. To mitigate the risk of system failure in Boulder, UNAVCO is also developing a secondary NOC and archive at an offsite location. Servers and a mass storage system at this facility will be held in a warm failover status, ready to take over key functions rapidly when needed. Finally, the Data Management System is layered to minimize the risk of data loss, including local buffers at each station, large-capacity mass storage systems at each NOC, and multiple archives for each class of PBO data. Support for all these systems is included in the proposed budget.

Borehole Network Operations (2.3.4)

As part of PBO, UNAVCO will install 103 borehole strainmeter (BSM) stations, each consisting of a Gladwin tensor strainmeter (GTSM); a three-component borehole seismometer; environmental sensors that record information such as downhole temperature, pore pressure, and barometric pressure; a GPS receiver, where suitable; and power and telemetry systems. These instruments, which will be installed around tectonic and magmatic targets from Vancouver Island to southern California (Figure 4.9), are ideal for recovering transient deformation with periods from seconds to a month, and play a central role in observing phenomena that precede and accompany earthquakes, volcanic eruptions, and post-seismic transients.

This WBS element covers O&M activities, including all staff, facilities, travel, ongoing cost, and materials to support PBO BSM stations.

BSM O&M activities will primarily be handled by a staff of 4.5 field engineering FTEs, with backup provided by cross training with GPS operations staff and using UNAVCO field engineering staff. The BSM O&M staff include a field operations manager stationed in Boulder (0.5 FTE), who manages one field engineer and one network engineer based in Boulder, one field engineer based in Portland, and one field engineer based in Southern California (1 FTE each). The network

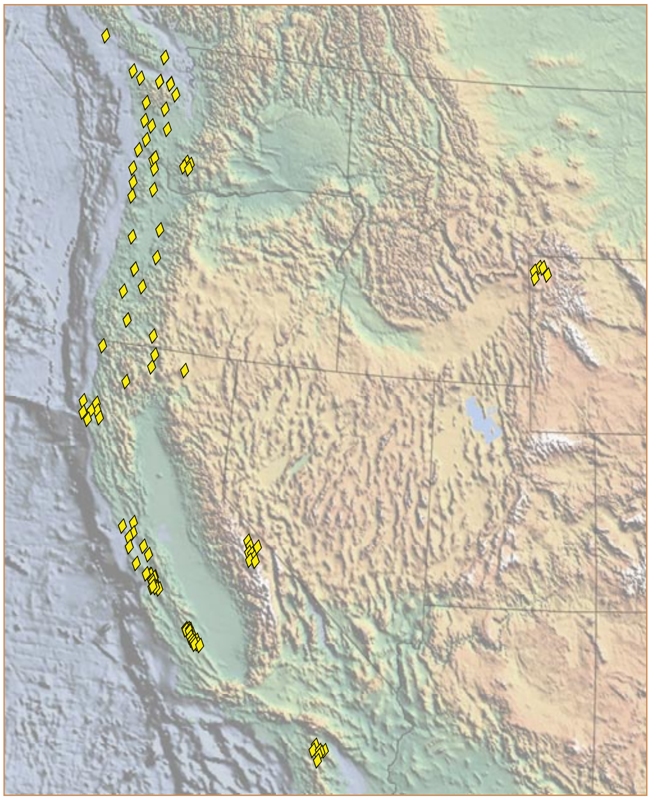


Figure 4.9. Map showing locations of PBO borehole strainmeter stations.

engineer monitors all borehole equipment, quality control, station configuration management, and O&M documentation. Field engineers will spend approximately 60% of the time in field maintaining and calibrating up hole electronics for strainmeters and seismometers with the remainder of the time spent assisting in GPS O&M activities and documentation. For example, time-dependent calibration of cable due to aging, stretch, and grout curing; downhole temperature calibration; and quadrature of strainmeter and cable response are all calibration activities that can not be performed remotely. Table 4.4 summarizes proposed BSM O&M staffing.

Biannual visits will be used to calibrate the GTSM and associated components. Biannual visits will be coordinated with two- and three-year scheduled maintenance trips during which expendable materials such as batteries and VSAT feed-horn elements will be replaced; power-supply systems, such as propane-powered thermoelectric generators, will be maintained (every six months); and software and firmware upgrades will be performed (as needed; certain components of the GTSM require a site visit for firmware upgrades, such as the GPS timing unit). The manufacturer of the GTSM instrument recommends three visits per year in the first few years after installation, decreasing to two per year as the instrument and hole exhibit long-term stability (> 1.5 years).

Despite preventative maintenance, we anticipate that stations will suffer failures and require unscheduled repairs. To

TABLE 4.4. PROPOSED BSM OPERATIONS AND MAINTENANCE STAFFING

REGION	LOCATIONS	FTES	BSM STATIONS	STATIONS PER FTE
Northwest	Portland, OR	1	33	33
Southwest	Los Angeles, CA	1	33	33
East	Boulder, CO	2.5	37	24
	TOTAL	**4.5**	**103**	**29**

minimize staff and maximize scientific benefit, we will ask the PBOSC to scientifically prioritize stations so that critical stations will be serviced according to the regular scheduled maintenance. For example, a key station for resolving strain associated with episodic tremor and slip events may be a higher priority than an inoperable station situated within a cluster. We estimate 20 such unscheduled visits per year.

We will achieve cost reductions by coordinating all maintenance activities so that multiple stations are visited together, by sharing facilities with GPS network operations staff, and by cross training GPS and BSM operations staff. BSM engineers are capable of maintaining collocated and nearby GPS stations; all GPS engineers will be trained to service basic power and communication problems of the borehole sites, allowing already remote or deployed engineers throughout PBO to service stations while minimizing the budget impact, especially in unplanned maintenance trips.

GPS Operations (2.3.5)

PBO will provide operations and maintenance support for 1100 permanently installed continuous GPS (CGPS) stations located throughout the contiguous United States and Alaska. As indicated in Figure 4.10, PBO will maintain a network that has a north-south extent of over 5600 km, stretching from the United States, to the Mexican border, to well north of the Brooks Range in Alaska, and an east-west footprint of over 7200 km stretching from the east coast of the United States to Amchitka Island at the western end of the Aleutian chain. Our proposed approach to operating and maintaining this network is fourfold: (1) streamlining the PBO regional office structure, (2) grouping maintenance visits to multiple stations at any one time, (3) sharing maintenance work with BSM operations staff, and (4) scientific prioritization of unscheduled maintenance visits.

O&M activities will be coordinated by the GPS Operations Manager in Boulder, who will manage a staff of ten remote field engineers. O&M activities will be based out of four primary regional offices, shared with the BSM Operations staff, and five satellite home offices (Table 4.5). Each of the regional offices will house one to two personnel and have a small warehouse for storing spares and maintenance equipment; each of the satellite offices will house 1 FTE and will have an associated self-storage locker to receive and store

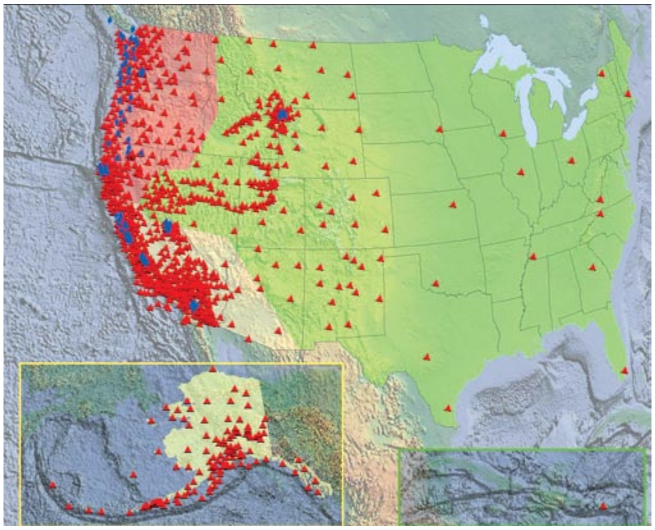


Figure 4.10. PBO GPS (red triangles) and strainmeter (blue triangle) instrumentation footprint. Map color coding indicates approximate division of resources for O&M. Alaska area is shown in light green and will be serviced out of the Anchorage, AK office. Red shading shows stations maintained out of the Portland, OR main office and Ellensburg, WA and Eureka, CA home offices. Blue shading show stations maintained out of the Southern California office and a home office in San Francisco. Large green shading indicate stations maintained out of home offices in either Reno or Salt Lake City, Bozeman, MT, and UNAVCO Boulder.

TABLE 4.5. GPS OPERATIONS AND MAINTENANCE STAFFING

REGION	WAREHOUSE AND SATELLITE OFFICE(S)	FTES	GPS STATIONS	STATIONS PER FTE
Northwest	Primary Office		300	100
	· Portland, OR	1		
	Home Offices			
	· Ellensberg, WA	1		
	· Eureka, CA	1		
Southwest	Primary Office		400	133
	· Greater Los Angeles Area, CA	1		
	Home Offices			
	· San Luis Obispo, CA	1		
	· San Francisco, CA	1		
East	Primary Office		258	129
	· Boulder, CO	1		
	Home Office			
	· Reno, NV or Salt Lake City, UT	1		
Alaska	Primary Office		142	71
	· Anchorage, AK	2		
TOTAL		**10**	**1100**	**110**

equipment required to maintain a group of stations within the area of responsibility of each office (Figure 4.10). The UNAVCO office in Boulder will be used to service stations in the Rocky Mountains and the eastern United States and will act as a shipping and receiving warehouse for equipment. The distribution of offices shown in Table 4.5 and Figure 4.10 will maximize efficiency by minimizing travel time from the field offices to stations to be maintained.

Streamlining the regional office structure is one step toward the goal of operating and maintaining the network as efficiently as possible given budgetary constraints, while still providing a high level of scientific benefit. Further efficiencies will be achieved by cross training GPS and BSM field engineering staff so that they can be mutually supporting and by grouping maintenance visits to maximize the number stations visited in each trip.

The final key element to our proposed approach is to prioritize maintenance of inoperable stations on the basis of maximum scientific benefit, not on the basis of allowable down time. For example, a GPS station in the Pacific Northwest that becomes inoperable during an episodic tremor and slip event would be repaired as quickly as possible, whereas a non-operational backbone station in central Montana would not be repaired until it is cost effective to do so. During the construction phase, the PBOSC provided scientific and management advice to the project. As the project transitions to operations and maintenance, we will use the PBOSC to prioritize stations based on scientific value. The list of priorities will be constantly updated based on significant tectonic events and during monthly PBOSC conference calls. PBO will make every effort to repair the high-priority stations as quickly as possible, while working within the constraints of the budget. The expected level of operation for any given time for the entire GPS network will be 80% network uptime. We believe that this is a reasonable expectation of performance given the budget realities and the unacceptable high operating costs associated with a system based on allowable down time.

As Table 4.5 indicates, there is an average of 110 GPS stations to be maintained by each field engineer. The number of GPS stations maintained per person is high, but we believe the efficiencies gained by using geographically distributed home offices, prioritizing maintenance based on scientific priority, and efficiencies gained by combining routine and unscheduled maintenance visits will result in fewer engineers needed to maintain more stations. Combining unscheduled and scheduled maintenance, cross training strainmeter and GPS personnel, and using PBO management and UNAVCO facility engineering staff as maintenance resources will further increase our efficiency and ability to meet 80% uptime under the existing budgets.

As part of the MREFC, PBO purchased and supports 100 campaign GPS systems used to support PI-funded science projects. These systems will require maintenance during the O&M phase of EarthScope. The repair and maintenance of the equipment is to be performed by the UNAVCO Facility and funded by the Facility's core NSF support, as is any field engineering support associated with these projects. This proposal requests 50% support for a campaign project engineer to manage the equipment pool, assist PIs in the technical and scientific aspects of project development and proposal and budget preparation, and provide advice and support during and after the field experiment.

PBO Education and Outreach

During the MREFC phase, PBO E&O has provided materials for public outreach via various media, developed a program to employ students in the construction of PBO, put on events associated with local installations, developed curricular materials for middle, secondary, and tertiary teachers and faculty for use in their classrooms, developed educator-friendly access to PBO data via the Web, and started a series of short courses to enhance the scientific community's use of PBO data. FY09 through FY13 will build upon this groundwork to more broadly disseminate these products and programs in areas within the PBO footprint and elsewhere in the nation.

Broadening participation of underrepresented groups in EarthScope has been and will continue to be a high priority for PBO. Already the short-course series on using data and data products from GPS and borehole strainmeters have attracted young scientists (undergraduate and graduate students, post doctoral fellows), international scientists, and new users to our community. The summer program for students to be involved in the building of the PBO will continue, and in FY09–13 of EarthScope, PBO will host an undergraduate research intern to help provide a sustainable base for the established Research Experience in Solid Earth Science for Students (RESESS) (http://resess.unavco.org) program. Hence, EarthScope will be a full partner in this program which actively recruits students from minority-serving institutions across the country.

The Director of the UNAVCO Education and Outreach Program will manage the PBO E&O activities and supervise a full-time educator to implement the other activities:

- Presenting regional and local teacher professional development workshops as well as short courses at national meetings
- Developing new and disseminating existing materials and/or training for interpreters at local, state, and national parks
- Writing new materials to be used in EarthScope activities, such as the Web site, Distinguished Speakers series, and newly developed EarthScope-led E&O activities.
- Recruiting students for summer PBO student program
- Recruiting students from underrepresented groups to the RESESS program
- Working with EarthScope committees to establish priorities for short courses for scientists and implement those short courses.

Collaborative activities with USArray include:

- Co-editing the quarterly *OnSite* newsletter
- Providing PBO-related scientific information and interpretation of PBO data for the EarthScope Web site and the Active Earth display
- Providing classroom activities for collaborative teacher professional development workshops
- Working with IRIS to implement other activities as defined by the EarthScope Advisory Committee and the EarthScope National Office

USArray (2.4)

This section identifies O&M activities to be conducted during the five years addressed by this proposal for each of the six USArray components: USArray Management, Transportable Array, Flexible Array, USArray Data Management, Siting Outreach, and Magnetotellurics. The work breakdown structure (Figure 4.11) identifies these six active components plus the Reference Network component that was completed under the MREFC phase and for which O&M responsibility now has been transferred to the USGS. The description of tasks in this section is presented in terms of the work breakdown structure shown in Figure 4.11. The budget plan in Section 5 and budget details in Section 7 are linked via the same organization and numbering conventions.

Over the next five years, the primary tasks to be undertaken by USArray to support EarthScope's scientific goals are to:

- move the location of half of the 400 Transportable Array stations each year while maintaining the data return from the installed stations at 85% or above
- make 90% of the portable Flexible Array instrument pool available for deployment
- maintain the permanent MT stations with an average data return of 85% or above
- deploy at least one MT experiment with transportable instruments each year
- manage all of EarthScope's seismic data and distribute the data quickly and easily via the Internet to all interested parties.

USArray Management and Overall Support (2.4.1)

USArray is being implemented as a large and complex project that extends across all of the IRIS core programs. This integration between USArray and the core IRIS programs is designed to maximize integration with the IRIS core programs so as to gain experience, resources, and efficiency, and ensure minimum impediment to access to data and facilities for researchers. Thus, the Flexible Array is managed as part of the PASSCAL program; data archiving and distribution is handled through the IRIS Data Management System (DMS); and Siting Outreach through IRIS E&O.

To take advantage of and maintain the synergy between the core program elements and the corresponding EarthScope components, USArray provides partial support for the core Program Manager salaries (10% of the PASSCAL Program

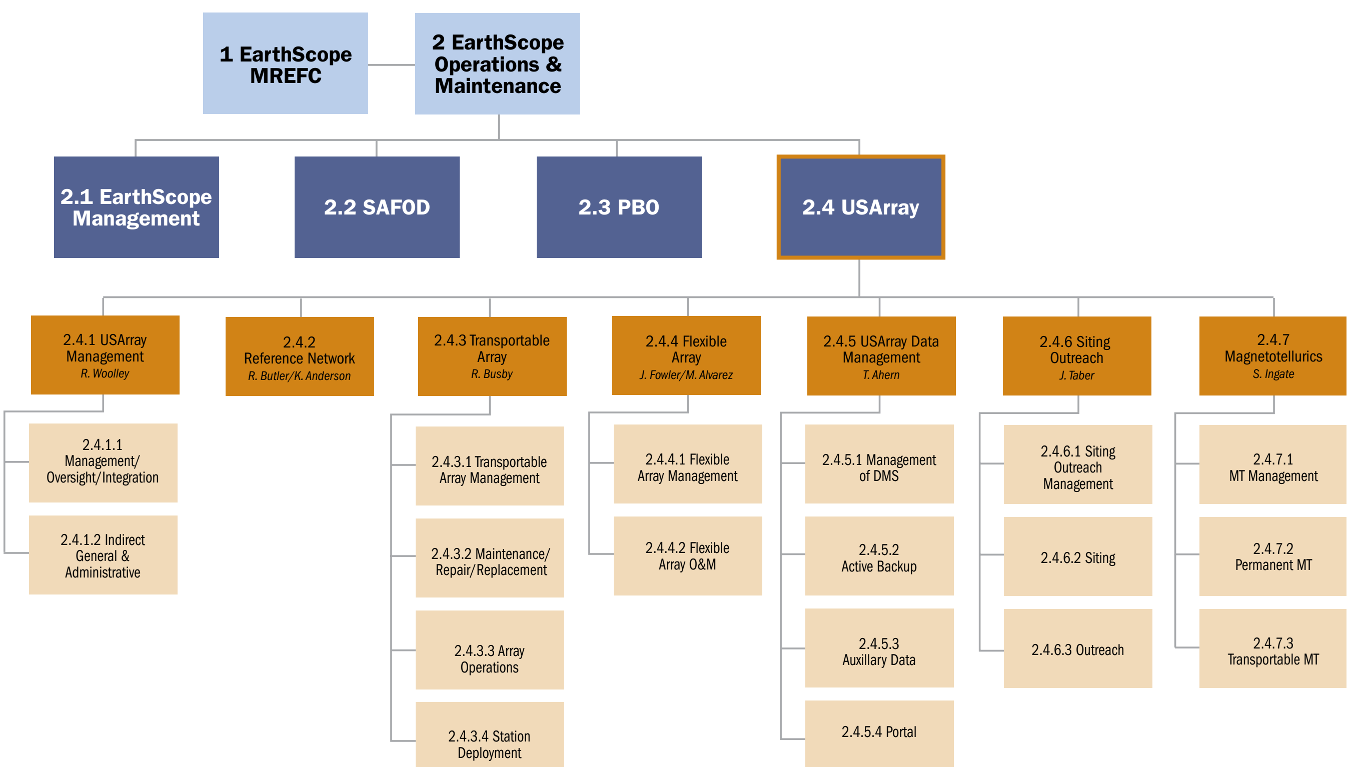


Figure 4.11. Work breakdown structure for USArray O&M activities. The figure identifies the six active USArray components for which O&M is requested in this proposal, and one component for which O&M responsibility has been transferred to the USGS (Reference Network).

Manager and 75% of the Deputy Program Manager for the Flexible Array; 10% of the E&O Program Manager for Siting Outreach, 20% of the Data Management System Program Manager for Data Management, and 20% of the Director of Operations for Magnetotellurics). A full-time manager is supported for the challenging and complex Transportable Array. A full-time Director of Project Administration knits this diverse group into a cohesive whole. USArray is currently accomplished with fewer than four management FTEs. IRIS is recruiting for a USArray Director with the encouragement of NSF. This proposal includes funding to support this position. When this position is filled, the time allocation for the Director of Project Administration during the O&M phase will be reduced to 50%, keeping USArray management near 4 FTE.

The management group is responsible for assuring consistent and defensible budgets are assembled and adhered to, schedules are established and adhered to, changes are appropriately considered and documented, equipment and services are procured fairly and efficiently, and stakeholders are kept adequately informed. Over the five years of this proposal, USArray management will:

- ensure that reports are prepared in accordance with NSF requirements and submitted quarterly. Reports will compare planned to actual expenditures and will provide NSF with narrative descriptions of accomplishments and concerns.
- conduct annual budget reviews to ensure that expenditures are accurately planned based on actual experience.
- assure that procurements are adequately planned and made efficiently and fairly in accordance with NSF requirements.
- determine risks to on-time completion within scope and arrange for appropriate risk mitigation. These activities will be accomplished by compiling a risk register and reviewing the identified risks periodically with the USArray component managers.
- assure policies and procedures are in place to comply with NSF requirements and any applicable regulations.
- assure timely responses to questions and requests from NSF and obtain timely approvals from the EarthScope Management Team and NSF.
- assess and assure adequate staff and organizational relationships for USArray to meet its goals.
- assemble, justify, and obtain approvals for significant changes in the scope, schedule, or budget for the program.

By conducting the above activities, USArray management will assure that operations and management of USArray achieves its mission, goals, and objectives.

Another key feature of USArray management is the involvement of the scientific community. Community representatives participate in committees that review and make key recommendations to the IRIS Board and management on the implementation of USArray. The eight-member USArray Advisory Committee (USAAC) oversees the entire project and makes recommendations to the IRIS Board of Directors regarding USArray operations to optimize the use of limited resources to the maximum benefit of the science community. The USAAC has two conference calls and two meetings annually and the Chairman represents the Committee at regular IRIS Board of Directors meetings.

Supporting USAAC are two committees focused on the parts of USArray that significantly depart from traditional IRIS activities and programs—the Transportable Array and Magnetotellurics. The eight-member Transportable Array Working Group (TAWG) closely oversees the progress and initiatives of the Transportable Array through monthly phone calls and an annual meeting. The TAWG chairman represents the Committee on USAAC conference calls and at meetings. Similarly, the eight-member Electro-Magnetic Working Group (EMWoG), endorsed by the Electro Magnetic Studies of the Continents (EMSOC) consortium, guides the MT activities and makes recommendations to USAAC.

Maximizing the efficiencies associated with the similarities between IRIS core programs and USArray components and taking advantage of willing science community representatives in a workable structure results in an effective and efficient management system for USArray.

Reference Network (2.4.2)

An essential component of USArray is the Backbone Network of the USGS Advanced National Seismic System (ANSS), which acts as a Reference Network for the Transportable Array. Under the MREFC phase of EarthScope, USArray contributed resources for the construction or upgrade of 39 stations to the ANSS to aid in completion of the Backbone. Operation of these stations has now been transferred to USGS. The USGS is responsible for maintaining these stations, tracking performance, quality assurance and providing the data from all stations of the Backbone Network to the IRIS DMC for merging and distribution with the other USArray stations. To remain consistent with the existing WBS structure for EarthScope, this WBS element is retained, although no budget is requested in this proposal.

Transportable Array (2.4.3)

The Transportable Array component of USArray is a network of 400 broadband seismic stations that are designed to be installed for a 24-month period of operation and then removed and installed again as the array migrates from west to east across the United States and finally to Alaska. Activities for the Transportable Array differs from most other components of EarthScope during the O&M phase in that, rather than operating equipment in place, the Transportable Array will be constantly on the move, with stations being installed at an average rate of approximately five installs and removals per week. One of the primary scientific goals of the array is to form a three-dimensional image of the velocity structure beneath the North American continent using a variety of techniques that produce structural information at different depths. To achieve this goal requires instrumenting a large geographic area simultaneously and operating at high-performance levels. Over the course of the experiment, each station will be installed five times (Figure 4.12).

By September 2007, MREFC funds will have been used to acquire all of the major equipment items for the Transportable Array and to support the establishment of the first footprint of 400 stations in the western United States. The O&M phase of the project requires funds for five removals and four more deployments, and station operation and data collection when not in transit. During the MREFC funding cycle, an efficient model for station installation has evolved and we have administratively separated costs by task. These task definitions are being retained in the O&M phase to benefit from the detailed cost experience. New techniques or methods for station installation will still be considered, but need to maintain consistent data quality and the enormous size of the deployed array means that, in practice, changes are evolutionary. Indeed, basic station design has evolved from a similar design employed by TriNet in southern California.

The Transportable Array budget and tasks are aligned with general operational aspects by function: management, maintaining the equipment pool, operating the array, and rolling station deployments.

The field activities that represent the core operational tasks of the Transportable Array are supported by two centralized functions: (1) management of the whole enterprise, which mainly involves status reporting in a variety of forums, planning the coordination of tasks, staffing, committee oversight, and budgeting and (2) equipment-pool upkeep and inventory control, a function modeled after PASSCAL and performed by the staff for the Array Operations Facility at the PASSCAL Instrument Center. As part of the upkeep of the equipment pool, costs for hardware replacement are based on percentages of capital assets.

Operating the Transportable Array involves two functions. The first function is servicing operating stations. A small mobile staff corrects any problem that may develop at a station, such as vandalism, landowner concerns, weather issues, or communication failure. By design, the stations do not normally require visits and can operate unattended for the entire two-year deployment. The second function is data collection, which includes the cost of telemetry providers (not the equipment itself) and a subaward to the University of California, San Diego for the Array Network Facility (ANF). This facility acquires data automatically, monitors and evaluates station quality, and assembles essential metadata that describe the station hardware in terms of instrument type and response, serial number, and other parameters. These metadata are passed to the IRIS DMC, which transfers this information to the end user. The ANF also maintains net-

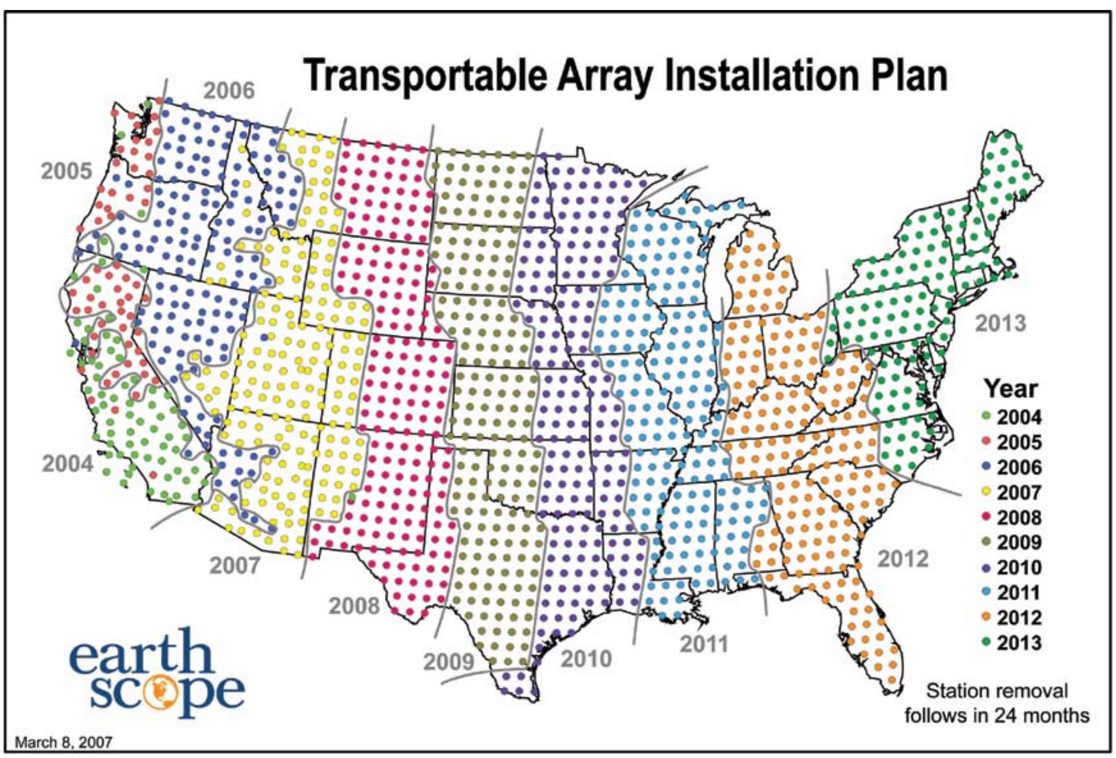


Figure 4.12. Current and planned installations for the Transportable Array. The stations indicated for 2004, 2005, 2006, and most of those for 2007 represent the first 400-station footprint to be installed under MREFC funding (compare with Figure 2.1 for a more specific MREFC map). Future years show the installation schedule under O&M funding for calendar years 2008–2013. In 2014, the array will begin deployment in Alaska.

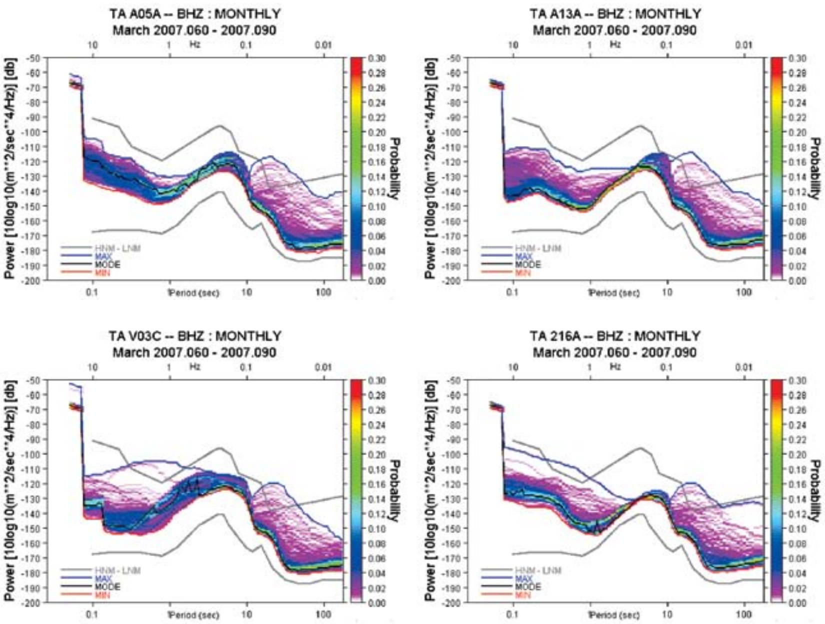


Figure 4.13. Examples of the noise performance (power spectral density plots) for typical Transportable Array stations. The range of noise levels over a one month time interval is shown. The brighter colors indicate the most probable levels; outliers indicate less frequent changes in signal level due to wind, traffic, or earthquakes. The microseismic peak near 8 sec is typical of continental stations, The noise levels over the entire range shown compares favorably with the performance of other permanent stations of the GSN and ANSS.

work-to-network data connections to facilitate data access for shared stations that are critical to the monitoring needs of collaborating regional networks. The ANF provides Web-accessible status information and details about stations, including photos and noise calculations, and provides a wealth of array-performance reports for online diagnosis (Figure 4.13). Data also flow to the IRIS DMC, which (as a separate proposal task) is responsible for the long-term management of USArray data and the distribution of Transportable Array data to the scientific community and the public. The separation of tasks for operation, in which field crews are responsible for station maintenance, the Array Network Facility tracks communications and data flow and the DMC is responsible for archiving and distribution has proven to be effective for both USArray and IRIS core operations, through inherent checks and balances and by focusing key talents on critical parts of the data collection process.

