PBO Mini-Proposal: Network Design and Real-Time Infrastructure

Yehuda Bock and Frank Vernon
Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
La Jolla, California

Abstract
Any decision on the deployment of continuous GPS instruments within the PBO region should take into consideration new or anticipated developments in the GPS constellation, GPS hardware, global and regional tracking infrastructure, and analysis techniques. Furthermore, any deployment of continuous GPS instruments and other sensors should strive for a real-time strategy for collection, analysis and dissemination of data.

Network Design
The purpose of the second PBO workshop is to determine siting priorities for the PBO, or in simpler terms to determine the geographic extent of the PBO region and to place dots on a map of that region. Although there is little controversy regarding the need for a backbone of stations, there has been little thought given to the actual spacing required other than a general statement of approximately 100 GPS receivers at a spacing of 100 to 200 km. The second least controversial item is the need for a PBO "cluster" to cover the San Andreas Fault System (~400 instruments) and a special group has been formed to study this issue and provide recommendations. Finally, the remaining permanent GPS resources will be allocated through the mini-proposal process initiated at this workshop (~275 instruments off the SAFS and ~100 instruments at volcanic centers).

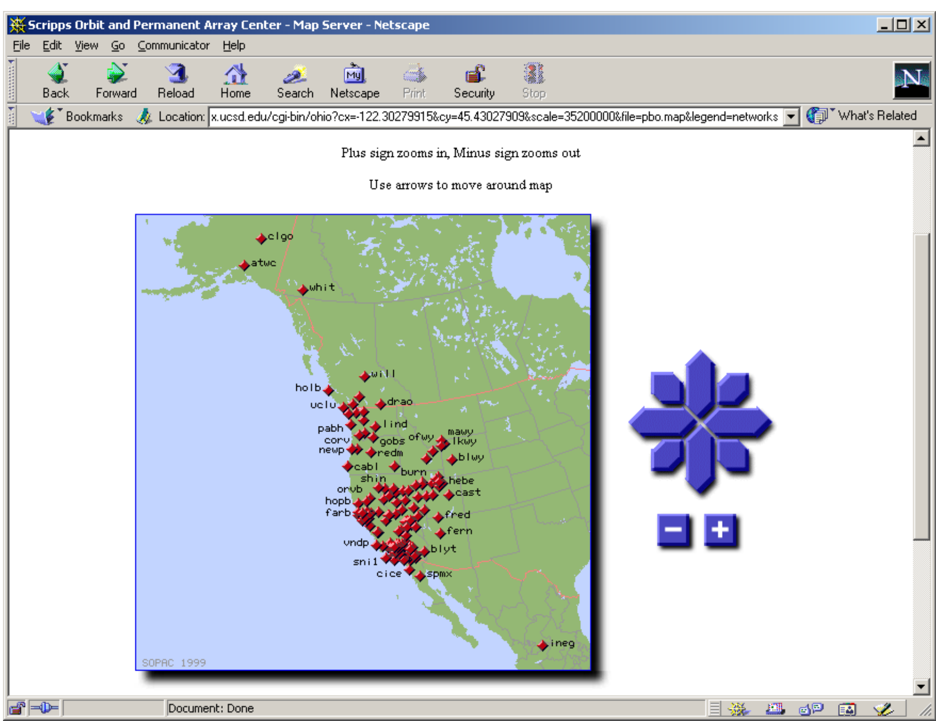

Figure 1. Current distribution of continuous GPS sites within the PBO region (source, SOPAC Web Page (http://lox.uscd.edu).

Besides the strictly scientifically-motivated criteria, the final network design needs to take the following issues into account:

(1) *Existing stations and infrastructure*. There are currently 316 geodetic-quality continuous GPS sites in Western North America whose data are archived at the Scripps Orbit and Permanent Array Center (SOPAC) (see Figure 1). These include sites from the existing AKDA, BARGEN, BARD, EBRY, PANGA, SCIGN and WCDA networks (see http://lox.ucsd.edu/permanentGPSSites/ for maps of these arrays and for a single map of the PBO region). For example, SCIGN includes a large concentration of GPS station in the Los Angeles metropolitan region informally coined the DGGA (Dense GPS Geodetic Array) all of which may need not be integrated into PBO. However, the regional component, the PGGA (Permanent GPS Geodetic Array) now includes about 100 well-distributed stations throughout southern California and northern Baja California as well as on the offshore islands. These sites could be folded into the SAFS cluster (and the backbone) in the final network design by allocating some resources to upgrade and maintain these stations but allowing the bulk of new resources to be focused elsewhere.