The rolling station deployment aspect of the Transportable Array can be thought of repeating five basic tasks in any and every imaginable field setting, climate, and landownership situation. The five tasks (Table 4.6) are permitting, construction, installation, operation, and removal. The tasks at some station sites are easily accomplished at low cost, but can become challenging at others. Despite the wide variation in task costs, large numbers provide robust averages for cost estimates. These are detailed below.

The strategy for construction and installation that the Transportable Array has developed through the MREFC period delegates each field task to a team of individuals, usually contract employees, that specialize in this activity. IRIS staff or direct subawards from IRIS (e.g., the Transportable Array Coordinating Office at the IRIS PASSCAL Instrument Center in Socorro, NM) maintain coordination among teams. The field teams can be expanded or contracted in size and effort to realize quick progress when the situation allows and reduce costs when weather or shortages cause delays. The long time horizon for the project is both daunting and in many ways reassuring to the staff. There is time to take pride in the work and do things right. Thus far, staff enthusiasm remains very high. It is important to recognize that the field crews are continuously deployed, migrating from region to region with no fixed base of operation.

Two tasks bear special attention in the budget forecasts. Removal of stations has only been tested and we have little cost experience. Obtaining legal release that the site is reclaimed to original condition may result in costs that we have not estimated properly. Operation of the Transportable Array, in terms of the number of service visits and effort, has just Year Four of the MREFC phase for meaningful comparison. It is tempting to refer to regional networks for cost comparisons in this regard, yet these are not wholly appli-

TABLE 4.6. TASKS AND FTE LEVELS FOR CONSTRUCTION, INSTALLATION, OPERATION AND MAINTENANCE OF TRANSPORTABLE ARRAY STATION

OPERATION	Maintaining data performance metrics for 400 TA stations	7 FTE at ANF 3 FTE in field service 1 FTE in office
REMOVAL	Recovering equipment, reclaiming the vault, remediating site disturbance, and transiting equipment to next depot	4 FTE in field
PERMITTING	Locating a suitable site and receiving written permission to deploy a station there	2 FTE in office 4 FTE in field
CONSTRUCTION	Arriving onsite with the station-vault materials, excavation, and assembly of vault components	1 FTE in office 4.5 FTE in field Also includes operation and transport of excavation equipment.
INSTALLATION	Delivering, installing, and commissioning the seismic equipment and data-telemetry equipment	1 FTE in office 4 FTE in field

cable. The Transportable Array spans all five major western regional networks, at the same time. The array does not have an operational responsibility in responding to earthquakes, therefore the response time to service issues is less immediate. Our service teams tend to migrate around the array attending to issues regionally and with a response time about three weeks for stations with outages. Data are backed up on site on internal disks so that these infrequent outages, which are usually related to communication problems, do not necessarily result in data loss.

Station operations must be performed everywhere with strict adherence to schedule and with high reliably so that there is little opportunity for customization at individual sites. The standardization in operations, and optimization for overall efficiency and cost benefit, was an important aspect of the initial development of the Transportable Array. Significant efforts were made to optimize the vault design and field procedures to provide ease of installation and high performance in the frequency band of interest for tomographic studies (Figure 4.14). The data quality that has been achieved, which compares favorably with that at the best of permanent installations, and the success in achieving the target deployment rates shows the value of these early investments in careful planning and design.

As stations of the Transportable Array are installed, the appearance of a great many high-quality stations inevitably has spurred local interests to retain some of the stations as part of established regional networks. In California and Washington (Figure 4.15) there has already been significant success in working with regional networks to "adopt" stations to improve long-term regional coverage and create a lasting "legacy" for EarthScope. During the MREFC phase, the Transportable Array is supporting these efforts as a management task, but with a careful shepherding of the process in the hope that it becomes a common procedural avenue for future "adoptions." To reduce uncertainty in field operations, and significantly simplify the concept and execution of such asset transfer, the Transportable Array applies two basic rules when interacting with regional entities for transfer of equipment and operational responsibility: we incur no net loss of equipment inventory (in hand and available for deployment) and we do not disrupt the schedule for station installation and removal. In addition, the Transportable Array imposes a condition that all data produced by these stations continue to be available to the IRIS DMC. Arrangements are being established, with concurrence from NSF, to allow transfer and replacement of equipment. The ideal transfer involves an itemized inventory of equipment that is invoiced to the new operator and the Transportable Array purchases new equipment in routine annual procurements. The installed equipment remains untouched and in operation. The timing of the agreements and schedule of new procurements is critical so that Transportable Array operations can continue without in-

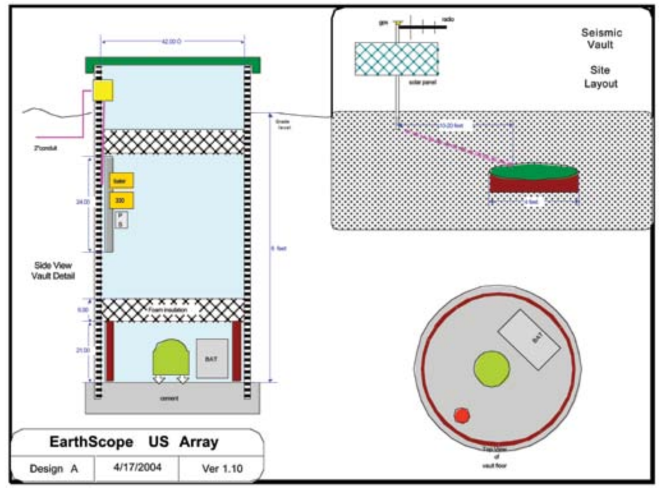


Figure 4.14. Details of the standard site vault developed for Transportable Array stations. Photographs of installation and sites are shown in Figure 2.2.

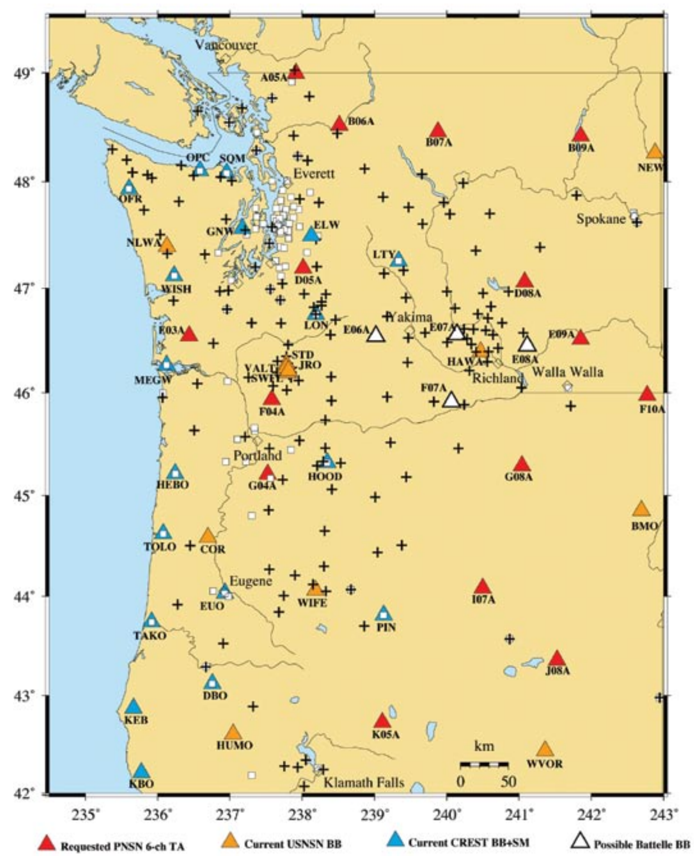


Figure 4.15. Stations of the Pacific Northwest Seismic Network (PNSN) showing current short period stations (crosses) and U.S. National Seismic Network (USNSN) broadband stations (yellow and blue triangles). The stations shown as red triangles will be transferred from the Transportable Array to the PNSN at the completion of the normal Transportable Array operating period in 2007. Funds provided by the Murdock Foundation will be used to replace the Transportable Array equipment and ongoing operational support will be provided by the USGS. Negotiations are underway for the additional stations shown as white triangles to be transferred with support from Battelle.

terruption. The incorporation of new equipment as opposed to redeploying existing equipment is expected to occur at small levels (fewer than 25 sites per year) and is not expected to involve significant cost or schedule impact. Once transfer has taken place, USArray does not accept any responsibility for ongoing support of these stations, but works closely with the regional network operators and other entities, such as the USGS, to encourage development of a stable plan for long-term operations.

Flexible Array (2.4.4)

The Flexible Array is a pool of instruments available for use by the research community in individual PI-driven studies. These investigations are designed to augment the Transportable Array footprint by imaging key targets at higher resolution than other USArray components (Figure 4.16). The mode of operation for the Flexible Array builds on many of the technical and organizational structures developed for the existing PASSCAL program. Maintenance, warehousing, training, and support services are provided through the Array Operations Facility (AOF) at the PASSCAL Instrument Center in Socorro, NM. In addition to the acquisition and maintenance of the instrument pool itself, the Flexible Array provides data processing support and station construction materials to the PI to help hasten data archiving and to establish uniformity in data quality.

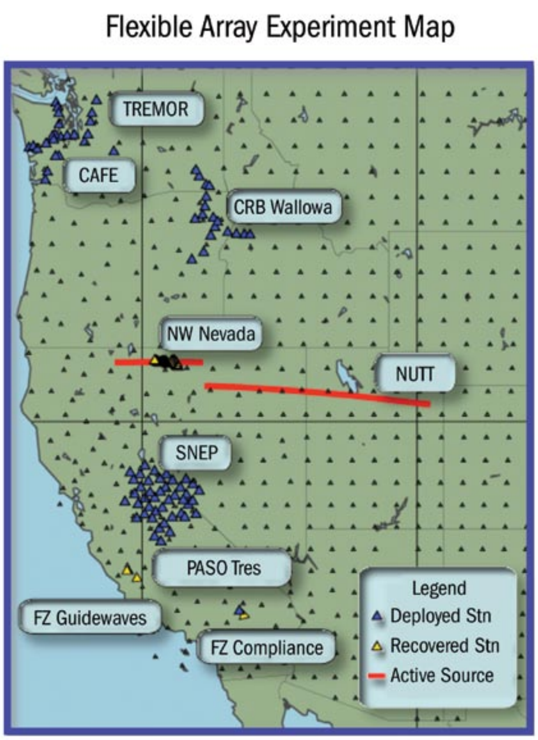


Figure 4.16. Completed Flexible Array experiments overlain on the Transportable Array grid (small blue triangles) as of January 2007. The map shows the dense deployments of broadband sensors (large triangles) and active-source experiments (red lines). These experiments are led by PIs who receive funding directly from NSF. Instruments, training and data archiving are provided by the Array Operations Facility staff.

The current plan for the Flexible Array calls for 291 broadband seismic stations, 120 short-period stations, and 1700 single-channel, active-source stations. A seismic station consists of a sensor, data acquisition system (DAS), solar power system, equipment enclosures, and communications for some stations. An active-source station consists of a single-channel DAS "Texan" with a vertical-component, high-frequency sensor. All or part of the pool can be used in multiple experiments of various size and duration. USArray personnel stationed at the AOF are responsible for equipment integration and maintenance, and provide technical assistance with deployment and data collection. The primary responsibility for instrument deployment and operation, however, rests with the PIs of the individual research programs. Many of the instruments will be deployed with telemetry. Data will be archived in the IRIS DMC as quickly as possible, and will be available through the DMC.

Flexible Array Management (2.4.5.1)

The IRIS PASSCAL Deputy Program Manager manages operation and maintenance of the Flexible Array, with assistance from the IRIS PASSCAL Program Manager. This dual oversight assures consistency between the Flexible Array and PASSCAL instrument pools and takes advantage of the wealth of experience accrued by the PASSCAL Facility while conducting similar experiments for over 18 years. The PASSCAL Deputy Program Manager (75%) and Program Manager (10%) will work closely with the staff of the AOF to coordinate activities in support of the Flexible Array.

Flexible Array Operations & Maintenance (2.4.5.2)

The Flexible Array instruments are predominantly intended for use in the field under harsh environmental conditions. The repair and maintenance of these instruments is an essential component of the program to ensure the viability of the pool into the future. To use the PASSCAL pool of instruments as an example, broadband sensors purchased in 1988 are still in field service today. This is only possible due to the diligent attention and expertise of Instrument Center staff who regularly repair these instruments each time they cycle through the facility. A full system checkout of each Flexible Array station is performed before being sent on a deployment. The maintenance goal is for 95% of the instrument pool to be available for field deployment.

Estimates for the repair and maintenance of these instruments are based on experience from current operations. The estimate is adequate to replace damaged, stolen, or destroyed equipment but not for modernization of the entire equipment pool. The effort can be divided into the following categories:

- Sensors (291 broadband, 120 short period, 1700 active source):
  - 3% of total sensor cost applied for maintenance, repair and estimated loss. Purchasing complete sensors is less expensive than stocking individual components. A combination of spare parts and new sensors are planned for this proposal
  - Spare parts for sensors include; element pivots, replacement boards, sensor caps, O-rings, connectors
- Cables (sensor and power system):
  - 3% of total cable costs applied for maintenance, repair, and estimated loss
  - Spare parts for cables include insulated wire, connectors, and potting components
- Data Acquisition Systems (411 Reftek R130, 1700 Reftek R125 “Texans”):
  - 3% DAS costs applied for maintenance, repair, and estimated loss
  - Spare parts for DASs include compact flash memory, connectors, replacement PC boards, O-rings, spare cases, replacement GPS antennas
- Materials and Supplies (power systems, communication, computers):
  - 3% materials and supplies costs applied for maintenance, repair, and estimated loss
  - Spare parts include solar modules, power regulation boxes, mounting brackets, shipping cases, sensor vault systems, radios, antennas, field computers, laptops, test equipment

The AOF, which is operated under subaward from IRIS to New Mexico Tech, supports similar Flexible Array and Transportable Array operations. It has plans for a staff of 14, including the Center Director, software engineers, hardware engineers, office managers, and an administrative assistant. AOF costs are split evenly (50/50) between the Transportable Array and the Flexible Array. The tasks performed by the AOF in support of the Flexible Array are the following:

- Repair, inventory, maintain, test, and ship 291 broadband stations, 120 short-period stations, and 1,700 active-source stations
- Provide training and documentation for PIs for the use of equipment
- For broadband and short-period experiments, provide limited field support for new deployments in the form of logistics, huddle testing, in situ training, and repair
- For active-source experiments, provide field support in the form of logistics, instruments programming, in situ training, repairs, and data downloading
- In cooperation with the PIs who are responsible for providing metadata and performing station service, archive data at the DMC
- Create and maintain tools to facilitate quality control, instrument control, and archiving of data from data loggers in the Flexible Array pool
- Real-time data processing
- Personnel recruitment and management

The tasks identified above are constrained by the following assumptions estimated for the Flexible Array:

- The pool of active-source stations is estimated to be deployed as a single pool for two experiments per year. For budgeting purposes, it is also assumed that active-source experiments will take place within the United States and be comprised solely of USArray instruments. It is anticipated that relaxation of this condition may evolve with time as new policies are developed with NSF to optimize the combined use of these instruments with the existing PASSCAL pool. If so, arrangements will be made with PIs and NSF for any augmented support required to support larger experiments or non-U.S. deployments.
- The number of total passive (broadband and short period) experiments, hence the volume of data anticipated, is estimated to be fewer than 10 per year, with an average of three annual service runs each.

The PI provides travel support for AOF field personnel for the experiment. Travel for extra training and problem resolution is also part of the activity planned.

USArray Data Management (2.4.5)

During the O&M phase of EarthScope, the IRIS DMS will continue to be responsible for receiving, archiving, and distributing data from multiple EarthScope sources. The sources include USArray (Reference Network, Transportable Array, Flexible Array, and magnetotelluric), PBO (borehole seismic, borehole strain, and laser strain), and SAFOD (250-hz monitoring data, event-windowed 4-khz data, and continuous 4-khz data).

The data-flow paths established during the MREFC phase are fairly mature at this point within USArray and EarthScope. Figure 4.17 shows both the path and types of data that currently flow within the DMS.

IRIS DMC staff will continue to apply quality-control procedures to data as appropriate. One of the primary aspects of quality assurance is to work with the data providers (i.e., Transportable Array, Flexible Array, PBO, and SAFOD) to ensure that the DMC holdings are synchronized with the data provider’s holdings and when not, participate in the process of transferring missing data to the DMC. USArray data analysts constantly monitor the usability of the data collected by USArray instrumentation. Significant effort is directed toward validating metadata that are provided by other EarthScope facilities. Waveform quality is also monitored for usability and, although waveform data cannot be retroactively corrected, USArray staff report significant problems to field operations to have problems addressed. Selected EarthScope data channels are also processed within the real-time quality assurance system at the IRIS DMC, called QUACK. This automated system continuously measures a variety of data metrics that capture specific aspects of data quality (Figure 4.18).

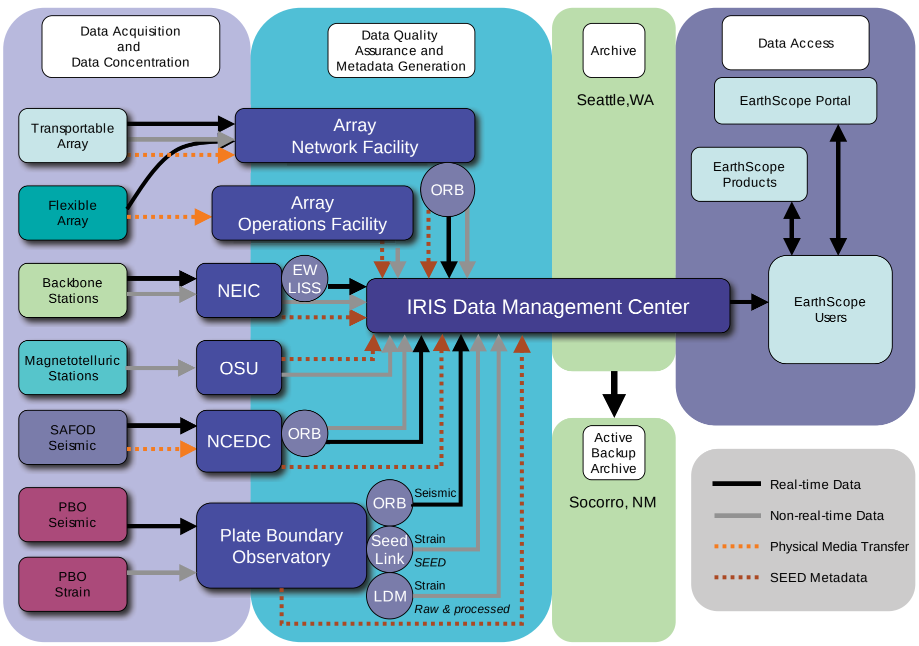


Figure 4.17. Dataflow within the Data Management System. This figure shows the variety of sources that send their data to the IRIS DMC from EarthScope sources. These include strain and seismic data from PBO, high-rate seismic data from SAFOD, magnetotelluric data from USArray, as well as seismic data from the Reference Network, Transportable Array, and Flexible Array. Data flow is complex and reaches the DMC from six different facilities using a variety of communication protocols.

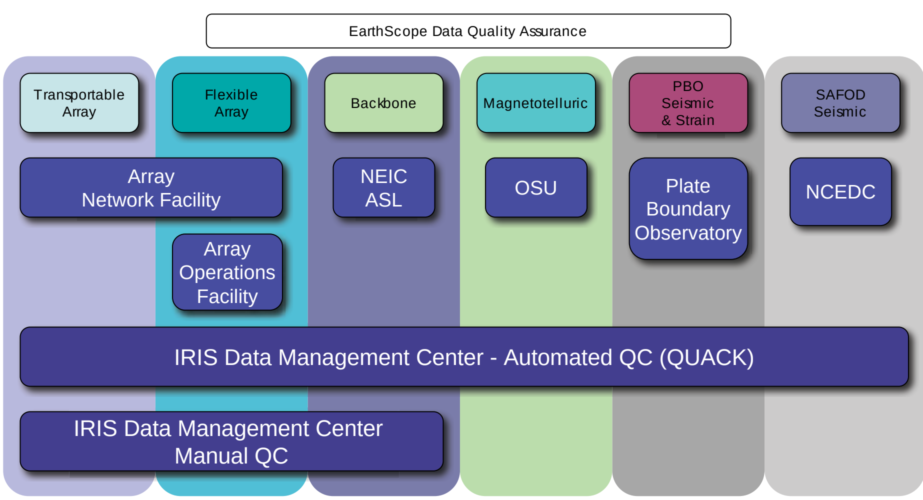


Figure 4.18. Application of Quality Assurance. This figure shows the facilities involved in quality assurance of EarthScope data for all data sources managed at the IRIS DMC. For example, data from the Flexible Array can receive QA at the ANF, AOF, the IRIS DMC, or through the automated QUACK system at the DMC.

Level 0-2 Products

The IRIS DMS will continue to produce level 0, 1, and 2 data products that were generated in the MREFC phase of EarthScope (0=raw waveforms; 1=quality-controlled waveforms; 2=low-level, derived products). Continued support of the SPADE Product Management System will also continue during the O&M phase of EarthScope. Some community-generated products will transition from being PI-generated to facility-generated products during the O&M phase. The DMC will work with PIs and the NSF to enable this technology transfer but the cost of doing large amounts of such migration has not been included in the O&M budgets since this would be an expansion in scope.

Performance Metrics

The formal measure used to evaluate performance of USArray data is the percent of data placed in the archive compared to the total amount of data possible for each station. USArray's goal as established under the MREFC is to maintain at least 85% data return. Performance metrics will continue to be measured early in the month for data received in the previous month as well as for the month three months earlier. Generation of USArray performance metrics during the MREFC phase of EarthScope has allowed us to focus on problems with data delivery in the case of the backbone network and to highlight the very high availability of data from components such as the Transportable Array.

IT Infrastructure

EarthScope heavily leveraged the IT infrastructure in place at the IRIS DMC. To manage the increased volume of data generated by EarthScope, the server and storage infrastructures were increased appropriately. The need to upgrade servers and add to the capacity of storage systems is an activity that must continue during the O&M phase of EarthScope.

A significant part of the cost for operations at the IRIS DMC is the maintenance of hardware and software systems. These maintenance costs are prorated among sources (IRIS core, USArray, SAFOD, and PBO) in proportion to the annual data-ingestion rate. For instance, in Year Four of EarthScope, USArray was charged for roughly 23% of maintenance costs at the DMC, and SAFOD and PBO were charged lesser amounts. Core funding from the NSF Division of Earth Sciences' Instrumentation and Facility Program still pay roughly half of the ongoing maintenance costs for hardware and software systems at the DMC.

IRIS has been able to leverage the superior connectivity of the University of Washington to ingest all data from EarthScope without augmenting leased circuits. We have also been able to distribute data using the existing Internet-2 connectivity through the University of Washington, and changes should not be required to this mode of operation through the O&M phase of EarthScope. EarthScope does pay for a portion of the connectivity by contributing to the DMC overhead, but it is very modest.

EarthScope MREFC provided funds for acquiring a tape-based mass storage system that forms the heart of a DMC Active Backup System being established at the PASSCAL Instrument Center in Socorro. This system is automated, allowing data from EarthScope and all other contributors to the IRIS DMC to continue to be received, archived, and distributed in the event of a catastrophic failure of the primary IRIS DMC (e.g., fire, earthquake). The cost of operating and maintaining this system will be shared between NSF Instrumentation and Facilities funds and EarthScope.

Siting Outreach (2.4.6)

Siting Outreach supports Transportable Array siting and deployment by assisting in finding potential sites, including organizing and training student reconnaissance teams, promoting the scientific value of the array during deployment, and providing a legacy for the local community after relocation of the Transportable Array. Siting Outreach is designed to be integrated with the permitting process, creating community awareness and interest as the Transportable Array arrives in a state and during its deployment.

Involving local universities and students in the siting process has proven to be very effective in selecting initial sties. Students conduct suitability analyses with map-based GIS systems to identify locations that meet many of the station criteria and then go into the field to make initial contact with landowners and further explore the suitability of each selected location. USArray staff then follow up to finalize permits and logistical details. In 2005, during the initial pilot project to test this concept, eight students identified more than 45 sites in Oregon over a 10-week period. The following summer, about 110 sites were selected by 13 students in Idaho, western Montana, and Utah. This activity engages the wider earth science community; makes use of local knowledge of seismicity, geography, geology, and land use; and provides students with an opportunity to engage in a continental-scale scientific experiment. This approach will continue as the Transportable Array rolls across the United States. Information about EarthScope and USArray will be disseminated via a variety of media, including newsletters, Web site, information sheets, posters, and a new Web-based museum and visitor center display known as the Active Earth display.

The IRIS Education and Outreach Program Manager will manage Siting Outreach operations and maintenance, and the full-time Siting Outreach Coordinator will handle day-to-day operations. Siting Outreach tasks will include the following:

- Co-editing the quarterly *OnSite* newsletter that is distributed to landowners and other hosts of EarthScope sites. This task is shared with PBO, with the lead editor role alternating between PBO and USArray.
- Providing a liaison between the universities involved in regional siting and the Transportable Array Manager. Tasks include organizing an annual workshop for university staff and students involved in regional siting and coordinating the reconnaissance subawards to the universities.
- Creating and updating information sheets for potential Transportable Array hosts and the general public.
- With the EarthScope National Office, coordinating public relations opportunities during siting, installation, and deployment.
- Coordinating efforts to provide simple data viewing and access for Transportable Array hosts and the general public such the USArray station monitor and the Rapid Earthquake Viewer.
- Providing simple educational seismographs and classroom activities to schools that host a Transportable Array site. The schools become part of an existing educational seismology network of over 120 schools.
- Providing content for the USArray Web site and the Active Earth display.
- Coordinating an annual subaward to a university or educational group to conduct USArray outreach with schools and the public in their region.

Magnetotellurics (2.4.7)

The Magnetotelluric (MT) facility records naturally occurring electric and magnetic fields at Earth's surface caused by currents flowing in the ionosphere and also deep within Earth. The Backbone component consists of seven permanent MT stations installed across the United States as a reference and deep-sounding network. The Transportable component is a mobile array of 20 MT systems that will each be deployed for a period of about one month in regions of identified interest with a spacing of approximately 70 km. These instruments were acquired during the MREFC phase. With O&M funds, both transportable and permanent equipment will be maintained and at least one transportable experiment will be conducted each year.

The IRIS Director of Operations manages the MT component of USArray. Management activities include coordinating the USArray Electo-Magnetic Working Group (EMWoG) technical and scientific tasks with EMSOC and other interested groups, organizing meetings, maintaining subawards, preparing reports, budgets, and proposals, as required, and re-bidding service contracts to conduct annual campaigns, as necessary.

MT Field Systems

A MT campaign experiment will occupy 50–60 sites over a period of 3–4 months using 20 Transportable MT systems augmented with additional systems from EMSOC, if available. Study areas are recommended by the EMWoG, representing the MT community, and approved by the USArray Advisory Committee, the EarthScope Management Team, and NSF.

A professional geophysical services company will be contracted to select sites, permit install and demobilize the equipment at each location. Each station will collect data for 2–4 weeks. Site selection and permitting will precede installation by at least one month. Because the MT systems do not have telemetry capabilities, data are recorded in situ. Following installation, the company will service the station every two weeks to recover data; check system state-of-health; and conduct in situ repairs, if necessary. MT data and metadata collected at each station will be sent to Oregon State University for processing and then archived at the IRIS DMC.

Contracted personnel will continue to operate and maintain seven permanent MT stations. Typical tasks include the repair and replacement of parts that are worn, malfunctioning, or have become non-operational, replenishment of the electrolyte approximately four times each year, and conducting visual and electronic tests of station equipment. Data will be telemetered to the ANF and shipped to the IRIS DMC for distribution and archiving. Data quality-control analysis and metadata maintenance will be conducted through a subaward to Oregon State University.

Oregon State University will be responsible for collecting data, formatting data into mini-SEED, and performing quality control checks on data from each transportable MT station. Oregon State University will also be responsible for maintaining station metadata. Other tasks include maintaining software applications for ingesting and analyzing the data and serving as the point of contact for field service contractors handling hardware and siting issues. The ANF will be responsible for receiving any real-time telemetered data and automatically formatting into mini-SEED.

A centralized maintenance and storage facility at Oregon State University serves both transportable and permanent activities. At the storage facility, equipment and spares are stored and maintained and staff ensures safe storage and disposal of electrolytes. Facility staff also test and prepare equipment before each deployment, train service contractors, and at the end of each campaign, clean the systems, ensure safe storage of electrode chemicals, and check and repair all systems prior to storage. During storage, batteries will be maintained.

Pan EarthScope

EarthScope Web Presence and Portal

In January 2007, following the closing of the EarthScope Facility Office and the start of transition to the Operation and Maintenance phase, UNAVCO assumed responsibility for coordination of EarthScope electronic documents and maintenance of the EarthScope Web presence. In collaboration with the other EarthScope facilities, NSF, and the new EarthScope National Office, UNAVCO will collect and archive all critical documents relating to the EarthScope facility project and use these, with other materials as appropriate, to maintain a Web site with current information on the EarthScope facilities and associated activities and data. In collaboration with the other components of EarthScope, PBO will use the Web presence to maintain an EarthScope "portal" that will provide centralized access to all data produced by the MREFC-funded EarthScope facilities.

PBO operates and maintains the EarthScope Web presence, which is primarily composed of:

1. EarthScope Web site
   This is the primary "public face" of EarthScope, where members of the broad community we serve can go to get the latest information on EarthScope status, science and program highlights, and so on. Its main elements are the main home page, the EarthScope Information System (used to provide up-to-the minute status of the EarthScope networks), and a set of subsidiary pages intended to provide access to information targeted for the science, education, government, and public communities we serve. Figure 4.19 shows the current EarthScope home page.
2. Document Management System
   This system provides Web-based access to all critical EarthScope documents in a central, secure system. Currently, this is part of the larger UNAVCO Document Management System. Documents in this system may be made public, as appropriate, or have access limited subsets of EarthScope personnel.
3. Image Archive
   This system will provide Web-based access to EarthScope images. It will provide search and retrieval capabilities, and is designed to facilitate the use of EarthScope imagery in research, education, outreach, and the like.
4. Portal
   The next section describes the EarthScope Portal.

During the O&M phase, we anticipate the principal effort will include system hardware replacement once every three to four years, software upgrades made only as often as necessary to support critical operations, and modest hardware growth to support the EarthScope Portal.

Large, dynamic projects with multiple key customers, such as EarthScope, will require significant attention be paid to keeping content updated and the EarthScope Web design fresh. To maximize responsiveness to NSF and other stakeholders, and to minimize cost and complexity, UNAVCO will

Figure 4.19. Current EarthScope home page (left) and new home page design (right). The main page provides access to recent events and current status information. The navigation panel to the left provides access to subpages that provide deeper information on current EarthScope status, the EarthScope components, EarthScope Education and Outreach, and other activities.

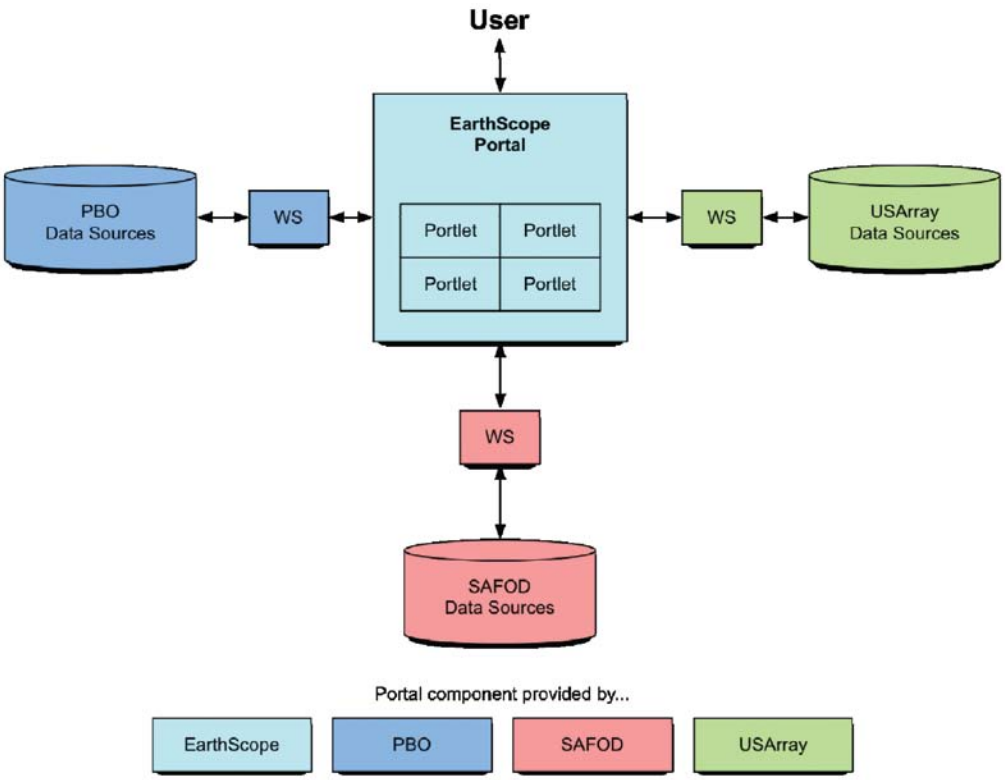


Figure 4.20. Conceptual diagram of the EarthScope Portal. Each EarthScope component will develop Web services to provide access to data managed by that component. The Web services will connect to a central portal, based on portlet technology, that will be developed by an outside contractor. The portal will provide integrated data discovery and access to digital data generated by the EarthScope components using MREFC funding. During the Operations and Maintenance phase, the portal will serve as the primary data access point for EarthScope and will be operated from the EarthScope Web site.

implement a content management system for EarthScope during the MREFC phase. Such a system allows multiple users to create, edit, and update content in a coherent framework, allowing a significant reduction in staff effort over what would be required in a traditional Web environment. The EarthScope Senior Web Administrator will be responsible for all tasks associated with operating and maintaining the EarthScope Web presence, and will be supported in this effort by a software developer primarily tasked to maintenance of the EarthScope Portal. The PBO budget request includes support to maintain and continue to operate this system during the O&M phase.

Operations and Maintenance for the EarthScope Portal

One of the key goals of EarthScope is to provide integrated, single-point access to EarthScope digital data products. To meet this goal, EarthScope will build, during the MREFC phase of the project, a centralized portal operated in conjunction with the EarthScope Web site. The present model is for a central portal based on portlet technology that is connected via Web services to the main data centers for the various EarthScope components. Figure 4.20 shows a conceptual diagram of the structure of the EarthScope Portal, and Figure 4.21 shows a general mockup of the look-and-feel that may be developed for the portal. Each component is responsible for the development of Web services at their data centers during the MREFC phase. This includes the UNAVCO data center for PBO data, the ICDP for SAFOD data, and the IRIS DMC for the USArray seismic and PBO and SAFOD seismic and strain data. The central portal will be developed by subaward during the MREFC phase of EarthScope but it will be operated as part of the EarthScope Web presence by the PBO during the O&M phase.

The O&M costs for maintaining the portal and acquiring new computing infrastructure in the form of servers and storage systems are included in the PBO and USArray budgets described in Section 5. The budget for the O&M phase of EarthScope is only intended to maintain the portal capabilities developed during the MREFC. It is assumed that if new products are developed as part of NSF-funded EarthScope research projects, then the product development activities themselves will include the costs of integrating the data product into the portal.

Broader Impacts – EarthScope Education and Outreach

With its broad national reach and exciting links to real-time observations of earthquakes and volcanoes, EarthScope provides a natural opportunity to engage the public and educational communities in developing a deeper understanding of earth science. The facilities developed by PBO, SAFOD, and USArray can play an important role in fulfilling the

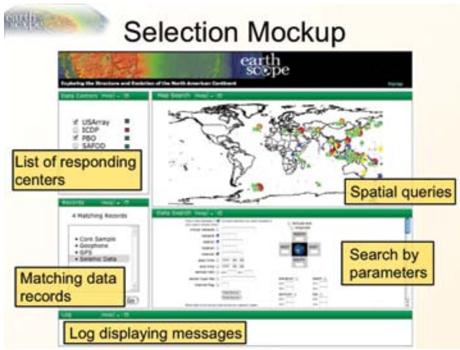


Figure 4.21. Mockup giving an example of one possible design for the front page of the EarthScope Portal. The portal will allow the user to search for and access EarthScope digital data products that match a variety of criteria, including spatial and temporal constraints, data type limitations, and other factors. Once the data have been selected through an interface similar to the above, the user will be able to add matching records they desire to a "data cart," similar to online shopping carts, through which the user will access the data they want.

part of the EarthScope mission by allowing the public to be directly engaged in an active program of data collection and research.

As a separately funded program initiated in parallel with the facilities during the MREFC phase, the EarthScope E&O Program has produced an implementation plan approved by the community and a structure to support this plan. The primary goals described in this implementation plan are:

- ***Goal 1:*** *Create a* ***high-profile public identity*** *for EarthScope that emphasizes the integrated nature of the scientific discoveries and the importance of EarthScope research initiatives.*
- ***Goal 2:*** *Establish a* ***sense of ownership among scientific, professional, and educational communities and the public*** *so that a diverse group of individuals and organizations can and will make contributions to EarthScope.*
- ***Goal 3:*** *Promote science literacy and understanding of EarthScope among all audiences through* ***informal education venues****.*
- ***Goal 4:*** *Advance* ***formal earth science education*** *by promoting inquiry-based classroom investigations that focus on understanding Earth and the interdisciplinary nature of EarthScope.*
- ***Goal 5:*** *Foster* ***use of EarthScope data****, discoveries, and new technology in resolving challenging problems and improving our quality of life.*

The EarthScope National Office and the E&O advisory committee (EEOSC) will provide the leadership in the E&O initiative. The primary funding for these activities will transition from the current EarthScope E&O award (through IRIS) to the National Office. The details of the structure, responsibilities, and mode of operation for the EarthScope National Office are yet to be determined, but the EarthScope facilities are committed to working with this Office throughout the O&M phase to provide information on facility activities, access to data, and coordination in educational endeavors with facility operations.

PBO, USArray, and SAFOD facilities will undertake specific outreach activities within the support of the O&M of each project that will complement the broader EarthScope E&O plan. Specifically, Siting Outreach for the Transportable Array focuses on strategic activities that support the movement of this facility across the United States. PBO activities focus on serving the communities in which the PBO facility is based and on engaging broader audiences in EarthScope. These audiences include middle and secondary students and teachers; the public who visit museums, interpretive centers, and public parks; undergraduate students; and a variety of scientific users. Publication of the *OnSite* newsletter, created to inform landowners at PBO and USArray field sites, has evolved into a widely distributed opportunity for informing the public of EarthScope operations and science. These facility-related activities are described within the O&M tasks for USArray and PBO and identified as specific items in the associated budget section. As they did during SAFOD Phases 1 and 2, SAFOD PIs and scientists will continue to conduct outreach activities aimed at both the general public and the scientific community during the O&M phase. These activities will include giving public and scientific lectures to various groups, appearing in documentary films, giving media interviews, hosting field trips and "media days" at the drill site, and working with NSF, Stanford University, and the USGS to issue press releases detailing the latest discoveries arising from this project.

In addition to the specific tasks supported under this O&M proposal, EarthScope E&O will benefit from close coordination with E&O programs separately funded as part of the core IRIS and UNAVCO activities and with ongoing E&O activities at the USGS and Stanford University. For example, IRIS E&O has well-established programs for seismometers in schools and museum displays that have been leveraged into EarthScope activities. Both IRIS and UNAVCO have developed educational posters and classroom materials on Earth science topics that link directly to EarthScope E&O. EarthScope will become a full partner in an existing program Research Experience in Solid Earth Science for Students (RESESS) (http://resess.unavco.org/) led by UNAVCO in collaboration with IRIS to increase participation in the geosciences by members of underrepresented groups in science and technology fields.

5. Budget Plan

This section describes the budget structure and costs for accomplishing the activities presented in the last section. An overall project budget is summarized Tables 5.1 and 5.2, followed by descriptions for each of the three EarthScope components. The budget explanations follow the work breakdown structure introduced in the last section. At the end of each component section is a table showing the budget broken down to the lowest level in the work breakdown structure.

This proposal requests support for five years and provides estimates for the next five years. The funds provided will be expended starting October 1, 2008 (start of FY09) and ending September 30, 2013 (end of FY13). The years in the text and tables of this proposal refer to the fiscal year in which the funds are planned for expenditure.

The total requested for five years is $125,506,820 as shown in Table 5.1.

The total estimated for the following five years is $144,444,754 as shown in Table 5.2 .

TABLE 5.1

WBS ELEMENT		FY09	FY10	FY11	FY12	FY13	TOTAL
2.2.1 SAFOD							
2.2.1	Management	166,019	140,694	129,980	133,880	137,896	708,470
2.2.2	Fiber Optics Laser	206,000	242,000	264,160	272,085	280,247	1,264,492
2.2.3	Seismic Data Processing	76,160	79,426	82,349	85,346	88,426	411,707
2.2.4	Physical Sample Curation	26,529	27,048	27,582	28,143	28,719	138,021
Management Fees		-	-	-	-	-	-
SAFOD TOTAL		**474,708**	**489,168**	**504,071**	**519,454**	**535,288**	**2,522,690**
2.3.1 PBO							
2.3.1	Overall Support	1,383,049	1,520,621	1,562,304	1,604,472	1,647,797	7,718,243
2.3.2	Long-baseline Strainmeter	264,750	271,275	277,696	283,996	290,443	1,388,160
2.3.3	Data Products	1,632,741	1,698,179	1,776,718	2,065,105	2,048,021	9,220,764
2.3.4	Borehole Strainmeter Operations	1,551,363	1,605,953	1,647,602	1,689,229	1,731,925	8,226,072
2.3.5	GPS Operations	4,608,097	4,683,972	4,845,679	4,967,198	5,091,814	24,196,760
Management Fees		40,000	40,000	40,000	40,000	40,000	200,000
PBO TOTAL		**9,480,000**	**9,820,000**	**10,150,000**	**10,650,000**	**10,850,000**	**50,950,000**
2.4.1 USARRAY							
2.4.1	Management	1,270,382	1,305,273	1,340,756	1,376,829	1,413,917	6,707,157
2.4.2	Permanent Array	-	-	-	-	-	-
2.4.3	Transportable Array	8,836,873	9,104,251	9,381,577	9,666,280	9,953,182	46,942,165
2.4.4	Flexible Array	1,368,399	1,415,752	1,464,396	1,514,365	1,566,124	7,329,035
2.4.5	Data Management	1,324,910	1,362,902	1,401,631	1,441,101	1,481,696	7,012,240
2.4.6	Siting & Outreach	244,435	251,343	258,361	265,487	272,813	1,292,440
2.4.7	Magnetotellurics	500,000	512,717	525,290	537,694	550,393	2,626,093
Management Fees		25,000	25,000	25,000	25,000	25,000	125,000
USARRAY TOTAL		**13,570,000**	**13,977,239**	**14,397,011**	**14,826,756**	**15,263,124**	**72,034,130**
EARTHSCOPE TOTAL		**23,524,708**	**24,286,407**	**25,051,082**	**25,996,210**	**26,648,412**	**125,506,820**

TABLE 5.2

WBS ELEMENT		FY14	FY15	FY16	FY17	FY18	TOTAL
2.2.1 SAFOD							
2.2.1	Management	142,033	146,294	150,683	155,203	159,859	754,072
2.2.2	Fiber Optics Laser	288,655	297,314	306,234	315,421	324,883	1,532,507
2.2.3	Seismic Data Processing	91,079	93,811	96,625	99,524	102,510	483,550
2.2.4	Physical Sample Curation	29,581	30,468	31,382	32,323	33,293	157,047
MANAGEMENT FEES		-	-	-	-	-	-
SAFOD TOTAL		**551,347**	**567,888**	**584,924**	**602,472**	**620,546**	**2,927,177**
2.3.1 PBO							
2.3.1	Overall Support	1,692,311	1,738,047	1,785,039	1,833,323	1,882,934	8,931,654
2.3.2	Long-baseline Strainmeter	297,037	303,783	310,684	317,743	324,965	1,554,212
2.3.3	Data Products	2,083,107	2,139,847	2,198,182	2,258,157	2,319,820	10,999,113
2.3.4	Borehole Strainmeter Operations	1,775,719	1,820,638	1,866,714	1,913,975	1,962,452	9,339,498
2.3.5	GPS Operations	5,219,607	5,350,660	5,485,057	5,622,886	5,764,234	27,442,444
MANAGEMENT FEES		**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**200,000**
PBO TOTAL		**11,107,781**	**11,392,975**	**11,685,677**	**11,986,084**	**12,294,405**	**58,466,922**
2.4.1 USARRAY							
2.4.1	Management	1,432,814	1,471,578	1,511,435	1,552,419	1,594,560	7,562,806
2.4.2	Permanent Array	-	-	-	-	-	-
2.4.3	Transportable Array	10,149,577	10,482,480	10,826,946	11,183,396	11,552,266	54,194,666
2.4.4	Flexible Array	1,619,740	1,675,283	1,732,823	1,792,436	1,854,199	8,674,482
2.4.5	Data Management	1,523,448	1,566,391	1,610,558	1,655,986	1,702,710	8,059,093
2.4.6	Siting & Outreach	280,344	288,086	296,044	304,226	312,637	1,481,336
2.4.7	Magnetotellurics	563,393	576,703	590,330	604,281	618,564	2,953,272
MANAGEMENT FEES		**25,000**	**25,000**	**25,000**	**25,000**	**25,000**	**125,000**
USARRAY TOTAL		**15,594,318**	**16,085,520**	**16,593,138**	**17,117,744**	**17,659,935**	**83,050,655**
EARTHSCOPE TOTAL		**27,253,446**	**28,046,383**	**28,863,739**	**29,706,300**	**30,574,886**	**144,444,754**

SAFOD Budget Summary

Table 5.3 summarizes the different elements of the SAFOD O&M budget for FY09–13, corresponding to the major SAFOD O&M activities described under Section 4.2.2. Detailed justification for each of these budget elements is as follows.

SAFOD Management (2.2.1)

Salaries: Salary is requested for the PI (one month summer) and 0.25 FTE for the Project Coordinator. The Project Coordinator has responsibilities for procurement and inventory, coordination of panel and advisory boards, reporting, cost/schedule management, and helping to coordinate education and outreach activities. This is a reduction from 0.5 FTE for the position during the MREFC. The salaries are adjusted for inflation and cost of living increases at 3% per year. Salaries include the cost of fringe benefits at Stanford's current rate of 29.7%.

Other Direct Costs: Other direct costs include miscellaneous project costs, field work, travel, communications, office equipment and publication costs. We request $30,000 (subsequently adjusted for inflation) for these items.

Indirect Costs: Stanford overhead is set by the Office of Naval Research at 58%. It is charged on the first $25,000 of subawards, and on all other categories except for equipment valued over $5,000.

Seismic Data Processing at the NCEDC (2.2.3)

As shown in Figure 4.3 and explained above, processing the seismic data from the SAFOD observatory will be a joint responsibility of the staff of the Northern California Earthquake Data Center (NCEDC) at the University of California, Berkeley, and the U.S. Geological Survey (USGS), in Menlo Park, CA. The NCEDC will perform data conversion, data quality control, and partial archiving of the SAFOD data at the NCEDC. The NCEDC will transmit all converted data to the IRIS Data Management Center (DMC). The NCEDC is uniquely qualified to perform these functions. Staff associated with the NCEDC have operated a borehole network in the Parkfield region for over two decades, have extensive experience analyzing Parkfield borehole seismic data, and have archived and distributed northern California data for the past 15 years.

Table 5.4 shows the NCEDC budgets for SAFOD seismic data handling. This budget assumes that the NCEDC will provide one disk-based copy and two tape copies of all data that will be permanently archived at the NCEDC, specifically, decimated waveforms, spectrograms, and triggered segments of high-sample-rate SAFOD seismic data. The disk copy provides rapid access in response to requests, and the tapes are standard onsite and offsite backups The NCEDC will also provide one copy of the recent continuous SAFOD seismic data on RAID storage. All data are also sent to the IRIS DMC.

TABLE 5.3. SAFOD BUDGET SUMMARY

WBS ELEMENT		FY09	FY10	FY11	FY12	FY13	TOTAL
	Salary+ Fringe	47,544	48,970	50,439	51,952	53,511	252,415
	Other Direct Exp	30,000	30,900	31,827	32,782	33,765	159,274
2.2.1.1	Total Direct	77,544	79,870	82,266	84,734	87,276	411,690
2.2.1.2	Indirect	88,475	60,825	47,714	49,146	50,620	238,780
2.2.1	**Stanford Management**	**166,019**	**140,694**	**129,980**	**133,880**	**137,896**	**708,470**
2.2.2.1	Fiber Optics Laser Strain Meter (UCSD)	30,000	30,900	31,827	32,782	33,765	159,274
2.2.2.2	Monitoring Array (Annualized Replacement Cost)	176,000	211,100	232,333	239,303	246,482	1,105,218
2.2.2	**Monitoring Total**	**206,000**	**242,000**	**264,160**	**272,085**	**280,247**	**1,264,492**
2.2.3	**Seismic Data Processing at UC Berkeley (NCEDC)**	**76,160**	**79,426**	**82,349**	**85,346**	**88,426**	**411,707**
2.2.4	**Physical Sample Curation at IODP-GCR, Texas A&M**	**26,529**	**27,048**	**27,582**	**28,143**	**28,719**	**138,021**
2.2	**TOTAL**	**474,708**	**489,168**	**504,071**	**519,454**	**535,288**	**2,522,690**

This budget also includes periodic replacement of the RAID storage systems and computer servers that will store, archive, and distribute the SAFOD spectrograms, the archived subset of data waveform data, and the large buffer of most recent continuous SAFOD waveform data. The budget justification for the main NCEDC cost categories is as follows.

Salaries: This project will be supervised by the Principal Investigator, whose time is contributed without cost to this project. We request .05 FTE/year of Computer Resource Manager time for project management and reporting tasks. To support all data conversion and metadata for SAFOD seismic data, we request 0.33 FTE/year for a Programmer/Analyst III. This position will be responsible for assembling the metadata for all SAFOD data flowing through the NCEDC, all seismic data conversion and data conversion QC, archiving the spectrograms, and overseeing the data flow from the NCEDC to the IRIS DMC. The database administration for metadata and waveform inventory will be managed by the NCEDC Database Administrator, whose time is contributed without cost to this project. Salaries are based on current levels with projected annual merit increases of 3.5% for staff as applicable effective October 1.

Equipment: The budget allocates $10K/year for periodic replacement of data storage and computer servers used to archive, maintain, and distribute the SAFOD data. This includes the permanently archived subset of SAFOD data, the large buffer of recent continuous SAFOD data to be made available to the community, and computers and disk storage used for the conversion and assembly of the SAFOD data sets housed at both the NCEDC and IRIS.

Supplies: Tapes are used for system backup and for both onsite and offsite backup of the SAFOD data permanently archived at the NCEDC.

Other Direct Costs: We have budgeted funds for a small portion of the shared support of the NCEDC hardware and software systems used to process, archive, and distribute SAFOD data. These funds may also help cover network and space charges for housing the NCEDC equipment in the seismically braced secure campus computer center.

Physical Sample Handling at the IODP Gulf Coast Repository (2.2.4)

All costs associated with curation of core, cuttings, and fluid samples at the Gulf Coast Repository (GCR) of the Integrated Ocean Drilling Program (IODP) will be handled through the non-profit Texas A&M Research Foundation (TAMRF). The costs for storing core, cuttings, and fluid samples at the GCR and carrying out the activities described above are shown in Table 5.5. The GCR has decades of experience in core curation and subsampling as well as the excellent equipment, facilities, and records-keeping, making it the ideal place for long-term storage and curation of SAFOD

TABLE 5.4. BUDGET FOR THE NORTHERN CALIFORNIA EARTHQUAKE DATA CENTER

		FY09	FY10	FY11	FY12	FY13
SALARIES						
	FTE					
Barbara Romanowicz, PI	0	-	-	-	-	-
Computer Resource Manager	0.05	4,543	4,702	4,866	5,036	5,213
Programmer Analyst III	0.33	27,856	28,831	29,840	30,884	31,965
Employee Benefits		7,127	7,142	7,392	7,650	7,918
SALARY TOTAL		**39,526**	**40,675**	**42,098**	**43,570**	**45,096**
SUPPLIES AND MATERIALS						
Supplies and Materials		4,000	5,000	5,500	6,000	6,500
TOTAL		**4,000**	**5,000**	**5,500**	**6,000**	**6,500**
EQUIPMENT						
Periodic Hardware Replacement: Computer Servers, Storage, Tape Library		10,000	10,000	10,000	10,000	10,000
TOTAL		**10,000**	**10,000**	**10,000**	**10,000**	**10,000**
Total Direct Costs		53,526	55,675	57,598	59,570	61,596
Indirect Costs (52%)		22,634	23,751	24,751	25,776	26,830
TOTAL		**76,160**	**79,427**	**82,349**	**85,346**	**88,426**

TABLE 5.5. BUDGET FOR IODP GULF COAST REPOSITORY

	FY09	FY10	FY11	FY12	FY13	TOTAL
John Firth, PI	4,106	4,229	4,356	4,487	4,621	21,799
GCR Superintendent	1,796	1,850	1,906	1,963	2,022	9,537
Student Workers, TBD	4,320	4,320	4,320	4,320	4,320	21,600
Fringe Benefits	2,961	2,989	3,017	3,107	3,201	15,275
Salary Subtotal	13,183	13,388	13,599	13,877	14,164	68,211
Materials and Supplies	4,300	4,429	4,562	4,653	4,746	22,690
Shipping	750	773	796	812	828	3,959
Total Direct Costs	18,233	18,590	18,957	19,342	19,738	94,860
IODP Overhead	8,296	8,458	8,625	8,801	8,981	43,161
TOTAL COSTS	**26,529**	**27,048**	**27,582**	**28,143**	**28,719**	**138,021**

core, cuttings, and fluid samples. The budget justification for the main GCR cost categories is as follows.

Salaries: The Principal Investigator will directly supervise work performed at the GCR. GCR scientific and core curation staff, and undergraduate student workers, will support the PI. The GCR Superintendent will be responsible for the day-to-day activities performed by the GCR. We request 3.6% of the Superintendent's annual salary in FY09–13.

Equipment: No equipment purchases, as defined by the IODP Property Policies, are anticipated to complete the required tasks.

Supplies: To carry out sample curation and sample distribution, we request brackets and pipe to fabricate 15 core racks, shrink wrap, replacement rock cutting blades and bits, miscellaneous steel and welding supplies, and miscellaneous sampling supplies.

Travel: No travel funds are requested.

Shipping: Costs include shipping of samples from the GCR to PIs within the contiguous United States only.

Monitoring (2.2.2)

Fiber Optic Strainmeter O&M and Data Handling at the University of California, San Diego (2.2.2.1)

Optical fiber strain sensors are a relatively new technology that is proving to be useful and cost-effective. Following Phase 1 drilling, three optical fiber cables were cemented in place in the vertical section of the borehole in the annular space between casings. These cables terminate at depths of 782 m, 864 m, and 1320 m below ground surface. The two shallower cables are tensioned optical fiber loops; the deep cable terminates in a Mach-Zehnder interferometer spanning the interval between 1280 m and 1320 m. Optical tools monitor the change in lengths of the fibers over these distance intervals, which allows us to measure strains of 10^{-11}–10^{-10} over short time periods. To achieve this precision, an ultra-stable, custom-built laser operating in a single mode between 1300 nm and 1500 nm is required. The laser measurement system samples the interference fringe pattern at 100,000 samples per second, solves for optical phase, and decimates the result to a recorded sample rate of 200 samples per second.

The budget for operation and maintenance and data handling for the fiber optic strainmeter is shown in Table 5.6. The Principal Investigator has installed similar systems in boreholes at Piñon Flat Observatory and in the Long Valley Exploratory Well and the estimated costs are based on experience operating interferometric laser strainmeters at these sites. The labor includes salaries and benefits for the PI at 0.15 month/year. Labor also includes support for one month each of a Programmer Analyst and a Development Technician, and for ongoing maintenance of the sensor and data systems. The Analyst currently maintains the software needed to process the interferometric fringe signals and process the corrected strain record. The Development Technician is responsible for optical fiber fabrication and maintenance. Also included is 0.15 month/year for a Research Project Assistant.

TABLE 5.6. BUDGET FOR UNIVERSITY OF CALIFORNIA, SAN DIEGO

			FY09	FY10	FY11	FY12	FY13
SALARIES							
	Rate	# Month					
Mark Zumberge, PI	13,417	0.15	2,013	2,073	2,135	2,199	2,265
Programmer Analyst	10,885	1	10,885	11,212	11,548	11,894	12,251
Development Technician	4,324	1	4,324	4,454	4,587	4,725	4,867
Research Project Assistant	4,875	0.15	731	753	776	799	823
SALARY TOTAL			**17,953**	**18,492**	**19,046**	**19,617**	**20,206**
SUPPLIES AND MATERIALS							
Supplies and Materials			450	464	477	492	506
TOTAL			**450**	**464**	**477**	**492**	**506**
TRAVEL TO PARKFIELD, CA							
Lodging			323	333	343	354	364
Rental Car			110	113	117	120	124
Per Diem			198	204	210	216	223
TOTAL			**631**	**650**	**670**	**690**	**711**
OTHER EXPENSES							
IGPP Computer Network			185	190	196	202	208
Communications			199	204	211	217	224
TOTAL			**384**	**394**	**407**	**419**	**432**
Total Direct Costs			19,418	20,000	20,600	21,218	21,855
indirect Costs (54.50%)			10,582	10,900	11,227	11,564	11,911
TOTAL			**30,000**	**30,900**	**31,827**	**32,782**	**33,765**

Ongoing support will require an annual visit to the SAFOD site. Thus, we request travel funds for two persons for two days once each year for routine maintenance. The "Other Expenses" category covers charges for access to the IGPP computer network, communications, office, and site supplies (Table 5.6). Also included is the University of California, San Diego, overhead charges at 54.5%.