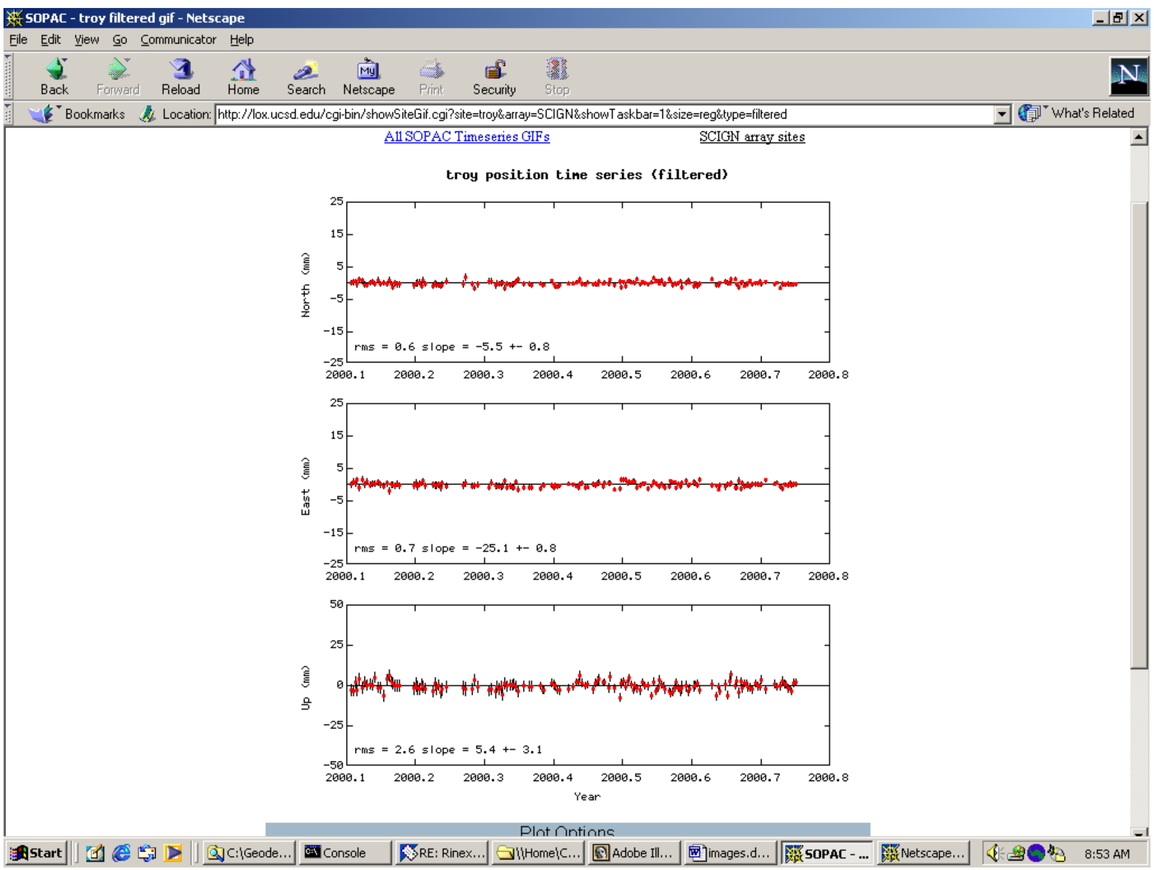

Figure 2. Time series for SCIGN station TROY in Newberry Springs, San Bernadino County. Uncertainties are based on white-noise assumptions.