Maintenance and Periodic Replacement of SAFOD Borehole Monitoring Array (2.2.2.2)

The wellbore instrumentation plan for the SAFOD monitoring program is unique. Never before have such detailed measurements of seismic and aseismic fault movements and related processes (such as fluctuations in pore pressure) been undertaken at the temperature, pressure, and physical conditions to be encountered at depth. The instrumentation must provide a robust spectrum of data from directly within the fault and operate continuously at temperatures of ~ 130°C and fluid pressures of 30 MPa.

There are no known commercial systems available for deployment deep within SAFOD under these conditions. The SAFOD borehole monitoring array, which will be deployed following the completion of Phase 3 drilling in the fall of 2007, will be constructed from various commercial components that are being retrofitted to handle higher temperatures and pressures. However, these sensors have never been integrated into a single system as required by SAFOD. The instrumentation to be deployed will also be subject to extremely high accelerations (possibly as high as 10 g) resulting from nearby M~2 earthquakes. Therefore, a conservative approach has been taken in specifying the instrumentation to be used.

The PIs have obtained advice on monitoring instrumentation system performance from the SAFOD Monitoring Instrumentation Technical Panel, experts associated with IODP and International Continental Scientific Drilling Program (ICDP), as well as the Geothermal Research Instrumentation Group at Sandia National Laboratories. All have investigated the potential longevity of the SAFOD permanent instrumentation systems and recommend the following practices, which are now being implemented for the SAFOD borehole monitoring array:

1. Employ instrumentation that allows long-term operation at elevated temperature and pressure in a corrosive environment. Replace polymer O-ring seals with metal-metal seals. Use only high-temperature, qualified electronic components. Encapsulate electrical conducting cables and optical fibers inside seemless stainless steel tubes that will be connected to the instrumentation sondes through welded or metal-to-metal seals.
2. Plan for the SAFOD monitoring instrumentation system to be replaced every three years.
3. Deploy instrumentation on 2-3/8-in-diameter tubing to facilitate installation and retrieval. This tubing will also be used to inflate a packer that will isolate pressure at the bottom of the hole for long-term monitoring of fluid pressure within the fault zone (see Figure 4.3).

The budget for operation and maintenance of the SAFOD Borehole Monitoring Array is based on the system that will be deployed at the end of the MREFC. It will consist of:

- A retrievable, three-level seismic instrument array (a combination of three-component geophones and three-component accelerometers)
- Deformation sensors (a biaxial tiltmeter at each level)
- Inflatable packer system (for hydraulically isolating the bottom of the hole)
- Pressure sensor (for monitoring pore fluid pressure below the packer)

This instrumentation system will be deployed at the bottom of SAFOD in the immediate vicinity of the M2 target earthquakes at a true vertical depth of ~ 2700 m and at a temperature of ~ 130°C.

The cost for complete replacement of the sensor packages, including system integration, and field operations to retrieve the current array and deploy the new array is $607,500. The details are shown in Table 5.7.

Pinnacle Technologies will be the instrumentation subcontractor. This company is the sole manufacturer of borehole tiltmeters capable of operating at the depths and temperatures required for SAFOD. Moreover, they have appreciable experience in working with borehole seismometers as part of their commercial activities monitoring hydraulic fracturing operations in the petroleum industry. Pinnacle provided the engineering services associated with testing and deployment of prototype systems in the SAFOD main hole and pilot hole

TABLE 5.7. REPLACEMENT COSTS USING ALL NEW EQUIPMENT

QTY	DESCRIPTION	UNIT COST	REPLACEMENT COST
6	DS150 3-component seismometers	23,650	141,900
3	MEMS accelerometers and mounting conversion	8,000	24,000
3	Pinnacle Technology tiltmeter	30,000	90,000
1	Cablehead (DS150)	24,000	24,000
2	interconnects, adapters	10,000	20,000
1	Pressure tool	25,000	25,000
1	Hydraulic packer	7,600	7,600
2	Crane and crew rental for instrumentation replacement	40,000	80,000
1	Stainless steel tube with fiber optics and electrical conducting wireline	120,000	120,000
1	Engineering services Pinnacle Technologies	75,000	75,000
TOTAL			**607,500**

that was critical to research and development for the permanent instrumentation system to be deployed in SAFOD in the fall of 2007.

Instrument Replacement Schedule

As mentioned earlier and described in more detail in the letter from Sandia National Laboratories (Figure 5.1), the major instrument systems comprising the SAFOD observatory will require replacement every three years, or possibly even sooner. Given the cost of replacement of the permanent monitoring array, SAFOD plans to replace the system twice during the five-year period covered by this proposal, or roughly every 2.5 years.

For the first redeployment during the O&M funding period, we will replace the instruments installed during the MREFC phase with all new equipment, at a total cost of $607,500 (Table 5.7). This cost includes not only new downhole instrumentation, but also a crane and crew for removal of the old array and installation of the new array, a replacement stainless steel tube containing fiber optics and electrical conductors, and engineering services from Pinnacle Technologies, the prime contractor on the SAFOD monitoring array. We anticipate that this first redeployment will occur in FY11.

For the second redeployment during the O&M funding period, we will refurbish most of the downhole instruments installed in FY11 (with the exception of the packer and pressure transducer, which cannot be refurbished and will have

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

Randy A. Normann
Principal Member of Technical Staff

P.O. Box 5800
Albuquerque, NM 87185-1033

Phone: (505) 845-9675
Fax: (505) 844-3952
Internet: ranorma@sandia.gov

December 6, 2004

Professor Mark Zoback
Department of Geophysics
Stanford University
Stanford, CA 94305

Dear Mark,

I am writing to briefly summarize the results of the work we have done in support of the SAFOD project related to assessing the potential longevity of suite of geophysical monitoring instrumentation to be deployed to total depth in the SAFOD borehole (Stage 3). My understanding is that you are currently developing a proposal for long-term Operations and Maintenance and the issue of instrumentation longevity is an important factor in the planning process.

First, it is important to emphasize the fact that the Stage 3 wellbore instrumentation requirements of the SAFOD project are unique. The instrumentation placed within the fault must work without failure at 135°C while providing a robust scientific set of fault data parameters. Unfortunately, there is no known COTS (commercial off the shelf) system available for deployment deep within the SAFOD well.

As such, a conservative approach to specifying the instrumentation to be placed deep within the SAFOD well is suggested.

Of course, the fossil energy industry is operating wells at temperatures as high as 225°C. However, at temperatures of 225°C, Measurement-While-Drilling (MWD) tools are limited to <100 hrs before refurbishment. Schlumberger reports target operating life times of 400 hrs for 175°C logging tools and 5 years for 150°C intelligent well completions called smart wells.

In fact, the closest fossil energy technology comparable to the SAFOD wellbore instrumentation is the smart well. Here the industry is primarily interested in monitoring wellbore pressure, temperature and flow. This information is used to control downhole valves. These valves are either hydraulically controlled from the surface or via electric motors located at the valve.

Smart well instrumentation designs will normally include a microprocessor, A/D (24 bits) and pressure sensors. Smart well instrumentation usually targets a slightly higher temperature and has the same measurement accuracy requirements. I understand that it would not be acceptable from a scientific perspective, but if SAFOD was to limit deep well instrumentation to only pressure and temperature measurements, the operation and maintenance plan replacement interval of the downhole instruments could be extended to >5 years, given the lower SAFOD temperature. However, as other measurements are required to monitor fault movement, any SAFOD wellbore instrumentation system will be more complex.

Exceptional Service in the National Interest

- 2 -

Sandia National Laboratories along with a majority of the drilling industry believes, "If it hasn't been tested within a well, it hasn't been tested." All HT life testing of components is conducted within laboratory ovens but overall system reliability is dependent on the weakest link which determines operating life. All wells have a host of issues that are unique to that well and these parameters are difficult to replicate and test within the laboratory. For example: all wells have some amount of free hydrogen created by the interaction of well brine and well carbon steel casing. Most wells have some small amount of H_2S and HCl as a natural byproduct of fluid flow in rock. As the well temperature increases, the amount chemical activity also increases. This chemical activity is hard to recreate in the laboratory.

With specific reference to seismic instrumentation, I have not found any commercially available seismic string, or stand-alone seismic data collection system, with a demonstrated reliability at temperatures near or above 135°C. Although I have not contacted everyone within the scientific or commercial well-instrumentation industry, all my conversations are leading to one basic conclusion. There isn't a commercial application driving seismic systems for proven reliability during long-term wellbore deployments, even at moderate temperatures over 85°C.

Commercial seismic systems are normally deployed within a well for a period of two days, occasionally up to one month. If a channel or two is lost during any test, the seismic string normally has enough remaining working channels that the experiment is still a success and allows the system to be repaired after the experiment.

Fortunately, it does appear that most of the elements for building a seismic array suitable for use in SAFOD's Stage 3 system may exist in other forms used with intelligent wellbore completions. A conservative design based on known reliable components and materials might be possible for SAFOD's initial Stage 3 deployment; but it is essentially impossible to thoroughly evaluate the likely operating life time of these systems before its required installation in the fall of 2007.

Because of this, a suggested target for a maintenance schedule of the SAFOD wellbore instrumentation should begin with a conservative design that has an expected replacement within 3 years followed, hopefully, by an improved system (both in expected operating life and performance) covering the next 5 to 7 years.

I hope these comments are helpful in planning for monitoring operations at SAFOD.

Sincerely,

Randy Normann

PMTS Geothermal Research Department
IP High-Temperature Electronics and Fiber Optics

Figure 5.1. Letter from Sandia National Laboratories Geothermal Research Group.

to be replaced). As shown in Table 5.8, these instruments can be refurbished at approximately half the cost of new instruments, yielding a total cost for the second redeployment of $497,718. This cost includes refurbishment or replacement of the downhole instruments, a new stainless steel telemetry/power tube, engineering services from Pinnacle Technologies, and a data logger to replace the system currently in use at SAFOD. We anticipate that this second redeployment will occur in FY13.

Thus, the total for the two replacements of the instrumentation package to be covered under this proposal (combining Tables 5.7 and 5.8) is $1,105,218. This cost will be spread out over the five-year period covered by this proposal, through the annualized replacement costs shown in Table 5.3.

O&M Budget Projections for FY14–18

Table 5.9 shows the estimated costs for SAFOD Operations and Maintenance during FY14–18. The costs start at $551,347 for FY14 and are escalated by 3% per year for each WBS element. The total estimated cost in FY14–18 for SAFOD O&M is $2,927,177.

TABLE 5.8. COSTS FOR REFURBISHED INSTRUMENTATION DEPLOYMENT

QTY	DESCRIPTION	UNIT COST	REPLACEMENT COST
6	DS150 reconditioning	11,825	70,950
3	MEMS reconditioning	4,000	12,000
3	Tiltmeter reconditioning	10,000	30,000
1	Cablehead reconditioning	12,000	12,000
2	Interconnects, adapters	10,000	20,000
1	Pressure tool	25,000	25,000
1	Hydraulic packer	7,768	7,768
2	Crane and crew rental for instrumentation replacement	40,000	80,000
1	Stainless steel tube with fiber optics and electrical conducting wireline	120,000	120,000
1	Datalogger	45,000	45,000
1	Engineering services PinnTech	75,000	75,000
TOTAL			**497,718**

TABLE 5.9. SAFOD BUDGET PROJECTIONS FOR YEARS FY14–18

WBS		FY14	FY15	FY16	FY17	FY18	TOTAL
2.2.1	Management Total	142,033	146,294	150,683	155,203	159,859	754,072
2.2.2	Monitoring Total	288,655	297,314	306,234	315,421	324,883	1,532,507
2.2.3	Time Series Data	91,079	93,811	96,625	99,524	102,510	483,550
2.2.4	Physical Samples	29,581	30,468	31,382	32,323	33,293	157,047
2.2	**TOTAL**	**551,347**	**567,888**	**584,924**	**602,472**	**620,546**	**2,927,177**

PBO Budget Summary

This section summarizes the PBO operations and maintenance budget. Detailed explanations for the budget basis are presented for each WBS element of PBO in the WBS dictionary (Section 7). This section discusses general assumptions used in assembling the budget.

Introduction

The PBO network is unprecedented in its geographic extent, the complexity of instruments, and the scope of data products. Budgeting adequate resources for proper operations and maintenance of the PBO network within a limited NSF funding environment has been a challenge. To meet the objectives of maximizing station uptime, minimize interruptions to data flow and data products delivery, and meet the budget targets we have made the following assumptions:

- To operate and maintain the stations and manage data flow and data products we will use personnel trained on the PBO MREFC Project and use the UNAVCO facility for data archiving and, as needed, for engineering support.
- All field personnel will be cross-trained to maintain GPS, seismic, strainmeter, and tiltmeter operations and maintenance activities. Data Management personnel will cross train in strainmeter, seismometer, and GPS data flow.
- All managers will have a fraction of their FTE devoted to O&M or data management responsibilities.
- To meet year-to-year budget targets we will ask the scientific community to prioritize those stations requiring greater or lesser degrees of up time.

Using the above, we propose to operate and maintain 1100 CGPS stations, 100 campaign GPS systems, 103 borehole strainmeters, six long baseline laser strainmeters, and the associated data archiving and data products generation with 29 FTE personnel.

General Rate Assumptions

A number of general cost assumptions guided the preparation of the PBO budgets. These include the costs associated with fringe benefits, overhead rates, facility rates, material and salary yearly cost increases and escalation, and management fees.

Personnel costs for PBO include salaries, fringe, and overhead. For the purposes of estimating salary costs in this proposal, salaries are increased 3% annually. Fringe benefits associated with direct salaries are treated as a direct cost. The current UNAVCO fringe benefits rate is only applied to 86.35% of the salary costs. That rate is forecasted to be 53.25% throughout the O&M proposal.

UNAVCO overhead rates are projected to be 11% in calendar year 2008 and 15% in calendar year 2009 and later. The increase in the indirect rate between 2008 and 2009 is the result of a large reduction of UNAVCO base funding due to an ending of the PBO MREFC effort.

The UNAVCO Boulder headquarters building, utilities, and phone and Internet communications costs are charged to the project as an indirect expense. These facilities expenses are based on $32.50/sqft times 9532 sqft dedicated to PBO for the first year of O&M. This expense is escalated annually by a non-labor escalation percentage.

The annual increase in budget costs are based on a 3% salary increase each year, while non-labor costs (travel, materials, supplies, equipment, facilities costs) increase at 2.5% in FY09, 2.4% in FY10, and 2.3% in FY11. This escalation rate is based on the Consumer Price Index for Urban Wage Earners and Clerical Workers (CPI-W) as provided by NSF assumptions for large facility projects.

Exceptions to the above escalation rates are detailed below. GPS materials, equipment, travel, and supplies are not increased between FY09 and FY10 to meet the first year budget. GPS communications was reduced by 11% between FY09 and FY10 to correspond with an anticipation of better cellular modem prices and clustering of multiple GPS units on a common connection. IT equipment and supplies were increased by $29,000 between FY10 and FY11 and then increased another $19,000 between FY11 and FY12 for server replacement and a higher overall replacement assumptions due to aging equipment.

UNAVCO management fees are included at $40,000 per year. This is the same fee that is currently applied to the MREFC. No increase or escalation of management fees is anticipated.

PBO O&M Elements

The budget for the Operations and Maintenance Project is broken out into five major WBS elements (legs) (Figure 5.2):

- Overall Support (Project Management)
- Long Baseline Laser Strainmeter
- Data Products
- Borehole Strainmeter Operations
- GPS Operations

The project is further divided into major tasks. With the exception of the long baseline laser strainmeter (LSM) subaward, all items are broken down to the fourth WBS level and in some cases, the budget is broken to the fifth level. The LSM task is shown at the third level in the WBS but is managed through a subaward with a separate budget breakdown.

Presenting the budget based on the WBS provides transparency into work and budget categories, and streamlines the program for cost analysis and NSF required reporting. Using this methodology, actual expenditures can be closely tracked to budget, risk areas identified, and cost and schedule issues quickly recognized and mitigated (Figure 5.3).

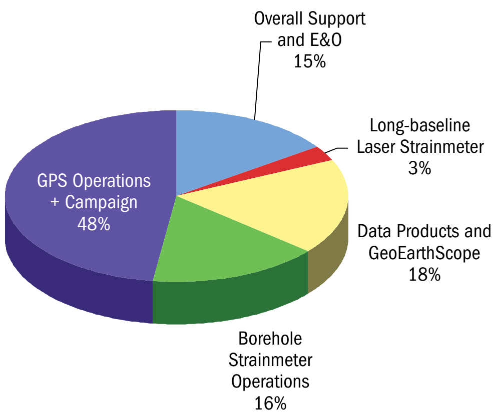


Figure 5.2. An overview of weighting of the major WBS elements (legs) for the first five years of the PBO Operations and Maintenance Project.

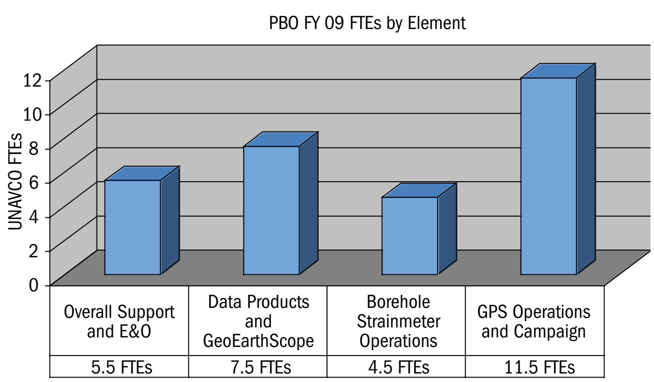


Figure 5.3. PBO FTEs for FY09 for all of the legs or elements of the WBS. The text gives an overview of each element of the WBS. Additional detail is included in Section 7 in the PBO WBS Dictionary.

Overall Support (Project Management) (2.3.1)

The PBO overall support component includes the management of PBO from UNAVCO headquarters in Boulder, CO. This includes one Project Director and one Administration Support person. It also includes maintenance of existing station permits (0.5 FTE), senior engineering support of the overall project (0.5 FTE), coordination of all project cost and schedule issues and management of laser strainmeter subaward (1 FTE), PBO IT support (1 FTE), and support of E&O activities (0.5 FTE FY09, 1 FTE FY10, and forward). Overall support also includes the PBO's portion of Boulder Facilities costs (indirect rates based on sq ft occupied), telephone expenses, and participant support costs. A more detailed description of this element's scope and assumptions are included in Section 7. Figure 5.4 illustrates the various task weighting within this element for FY09.

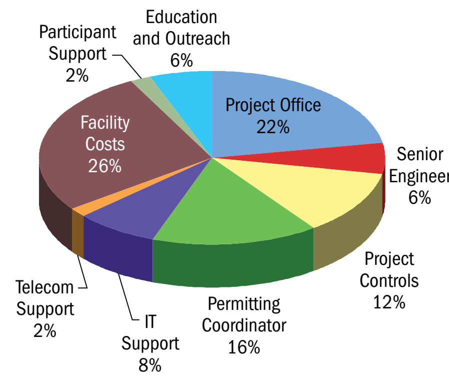


Figure 5.4. Overall support.

Long Baseline Laser Strainmeter (2.3.2)

The Long Baseline Laser Strainmeter element consists of six instruments maintained by the University of California, San Diego. Operation and maintenance of these instruments includes funding for University of California, San Diego support personnel; replacement of necessary equipment, materials, and supplies; and necessary travel expenses to the sites. The costs also support data transmission to the PBO strainmeter archive and the generation of strainmeter data products. The management of this subaward is not included in this element and is performed by the PBO Cost Schedule Coordinator (overall support). A more detailed description of this element's scope and assumptions are included in Section 7.

Data Products (2.3.3)

All personnel (7.5 FTEs rising to 9.5 FTEs in FY12), hardware, software, materials, and subcontract costs used to support the PBO data management system (DMS) and GeoEarthScope support.

The PBO DMS handles raw (Level 0 and 1) products from all PBO stations, Level 2 products derived from these data, and metadata associated with both sets of product. This task includes archiving of all station metadata, maintenance information, and data products, and the generation of data products up to and including Level 2. Data products will be made available from the PBO archives via current archive distribution mechanisms, including Web and ftp access and data distribution clients, as well as the PBO Web site and EarthScope Portal.

This element also includes subawards for archiving and data products generation and ongoing support of the GeoEarthScope task. A more detailed description of this element's scope and assumptions are included in Section 7. Figure 5.5 illustrates the various task weighting of within this element for FY09.

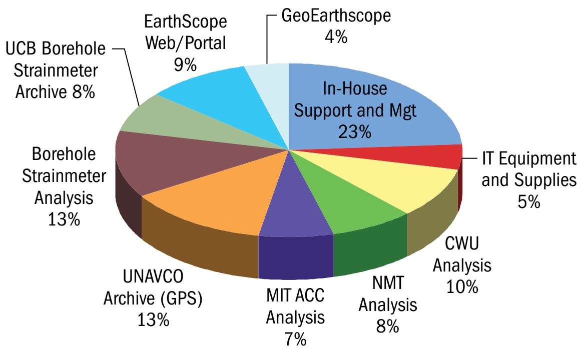


Figure 5.5. Data products graph.

Borehole Strainmeter Operations (2.3.4)

This element includes the operation of the Borehole program including, 103 BSM instruments, borehole seismometers, 28 tiltmeters, and ancillary equipment. The element also includes materials, equipment, and supplies that support regular scheduled and unscheduled maintenance visits for the 103 borehole strainmeter stations (which includes borehole seismometers and tiltmeters). In addition, recurring costs associated with borehole strainmeter station communication connectivity and power are included. Labor, travel, and the associated indirect costs for 4.5 FTEs are included in this element. Facilities expenses to support regional office activities are also included. A more detailed description of this element's scope and assumptions can be found in Section 7. Figure 5.6 illustrates the various task weighting within this element for FY09.

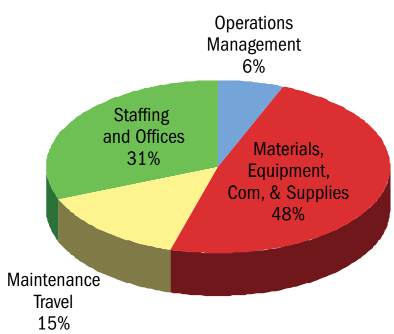


Figure 5.6. Borehole strainmeter operations.

GPS Operations (2.3.5)

This element includes the operation of 100 campaign and 1100 permanent GPS instruments. The element also includes materials, equipment, and supplies that support regular scheduled and unscheduled maintenance visits for the permanent GPS stations. In addition, recurring costs associated with GPS station communication connectivity and power are included. Labor, travel, helicopter, and the associated indirect costs for 11.5 FTEs are included in this element as are facilities expenses to support regional office activities. A more detailed description of this element's scope and assumptions can be found in Section 7. Figure 5.7 illustrates the various task weighting within this element for FY09.

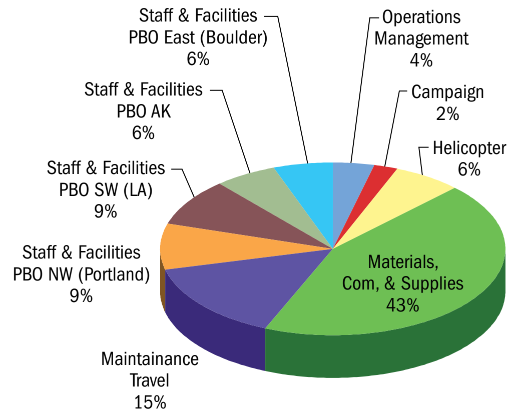


Figure 5.7. GPS perations.

PBO O&M Budgets

Figure 5.2 provides an overview of the first five years of costs for the PBO Operations and Maintenance Project.

Table 5.10 provides the first five years of costs in detail. The costs start at $9,480,000 for FY 09. FY10 escalates labor costs by 3% and equipment, materials, supplies, travel, and facilities costs by 2.5%. FY11 escalates labor costs by 3% and equipment, materials, supplies, travel, and facilities costs by 2.4%. For FY11 and forward, labor costs are escalated by 3% and equipment, materials, supplies, travel, and facilities costs by 2.3%. The cumulative PBO Operations and Maintenance Costs at the end of FY13 is $50,950,000.

Table 5.11 illustrates the second five years of costs for the PBO Operations and Maintenance Project. Costs start at $11,107,781 for FY14. For FY15 and forward labor costs are escalated by 3% and by 2.3% for equipment, materials, supplies, travel, and facilities. The total estimated cost for 10 years of PBO Operations and Maintenance is $109,416,922.

The scope from WBS tasks illustrated in Tables 5.10 and 5.11 are described in general in Section 4 of this Volume I document, and are described in detail in Section 7, including assumptions and basis of estimated costs.

TABLE 5.10. PBO OPERATIONS AND MAINTENANCE FY 09–FY 13

2.3 PBO		FY 09	FY 10	FY 11	FY 12	FY 13
2.3.1 OVERALL SUPPORT		1,383,049	1,520,621	1,562,304	1,604,472	1,647,797
2.3.1.1	Project Office	306,099	317,950	327,368	337,046	347,010
2.3.1.2	Senior Engineer	83,583	86,823	89,399	92,047	94,774
2.3.1.3	Project Controls (Cost/Schedule) Office	163,142	169,475	174,517	179,702	185,041
2.3.1.4	Permitting Coordinator/Permits	215,811	223,521	229,349	235,180	241,161
2.3.1.5	Facility and Program Support					
2.3.1.5.1	IT Support	106,149	110,264	113,536	116,900	120,364
2.3.1.5.2	Telecommuncation Support	25,650	26,522	27,158	27,783	28,422
2.3.1.5.3	Facility Costs	373,601	386,300	395,571	404,669	413,977
2.3.1.6	Participant Support:	28,500	29,469	30,176	30,870	31,580
2.3.1.7	Education and Outreaach	80,515	170,297	175,229	180,275	185,467
2.3.1 CUM (PV)		**1,383,049**	**2,903,670**	**4,465,975**	**6,070,447**	**7,718,243**
2.3.2 LONG BASELINE LASER STRAINMETER		264,750	271,275	277,696	283,996	290,443
2.3.2.1	Long Baseline Laser Strainmeter Subaward	264,750	271,275	277,696	283,996	290,443
2.3.2 CUM (PV)		**264,750**	**536,025**	**813,721**	**1,097,717**	**1,388,160**
2.3.3 DATA PRODUCTS		1,632,741	1,698,179	1,776,718	2,065,105	2,048,021
2.3.3.1	In-house Support and Management	391,340	406,542	418,646	653,384	619,892
2.3.3.2	Recurring Communication					
2.3.3.2.1	IT Equipment and Supplies	75,533	78,100	112,944	134,685	118,199
2.3.3.3	GPS Analysis					
2.3.3.3.1	Central Washington University Analysis	155,835	156,465	160,028	163,674	167,408
2.3.3.3.2	New Mexico Tech Analysis	126,832	129,909	132,938	135,908	138,948
2.3.3.3.3	MIT ACC Analysis	113,395	116,148	118,942	121,544	124,301
2.3.3.4	UNAVCO GPS Archive					
2.3.3.4.1	UNAVCO Archive (GPS)	214,890	222,760	228,804	234,906	241,174
2.3.3.5	Borehole Strainmeter Analysis	206,321	214,331	220,708	227,266	234,019
2.3.3.6	UC Berkeley Borehole Strainmeter Archive	123,750	140,559	143,658	146,864	150,187
2.3.3.7	EarthScope Office Support					
2.3.3.7.1	EarthScope Web and Portal Support	154,844	160,677	165,238	169,884	174,663
2.3.3.8	GeoEarthscope	70,001	72,688	74,812	76,988	79,229
2.3.3 CUM (PV)		**1,632,741**	**3,330,920**	**5,107,638**	**7,172,743**	**9,220,764**
2.3.4 BOREHOLE STRAINMETER OPERATIONS		1,551,363	1,605,953	1,647,602	1,689,229	1,731,925
2.3.4.1	Borehole Strainmeter Operations Management	93,615	97,196	100,021	102,914	105,890
2.3.4.2	Borehole Strainmeter Materials and Supplies	751,006	775,879	794,500	812,774	831,467
2.3.4.3	Borehole Strainmeter Maintenance Travel	225,411	233,073	238,667	244,156	249,772
2.3.4.4	Borehole Strainmeter Operations Staffing and Offices	481,330	499,805	514,414	529,385	544,796
2.3.4 CUM (PV)		**1,551,363**	**3,157,316**	**4,804,918**	**6,494,147**	**8,226,072**

Table continues on next page...

Table 5.10 continued from last page...

2.3.5 GPS OPERATIONS		4,608,097	4,683,972	4,845,679	4,967,198	5,091,814
2.3.5.1	GPS Operations Management	184,440	191,571	197,233	203,048	209,036
2.3.5.2	GPS Campaign	101,124	104,985	108,028	111,142	114,347
2.3.5.3	GPS Helicopter	285,000	294,688	301,760	308,700	315,801
2.3.5.4	GPS Materials and Supplies	2,030,070	2,028,609	2,100,726	2,149,043	2,198,471
2.3.5.5	GPS Maintenance Travel	676,999	682,938	716,812	733,298	750,164
2.3.5.6	GPS Regional Maintenance Staff					
2.3.5.6.1	GPS Regional Maintenance Staff - PBO NW (Portland, Oregon)	392,713	407,698	419,506	431,585	444,015
2.3.5.6.2	GPS Regional Maintenance Staff - PBO SW (Los Angeles, California)	412,012	427,604	439,828	452,302	465,133
2.3.5.6.3	GPS Regional Maintenance Staff - PBO Anchorage, Alaska	265,895	276,024	283,998	292,150	300,539
2.3.5.6.4	GPS Regional Maintenance Staff - PBO East (Boulder, Colorado)	259,844	269,855	277,789	285,929	294,309
2.3.5 CUM (PV)		**4,608,097**	**9,292,069**	**14,137,748**	**19,104,946**	**24,196,760**
TOTAL COSTS (BY YEAR)		**9,440,000**	**9,780,000**	**10,110,000**	**10,610,000**	**10,810,000**
MANAGEMENT FEES		**40,000**	**40,000**	**40,000**	**40,000**	**40,000**
TOTAL W/FEE (BY YEAR)		**9,480,000**	**9,820,000**	**10,150,000**	**10,650,000**	**10,850,000**
TOTAL (CUM)		**9,480,000**	**19,300,000**	**29,450,000**	**40,100,000**	**50,950,000**

TABLE 5.11. PBO OPERATIONS AND MAINTENANCE FY 14–FY 18

2.3 PBO	**FY 14**	**FY 15**	**FY 16**	**FY 17**	**FY 18**
2.3.1 Overall Support	1,692,311	1,738,047	1,785,039	1,833,323	1,882,934
2.3.1 Cum (PV)	9,410,554	11,148,600	12,933,639	14,766,962	16,649,896
2.3.2 Long Baseline Laser Strainmeter	297,037	303,783	310,684	317,743	324,965
2.3.2 Cum (PV)	1,685,197	1,988,980	2,299,664	2,617,407	2,942,372
2.3.3 Data Products	2,083,107	2,139,847	2,198,182	2,258,157	2,319,820
2.3.3 Cum (PV)	11,303,872	13,443,719	15,641,901	17,900,059	20,219,879
2.3.4 Borehole Strainmeter Operations	1,775,719	1,820,638	1,866,714	1,913,975	1,962,452
2.3.4 Cum (PV)	10,001,791	11,822,429	13,689,143	15,603,117	17,565,570
2.3.5 GPS Operations	5,219,607	5,350,660	5,485,057	5,622,886	5,764,234
2.3.5 Cum (PV)	29,416,368	34,767,028	40,252,086	45,874,971	51,639,206
TOTAL (BY YEAR)	**11,067,781**	**11,352,975**	**11,645,677**	**11,946,083**	**12,254,406**
MANAGEMENT FEES	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**
TOTAL W/FEE (BY YEAR)	**11,107,781**	**11,392,975**	**11,685,677**	**11,986,083**	**12,294,406**
TOTAL (CUM)	**62,057,781**	**73,450,757**	**85,136,433**	**97,122,516**	**109,416,922**

USArray Budget Summary

This section summarizes the USArray O&M budget. Detailed explanations for the budget basis are presented for each WBS element of USArray in the WBS dictionary in Section 7. This section discusses general assumptions that were used in assembling the budget.

A number of general cost assumptions guided the preparation of the USArray budgets. These include the costs associated with fringe benefits, indirect rates, general management and administrative fees, material and salary yearly cost increases and escalation, and management fees.

Personnel costs for each program include salaries, fringe, and overhead. For the purposes of estimating salary costs in this proposal, salaries are increased 3% annually. Fringe benefits associated with direct salaries are treated as a direct cost. The current IRIS fringe benefits rate is 37%. Indirect rates are based on current IRIS rates. Overhead applicable to the Washington, D.C. office is applied at 30%. Overhead applicable to the Data Management Center is applied at 19%. Overhead is applied to the salaries of employees at each location.

General management and administrative (G&A) is applied to total costs less equipment, participant-support costs, and subcontract costs exceeding $25,000 per contract per year. The current IRIS G&A rate is 15%. G&A for all USArray programs is reported as a subtotal under USArray management.

The O&M activities for USArray are expected to remain relatively flat from FY09 forward. In general, the FY09 estimate is based on actual experience during the first 3.5 years of the current MREFC and O&M phase. The annual increases in budgeted costs are based on 3% salary increases each year, based on the average historical IRIS salary increases, and non-labor costs are escalated per the Consumer Price Index for Urban Wage Earners and Clerical Workers (CPI-W) as provided by NSF as economic assumptions for large facility projects (2.5% in FY10, 2.4% in FY11, and 2.3% in the out years).

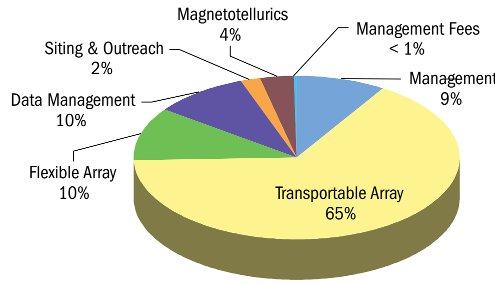


Figure 5.8. USArray O&M FY09–13.

IRIS management fees are included at $25,000 per year, which is the same fee currently applied to the MREFC. No increase or escalation of management fees is included.

The budgets for USArray operations and maintenance at Level 3 in the work break down structure for FY09–13 (proposal duration) is summarized in Table 5.12 and Figure 5.8.

Operating and maintenance estimates for USArray at WBS Level 3 for FY14–18 is summarized in Table 5.13. These estimates assume salary increases and escalation only.

In FY14–16, the Transportable Array will be installed in Alaska; in FY16–18, the Alaska installations will be demobilized. While well beyond our planning horizon, these estimates assume that the actual Transportable Array configuration that is deployed to Alaska will be constrained by the available funding. That is, due to the increased costs associated with operations in Alaska, it is unlikely that all 400 stations will be deployed and the actual number deployed will be determined by the funds available.

TABLE 5.12. BUDGET SUMMARY FOR USARRAY (FY09–FY13)

WBS ELEMENT	FY09	FY10	FY11	FY12	FY13	TOTAL
2.4.1 USARRAY						
2.4.1 Management	1,270,382	1,305,273	1,340,756	1,367,829	1,413,917	6,707,157
2.4.2 Permanent Array	-	-	-	-	-	-
2.4.3 Transportable Array	8,836,873	9,104,251	9,381,577	9,666,280	9,953,182	46,942,165
2.4.4 Flexible Array	1,368,399	1,415,752	1,464,396	1,514,365	1,566,124	7,329,035
2.4.5 Data Management	1,324,910	1,362,902	1,401,631	1,441,101	1,481,696	7,012,240
2.4.6 Siting & Outreach	244,435	251,343	258,361	265,487	272,813	1,292,440
2.4.7 Magnetotellurics	500,000	512,717	525,290	537,694	550,393	2,626,093
MANAGEMENT FEES	**25,000**	**25,000**	**25,000**	**25,000**	**25,000**	**125,000**
USARRAY TOTAL	**13,570,000**	**13,977,239**	**14,397,011**	**14,826,756**	**15,263,124**	**72,034,130**

TABLE 5.13. ESTIMATES FOR USARRAY (FY14–18)

WBS ELEMENT	FY14	FY15	FY16	FY17	FY18	TOTAL
2.4.1 USARRAY						
2.4.1 Management	1,432,814	1,471,578	1,511,435	1,522,419	1,594,560	7,562,806
2.4.2 Permanent Array	-	-	-	-	-	-
2.4.3 Transportable Array	10,149,577	10,482,480	10,826,946	11,183,396	11,552,266	54,194,666
2.4.4 Flexible Array	1,619,740	1,675,283	1,732,823	1,792,436	1,854,199	8,674,482
2.4.5 Data Management	1,523,448	1,566,391	1,610,558	1,655,986	1,702,710	8,059,093
2.4.6 Siting and Outreach	280,344	288,086	296,044	304,226	312,637	1,481,336
2.4.7 Magnetotellurics	563,393	576,703	590,330	604,281	618,564	2,953,272
MANAGEMENT FEES	**25,000**	**25,000**	**25,000**	**25,000**	**25,000**	**125,000**
USARRAY TOTAL	**15,594,318**	**16,085,520**	**16,593,138**	**17,117,744**	**17,659,935**	**83,050,655**

USArray O&M Elements

A brief summary of the cost elements for each component of USArray follows.

USArray Management (2.4.1)

The USArray Management component supports the overall management of USArray from IRIS headquarters in Washington, D.C. It provides support for a new USArray Project Director, the IRIS Director of Project Administration, a shared Project Associate, USArray Advisory Committee meetings, participation on the EarthScope Management Team, and general and administrative costs for all of USArray.

Transportable Array (2.4.3)

The Transportable Array consists of 400 sets of broadband seismic instruments acquired under the MREFC project, to be deployed at up to 2,000 sites across the continental United States and Alaska. The first 400 sites are being installed in the western United States under the MREFC project. Relocation of these instruments to the remaining 1,600 sites is a unique feature of USArray O&M. This temporary endeavor will be completed during the out-year estimate phase of this proposal.

This proposal supports Transportable Array management, maintenance, operations, and deployment activities. Management support is requested for a Transportable Array Manager, Deputy Manager, and shared Project Associate Maintenance of the 400 operating stations involves provisions for spare sensors and data acquisition systems and repair of damaged equipment, primarily through a subaward to New Mexico Tech for the Array Operations Facility (AOF). Transportable Array operations include support for IRIS and subawardee field personnel, data collection through a subaward to the University of California, San Diego for the Array Network Facility (ANF), and data telemetry. Station deployment includes demobilization of stations and shipment of equipment to the new locations, finding new sites, obtaining permits for selected sites, excavation and civil works to prepare the site (construction), and installation of the instruments and telecommunications equipment using both IRIS and subawardee field personnel. A construction contractor, supervised by IRIS personnel or representatives, constructs the sites. Through a contract with Honeywell, the sites are then installed.

Transportable Array cost estimates for management, operations, and all but the demobilization of deployment activities are based on actual experience during the first three and a half years of the MREFC project. Costs for maintenance

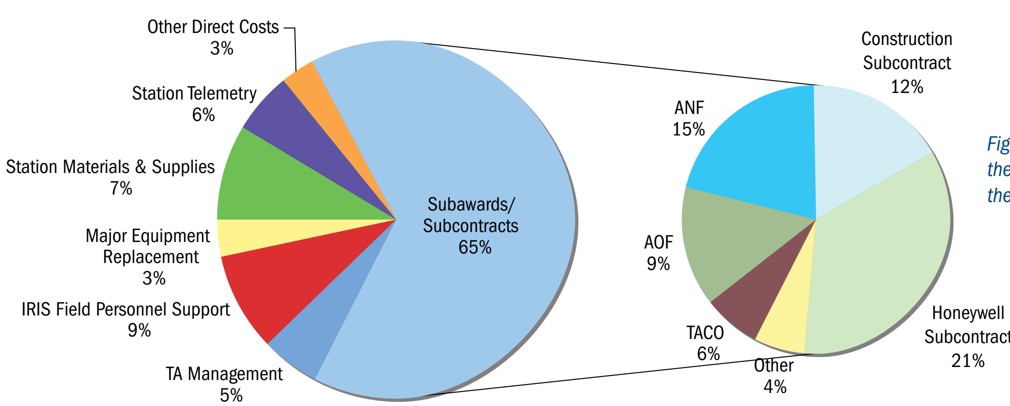


Figure 5.9. Summarizes the major cost elements of the Transportable Array.

are projected based on PASSCAL experience and assuming that half of the AOF costs are attributed to the Transportable Array. Demobilization costs are estimated based on a bottoms-up estimate of manpower and expenses associated with a conceptual process supported by an estimate in an unsolicited proposal. Unlike the other components of EarthScope in the O&M phase, the Transportable Array continues to construct and install stations on a definitive schedule. This is similar to the activities conducted during the MREFC phase, with one important difference—no contingency is explicitly included to address uncertainties in the budget assumptions. The budget is based on best current estimates, but as the Transportable Array progresses into a different operating environment in the eastern United States, it is possible that differences between the budget assumptions and reality will be encountered. If so, the installation schedule may be adjusted (up or down) in consultation with NSF.

Figure 5.9 summarizes the major cost elements of the Transportable Array.

Flexible Array (2.4.4)

The Flexible Array will be a pool of 291 broadband, 120 short-period, and 1700 single-channel active-source instruments acquired with MREFC funds. All or part of the pool will be used in multiple experiments of various size and duration. These instruments are deployed by individual principal investigators for experiments similar to the current PASSCAL operations. The Deputy PASSCAL Program Manager, supported by the PASSCAL Program Manager, manages Flexible Array activities. The major activities are acquisition of spares and replacements, based on PASSCAL Program experience. Maintenance, upgrades, and replacement of the instruments, and support for data archiving, is provided via a subaward to New Mexico Tech for the AOF. Half of the costs of the AOF are assumed attributable to Flexible Array support.

Figure 5.10 summarizes the major cost elements of the Flexible Array.

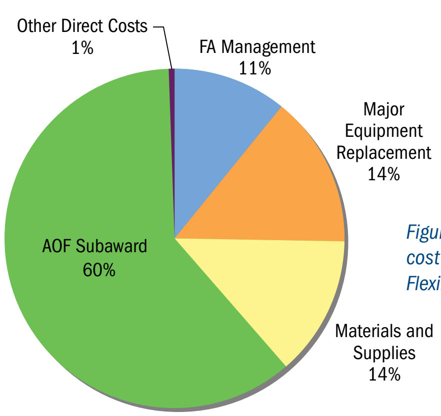


Figure 5.10. The major cost elements of the Flexible Array.

Data Management (2.4.5)

The IRIS Data Management System (DMS) is responsible for the reception, archiving, and distribution of all seismic data generated by USArray, PBO, and SAFOD installations.

The data management component of the O&M budget covers a variety of tasks required to manage these data effectively to meet the needs of the research community. The data management budget covers a small percentage of the DMS Program Manager's compensation. Operation and maintenance of the IRIS DMC is prorated with IRIS core activities, which include archiving and distributing all of the EarthScope seismic data. The DMC runs quality assurance routines on EarthScope generated data, and generates certain low-level data products.

Data management also includes operation of an active backup that was built as part of the MREFC project. The active backup provides redundancy in case of catastrophic failure of the DMC.

Data management also includes operation of the USArray portion of the EarthScope portal.

Data management costs, as shown in Figure 5.11, are largely personnel costs, as the DMC is staffed directly by IRIS.

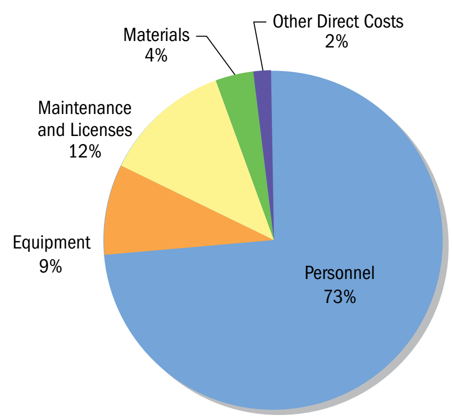


Figure 5.11. Data management costs.

Siting and Outreach (2.4.6)

Siting and Outreach supports Transportable Array siting and deployment by promoting the value to local communities of hosting a site, assisting in finding potential sites, and providing a legacy for the local community after relocation of the Transportable Array. The Siting and Outreach budget provides minimal resources for these essential services. A small portion of the IRIS E&O Manager, a full-time Outreach Specialist, and nominal support for publications and software support provide the staff for this function. Also included are university siting training workshops, the provision of seismographs to schools, and some support for Active Earth displays.

Magnetotellurics (2.4.7)

Two types of EarthScope magnetotelluric (MT) stations will be acquired during the MREFC stage. Twenty systems will be acquired for transportable type installations and seven were acquired and installed permanently. The budget includes management oversight, a subaward to a professional geophysical services company for the siting, permitting, and servicing of the 20 transportable stations, and a subaward to Oregon State University for the depot storage and maintenance of the equipment, data quality control, and the servicing of the seven permanent stations.

MT costs are largely based on actual experience operating permanent stations and conducting transportable experiments during the MREFC stage of EarthScope.

USArray O&M Budgets

Table 5.14 shows the USArray operations and maintenance budgets down to all WBS levels for FY09–13.

TABLE 5.14. BUDGET DETAIL FOR USARRAY (FY09–13)

		FY09	FY10	FY11	FY12	FY13	TOTAL
2.4 USARRAY OPERATIONS AND MAINTENANCE		**13,570,000**	**13,977,239**	**14,397,011**	**14,826,756**	**15,263,124**	**72,034,130**
2.4.1 USARRAY MANAGEMENT		**1,270,382**	**1,305,273**	**1,340,756**	**1,376,829**	**1,413,917**	**6,707,157**
2.4.1.1	USArray Management (Direct)	469,922	483,857	498,173	512,880	528,023	2,492,856
2.4.1.1.1	Personnel	437,502	450,627	464,145	478,070	492,412	2,322,755
2.4.1.1.2	Travel	20,000	20,500	20,992	21,475	21,969	104,936
2.4.1.1.3	Materials & Supplies	2,420	2,481	2,540	2,598	2,658	12,697
2.4.1.1.4	Other Direct Costs	10,000	10,250	10,496	10,737	10,984	52,468
2.4.1.2	General and Administrative	800,460	821,416	842,583	863,948	885,894	4,214,301
2.4.2 PERMANENT ARRAY							
2.4.2		0	0	0	0	0	0
2.4.3 TRANSPORTABLE ARRAY		**8,836,873**	**9,104,251**	**9,381,577**	**9,666,280**	**9,953,182**	**46,942,165**
2.4.3.1	Transportable Array Management	468,407	481,984	495,860	510,039	524,626	2,480,916
2.4.3.1.1	Personnel	373,498	384,702	396,244	408,131	420,375	1,982,949
2.4.3.1.2	Travel	60,000	61,500	62,976	64,424	65,906	314,807
2.4.3.1.3	Materials & Supplies	5,000	5,125	5,248	5,369	5,492	26,234
2.4.3.1.3	Other Direct Costs	29,909	30,657	31,392	32,115	32,853	156,926
2.4.3.2	TA Maintenance/Repair/Replacement	1,349,192	1,395,380	1,442,689	1,491,143	1,541,321	7,219,726
2.4.3.2.1	Station Equipment	205,120	210,248	215,294	220,246	225,311	1,076,219
2.4.3.2.1.1	Sensors	125,920	129,068	132,166	135,205	138,315	660,674
2.4.3.2.1.2	Data Acquisition Systems	79,200	81,180	83,128	85,040	86,996	415,545
2.4.3.2.2	Materials & Supplies	301,526	309,064	316,482	323,761	331,207	1,582,040
2.4.3.2.3	Subawards	830,546	863,768	898,319	934,252	971,622	4,498,506
2.4.3.2.4	Other Direct Costs	12,000	12,300	12,595	12,885	13,181	62,961
2.4.3.3	Array Operations	2,519,274	2,598,766	2,685,221	2,776,087	2,863,282	13,442,630
2.4.3.3.1	Field Service	623,911	643,777	664,204	685,208	706,895	3,323,994
2.4.3.3.1.1	Personnel	178,648	184,007	189,528	195,213	201,070	948,466
2.4.3.3.1.2	Subawards	360,263	372,644	385,460	398,727	412,458	1,929,551
2.4.3.3.1.3	Travel	85,000	87,125	89,216	91,268	93,367	445,976
2.4.3.3.2	Data Collection	1,300,512	1,345,266	1,396,661	1,452,162	1,502,980	6,997,581
2.4.3.3.3	Other Direct Costs	594,852	609,723	624,356	638,717	653,407	3,121,055
2.4.3.4	Station Deployment	4,500,000	4,628,121	4,757,807	4,889,012	5,023,953	23,798,894
2.4.3.4.1	Demobilization	800,000	823,260	847,046	871,370	896,397	4,238,073
2.4.3.4.2	Permitting	800,000	823,890	848,073	872,542	897,759	4,242,263
2.4.3.4.3	Construction	1,900,000	1,951,281	2,002,487	2,053,548	2,105,962	10,013,278
2.4.3.4.4	Installation	1,000,000	1,029,691	1,060,201	1,091,552	1,123,834	5,305,278
2.4.4 FLEXIBLE ARRAY		**1,368,399**	**1,415,752**	**1,464,396**	**1,514,365**	**1,566,124**	**7,329,035**
2.4.4.1	Flexible Array Management	146,830	151,185	155,659	160,255	164,988	778,917
2.4.4.1.1	Personnel	136,830	140,935	145,163	149,518	154,004	726,450
2.4.4.1.2	Travel	10,000	10,250	10,496	10,737	10,984	52,468
2.4.4.2	Flexible Array O&M	1,221,569	1,264,567	1,308,737	1,354,109	1,401,136	6,550,118
2.4.4.2.1	Equipment	197,561	202,500	207,360	212,129	217,008	1,036,558
2.4.4.2.2	Materials & Supplies	185,657	190,299	194,866	199,348	203,933	974,104
2.4.4.2.3	Array Operations Facility	830,546	863,768	898,319	934,252	971,622	4,498,506
2.4.4.2.4	Other Direct Costs	7,805	8,000	8,192	8,381	8,573	40,951

Table continues on next page...

Table 5.14 continued from last page...							
2.4.5 DATA MANAGEMENT SYSTEM		**1,324,910**	**1,362,902**	**1,401,631**	**1,441,101**	**1,481,696**	**7,012,240**
2.4.5.1	DMS Management	1,077,150	1,108,605	1,140,806	1,173,766	1,207,687	5,708,014
2.4.5.1.1	Personnel	905,196	932,352	960,323	989,132	1,018,806	4,805,810
2.4.5.1.2	Travel	20,000	20,500	20,992	21,475	21,969	104,936
2.4.5.1.3	Equipment	64,107	65,710	67,287	68,834	70,417	336,355
2.4.5.1.4	Materials & Supplies	21,000	21,525	22,042	22,549	23,067	110,182
2.4.5.1.5	Maintenance	61,847	63,393	64,915	66,408	67,935	324,497
2.4.5.1.6	Consultants	0	0	0	0	0	0
2.4.5.1.7	Other Direct Costs	5,000	5,125	5,248	5,369	5,492	26,234
2.4.5.2	Active Backup	41,123	42,199	43,271	44,338	45,431	216,363
2.4.5.2.1	Personnel	9,600	9,888	10,185	10,490	10,805	50,969
2.4.5.2.2	Materials & Supplies	6,000	6,150	6,298	6,442	6,591	31,481
2.4.5.2.3	Maintenance	24,523	25,136	25,739	26,331	26,937	128,667
2.4.5.2.4	Travel	1,000	1,025	1,050	1,074	1,098	5,247
2.4.5.3	Auxillary Data	127,103	130,329	133,516	136,658	139,875	667,481
2.4.5.3.1	SAFOD	39,919	40,917	41,899	42,863	43,849	209,446
2.4.5.3.2	PBO	87,184	89,412	91,617	93,795	96,026	458,035
2.4.5.4	Portal	79,533	81,769	84,038	86,338	88,703	420,381
2.4.5.4.1	Personnel	49,533	51,019	52,550	54,126	55,750	262,978
2.4.5.4.2	Equipment	30,000	30,750	31,488	32,212	32,953	157,403
2.4.6 SITING OUTREACH		**244,435**	**251,343**	**258,361**	**265,487**	**272,813**	**1,292,440**
2.4.6.1	Siting Outreach Management	173,435	178,568	183,839	189,252	194,824	919,919
2.4.6.1.1	Personnel	159,435	164,218	169,145	174,219	179,446	846,464
2.4.6.1.2	Travel	14,000	14,350	14,694	15,032	15,378	73,455
2.4.6.2	Siting	20,000	20,500	20,992	21,475	21,969	104,936
2.4.6.2.1	Participant Support	20,000	20,500	20,992	21,475	21,969	104,936
2.4.6.3	Outreach	51,000	52,275	53,530	54,761	56,020	267,586
2.4.6.3.1	Participant Support	4,000	4,100	4,198	4,295	4,394	20,987
2.4.6.3.2	Materials & Supplies	12,000	12,300	12,595	12,885	13,181	62,961
2.4.6.3.3	Publications	10,000	10,250	10,496	10,737	10,984	52,468
2.4.6.3.4	Subawards	25,000	25,625	26,240	26,844	27,461	131,169
2.4.7 MAGNETOTELLURICS		**500,000**	**512,717**	**525,290**	**537,694**	**550,393**	**2,626,093**
2.4.7.1	MT Management	106,375	109,251	112,141	115,043	118,020	560,830
2.4.7.1.1	Personnel	43,375	44,676	46,016	47,397	48,819	230,283
2.4.7.1.2	Travel/Misc.	12,000	12,300	12,595	12,885	13,181	62,961
2.4.7.1.3	Subawards	51,000	52,274	53,530	54,761	56,020	267,586
2.4.7.2	Permanent MT	68,245	69,951	71,630	73,277	74,963	358,066
2.4.7.2.1	Materials & Supplies	4,000	4,100	4,198	4,295	4,394	20,987
2.4.7.2.2	Subaward	60,000	61,500	62,976	64,424	65,906	314,807
2.4.7.2.3	Other Direct Costs	4,245	4,351	4,456	4,558	4,663	22,273
2.4.7.3	Transportable MT	325,380	333,515	341,519	349,374	357,409	1,707,197
2.4.7.3.1	Materials & Supplies	12,910	13,233	13,550	13,862	14,181	67,736
2.4.7.3.2	Subaward	312,470	320,282	327,969	335,512	343,229	1,639,461
MANAGEMENT FEES		**25,000**	**25,000**	**25,000**	**25,000**	**25,000**	**125,000**

6. Proposal Summary

NSF has spearheaded a major scientific undertaking by supporting the EarthScope project as an MREFC. The EarthScope facilities are almost completely built, and data are already flowing into exciting research applications. After a $200M capital investment, it is now critical to ensure that the EarthScope facilities continue to operate and successfully provide the research community with the data essential to fulfill the EarthScope science plan in all of its broad-reaching aspirations. Large facilities are always expensive to operate and maintain; the EarthScope facilities are no exception. They are distinctive relative to most NSF facilities in that they include extremely distributed and multi-faceted components, along with the need to repeatedly build and redeploy new seismic stations as the USArray Transportable Array sweeps across the country. Typical costs for operations and maintenance support of large NSF centralized facilities are in the range of 10–20% of the capital investment. By restraining the proposed O&M activities to only those that support critical functions of the EarthScope facilities, the proposed budget has been kept near the low end of this range despite the unusual demands of the project. This approach recognizes the tight budget situation under which NSF Division of Earth Sciences is currently operating and the need to provide parallel augmentations to the core research programs that will support scientific use of the EarthScope data, without diminishing core programs that support other earth science research.

EarthScope facilities supported by this proposal will provide fundamental data to address some of the outstanding questions facing geosciences today. PBO will operate an integrated observatory that will capture the three-dimensional deformation field, and its temporal variability, across the active boundary zone between the Pacific and North American plates in the western United States. USArray will conduct a rolling deployment of a seismic network that will provide multi-scale images of structure in the crust and upper mantle beneath North America. SAFOD will operate a borehole observatory directly within the San Andreas Fault to directly measure the physical and chemical conditions under which earthquakes occur. These state-of-the-art facilities will provide data that will serve multidisciplinary research on the structure and evolution of the North American continent at all scales—from the active nucleation zone of earthquakes to individual faults and volcanoes, to the deformation zone along the plate boundary, to the crustal and lithospheric structure of the entire continent. Continued operation of these facilities is key to addressing Earthscope science goals and to maximizing the scientific return on the capital investment made during the MREFC construction phase.

Realizing the full potential of the EarthScope project has the basic requirement of sustaining the facilities that provide the abundant high-quality data and data-collection capabilities that the EarthScope MREFC established. The nature of the facilities and the data being acquired is such that one or two years of operation is not sufficient; the geodetic and seismic data will need to be acquired over a period of 10–15 years, with a cumulative O&M support investment that will eventually exceed the initial capital investment. NSF augmentations of the Division of Earth Sciences budget over time will hopefully accommodate most of this long-term support, but there is no question that the overall field will be impacted by this sustained commitment, just as has been the case for major facilities such as oceanographic vessels in the ocean sciences, telescopes in astronomy, and polar laboratories in polar programs. The scientific potential for truly major advances in earth science research fully justifies the investment of long-term O&M support in the EarthScope facilities requested in this proposal. The impact is already beginning to emerge and holds the potential for exponential growth as data accumulate and research applications mature. The future is bright with expectation and promise. Now is the time for EarthScope to move forward toward its bright goals.

7. Work Breakdown Structure Dictionary

WBS Dictionary, Assumptions, and Basis of Estimate

Each element of the EarthScope O&M proposal has developed a work breakdown structure (WBS) Dictionary that provides the following for each Level 3 task:

1) **Definition** – explanation of the task scope
2) **Assumptions** – critical, technical, or scientific assumptions used for the basis of estimate, key issues that may alter task scope
3) **Basis of Estimate**- justification of the estimate through such mechanisms as previous experience, similarity to related efforts, actual costs of related efforts, parametric cost determination, or simply based best judgment.

The current format of the WBS Dictionary has been used during the EarthScope MREFC and O&M Projects. Over the past four years this dictionary has received positive feedback by the National Science Foundation and various independent advisory review panels and now represents EarthScope best practices.