(2) *Transient vs. steady-state deformation*. Measuring transient deformation requires continuous GPS deployments in well-selected areas or very rapid deployments in response to large earthquakes or anomalous signals. Measuring steady-state

deformation requires enhanced spatial coverage that may not be best accomplished solely by continuous deployments. There have been arguments in the past on the relative merits of continuous vs. survey-mode GPS measurements (e.g., Prescott, 1996 a,b; Savage, 1996, Thatcher, 1999), and the suggestion for hybrid approaches (e.g., Bevis et al., 1997). These questions needs to be revisited based on new technological developments and experience garnered from the existing continuous GPS arrays. In particular:

(a) Long spans of continuous GPS data indicate that with proper monumentation and site design (e.g., choosing low multipath environments) , state-of-the-art batch processing methods, and off-the-shelf geodetic-quality equipment the scatter (repeatability) of position determination with respect to a regional reference frame based on a 24-hour spans of data is sub-millimeter in the horizontal and about 3 mm in the vertical.

(b) Instantaneous and wide-area real-time-kinematic (RTK) positioning methods (at PBO cluster scales) make it possible to reduce significantly the relatively long occupation times currently required for regional GPS field surveys (e.g., Bock et al., 2000) and still achieve comparable precision compared to traditional batch processing methods. The key to these methods is ability to correctly resolve integer-cycle phase ambiguities which is primarily a function of the activity of the ionosphere as well as site-specific problems such as multipath. Modernization of the GPS satellite constellation including a third radio frequency and adding C/A code modulation on the L2 frequency band will enhance the ability to resolve phase ambiguities over longer distances and with shorter spans of data. Multipath suppression techniques employed by modern GPS receivers will also help in this regard.

Taking these factors into account, we propose the following approach. The backbone array is the critical component of PBO. It should have a station spacing of no more than 100 km. At this spacing, any receiver operating within the region (whether continuous or not) will be at most within 50 km of a backbone station. It has been shown that at this distance, ambiguity resolution is possible with even a single-epoch of dual-frequency measurements (Bock et al., 2000). Thus the backbone provides critical base station data. Furthermore, the backbone provides the definition of the regional reference frame to which all other GPS measurements can be related.

The PBO clusters should then be designed as networks of well-designed monuments with fixed antenna mounts, some of which will be permanently occupied with GPS receivers and some of which will be surveyed periodically according to the particular scientific problem to be addressed. Thus the number of stations in a cluster should be driven by scientific considerations and not by an artificial limit imposed by the total number of continuously operated sites affordable.

Real-Time Infrastructure

Let's take this one step further and turn the backbone sites and continuous cluster sites into transmitting base stations for wide-area real-time kinematic surveying. Currently most continuous GPS data for crustal deformation in the PBO region are being collected and archived once every 24 hours, with data made available freely via anonymous ftp as soon as they are archived (the exception are data from the northern California BARD array which are retrieved much more frequently through seismic data channels). Data are analyzed typically within several days of collection, again usually in 24-hour batches. The situation for strainmeter data is much worse.

We propose that the PBO sites be equipped to take advantage of wireless Internet and/or satellite-based communications systems to be able to retrieve, archive,

database, and broadcast data and data products in an operational real-time environment.

There are several reasons to establish a real-time system:

(1) Survey-mode GPS on fixed antenna mounts would become a highly reliable, efficient, and accurate operation. Using techniques being developed in the commercial sector (e.g., WRTK), positions could be determined within the receiver relative to the backbone stations transmitting real-time data.
(2) To achieve a much more reliable and robust treatment of data and data products (as experience has shown us with seismic and continuous GPS arrays).
(3) To respond very quickly to a large magnitude earthquake where response time is critical for computing a fault plane solution, hazards mitigation, etc.
(4) To better track and react to strain transients.
(5) To service a large community of non-scientific GPS users who would benefit from real-time access to hundreds of sites in Western North America (see mini-proposal from Bock and Snay).

Finally, the continuous GPS sites of the backbone array and PBO clusters could also serve as real-time displacement meters (seismic arrays) in the event of a medium to large earthquake within the region. Nikolaidis et al. (2000) have shown that dynamic ground displacements induced by the 1999 Hector Mine earthquake in southern California were directly measured with instantaneous GPS positioning (Figure 3), offering long-period constraints to the deconvolution of seismic velocities and accelerations.