During the review of a proposal submitted earlier, NSF subjected EarthScope to an independent cost review. This was a detailed review of proposed O&M costs conducted by an outside firm with expertise in cost estimating. In part, it concluded, "With few exceptions, we determined that the EarthScope proposal for facility O&M is reasonable, adequately documented, and justified. It clearly documents the project scope, describing the proposed work and activities in a readable and understandable fashion" (see "EarthScope Independent Cost Review," Report NSF 50T1, May 2005). The EarthScope cost basis included in this WBS Dictionary is a revision of the basis that garnered this review.

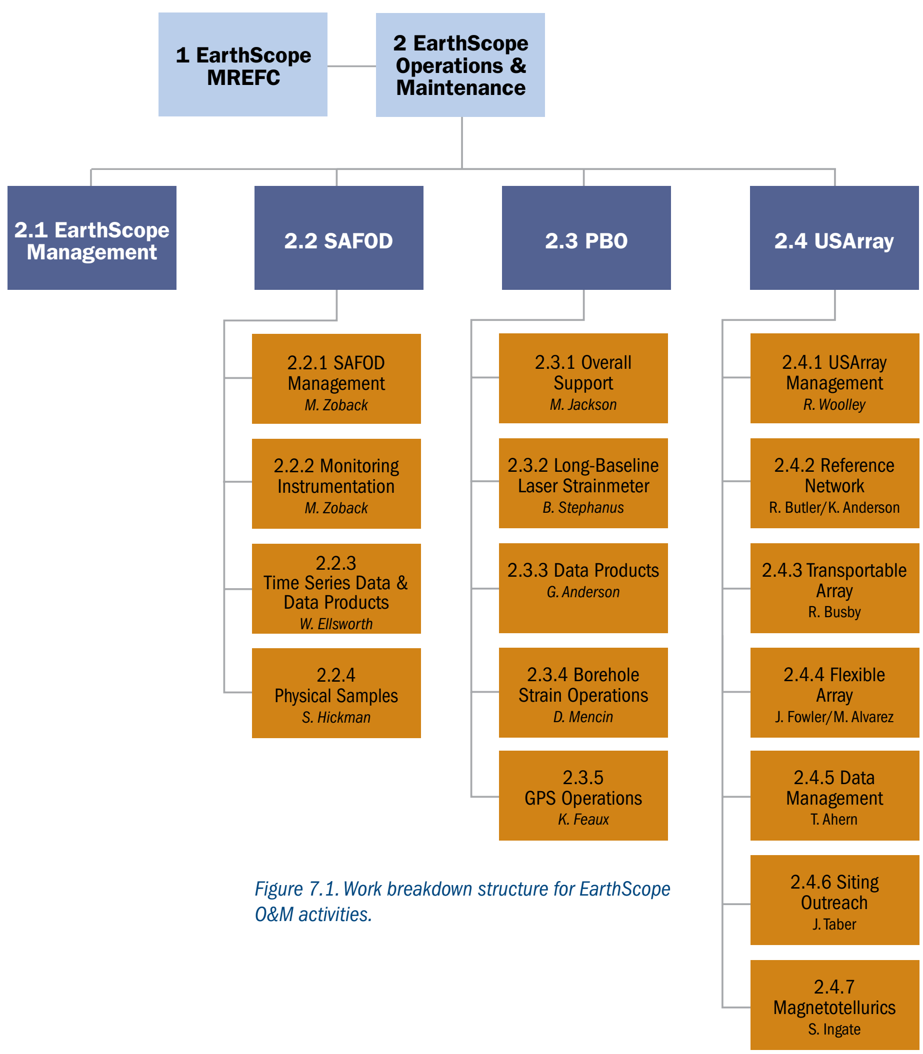


Figure 7.1. Work breakdown structure for EarthScope O&M activities.

San Andreas Fault Observatory At Depth (SAFOD) Work Breakdown Structure Dictionary

WBS Element 2.2.1: SAFOD Management

Definition: This is a summary task for all project management activities, including staff salaries, supplies, and overhead. This task is broken down to match Stanford accounting practices of reporting salaries, including fringe benefits and other direct expenses, separately from indirect charges.

WBS Element 2.2.1.1: SAFOD Management

Definition: All direct expenses related to SAFOD management and operations, such as salary for SAFOD PI and Program Coordinator, travel, and other office supplies.

Assumption: Salaries are set by Stanford University policies. Rates include fringe benefits. Annual increases are included at the rate of 3%.

Basis of Estimate: The SAFOD PI requests one month summer support compared to two months during MREFC. The Project Coordinator will be 25% FTE instead of their current 50%. The reduction results from decreased procurement activities and a reduction in the number of meetings.

WBS Element 2.2.1.2: General and Administrative

Definition: This task covers the Stanford indirect charges on salaries, supplies, travel, and all other direct expenses.

Assumption: The subawards under O&M will not be continuations of subawards issued under the MREFC and thus will be subject to indirect charges. Indirect charges apply only to the first $25,000 of subawards.

Basis of Estimate: The Stanford University indirect rate is 58% of total direct costs.

WBS Element 2.2.2: Monitoring Instrumentation

Definition: This summary task consists of all support for procurement, subcontracts, installation, operations, and maintenance of the SAFOD monitoring instruments.

WBS Element 2.2.2.1: Behind Casing Fiber-Optic Interferometric Strainmeter

Definition: This task covers all instruments and maintenance matters related to the fiber optic strainmeter cemented behind casing during Phase 1 drilling.

Assumption: This is an experimental project, as this type of installation has not been previously attempted at these depths and conditions. The data quality depends on an ultra-stable laser that is sensitive to environmental conditions.

Basis of Estimate: The estimate covers one month time for two engineers to monitor and track experimental operations and to provide data quality assurance. There is also nominal support for the PI and a project assistant. Also included are expenses for one site visit per year.

WBS Element 2.2.2.2: Permanent Main Hole Multilevel Monitoring Array

Definition: This is the key instrument of the San Andreas Fault Observatory. The instrument is a retrievable, 3-level instrument array that can operate for long periods in the main hole. Each level will have an accelerometer, a seismometer, and a tiltmeter. The package will also contain an inflatable packer and a fluid pressure sensor.

Assumption: This instrument will operate at bottom of the main hole (~ 2.7-km depth) at a temperature of ~ 130°C. The temperature and pressure conditions are very challenging to the sensors, fittings, electrical/fiber-optic conduits, and downhole electronics. Consequently, the lifetime of the equipment is short. The instrument will have a modular design and it will need to be completely replaced every three years. If the instruments fail before three years, they will remain in the hole, inoperable, until there is sufficient funding. There are no commercially available sensor systems that have anything like the required capability. The instrument package will be strapped to steel production tubing and lowered into the well during deployment.

Basis of Estimate: The longevity estimate for the instrument is based on an analysis carried out by the Geothermal Instrumentation Research Group at Sandia National Laboratory, the nation's leading experts on the operation of high-temperature equipment. The cost of the instrument is based on quotes from our system integrator, Pinnacle Technologies. The cost is based on installing new equipment during FY11 (to replace the downhole array installed during the MREFC period) and refurbishing these sensors for redeployment during FY13. Due to the long lead times needed to procure much of the equipment, the per-annum budget for the five-year funding period is approximately 20% of the total cost.

WBS Element 2.2.3: Time-Series Data and Data Products

Definition: This summary task consists of all support for data collection, data processing, and data distribution, including telemetry.

WBS Element 2.2.3.1: Site Infrastructure

Definition: This task covers activities related to site infrastructure such as power, telemetry, electronics, computer systems, buildings, telemetry towers, and security. It also includes software/hardware support for establish-

ing a virtual private network (VPN) for the Northern California Earthquake Data Center (NCEDC).
Assumption: This task is covered by USGS contributions.
Basis of Estimate: This task is covered by USGS contributions.

WBS Element 2.2.3.2: Real-Time Data Subset

Definition: This task covers activities related to producing up to six channels of real-time data from the SAFOD permanent array. These data will be downsampled to 250 samples/second and transmitted via the Internet from the SAFOD site to the USGS in Menlo Park, CA.
Assumption: Most of the effort for this task will be managed by the USGS. Several key elements, however, will need to be managed by the NCEDC and funded directly by NSF through this proposal. These tasks include conversion of the waveform data from USGS Earthworm to miniSEED format, developing dataless SEED volume metadata, and ensuring that the data flow to the IRIS Data Management Center (DMC).
Basis of Estimate: Cost is derived from 0.38 FTE at NCEDC for all of the SAFOD data management tasks.

WBS Element 2.2.3.3: Continuous and Triggered Full-Sample-Rate Data

Definition: This task covers activities related to producing usable full-sample-rate data products from the SAFOD permanent array. This includes converting the raw data to SEED format with appropriate SEED metadata, and also developing a list of events or triggers to help point researchers to the more useful data.
Assumption: The data will be recorded at 4000 samples/second and written to two redundant tape drives at the SAFOD site. Tapes will be shipped to the NCEDC data center on a monthly basis. The deployment metadata will change at a rate of once every three years.
Basis of Estimate: Cost is derived from 0.38 FTE at NCEDC for all of SAFOD data management tasks, including producing SEED metadata, converting the raw data to miniSEED, and indexing the data against existing (Northern California Seismic System) catalogs.

WBS Element 2.2.4: Physical Samples and Sample Handling

Definition: This summary task consists of all support for collecting, archiving, and distributing physical samples obtained during the drilling and coring of SAFOD.

WBS Element 2.2.4.1: Long-Term Curation of Samples

Definition: This covers the activities related to storing, distributing, tracking, and recovering core and other samples maintained at the Gulf Coast Repository (GCR) at Texas A&M University.
Assumption: This task covers the following activities: (1) storing all SAFOD core, cuttings, and fluid samples in refrigerated storage lockers at 4°C; samples will be maintained in this condition indefinitely, until otherwise instructed by NSF in consultation with the SAFOD Sample Committee (SSC); (2) preparing and distributing core, cuttings, and fluid subsamples to principal investigators (PIs) in the United States and abroad in response to sample requests approved by the NSF and the SSC; (3) assisting PIs with specialized sampling needs using equipment available at the GCR or provided to the repository by SAFOD staff or by the PIs themselves, including obtaining oriented sub-cores, deriving mineral separates from cuttings, and extracting borehole fluid sub-samples from pressurized and non-pressurized sample containers; (4) restocking and repackaging of samples returned to the GRC; and (5) maintaining records of core, cuttings, and fluid sample requests filled (to whom these samples were provided and final disposition of samples [date samples returned and condition of samples]).
Basis of Estimate: The cost estimate is based on a proposal from the GCR to handle long-term curation, subsampling, restocking, and record-keeping for the SAFOD core, cuttings, and fluid samples.

Plate Boundary Observatory Work Breakdown Structure Dictionary

WBS Task 2.3: PBO Operations and Maintenance

Definition: Provide operation and maintenance for global positioning system stations, borehole strainmeters, long baseline laser strainmeters, and portable campaign GPS instruments, located throughout the United States.

WBS Task 2.3.1: Overall Support

Definition: Overall PBO project management and project support.

WBS Task 2.3.1.1: Project Office

Definition: Overall management and administration of the PBO O&M program.
Assumptions: Continuation of selected staffing and other costs from the MREFC program.
Basis of Estimate: Facility Project Director salary and travel, Administrative Assistant salary. The majority of the estimate is based on actual costs incurred under the MREFC program.

WBS Task 2.3.1.2: Senior Engineer

Definition: Overall engineering and technical management of the O&M program. Oversight of technical documentation for PBO. Overall communications engineering for the PBO O&M program. Engineering and communications problem support for regional engineering staff.
Assumptions: Continuation of selected staffing and other costs from the MREFC program. Experience has shown that a critical component to the success of large and complex networks is the management, documentation, and dissemination of the technical aspects of the project.
Basis of Estimate: 50% of Senior Engineer salary and travel. In some cases the Senior Engineer's travel and expenses may be paid by the applicable in-region travel budget if the Senior Engineer is supplementing their crew by performing work unrelated to his Senior Engineering scope. Any travel done to support the Senior Engineering duties is included in this budget. The majority of costs are based on actual costs incurred under the MREFC.

WBS Task 2.3.1.3: Project Controls (Cost/Schedule) Office

Definition: Overall cost and schedule administration of the PBO O&M program. This includes producing reports, budget forecasts, risk assessment, and analysis. In addition, management of the Laser Strainmeter subaward is done out of this office. This task includes a Cost/Schedule Manager but does not include the charges of any PBO Cost Account Managers. These managers will charge their time for cost/schedule activities to their specific task account.
Assumptions: Continuation of staffing and other costs from the MREFC program.
Basis of Estimate: Cost/Schedule Manager salary and travel. The majority of the estimate is based on actual costs incurred under the MREFC program.

WBS Task 2.3.1.4: Permitting Coordinator/Permits

Definition: Labor, travel, recurring fees, and reporting expenses to support PBO permitting.
Assumptions: The PBO Permitting Coordinator is responsible for ensuring that PBO's regulatory and statutory obligations for the ongoing site permits are met. Salary, travel, and permitting costs for the time period September 1, 2003 to September 30, 2008 come from MREFC funds. As of October 1, 2008 the costs will move to O&M. The PBO permitting coordinator will be responsible for the renewal of permits that require renewals, paying annual rental fees, reporting requirements to federal landowners, managing relationships with all GPS and Strainmeter landowners, and providing information to landowners about the project. The Permitting Coordinator will travel to each remote office once a year, visit with landowners as needed, and will also participate in some network maintenance.
Basis of Estimate: 0.5 FTE of the Permitting Coordinator will be required on O&M. The travel and salary costs are based on actual costs incurred during MREFC. Annual site rental and renewal costs are based upon the subset of sites that fit this category as of February 1, 2007 and are extrapolated upward based on the number of sites remaining to be permitted.

WBS Task 2.3.1.5: Facility and Program Support

Definition: Facility support of the PBO program including prorated Boulder office facility lease costs, general office budget expenses, and cellular phone expenses.

WBS Task 2.3.1.5.1: IT Support

Definition: The PBO O&M will have 1 FTE for the overall IT administration of the PBO computer, software, and networking equipment. This task includes the salary and travel budget for the PBO Systems Administrator. It includes the costs of supporting IT equipment in all PBO locations. Support includes:

- End-user hardware, software, and network support, including security monitoring and patches
- Replacement of desktop and laptop computers ac-

cording to anticipated intervals

- Annual travel to each regional office for user support and equipment maintenance/replacement
- Maintenance, repair, and replacement of Data Management servers and network infrastructure with resources from a pool that is maintained based on observation of failure rates seen during the PBO MREFC
- Maintenance of the data retrieval network from the field endpoints to UNAVCO

Assumptions: Continuation of staffing and other costs from the MREFC program. Travel is based on annual visits to three regional offices. Desktops and laptops are on a three-year replacement cycle. The equivalent of one server is replaced per year

Basis of Estimate: PBO Systems Administrator salary and travel (1 FTE). The majority of the estimate is based on actual costs incurred under the MREFC program. Hardware, software, maintenance, and travel costs are based on similar costs encountered in the PBO MREFC. Data flow server costs are based on an anticipated failure of one server per year based on observed failure rates during the PBO MREFC.

WBS Task 2.3.1.5.2: Telecommunication Support

Definition: All PBO cell phone charges for PBO staff.

Assumptions: Based on PBO personnel.

Basis of Estimate: Cell phone connect charges are based on the number of personnel on the PBO project multiplied by the average cell phone cost.

WBS Task 2.3.1.5.3: Facility Costs

Definition: Overall facility support for the PBO program including prorated Boulder office facility lease costs, general office budget expenses, express mail, postage.

Assumptions: Continuation of costs from the MREFC program.

Basis of Estimate: The facility costs included in this operations and maintenance proposal are a prorated share of the UNAVCO facilities costs. These costs include the lease costs of UNAVCO's Boulder, CO office and warehouse space, associated utilities, taxes, building maintenance, and telecommunications costs. This pool of costs is allocated to the various UNAVCO projects based on the square footage the project occupies. This indirect rate is part of an indirect pricing proposal that is submitted to the National Science Foundation. General office expenses, express mail, and postage are based on the MREFC program history.

WBS Task 2.3.1.6: Participant Support

Definition: Participant costs will be used to support the PBO Standing Committee (PBOSC) for an annual meeting to review how PBO is meeting science and management goals. The PBOSC will also scientifically prioritize stations for acceptable downtime and ensure that data products and software tools meet the user communities needs. This WBS covers travel and per diem expenses. This budget is not for use by UNAVCO employees.

Assumptions: N/A

Basis of Estimate: Estimate of travel and per diem expenses for user community (non-UNAVCO personnel) support of PBO activity.

WBS Task 2.3.1.7: Education and Outreach

Definition: Support of PBO education and outreach function.

Assumptions: Cost estimate for an education and outreach professional and associated travel and material and supplies costs. Costs for hosting short courses on PBO related activities. Tasks for PBO Education and Outreach under O&M will be focused on serving the communities in which PBO equipment is based. During the installation phase of PBO, the UNAVCO Education and Outreach program has concentrated on producing curricular modules, which use PBO data and scientific goals, and, in later years, highlight the science discoveries made from PBO data. These will have been evaluated and revised by the inception of the O&M phase of the project and will be widely disseminated during O&M. The 0.5 FTE (FY09) /1 FTE (FY10–13) in Education and Outreach will work closely with the ENO to bring the science discoveries to local venues in areas throughout the PBO footprint. These will include (1) regional and local teacher professional development workshops tied to individual school districts as well as regional professional teacher meetings (National Science Teachers Association, National Association of Geoscience Teachers, Geological Society of America, and others), (2) working with local, state, and national park services on training for interpreters, (3) collaborative project with IRIS using an interactive Web-based museum exhibit with ancillary printed materials, and (4) preparing PBO-based materials for broader dissemination through other EarthScope-driven activities such as the Distinguished Speakers Series initiated in 2007.

Basis of Estimate: One 0.5 FTE plus a forecast of materials and supplies required to support course and travel activity. This rises to 1 FTE in the second year of O&M effort. Funds are requested for support of one undergraduate per year to participate in Research Experience in Solid Earth Science for Students (RESESS) (http://resess.unavco.org). The institutional support by large NSF projects for increasing diversity in the geosciences is essential for a future robust workforce. PBO's participation in recruiting for RESESS during the installation phase and recruiting students for summer jobs in PBO is an important cornerstone for NSF programs and for the larger geoscience community. Each year, at least one student will participate in a research project related to the operation and maintenance of PBO. Short Courses: Funds are requested for three short courses per year. Anticipated topics include "Using strainmeter Data," "Using EarthScope Data," and "Integration of Seismic and Geodetic Data." Requested funds cover expenses for the instructors, limited refreshments, and scholarships for students.

The UNAVCO Short Course Series started in 2005 with a course "Strainmeter Data—a short course" taught over three days by D. Agnew, E. Roeloffs, and K. Hodgkinson (http://www.unavco.org:8080/cws/straindata/). In 2006, a course on strainmeter data and one on GPS processing together had 32 participants. Of these, there were six foreign institutions, nine Hispanic/Latino participants, 11 graduate students, three post-docs, three undergraduates, and ten women. These courses both broaden our current and future community's ability to use PBO data and also broaden participation beyond the traditional demographics.

WBS Task 2.3.2 Long Baseline Laser Strainmeter

Definition: Operation and maintenance of six long baseline laser strainmeter units.

WBS Task 2.3.2.1: Long baseline Laser Strainmeter Subaward

Definition: Supports the operation and maintenance of six long baseline laser strainmeters. One instrument is located at Durmid Hill, CA, next to the eastern side of the Salton Sea and within 2 km of the southeastern terminus of the San Andreas Fault; two instruments are on the western side of the Salton Sea near the historically seismogenic San Jacinto fault; and one instrument is at Glendale, CA, next to the San Gabriel Mountains and near Los Angeles basin blind-thrust faults. Two additional instruments will be at Cholame, CA, near the posited initiation point of the 1857 San Andreas Fault earthquake.

The operations and maintenance of these instruments includes funding for University of California, San Diego support personnel, replacement of necessary equipment, materials, and supplies, and necessary travel expenses to the sites. The costs also support data transmission to the PBO strainmeter archive and the generation of strainmeter data products. These costs only have UNAVCO headquarters' burden applied to the first $25,000 of costs.

Assumptions: Six long baseline laser strainmeter units based on 2002 O&M Proposal unit cost

Basis of Estimate: Subaward estimate

WBS Task 2.3.3 Data Products

Definition: This summary task consists of all personnel, hardware, software, materials, and subcontract costs used to support the PBO data management system (DMS). The PBO DMS handles raw (Level 0 and 1) products from all PBO stations, Level 2 products derived from these data, and metadata associated with both sets of products.

Assumptions: Task includes archiving of all station metadata, maintenance information, data products, and the generation of data products up to and including Level 2. Data products will be made available from the PBO Archives via current Archive distribution mechanisms, including Web and ftp access and data distribution clients, as well as the PBO Web site and EarthScope Portal.

WBS Task 2.3.3.1: In-house Support

Definition: This task provides salary and travel support for a Data Products Manager (1 FTE), a database programmer (1 FTE), a data engineer (0.5 FTE), and a Senior Web Administrator (0.5 FTE); beginning in FY12, it also includes salary support for a Software Engineer (1 FTE) and the 0.5 FTE data engineer becomes 1 FTE. The Data Products Manager oversees all PBO data management activities. The database programmer, data engineer, and Senior Web Administrator will provide minimal software engineering support to operate and maintain PBO software systems critical for PBO data management, maintain the PBO Web presence, and develop any additional tools the community requires to meet evolving needs for PBO data products.

Assumptions: The proposed staffing level of 3 FTEs for this task is lower than that of other large GPS networks, and this represents a significant management challenge. PBO management expects to meet this challenge by sharing data management activities among the GPS Operations, Data Management, and UNAVCO Facility staff; by cross-training Data Management staff to provide backup and coverage for critical activities; and through aggressive development of automated data management systems during the MREFC period.

GPS data management tasks will be coordinated among the data engineer, GPS Operations staff, and UNAVCO Facility GPS archive staff to maximize resource efficiencies and ensure coverage on critical data flow tasks. Data flow will use automated systems that also provide network monitoring and data quality control that DMS and Operations staff will use to monitor data flow; Figure 7.2 shows the overall flow of data from PBO GPS stations using these automated systems.

Basis of Estimate: Labor and travel for the Data Products Manager, database programmer, 50% FTE data engineer, and 50% FTE Senior Web Administrator; starting in FY12, includes 1 FTE data engineer and 1 FTE software engineer. The majority of costs are based on

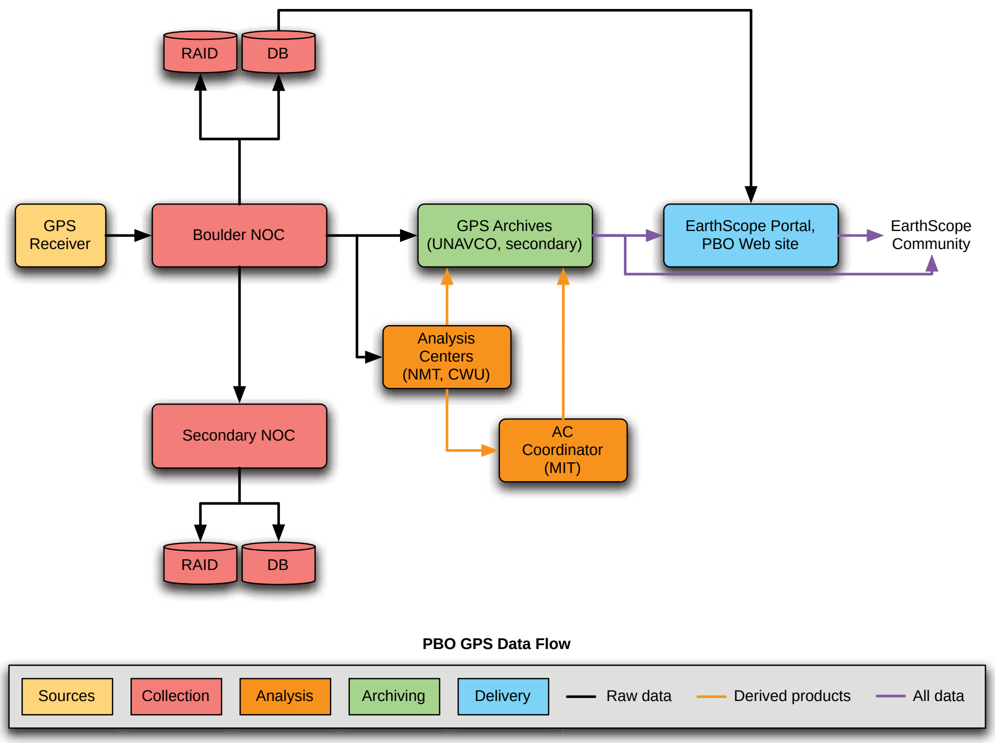


Figure 7.2. Flow of data through PBO GPS Data Management System. The Boulder Network Operations Center (NOC) downloads data from GPS stations, copies the data to a local RAID system, extracts necessary metadata into the PBO Operational Database (DB), and transmits data to the UNAVCO Facility Archive and the secondary NOC. Data flow to the GPS Analysis Centers for processing, and all data products flow to the UNAVCO Facility Archive and an offsite backup archive for archiving and delivery to end users. Either NOC can provide critical data flow control functions; either archive can receive, archive, and distribute data products; and analysis can be done with only one operational Analysis Center. Redundant, geographically distributed data collection centers and archives ensure high reliability and availability of data products despite possible system failures at any one center. See section 2.3.3.1 for more details on the Boulder NOC, 2.3.3.3 for the roles of the GPS Analysis Centers, and 2.3.3.4 for details on the UNAVCO Facility Archive.

actual costs incurred under the MREFC program; other large network operations such as the USGS in southern California, SCIGN, and PANGA; advice from existing regional network operators; and 20 years of experience by the UNAVCO Facility supporting data management activities for NSF- and NASA-funded instrumentation networks.

WBS Task 2.3.3.2: IT Equipment and Supplies

Definition: This task covers all hardware, software, and material costs associated with supporting PBO data flow, quality control, network monitoring, and network control. This includes servers and software, VPN hardware and software, network storage and backup, individual workstations and software, and maintenance contracts on all of the above.

Assumptions: Servers and other systems required for Data Management activities will be purchased and made operational during the MREFC phase; funding requested in this proposal will cover system maintenance and replacement of systems as needed. Systems will be maintained at a minimum level compatible with maintaining stable data flow with 80% uptime. Systems at the secondary NOC will be maintained in a warm failover status. We assume servers have a five-year average replacement cycle, desktop systems an average four-year replacement cycle, and that laptop computers are replaced on average once every three years. We assume that replacement will be minimal during the first three years of O&M with the budget increasing in FY12 by $30,000 per year. We believe the requirements will be minimized for the first three years because the equipment will have just been purchased near the end of the MREFC phase. After three years, we will require a more normal replacement cycle. FY12 also has a one-time increase of $19,000 for server replacement.

Basis of Estimate: Hardware, software, maintenance, and personal computer costs are based on similar costs incurred under the MREFC program. System replacement cycles are based on industry standards

WBS Task 2.3.3.3: GPS Analysis

Definition: This task includes costs associated with operating and maintaining two GPS Analysis Centers and an Analysis Center Coordinator. The Analysis Centers process Level 1 GPS data to generate Level 2a data products, which the Analysis Center Coordinator merges to generate Level 2b products (Table 4.2). See Figure 7.2 for a graphical representation of the role these centers play in PBO GPS data flow.

WBS Task 2.3.3.3.1: Central Washington University Analysis

Definition: This task includes salary, travel, hardware, software, and material costs associated with operating and maintaining the GPS Analysis Center at Central Washington University.

Assumptions: Processing during the O&M phase will use systems developed during the MREFC phase; the proposed budget includes only required support for ongoing operations. The costs include 1.25 FTE for Analysis Center activities, replacement of systems for data processing activities, travel for CWU staff to attend required PBO data analysis meetings, and software and hardware maintenance agreements.

Basis of Estimate: Costs are based on a subaward proposal from Central Washington University.

WBS Task 2.3.3.3.2: New Mexico Tech Analysis

Definition: This task includes salary, travel, hardware, software, and material costs associated with operating and maintaining the GPS Analysis Center at the New Mexico Institute of Mining and Technology.

Assumptions: Processing during the O&M phase will use systems developed during the MREFC phase; the proposed budget includes only required support for ongoing operations. The costs include 1.17 FTE for Analysis Center activities, replacement of systems for data processing activities, travel for NMT staff to attend required PBO data analysis meetings, and software and hardware maintenance agreements.

Basis of Estimate: Costs are based on a subaward proposal from NMT.

WBS Task 2.3.3.3.3: MIT ACC Analysis

Definition: This task includes salary, travel, hardware, software, and material costs associated with operating and maintaining the GPS Analysis Center Coordinator at MIT.

Assumptions: Processing during the O&M phase will use systems developed during the MREFC phase; the proposed budget includes only required support for ongoing operations. The costs include 0.5 FTE for Analysis Center Coordinator activities, replacement of systems for data processing activities, travel for MIT staff to attend required PBO data analysis meetings, and software and hardware maintenance support.

Basis of Estimate: Costs are based on subaward proposal from MIT.

WBS Task 2.3.3.4: GPS Archive

Definition: This task includes staff, hardware, software and material costs associated with operating and maintaining a GPS data product archive at the UNAVCO Facility. See Figure 7.2 for a graphical representation of the role the Archive plays in GPS data flow.

WBS Task 2.3.3.4.1: UNAVCO Archive (GPS)

Definition: This task includes staff, hardware, software and material costs associated with operating and maintaining a GPS data product archive at the UNAVCO Facility and an off-site secondary backup archive operated by UNAVCO Facility staff. This system leverages significant prior NSF investments at the UNAVCO Facility and allows for backup, security, and recoverability of data. The UNAVCO Facility is responsible for archiving all PBO GPS data products, and will make them available to users both directly and via the EarthScope Portal.

Assumptions: The costs include a data engineer (1 FTE) with primary responsibility for routine data archiving and system maintenance, a database developer (.25 FTE) for metadata management tasks, and management support (0.1 FTE); hardware and software support costs for the ongoing archiving activities; and travel for Facility staff to attend required data management meetings.

Basis of Estimate: The majority of costs are based on actual costs incurred under the MREFC program; travel is based on one trip per year. System maintenance and replacement cycles are based on industry standards.

WBS Task 2.3.3.5: Borehole Strainmeter Analysis

Definition: This task includes salary and travel costs associated with operating and maintaining a borehole strainmeter (BSM) data Analysis Center (AC) located at the USArray Array Operations Facility in Socorro, NM. The Strainmeter Data Manager (1 FTE) oversees the production of Level 2 borehole strain data products, including supervising the activities of the Strainmeter Data Technician (1 FTE), operating and maintaining software systems required data analysis, and assisting Strainmeter Operations staff in monitoring the status of the PBO borehole strainmeter network. The Strainmeter Data Technician is primarily focused on routine data product production and metadata management tasks. See Figure 7.2 for a graphical representation of the role the BSM Analysis Center plays in PBO strainmeter data flow.

Assumptions: BSM data management tasks will be coordinated between the BSM AC staff, Strainmeter Operations staff, and staff of the PBO strainmeter archives in order to maximize resource efficiencies and ensure coverage on critical data flow tasks. Strainmeter Operations staff will be primarily responsible for monitoring and maintaining remote stations and communications systems, while strainmeter archive staff will be mainly responsible for archiving and distribution of data products. BSM AC staff will be responsible for monitoring data quality and producing Level 2 strain data products, and by so doing will also assist with monitoring stations and archiving.

Basis of Estimate: BSM data analysis cost estimates are based on two years of actual MREFC data analysis effort, twelve years of data analysis experience by the Strainmeter Data Manager, and discussions with strainmeter processing experts in the community.

WBS Task 2.3.3.6: UC Berkeley Borehole Strainmeter Archive

Definition: This task includes staff, hardware, software, and material costs associated with operating and maintaining strainmeter data product archives at the NCEDC and the IRIS DMC. These are both NSF-funded long-term archives, and this system allows for data backup while leveraging the prior NSF investments at these facilities. These archives are responsible for archiving all PBO borehole and long baseline strainmeter data products, and will make them available to end users. See Figure 7.3 for a graphical representation of the role the BSM archives play in PBO strainmeter data flow.

Assumptions: The proposed budget covers efforts at NCEDC, while IRIS is contributing staff effort as part of the USArray activities at the IRIS DMC. The costs include a 0.5 FTE programmer for routine data archiving and system maintenance, and two weeks/year for management and reporting; hardware and software support costs for the ongoing archiving activities; and travel for NCEDC staff to attend required PBO data management meetings.

Basis of Estimate: Costs are based on subaward proposal from NCEDC.

WBS Task 2.3.3.7: EarthScope Web and Portal Support

Definition: Salary and travel costs associated with supporting the EarthScope Web presence and PBO segments of the EarthScope Portal.

Assumptions: Continuation of staffing and other costs from the MREFC program, with a reduction in effort from develop to maintenance of PBO segments of the EarthScope Portal.

WBS Task 2.3.3.7.1: EarthScope Web Administration

Definition: This task includes salary and travel costs for a Senior Web Administrator (0.5 FTE) to operate and maintain the EarthScope Web presence. It also includes minimal Web subcontractor support.

Assumptions: This task will require a Senior Web Administrator (0.5 FTE) to operate and maintain the EarthScope Web presence, with minimal support from a Web consultant. This will include required system maintenance and upgrades; gathering, creation, and posting of new content on the EarthScope Web site; operating the EarthScope Document Management System; and related activities.

Basis of Estimate: Labor and travel for personnel supporting PBO Web administration. The majority of costs are based on actual costs incurred under the

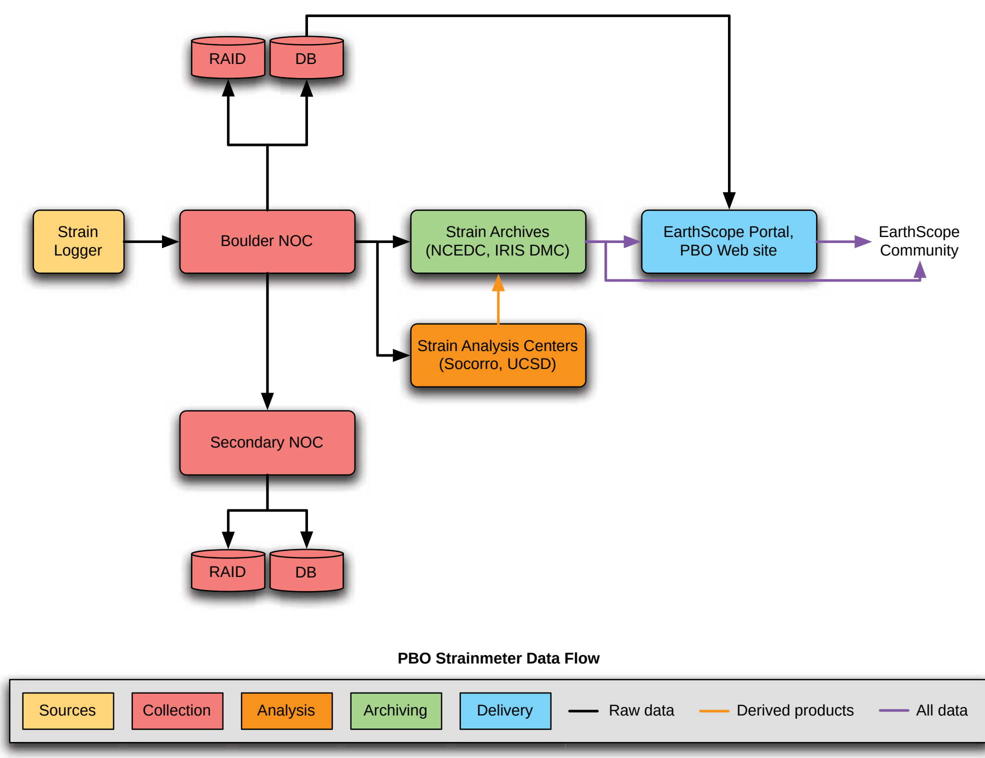


Figure 7.3. Flow of data through PBO Strain Data Management System. The Boulder Network Operations Center (NOC) downloads data from strainmeter stations, copies the data to a local RAID system, extracts necessary metadata into the PBO Operational Database (DB), and transmits data to the PBO strain archives at the Northern California Earthquake Data Center (NCEDC) and IRIS Data Management Center (DMC). The Boulder NOC will also mirror these data to the secondary NOC on a routine basis; the secondary NOC can take over all critical operations of the Boulder NOC in the event of system failure in Boulder. The Boulder NOC also delivers data to the PBO strain analysis centers at Socorro, NM (borehole) and University of California, San Diego (laser strain), which create Level 2 products that they send to the strain archives. Users can access PBO strain data products from the archives through a number of mechanisms, as well as via the PBO Web site and the EarthScope Portal. See sections 2.3.3.5 and 2.3.3.6 for more details.

MREFC program. Travel is estimated at four trips per year to national meetings, to Washington, D.C. for coordination with NSF, and to other required EarthScope meetings.

WBS Task 2.3.3.7.2: EarthScope Portal Support

Definition: This task includes salary and travel costs associated with support of the PBO component of the EarthScope Portal, which will provide single-point access to all EarthScope data products.

Assumptions: This task will require a software engineer (0.5 FTE) for maintenance of Web services for PBO data product access, assisting with maintenance and development of the central EarthScope Portal, and ensuring that the PBO Web services infrastructure evolves as needed to handle evolving data product generation and distribution requirements. Necessary management and reporting activities are included in the effort under WBS element 2.3.3.1.

Basis of Estimate: Labor and travel for personnel supporting the PBO element of the EarthScope Portal. The majority of costs are based on actual costs incurred under the MREFC program. Travel is estimated at two trips per year for coordination of Portal activities with SAFOD and USArray staff.

WBS Task 2.3.3.8: GeoEarthScope

Definition: This task includes salary and travel support for the GeoEarthScope project manager (GPM; 0.5 FTE). The GPM oversees maintenance of imagery products collected during the MREFC phase, tracks MREFC awards covering ongoing geochronology activities (those using committed MREFC funds but not completed by the end of the MREFC), and manages the archiving and distribution of the results of those activities. The GPM also participates in ongoing education and outreach activities.

Assumptions: The 0.5 FTE requirement for the GeoEarthScope O&M phase is estimated based on the level of effort required during the MREFC phase minus data acquisition and initial infrastructure development efforts. Travel is based on participation in meetings related to EarthScope and UNAVCO, as well as European Space Agency (ESA) meetings as requested by ESA officials as a condition of authorizing InSAR imagery acquisition proposals.

Basis of Estimate: The majority of costs are based on actual costs incurred during the MREFC program. Travel is based on three trips per year

WBS Task 2.3.4: Borehole Strainmeter Operations

Definition: Staff, facilities, travel, vehicle lease, insurance and vehicle maintenance, ongoing costs, and materials to support the 103 PBO borehole strainmeter stations.

WBS Task 2.3.4.1: Borehole Strainmeter Operations Management

Definition: Labor and travel to support the PBO Borehole Strainmeter Manager.

Assumptions: The Operations Manager over sees the operation of the Borehole program of the PBO O&M program including, BSM instruments, borehole seismometers, tiltmeters and ancillary equipment. The Operations Manager sets and enforces operations and maintenance procedures for the borehole network and ensures relevant staff maintain equipment and achieve prescribed data return and up-time targets. The Borehole Operations manager is expected to conduct fieldwork in support of these targets at the 50% level during the O&M phase of PBO. The Operations Manager is also expected to be the primary interface to the scientific community on the operations of the borehole network and related issues concerning interpretation of the borehole instruments from an engineering standpoint.

Basis of Estimate: The travel costs are based the actual travel costs incurred under the MREFC program. Salary costs are based on the Operations Manager MREFC salary including cost-of-living increases.

WBS Task 2.3.4.2: Borehole Strainmeter Materials and Supplies

Definition: Materials and supplies that support regular scheduled and unscheduled maintenance visits for the 103 borehole strainmeter stations (includes borehole seismometers and tiltmeters). Recurring costs associated with Borehole strainmeter station communication connectivity and power. Communications connectivity consists of recurring monthly Internet service providers, bridges, VSAT systems, DSL equipment, radio links, and other associated instruments.

Assumptions:

- Scheduled Maintenance: Battery replacement will be scheduled for every four years. VSAT stations will be visited every two years to replace specific VSAT components recommended by manufacturer. Manufacturer also recommends three yearly visits to the BSM instruments gradually being reduced to two visits a year at the end of the PBO O&M (FY13) program. This budget assumes twice yearly scheduled visits on average over the program.
- Unscheduled Maintenance: We assume that 20 of stations will require a visit each year following installation to repair failures due to equipment failure, lightning strike, vandalism, or theft. This low number represents that most failure modes will be sequenced in with the normal maintenance schedule. Experience has shown that large weather and vandalism related events in the required unplanned visits each year that cannot be sequenced into normal operations.

- Data Communications: 97 of the 103 borehole stations are on VSAT communications. The remaining are on land based Internet providers.
- Power: 83 of the borehole stations are on A/C power and require yearly service payments and the other 20 are on solar/TEG combinations that require regular propane delivery.

Basis of Estimate:

- Unscheduled/Scheduled Equipment Replacement: Individual unit costs are based on manufacturers' estimates and costs encountered during the MREFC phase of the project. The predicted equipment failure rates of 2%–6% per year for most system equipment are based on UNAVCO engineering judgment from past experience with the PBO and other networks. There is a small component included (1%–2%) for scheduled replacement.
- Data Communications: The data communication costs are based on actual costs incurred under the MREFC program.

WBS Task 2.3.4.3: Borehole Strainmeter Maintenance Travel

Definition: Travel, per diem, and lodging costs that support regular scheduled and unscheduled maintenance visits for the 103 BSM stations (includes borehole seismometers and tiltmeters).

Assumptions: Assumptions on the number of visits are derived from the maintenance schedule described in 2.3.4.2, with the bulk of visits consisting of the twice-yearly planed visits. Planned visits will capitalize on visiting an entire array within a given trip. Having staff based in three locations (collocated with GPS personnel) will reduce both the total mileage driven and the amount of air travel. A typical visit requires a minimum of 1.5 days, with experience and actuals showing 2.25 days a more realistic estimate, depending on the actual maintenance that must be performed. We assume that an average trip requires 500 miles of driving, that 33% require air travel, and that 25% of the visits require field engineer.

Basis of Estimate: Travel, per diem, and lodging costs that support regular scheduled and unscheduled maintenance visits for the 103 borehole strainmeter stations. The majority of costs are based on actual costs incurred under the MREFC program. A reduction of travel budget between 5–10% has been made from FY09–13. This is in anticipation of travel efficiencies gained improved grouping of schedule strainmeter maintenance.

WBS Task 2.3.4.4: Borehole Strainmeter Regional Maintenance Staff/Facilities

Definition: Labor, travel, facility, and vehicle lease, insurance, maintenance and other related costs for the BSM regional personnel (to support BSM instruments, seismometers, and tiltmeters).

Assumptions: Based on the same assumptions for scheduled and unscheduled maintenance, average days per trip, number of field engineer required per visit, as outlined above in the travel estimate. Four field engineers plus the operations manager will be the minimum staffing level required to achieve the target level of operation of 80% for the network. This assumes a 200 days/year in the field for each field engineer. The four field engineers will be split among three regions of PBO—NW (based in Portland, OR), SW (based at a location near Los Angeles, CA), and East (based in Boulder, CO).

Basis of Estimate: Labor, travel, and facility related costs for the BSM region. The majority of costs are based on actual costs incurred under the MREFC program.

WBS Task 2.3.5: GPS Operations

WBS Task 2.3.5.1: GPS Operations Management

Definition: Labor and travel to support the PBO Operations Manager.

Assumptions: The Operations Manager provides a key coordination role between the PBO regional offices and sets and enforces operations and maintenance procedures for the network. This coordination is essential for maintaining a homogeneous network. The Operations Manager will be expected to travel to the remote offices at least twice a year. The Operations Manager will also be expected to provide field support to help maintain the network.

Basis of Estimate: The travel costs are based the actual travel costs incurred under the MREFC program. Salary costs are based on the Operations Manager MREFC salary including cost of living increases.

WBS Task 2.3.5.2: GPS Campaign Support

Definition: Personnel, travel, materials and supplies costs associated with the portable GPS systems used for the support of EarthScope-funded PI science projects.

Assumptions: There are 100 complete GPS systems owned by PBO for use in EarthScope-funded PI science projects. To properly support these systems professional-level management is required to assist PIs in the technical and scientific aspects of project development, proposal preparation, and equipment-pool oversight. Travel to a professional conference and two meetings with investigators annually is included. The systems are subjected to a high degree of wear and tear during normal use requiring costs for the replacement and repair of various system components.

Basis of Estimate: The 0.5 FTE management-level staffing estimate and travel requirements are based on to-date experience of support necessary to manage this activity as applied to expected EarthScope science activity during the performance period. Materials and supplies are actual costs of the replacement of two complete systems, including Topcon GB-1000 GPS receiver and antenna, solar panel, regulator and battery, custom designed enclosure and antenna mount. Based on experience and expected activity level, approximately 2% of hardware will need replacement annually, and will require associated shipping costs.

WBS Task 2.3.5.3: GPS Helicopter

Definition: Helicopter and associated transportation costs to maintain volcano and out non-road assessable GPS sites.

Assumptions: There are a total of 86 helicopter-accessible GPS sites in the PBO network (41 stations clustered on volcanoes, 45 non-volcano sites). Thirty-five helicopter days per year will be required for work in Alaska and 10 helicopter days per year in the Lower 48. This estimate is based on normal weather conditions in these areas, not on a worst-case scenario.

Basis of Estimate: The cost estimate is based on actual costs for helicopter maintenance and installation activities during the Alaska 2006 summer season. The actual costs in Alaska in 2006 were approximately $5,555 per day, which includes mob/demob, fuel, mechanic time, flight hours, and miscellaneous expenses. Forty-five helicopter days per year multiplied by $5,555 per day gives the $250,000 used in the estimate. PBO will capitalize on any opportunities for cost sharing with other agencies that access remote sites. PBO has taken advantage of these opportunities in the past.

WBS Task 2.3.5.4: GPS Materials/Supplies and Data Communications/Power

Definition: Materials and supplies that support regular scheduled and unscheduled maintenance visits. Recurring costs associated with GPS station communication connectivity and power. Communications connectivity consists of recurring monthly internet service providers, cellular routers, bridges, VSAT systems, DSL equipment, radio links, and other associated instruments.

Assumptions:

- Scheduled Maintenance: Battery replacement will be scheduled for every four years. VSAT stations will be visited every two years to replace specific VSAT components recommended by manufacturer.
- Unscheduled Maintenance: We assume that 25% of stations will require a site visit each year following installation to repair failures due to equipment failure, lightning strike, vandalism, or theft. Experience by the UNAVCO Facility and SCIGN and other large network operators suggest that some stations require multiple visits per year while others require no unscheduled maintenance. UNAVCO historical experience suggests that 25% is a reasonable average for unscheduled maintenance. This is also consistent with what we have seen for the PBO network to date, excluding early hardware problems with the GPS receiver and cellular modems.
- Data Communications: The expected data communications breakdown for the GPS network by type is 51% cellular, 21% VSAT, 14% radio networks, 10 DSL, 2% manual downloads, and 2% Other (no-cost). The GPS network data communications is shown in Figure 7.4.
- Power: We assume that 9% or 99 stations will have AC power. Of these stations, 10% or 10 stations will have ongoing communications costs.
- Safety/Tooling Equipment**:** Periodic replacement of safety equipment and tools will be required. A small, but adequate, part of the materials and supplies budget is allocated to replacement of this equipment.

Basis of Estimate:

- Unscheduled/Scheduled Equipment Replacement: Individual unit costs are based on manufacturers' estimates and costs encountered during the MREFC phase of the project. The predicted equipment failure rates of 2–4% per year for most system equipment are based on UNAVCO engineering judgment from past experience with the PBO and other networks. For major hardware, failure/replacement rates of 4–10% are used. A complete cost breakdown of equipment replacement based on expected failure/loss rates is shown in Table 7.1. These rates are consistent with actual replacement rates incurred during the MREFC phase of the project. One exception is a lower expected failure rate used for the GPS receiver than we actually experienced in the MREFC. There were problems with the initial line of Trimble NetRS receivers purchased, but we do not expect a repeat of the higher rate of receiver failures. If

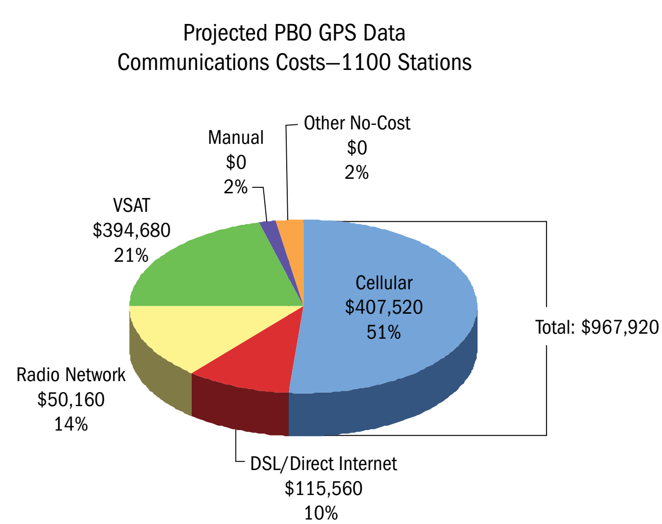


Figure 7.4. Projected PBO GPS Data Communications Costs - 1100 Stations

TABLE 7.1. GPS EQUIPMENT REPLACEMENT COST ESTIMATE

UNSCHEDULED (Qty installed after YR5 = 1100 [Lower-48 = 958; Alaska = 142])					
ITEM ID	**DESCRIPTION**	**COST**	**FAIL RATE**	**QTY**	**COST**
PWR-026	Lightning Arrestor (Huber Suhner 3402.17.k w/73z-0-0-448)	$130.00	2.0%	44	$5,720
PWR-027	DC back panel	$330.00	2.0%	22	$7,260
PWR-055	Batteries, CONUS (DEKA 8G31, w/stud terminal)	$135.00	5.0%	281.25	$37,969
PWR-057	Solar Panels, CONUS (Shell SQ-80 or equivalent)	$425.00	10.0%	330	$140,250
COM-001	CDMA Modem (Proxicast 1XMG-401)	$845.00	8.0%	35.2	$29,744
COM-010	Intuicom Ethernet Bridge, model FIP1-900C2M-E	$1,170.00	2.0%	7.26	$8,494
COM-020	Ethernet Router (Cisco 831)	$415.00	2.0%	5.5	$2,283
COM-805	VSAT Kit, Boulder	$1,450.00	6.0%	16.5	$23,925
	GPS Antenna	$3,220.00	4.0%	44	$141,680
GPS-801	GPS Kit	$3,220.00	4.0%	44	$141,680
DOM-002	Radome, tall SCIGN	$200.00	2.0%	22	$4,400
PWR-804	Type 2 Enclosure (4-battery DC kit)	$1,200.00	2.0%	22	$26,400
UN030423	Three-Panel Mount	$450.00	2.0%	22	$9,900
Enclosures	Enclosures - Alaska Huts	$3,000.00	2.0%	2.84	$8,520
SCIGN Mount	GPS antenna mount	$500.00	0.5%	5.5	$2,750
Misc.	Cables, Hardware, Misc	$450.00	3.5%	38.5	$17,325
TOTAL UNSCHEDULED EQUIPMENT COSTS					**$608,299**
SCHEDULED (Qty installed after YR5 = 1100)					
ITEM ID	**DESCRIPTION**	**COST**	**REPLACE-MENT RATE**	**QTY**	**COST**
PWR-055	Batteries, CONUS (DEKA 8G31, w/stud terminal)	$145.00	25.0%	1406.25	$203,906
	VSAT RV Protector	$150.00	50.0%	137.5	$20,625
TOTAL SCHEDULED EQUIPMENT COSTS					**$224,531**

the failure rate of the equipment turns out to be higher than budgeted, the overall percentage of sites operational will decrease as well.

An additional reduction of 5–14% has been made in material budgets during the first three years of O&M. We believe this reduced material need is likely because of the new equipment and the utilization of any residual MREFC and PBO Nucleus material and supplies inventories.

- Data Communications: The data communication costs are based on actual costs incurred under the MREFC program. The total data communications based on the expected breakdown of communication types is shown in Figure 7.4.

  We have further reduced the budget in the first three years of O&M by 5–10% in anticipation of shifting of some stations to less expensive communications requirements.

WBS Task 2.3.5.5: GPS Maintenance Travel

Definition: Travel, per diem and lodging costs that support regular scheduled and unscheduled maintenance visits.

Assumptions: We assume that 25% of stations will require a visit each year following installation to repair failures due to equipment failure, lightning strike, vandalism, or theft. Experience by the UNAVCO Facility and SCIGN and other large network operators suggest that some station require multiple visits per year while others require no unscheduled maintenance. Twenty years of experience suggests that 25% is a reasonable average for unscheduled maintenance.

The satellite office approach will reduce travel costs by decreasing drive time. We anticipate an average of 500 miles round trip for each field visit. The average number of days required for each trip is two days in the coterminous United States and four days for Alaska.

Scheduled maintenance will consist of battery replacement every four years, and VSAT component replacement every two years. We will combine these visits with unscheduled maintenance when it is cost effective to do so.

GPS stations will require maintenance in the winter and will require travel to remote areas in bear country in Alaska and other very remote parts of the network. For safety, PBO engineers will be required to travel in pairs in some situations. For Alaska, we have estimated 50% of the site visits will require two engineers. In the coterminous United States, 35% of the sites visits will require two engineers.

The satellite office approach will reduce costs by minimizing drive time. However, inter-region flights will still be necessary, especially to support Alaska, Southern California, and the sites in the eastern United States. Part of travel budget includes costs associated with this support.

Basis of Estimate: The majority of costs are based on actual travel costs incurred under the MREFC program. The expected costs per field visit broken down for Alaska and the coterminous United States are shown in Table 7.2. The forecast of costs per trip are based on 20 years of UNAVCO Facility GPS station support; three years of PBO operations and maintenance actuals; other large network operations such as the USGS in Southern California, Cascades, and Alaska; and experience from existing regional network operators. Because of very different logistics costs, separate unit costs have been forecasted for maintenance travel costs in the coterminous United States and Alaska. In the coterminous United States, an additional 25% savings is assumed for clustering of stations. This savings will generally not be applicable to Alaska, where stations are so distant that clustering cannot be considered as a cost savings, with the exception of volcano stations. All travel costs per trip are combined with the GPS expected number of visits to produce a total travel cost shown in Table 7.3.

TABLE 7.2. PLANNED AND UNPLANNED MAINTENANCE TRAVEL AVERAGE COST PER TRIP

LOWER 48 GPS			
ITEM	**DAYS/TRIPS/MILES**	**RATE**	**TOTAL**
PerDiem	2	$45	$90
Hotel	2	$96	$192
Mileage	500	$0.42	$210
Miscellaneous	1	$45.00	$45
SUBTOTAL			**$537**
EFFICIENCY REDUCTION FOR GROUPING OF SITES			**0.25**
TOTAL			**$403**

ALASKA GPS				
ITEM	**RURAL**	**HIGHWAY**	**HELICOPTER**	**TOTAL**
Number of sites	46	31	65	142
Airfare	$625		$625	
Hotel	$450	$300	$450	
Per Diem	$315	$135	$315	
Car Rental	$200			
Fuel	$110	$252		
Misc.	$75	$75	$75	
Crew Lodging			$450	
Pilot Lodging			$450	
Total cost per site	$1,775	$762	$2,005	
% of total sites	32.4%	21.8%	45.8%	
Weighted Average	$575	$166	$918	
SUBTOTAL				**$1,659**
Highway rates for Alaska based on two day travel time Other rates for Alaska based on four day travel time				

WBS Task 2.3.5.6: GPS Regional Maintenance Staff

Definition: Staff labor, travel, facility, insurance, and maintenance costs for PBO area personnel.

Assumptions: Ten field engineers plus the operations manager will be the minimum staffing level required to achieve the target level of operation of 80% for the network. This target is the best estimate based on a limited budget. The assumptions made are shown in Table 7.4. Twenty-five percent unscheduled maintenance every year is assumed. Once every four-year scheduled battery replacement and once every two-year replacement of specific VSAT components are assumed. With these assumptions, there could be up to 626 field visits per year. Some of these visits will be in the winter or in bear

TABLE 7.3

TRAVEL	COST PER UNIT	NUMBER OF UNITS	COST
Helicopter			$250,000
Cost Per FE-Trip: Lower 48	$403	711.3	$286,482
Cost Per FE-Trip: AK	$1,659	149.1	$247,377
Travel expenses associated with inter-region travel - flights, cars, etc.	$600	100.0	$60,000
TOTAL TRAVEL			**$593,859**
TOTAL COSTS			**$843,859**

TABLE 7.4

	TOTAL PBO	LOWER 48	ALASKA
Number of Stations	1100	958	142
Station-Years	582		
Total Visits (from Actuals)	477		
% of stations visited per year (Actuals)	0.82		
% of stations visited per year w/o Trimble/ Proxicast visits (Acutals)	0.31		
% OF STATIONS VISITED PER YEAR - EXPECTED	**0.25**	**0.25**	**0.25**
Unscheduled Maintenance Visits (MV)	275	239.5	35.5
Scheduled Maintenance - batteries	275	239.5	35.5
Scheduled Maintenance - VSAT protector	76.3	47.9	28.4
TOTAL STATION VISITS	**626.3**	**526.9**	**99.4**
Total FE-Trips per Year (two engineers required 35% lower 48 and 50% Alaska)	860.4	711.3	149.1
Average travel days per trip	2.2	2.0	3.6
Total field days per year	1953.9	1422.6	531.3
Number of days in the field per year per FE	190.0	190.0	190.0
NUMBER OF FES NEEDED	**10.3**	**7.5**	**2.8**

* In Alaska, 2 days per/trip for highway, 4 days per trip for other stations

country, where multiple engineers will be required for safety considerations. PBO management expects two engineers to be required at 35% of the station visits in the coterminous United States and 50% of the station visits in Alaska. Two days per visit in the coterminous United States and four days per visit for most stations in Alaska is assumed. Lastly, each field engineer will be required to spend 190 days per year in the field. Given these assumptions, 10 field engineers will be required to adequately maintain the network. These field engineers will be split and managed between the four regions of PBO; Alaska, NW (based in Portland, OR), SW (based in a location TBD close to Los Angeles, CA), and East (based in Boulder, CO). There will be two engineers located in Alaska to maintain 142 stations. The additional 0.8 FTE needed will come from other regions and from Boulder. Likewise, Alaska engineers will travel to other regions in the winter, especially PBO-SW to help maintain the 400+ stations in that region. Also, students or other onsite contacts might be subcontracted to help maintain the network in some special cases where it is cost effective to do so. The staffing levels and areas of responsibility for each region are shown in Table 7.4. Of course, unscheduled maintenance will be combined with scheduled maintenance when possible to optimize efficiencies and to reduce costs.