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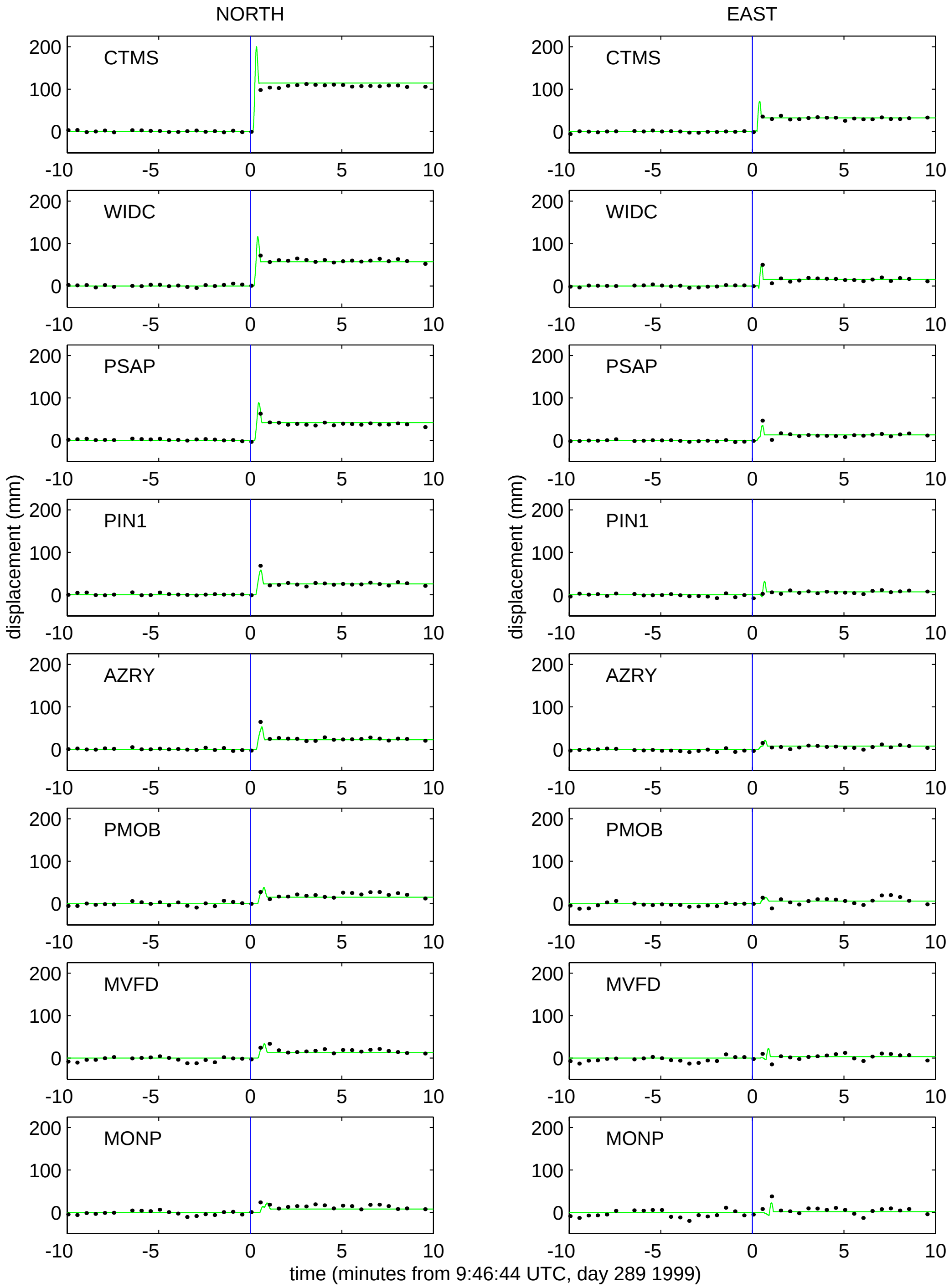

Figure 3. Observed horizontal displacements along a north-south profile of SCIGN stations within 10 minutes of the October 16, 1999 Hector Mine earthquake (blue line). Data are sampled at 30 s. Sites are in order of closest (top) to farthest (bottom) from the epicenter. The gray line shows model displacements based on a double couple source in a homogeneous elastic whole space.