Basis of Estimate: The costs and total number of 10 FTEs supported are based on 3.5 years of PBO operations and maintenance and actual maintenance records; other large network operations such as the USGS in Southern California, Cascades, and Alaska; advice from existing regional network operators; and 20 years of experience by the UNAVCO Facility. The MREFC program had 21 FTEs during the GPS construction phase. We estimate that 10 FTEs are required to adequately maintain the network. This will allow for an average of 110 stations per field engineering FTE. Furthermore, we anticipate that the data-communications strategies employed by PBO in the installation phase will allow for remote upgrades of firmware and improvements in network monitoring software will allow the PBO network to be maintained more efficiently than any of the currently operational regional networks. With these efficiencies, we estimate the overall number of PBO stations maintained per engineer to be approximately 110:1, as compared to the 25:1 ratio for the BARGEN network. Ten FTEs represent more than a 50% reduction in engineer staffing. PBO science goals, regularly scheduled maintenance, troubleshooting, repair, and replacement of failed stations and volcano maintenance require this as a minimum staffing level.

Continuation of staffing costs come from the MREFC program including cost of living increases.

WBS Task 2.3.5.6.1: GPS Regional Maintenance Staff– PBO-NW (Portland)

Definition: Labor, travel, facility and vehicle lease, insurance, maintenance, and other related costs for the Portland area personnel. This assumes one small office in the Portland area and other remote communications and storage support of satellite locations (home offices). The Portland office will share space with PBO Borehole Strainmeter Staff.

Assumptions: Three field engineers will be responsible for the maintenance of approximately 300 GPS stations. The office/warehouse for the PBO-Northwest region will be located in Portland, OR. These engineers will be expected to travel to Alaska and Southern California to support maintenance activities in those regions.

Basis of Estimate: Continuation of staff salaries and other costs from the MREFC program including cost of living increases. The facility costs are based on 75% of actual expenses incurred under the MREFC program. Satellite home office expenses include monthly costs for storage, Internet, phone, and shipping. These costs are well defined based on actual expenses during the MREFC program.

WBS Task 2.3.5.6.2: GPS Regional Maintenance Staff– PBO-SW (Greater Los Angeles)

Definition: Labor, travel, facility and vehicle lease, insurance, maintenance, and other related costs for the Los Angeles area personnel. This assumes one small office in the Los Angeles area and other remote communications and storage support of satellite locations (home offices).

Assumptions: Three field engineers will be responsible for the maintenance of approximately 400 GPS stations. The office/warehouse for the PBO-Southwest region will be located in a location to be determined in the greater Los Angeles area. Support will be provided from other regions to supplement the significant field engineering staffing requirements of this region. Field engineers from this region will travel to support the maintenance activities in other regions.

Basis of Estimate: Continuation of staff salaries and other costs from the MREFC program including cost of living increases. The facility costs are based on 75% of actual expenses incurred under the MREFC program. Satellite home office expenses include monthly costs for storage, Internet, phone, and shipping. These costs are well defined based on actual expenses during the MREFC program.

WBS Task 2.3.5.6.3: GPS Regional Maintenance Staff– PBO-Alaska (Anchorage)

Definition: Labor, travel, facility and vehicle lease, insurance, maintenance, and other related costs for the Alaska regional personnel.

Assumptions: One of the two field engineers in Alaska will manage the maintenance of 142 PBO stations in the region. This engineer will also manage the office/warehouse in Anchorage, AK. Seasonal help will come from other regions to provide the staffing level required in the summer months. These engineers will travel to other regions in the winter to support maintenance activities in other regions.

Basis of Estimate: Continuation of staff salaries and other costs from the MREFC program including cost of living increases. The facility costs are based on the actual expenses incurred under the MREFC program.

WBS Task 2.3.5.6.4: GPS Regional Maintenance Staff– PBO-East (Boulder)

Definition: Labor, travel, and vehicle lease, insurance, maintenance and other related costs for the Boulder regional personnel.

Assumptions: Two field engineers will be responsible for 258 GPS stations across the Basin and Range, the Eastern PBO stations, and some stations in California, Idaho, and Oregon. One engineer will be located at the office/warehouse shared with the UNAVCO Facility. The other field engineer will be based out of a satellite home office. These costs are well defined based on actual expenses during the MREFC program. Field engineers from this region will travel to support the maintenance activities in other regions.

Basis of Estimate: Continuation of staff salaries and other costs from the MREFC program including cost of living increases. The Boulder office/warehouse expenses are shown in task 2.3.1.5.3. Satellite home office expenses include monthly costs for storage, Internet, phone, and shipping. These costs are well defined based on actual expenses during the MREFC program.

USArray Work Breakdown Structure Dictionary

The following Dictionary provides a summary description of all the major USArray WBS tasks. Each element is defined, along with relevant assumptions and the basis for the cost estimate.

WBS Element 2.4.1: USArray Management

Definition: The main components of USArray (Reference Network, Transportable Array, Flexible Array and Data Management) are implemented through the management structure and core facilities of the Incorporated Research Institutions for Seismology (IRIS). Oversight, reporting and coordination at the overall USArray level are budgeted under this task as staff and resources associated with the IRIS headquarters office in Washington DC. Salaries for project management at the component level are covered under the appropriate WBS element. General and Administrative indirect expenses for all component budgets are summarized and reported under WBS 2.4.1.2.

WBS Element 2.4.1.1: Management/Oversight/ Integration (direct)

Definition: Management at the overall USArray level includes coordination of component activities, development of reporting and planning materials and provision of regular reports to NSF. Coordination of USArray activities includes interactions with NSF, the components of USArray, the USArray Advisory Committee and IRIS governance committees.

Assumptions: Committee members include the IRIS representative on the EarthScope Management Team (EMT) and the eight members of USArray Advisory Committee. Meeting schedule includes four EMT meetings and one USArray Advisory Committee meeting per year.

Basis of Estimate: Salaries, travel and associated business expenses for USArray Project Director (1 FTE), Director of Project Administration (0.5 FTE), and Project Associate (0.5 FTE) (shared with Transportable Array) at IRIS headquarters. Travel costs are included for USArray Advisory Committee and IRIS representative on the EarthScope Management Team (EMT).

WBS Element 2.4.1.2: General & Administrative (G&A) (indirect)

Definition: General management and administration expenses associated with the organization, and supporting all of its activities. These include management (President, Director of Operations, and Director of Planning) and business office salaries, governance committee expenses, audit and legal fees, payroll and human resource services. Since these costs are not within an individual program manager's control, the allocation of indirect expenses associated with all component budgets are summarized and reported as a total under this WBS element.

Assumptions: G&A indirect expenses are recovered through the application of a pre-determined rate negotiated annually with the National Science Foundation. IRIS submits its indirect rates for full indirect cost recovery with its anticipated funding and expenditure levels. The rate application base for G&A is total costs less equipment, participant support costs and subcontract costs exceeding $25,000 per subcontract per year. IRIS' projected funding profile assumes that its budget structure primarily consists of two cooperative agreements with NSF, one for the continued operations of IRIS core programs, and the second for EarthScope and USArray activities.

Basis of Estimate: G&A cost recovery is included in this budget at the current year's (FY07) G&A rate, 15%, for the proposal period.

WBS Element 2.4.2: Reference Network

Definition: The Reference Network provides a fiducial reference for the Transportable Array. The Network consists of USGS operated ANSS Backbone stations supplemented by up to 14 Transportable Array stations that are planned to be installed ahead of their scheduled date by the MREFC phase of the project to fill gaps in the ANSS Backbone. 39 stations were added to the ANSS Backbone during the MREFC stage of the project.

Assumptions: Operation of all Reference Network stations will be supported by USGS or other non-EarthScope sources.

Basis of Estimate: No costs are included in this proposal for support of the Reference Network.

WBS Element 2.4.3: Transportable Array

Definition: The MREFC acquired the equipment for 400 Transportable Array stations and installed stations in the western United States. Operations and Maintenance will remove these stations and redeploy the equipment to complete coverage across the conterminous United States and in Alaska. The bulk of the activities associated with operation of the stations will be carried out by field crews of both IRS and subawardee staff under the Transportable Array Manager for the Transportable Array. The Array Operations Facility (AOF) at the New Mexico Institute of Mining and Technology is responsible for system integration, testing,, and hardware maintenance. The Array Network Facility (ANF) at University of California San Diego (UCSD) monitors realtime data collection and coordinates data delivery to the IRIS Data Management Center (DMC). This task consists of all staff, equipment, travel, materials and supplies, subawards and other direct costs associated with USArray's operation and maintenance of the Transportable Array.

WBS Element 2.4.3.1: Transportable Array Management

Definition: This task consists of all management and senior staff support for operation and maintenance of the Transportable Array.

Assumptions: Operation and maintenance of the Transportable Array is under the direction of a full-time Transportable Array Manager (1 FTE) with support from a Deputy Manager (1 FTE) and a part-time Project Associate (0.5 FTE). IRIS PASSCAL management staff provides oversight and integration with the AOF facility operations.

Basis of Estimate: Salary, travel, and associated expenses for the Transportable Array Manager, Deputy Manager, and Project Associate.

WBS Element 2.4.3.2: Transportable Array Maintenance/Repair/Replacement

Definition: This task consists of costs associated with the maintenance, repair and replacement of equipment used in the Transportable Array. The Array Operations Facility (AOF) provides the depot services for these tasks in support of the Transportable Array field operations and is responsible for acquisition, testing and integration of equipment for field systems under the tasking of the Transportable Array Manager.

Assumptions: The initial western deployment of the Transportable Array stations will be supported under the MREFC. Once the initial Transportable Array stations complete their calibration period, all maintenance, repair and replacement costs as well as further redeployments are considered O&M. Maintenance, repair and replacement activities are conducted at the Array Operations Facility established at the PASSCAL Instrument Center at New Mexico Tech. This takes advantage of the experience and facilities resident at the AOF to maintain similar instruments associated with the Flexible Array and the PASSCAL Program.

Basis of Estimate: Staff requirements at the AOF (7 FTE) are based on experience gained during the initial stages of the MREFC project and with similar PASSCAL and GSN operations. Costs for equipment replacement and upgrades are based on PASSCAL experience. Replacement of sensors and data acquisition systems are based on a replacement rate of 2% per year. Due to their shorter life expectancy, communications, power systems and other spares replacement is based on a rate of 3% per year. Allowance is also included for incorporation of new communications technology for 80 stations per year at $2000 per station. This recognizes the expected continued evolution of communications and power technology over the life of the Array.

WBS Element 2.4.3.3: Transportable Array Operations

WBS Element 2.4.3.3.1 Field Service

Definition: This task supports activities associated with collection of Transportable Array data from field stations to the Array Network Facility and for monitoring station operations, maintenance of metadata, and quality assurance of the data. Additional tasks include the servicing of deployed stations when warranted by lack of telemetry or improper station operation.

Assumptions: Data from the 400 stations of the Transportable Array will be transmitted in near real time from station sites to the ANF, which will maintain metadata and remotely monitor the state of communications and field systems. Problems will be reported to the Transportable Array field teams that will be responsible for correction of problems. Data and metadata will be transmitted to the DMC (WBS 2.4.5) for archiving and distribution.

Basis of Estimate: Support for two IRIS Station Specialists (2 FTE) is included. A subaward for the Array Network Facility at UCSD provides for support of 7 FTE for real-time Transportable Array data collection, quality assurance, meta-data maintenance, routine data forwarding to the DMC, and real-time communications O&M. The level of effort and software system used is based on experience with existing regional networks and primarily with initial stages of the MREFC project. This task includes costs for one full-time test engineer (1 FTE) obtained through a subaward to New Mexico Tech for the Transportable Array Coordinating Office (TACO). A subcontract to Honeywell Technology Solutions, Inc. (HTSI) includes costs for one field engineer (1 FTE) to provide servicing, maintenance, and repair services to installed stations. Recurring costs for data telemetry systems vary according to site-specific conditions. This proposal assumes the current allocation of 60% of the stations utilizing cellular modems and the remaining 40% relying on portable VSAT.

WBS Element 2.4.3.4: Transportable Array Station Deployment

Definition: All activities associated with deploying (i.e., demobilization, permitting, construction, and installation) the 400 Transportable Array stations as they move across the United States and into Alaska.

Assumptions: The acquisition of equipment and initial deployment of the first 400 Transportable Array stations are supported by the MREFC project. Starting in FY08 of the MREFC project, stations will be deployed eastward across the United States at the rate of 200 per year. Transportable Array installations across the continental United States (1623) will be complete in FY13. The 400 instruments will then be deployed across Alaska. Station installation will be managed by the TA Manager for the Transportable Array and includes demobilization; permitting; construction; and installation.

Basis of Estimate: Staffing levels and costs for continued operation and maintenance of the Transportable Array are based on actual costs during the installation of the TA stations with MREFC funding, and on experience from operation of similar stations in PASSCAL experiments over the past ten years. Transportable Array station deployment is conducted by a small team of IRIS specialists supplemented by contract personnel. Support is included for one IRIS Station Specialist (1 FTE), two IRIS Reconnaissance Specialists (2 FTE), one IRIS Construction Engineer (1 FTE), a subcontract to HTSI to provide support for demobilization, construction, and installation (8 FTE), 3 FTE TACO support for site, permitting, and construction coordination, a commercial contract for construction activities, and university subawards to carry out regional site surveys for identifying potential sites. Costs developed on a task basis including FTE support, materials and travel expenses are compared with per station costs by comparison with other similar networks.

Overall estimates, including the support for the specialists and contracts identified above, are based on per station estimates. Station demobilization is estimated at $4000 per station; permitting at $4000 per station; construction at $9,500 per station and installation at $5000 per station. The permitting, construction and installation costs are derived from the actual costs of installing the 255 stations to date. The demobilization estimate is based on a bottoms-up estimate and bolstered by a recent proposal from HTSI.

WBS Element 2.4.4: Flexible Array

Definition: This summary task consists of all staff, equipment, travel, materials and supplies, subawards and other direct costs associated with USArray's operation and maintenance of the Flexible Array. The MREFC project will acquire the hardware for a total of 2111 Flexible Array instruments. The Flexible Array O&M follows the same model of current PASSCAL PI-driven experiments, with PIs funding deployments from their research grants. The O&M of this facility will consist of maintenance, upgrade and replacement of the hardware plus costs associated with limited field support for PIs during installation. In cooperation with the individual Investigators the AOF provides support for archiving data to the Data Management Center (DMC) O&M is carried out at the USArray Operations Facility (AOF). The AOF was provided by New Mexico Tech as a no-cost to EarthScope addition to the PASSCAL Instrument Center.

WBS Element 2.4.4.1: Flexible Array Management

Definition: Operation and Maintenance of the Flexible Array is managed by the IRIS PASSCAL Deputy Program Manager with assistance from the IRIS PASSCAL Program Manager. This assures consistent treatment of Flexible Array and PASSCAL instruments and takes advantage of the wealth of experience the PASSCAL Facility has in conducting similar experiments.

Assumptions: The PASSCAL Deputy Program Manager (0.75 FTE) and Program Manager (0.1 FTE) will work closely with the staff of the AOF to coordinate activities in support of the Flexible Array.

Basis of Estimate: Salary and travel support for the management staff.

WBS Element 2.4.4.2: Flexible Array O&M

Definition: Operations and maintenance of Flexible Array equipment covers maintenance of hardware at the AOF, miscellaneous packing and shipping the equipment for repair and replacement of broken, lost, or stolen equipment, provision of AOF staff for field training and huddle testing. Data archive support consists of creating tools and processing raw data provided by the PI, along with accompanying metadata, into verified SEED archives for passive deployments and SEGY format data for active-source deployments to the DMC.

Assumptions: Regular and ongoing maintenance is required sustain the life of the instruments to the end of the project. Capital equipment is estimated based on a 2.4% per year replacement rate. This is adequate to replace damaged, stolen or destroyed equipment but does not allow for modernization of the entire equipment pool. Personnel resources required to provide data archiving support is based on a final inventory of 291 broadband, 120 short period and 1700 active source stations. The number of total passive experiments, hence the volume of data anticipated, is estimated to be less than 10 a year using all of the instruments with an average of 3 yearly service runs each. Experience shows that all of the instruments will be fully utilized assuming 10 experiments per year. The pool of active source stations are estimated to be deployed as a single pool for two experiments a year. It is also assumed that active source experiments will take place within the United States and be comprised solely of USArray instruments. Maintenance of the Flexible Array equipment is conducted via a subaward to New Mexico Tech and carried out in a special facility provided by New Mexico Tech. Costs for support of the AOF facility are split 50% each between the Flexible and Transportable Arrays. Travel of AOF field personnel for experiment support is provided by the Principal Investigator. Additional travel funds for extra training and problem resolution are included in the AOF budget.

Basis of Estimate: AOF staffing levels (7 FTE) and associated costs for instrument replacement and maintenance are based on multi-year experience with the PASSCAL Instrument Center in Socorro.

WBS Element 2.4.5: USArray Data Management

Definition: The IRIS Data Management System is responsible for the reception, archiving and distribution of all seismic data generated by USArray stations including the Reference Network, Flexible Array and the Transportable array. This summary task consists of all staff, equipment, travel, materials and supplies, consultants and other direct costs associated with operation and maintenance of the IRIS Data Management Center for collection, quality control, archiving and distribution of USArray data. The IRIS DMC is the only location where all USArray data (TA, FA, and RN) will be managed and will be the only place where USArray-wide Quality Assurance techniques can be applied to the data. The IRIS DMC is tasked with insuring that USArray data will be available in perpetuity.

WBS Element 2.4.5.1: Management of DMS

Definition: This task consists of management and staff support at the IRIS Data Management Center for oversight of USArray activities. The activities also include the funds necessary to maintain established hardware and software systems as well as providing support for data technicians that review and maintain the quality of USArray data, systems administrators to maintain the hardware systems and a software engineer to maintain software developed under the MREFC award.

Assumptions: The IRIS DMS Program Manager (0.2 FTE) and an Executive Assistant (0.25 FTE) are responsible for management of USArray activities at the DMC. As USArray develops it will eventually be generating about 5 terabytes of primary observational data per year and the total amount of data to be managed will be more than 65 terabytes after ten years. With reasonable assumptions, the total amount of data managed will likely be in the neighborhood of 250 TB at the end of ten years (one copy at the IRIS DMC in the primary RAID system, two copies, time sorted and station sorted, in a tape based system and one copy of all USArray data at the Active Backup location). These activities will require the support of a Lead Data Control Analyst, three Data Control Analysts, two data technicians, a System Administrator, and a Software Engineer (8 FTE).

Basis of Estimate: The budget consists of salary, travel, equipment upgrades and replacements, and software and hardware maintenance agreements, supplies, consultants, and periodic replacement and upgrading of major compute servers, disk resources and upgrades made to the primary RAID storage system. Costs are based on experience with the IRIS core programs. Maintenance costs are prorated for the annual data volumes anticipated from USArray as a fraction of the total amount of new data arriving at the DMC. This percentage is adjusted annually. Total software and hardware maintenance costs are prorated by this fraction.

WBS Element 2.4.5.2: Active Backup

Definition: This task includes a contribution to the operation of the Active Backup System purchased using MREFC funds. It assumes that all data managed by the IRIS DMC is archived in a tape based mass storage system which includes USArray Seismic Data, PBO Seismic Data and SAFOD seismic data.

Assumptions: These costs include a small fraction of the senior systems administrator (0.3 FTE) to administer the Active Backup System, cost of tape media in the Active Backup to store USArray data and fractional costs of maintaining key COTS software and hardware at the Active Backup location.

Basis of Estimate: Costs are based on experience with IRIS core programs.

WBS Element 2.4.5.3: Auxiliary Seismic Data

Definition: In addition to the primary seismic data produced from USArray stations and networks, the IRIS DMC will also be responsible for activities related to the quality control, archiving and distribution of seismic and strain data produced by PBO and SAFOD. This task consists of all staff, equipment, travel, materials and supplies, and other direct costs associated with archiving SAFOD seismic, PBO seismic, and PBO strain data and performing quality assurance on selected PBO and SAFOD seismic data.

Assumptions: PBO seismic data will from field stations to PBO and then via Antelope to the IRIS DMC. The data are available in the IRIS real time systems. Costs for telemetry of data to PBO are the responsibility of PBO. PBO seismic and strain data will be roughly 3 TB per year. Approximately 104 stations are assumed to submit data to PBO. The Northern California Earthquake Data Center will be an archive for SAFOD seismic data. In addition, the data will be archived at the IRIS DMC both for redundancy and to ensure all the data are available through the DMC and supported by the DMC's Data Access System infrastructure and management techniques. IRIS DMC tasks will be limited to the reception of these data in real time, archiving, automated product production and distribution. This assumes that all of the metadata will be coming from the NCEDC in the form of dataless SEED volumes. SAFOD data received in real-time will be processed by the IRIS DMC Quality Assurance System. The 4000 sample per second data from SAFOD will be treated as second tier data at the IRIS DMC and only stored in the tape robotic systems.

Basis of Estimate: The O&M budget for Data Management for the seismic and strain data from the PBO element and the seismic data from the SAFOD element consists of personnel (four weeks per year of Systems Administration support) (0.1 FTE), a prorated share of hardware and software maintenance costs, media costs to store the data in the tape based systems and the cost of actual RAID capacity needed to store PBO and SAFOD seismic data. The costs also include the costs of replacing 2 SUN servers every four years.

WBS Element 2.4.5.4: Portal

Definition: A major goal of EarthScope is a common mode of access to all EarthScope data and integration of EarthScope data with other related data. Each of the major elements of EarthScope must support the data center infrastructure with which the data access system will interact. The DMC will be involved in the development and continuing maintenance and enhancement of services required for the USArray side of the EarthScope Portal.

Assumptions: It is assumed that the basic architecture and system is developed during the MREFC portion of EarthScope. The data access system is assumed to be a Web-services based system. The initial implementation at the DMC will leverage experience gained in the development of the existing IRIS Data Handling Interface (DHI). Development of Web-services-based connections to the databases, data sets and data products managed at the IRIS DMC will be developed.

Basis of Estimate: Salary, travel, and related support for a Web Services Software Engineer (0.35 FTE) and costs for the acquisition and replacement of Web services server systems every three years.

WBS Element 2.4.6: Siting and Outreach

Definition: Siting and Outreach supports Transportable Array siting and deployment by assisting in finding potential sites, including organizing and training student reconnaissance teams, promoting the scientific value of the array during deployment, and providing a legacy for the local community after relocation of the Transportable Array. Siting and Outreach is designed to be integrated with the permitting process, creating community awareness and interest as the Transportable Array arrives and during its deployment.

WBS Element 2.4.6.1: Siting and Outreach Management

Definition: USArray Siting and Outreach will use the resources of the IRIS Education and Outreach Program in support of siting for Transportable Array stations. This provides a cost-effective way to engage universities and regional organizations in the initial selection of sites.

Assumptions: The E&O Program Manager (0.1 FTE) will be responsible for overseeing Siting and Outreach O&M. This ensures coordination of USArray Siting and Outreach efforts with IRIS E&O program activities. An Outreach Specialist (1 FTE) will be engaged full time in USArray Siting and Outreach related activities. A Publications Designer (0.25 FTE) and DMC Software Engineer (0.1 FTE) will provide additional support.

Basis of Estimate: Salary and travel costs for the E&O Program Manager, Outreach Specialist, and Software Engineer.

WBS Element 2.4.6.2: Siting

Definition: IRIS member universities or other regional entities familiar with seismicity, geography, geology, and land use on a state-by-state basis will carry out initial surveys and selection of potential sites for the Transportable Array.

Assumptions: USArray Siting will coordinate with the IRIS E&O Program and the Transportable Array Manager to solicit and issue subawards to universities or other qualified organizations (2.4.3.4) in advance of USArray activities in states or regions across the United States. Expenses for conducting the annual workshop are included in this task. The subawards to the universities for conducting the siting activities are in the Transportable Array task.

Basis of Estimate: Estimates are based on travel costs for 20 students and faculty members to a siting training workshop.

WBS Element 2.4.6.3: Outreach

Definition: USArray Outreach will work with IRIS E&O, the EarthScope National Office and other partners to inform the public of USArray activities and make the results of USArray available for educational purposes.

Assumptions: A newsletter targeted at USArray and PBO site hosts will be published quarterly in cooperation with PBO. IRIS E&O efforts with museum installations and seismometers in schools will be adapted for use in USArray outreach. The Active Earth display will be maintained by a part-time software engineer (0.1 FTE). Five AS1 seismographs will be distributed to schools and museums each year as part of outreach to hosts of Transportable Array sites and training in the use of the seismographs will be provided.

Basis of Estimate: Costs are based on experience with the IRIS E&O program and the initial stages of USArray. USArray will support the incremental costs for development and installation of specific USArray facilities and activities.

WBS Element 2.4.7: Magnetotellurics

Definition: USArray will operate and maintain 27 MT systems; 7 stations have been installed across the US as a reference network that will operate for the duration of EarthScope. The other 20 systems are used within the Transportable field operations, which relocates each station on a monthly basis.

WBS Element 2.4.7.1: MT – Support

Definition: Provide management and technical oversight support for operations and maintenance associated with EarthScope MT.

WBS Element 2.4.7.1.1: Management Personnel

Definition: Provides for management of operations and maintenance of both permanent and transportable MT stations.
Basis of Estimate: Staffing level is based on actual costs derived during MREFC construction phase (0.2 FTE for the Director of Operations). Costs are also included for temporary project oversight by an contract scientist representing the EMSOC community (0.1 FTE), 0.5 FTE for depot tasks related to MT equipment (shipping, servicing, etc), and 0.5 FTE to provide QC and metadata for the MT data streams before the data are archived at the DMC.

WBS Element 2.4.7.1.2: Travel and Misc

Definition: Provides for staff travel and travel of EarthScope MT Working Group (EMWoG) members, as well as monthly EMWoG conference calls.
Basis of Estimate: Estimates are based on costs derived during MREFC construction phase.

WBS Element 2.4.7.1.3: Subawards

Definition: Provides for centralized equipment testing and maintenance, storage of equipment, shipping and handling of all materials and supplies, and contact with manufacturer ensuring timely factory-initiated system updates, data quality-control for both permanent and transportable systems, and temporary in-field scientific oversight during transportable system deployment.
Basis of Estimate: Estimates are based on costs derived from cost estimates provided by EMSOC and professional geophysical services contractors, and on actual costs derived during the MRE construction phase.

WBS Element 2.4.7.2: MT – Backbone

Definition: A reference array of seven equi-spaced thermally stable MT stations across the contiguous United States that will remain in place for the duration of the EarthScope experiment. All personnel, equipment, travel, materials and supplies, subawards and other direct costs associated with operation and maintenance of these permanent magnetotelluric installations.
Assumptions: All work associated with the construction of this reference network was conducted using MREFC funds. O&M funds are used for the on-going operations and maintenance. Operations and maintenance will be conducted under a subaward to Oregon State University (OSU). Incremental costs of reception of seven real-time data streams is presumed to be negligible and accommodated within other ANF functions.

WBS Element 2.4.7.2.1: Materials and Supplies

Definition: Provides sparing for equipment that may be damaged or stolen.
Basis of Estimate: Estimates are based 5% of the capital costs for the seven permanent MT systems.

WBS Element 2.4.7.2.2: Subawards

Definition: Provides for operations and maintenance of 7 permanent MT stations.
Basis of Estimate: Staffing levels (0.5 FTE) and costs for repairs and travel are based on actual costs provided by OSU contractor during the MREFC construction phase.

WBS Element 2.4.7.2.3: Other Direct Costs

Definition: Provides for ongoing costs and recurring charges of chemicals, permit renewals and monthly costs for phone-line leasing of seven permanent MT stations. Estimates for data telemetry are based on costs incurred by MT Transportable.
Basis of Estimate: Estimates are based on actual costs provided by OSU contractor during the MREFC construction phase.

WBS Element 2.4.7.3: MT – Transportable

Definition: A transportable array of 20 MT systems that will each be deployed for one-month durations across the contiguous United States with a spatial sampling of around 70 km in regions of identified interest. All activities associated with installing, relocating, reinstalling, maintaining and operating transportable magnetotelluric systems.
Assumptions: For the duration of the EarthScope project, Transportable MT stations will move eastward together with the Transportable Array (seismic) and regions of interest. Each MT system will occupy a site for 3–4 weeks only before being redeployed. In general, MT sites may not be collocated with Transportable Array (seismic) sites, and thus require fully independent crews. Most work will be done under contract to a professional geophysical services company. Estimate does not include depot maintenance and data QC. Each station is autonomous, with no telemetry provided and so data pickup is conducted through routine site visits.
Basis of Estimate: Staffing levels and costs for continued operation and maintenance of the Transportable Ar-

ray are based on actual costs and experience from operation during the Oregon Pilot Project conducted in 2006.

WBS Element 2.4.7.3.1: Materials and Supplies

Definition: Provides sparing for equipment that may be damaged or stolen.

Basis of Estimate: Estimates are based 5% of the capital costs for the 20 transportable MT systems.

WBS Element 2.4.7.3.2: Subawards

Definition: Provides for operations and maintenance for the field operations of the transportable MT stations.

Basis of Estimate: Staffing levels permit costs and travel are based on actual costs provided by EMSOC and professional geophysical services contractors during the Oregon Pilot Project. This task may be rebid in FY09.