Annual Progress Report
USGS Cooperative Agreement for Geodetic Monitoring Operations

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Geodetic Monitoring Project Name: Bay Area Regional Deformation Network (BARD)
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Major Goal(s) & Activities of the Geodetic Project:

The Bay Area Regional Deformation (BARD) network of permanent, continuously operating Global Positioning System (GPS) receivers monitors crustal deformation in the Bay Area and northern California (Murray et al., 1998a). It is a cooperative effort of the Berkeley Seismological Laboratory at UC Berkeley (BSL), the US Geological Survey (USGS), and several other academic, commercial, and governmental institutions, with the following goals: 1) to determine the distribution of deformation in northern California across the wide Pacific--North America plate boundary from the Sierras to the Farallon Islands; 2) to estimate three-dimensional interseismic strain accumulation along the San Andreas fault (SAF) system in the Bay Area to assess seismic hazards; 3) to monitor hazardous faults for emergency response management; and 4) to provide geodetic infrastructure in northern California in support of related efforts within the surveying and other interested communities.

The BSL's role in BARD is twofold: 1) it operates and maintains 27 bifrequencies BARD stations (Figure 1 and Table 1) and retrieves data continuously from these sites using radio or frame-relay telemetry. 2) Data from other stations in northern California are acquired either directly from the institutions that maintain the stations or from other GPS archives via the Internet. Recently, the number of stations thus collected and processed reached ~80: the number of GPS stations in Northern California is continually growing as GPS becomes an affordable tool for private and state agencies for their surveying and mapping purposes. It has recently been augmented in the framework of the Plate Boundary Observatory of Earthscope.

Accomplishments & Changes Implemented in this Reporting Period:

Site Upgrades: We have been involved in a systematic effort to upgrade the sampling rate at the BARD site from 15 or 30 s to 1Hz. This upgrade is an important step towards the integration of the GPS data with seismic data in the Bay Area, bringing significant constraints to the real-time determination of earthquake source parameters. In the last year, three sites have been upgraded to

1Hz (BRIB, HOPB, PTRB), bringing the total number of 1Hz sites to 16. The sites BRIB and HOPB are co-located with broad-band seismometers (BRIB, HOPS) of the Berkeley Digital Seismic Network (BDSN).

5Hz data in buffer. We started to experiment the use of 5Hz GPS data during August 2007. Today, the telemetry cost is too high to allow for the transmission of these data in real-time. However, at 5 sites (MHDL, UCD1, BRIB, DIAB, and UCSF, see Figure 1), these data can be brought back to Berkeley manually using the existing telemetry, and analyzed, although not in real time. Indeed, the storage capacity of NETRS receivers allows storing two days of data recorded at 5Hz.

Permit requests: We are in the process of permit agreements for the PTP1 site along the Hayward fault and the BDM site located in Black Diamond Mine Park. The permit for this site will be considered by the East Bay Regional Parks (EBPARK) board during the month of January 2008. The upgrade of these sites is an important step allowing for the comparison and integration of the GPS data with seismic records in the Bay Area.

Real-Time Kinematic (RTK) service. In the framework of the collaboration with East Bay Regional Parks (EBPARK), BSL is distributing RTK corrections at some sites (BRIB and EBMD). This experimental project aims at developing collaborations with private businesses or local institutions in northern California. We hope to densify the network and reduce monumentation and telemetry costs associated with the installation and operations of new sites. Conversion of ten PBO sites: P181, P222, P224, P225, P227, P228, P229, P230, P262, P256 to 1Hz sampling is under way. These sites will be included in the high rate real-time processing under development at Berkeley Seismological Laboratory. These operations are carried out in close collaboration with EBPARK and East Bay Municipal Utility District (EBMUD). These 10 sites will be operated through a radio network (Freewaves or Wi-LAN) using the existing telemetry paths. The cost of the installation will be shared by EBPARK and BSL. All sites will feed an NTRIP server installed this year on the BSL network by Doug Neuhauser. This server is providing RTK corrections while the streamed data is being converted into RINEX format. The first of the ten sites (P224) was equipped during december 2007. All radios and power installations are in place at this site.

Upgrade of the EBMD site: This site, operated in collaboration with EBMUD, is streaming Real Time Kinematic (RTK) messages to Berkeley via a Wi-LAN link to the Space Science Laboratory telemetry facility (Figure 1). This site is a prototype of the system that will be used for the 10 PBO sites (see above). This system is reliable and has proven its efficiency in terms of real-time navigation (Jim Swanson and Janine Hampton, personal communication). The RTK system is not able to provide accurate enough displacements for basic science purposes. The RTK accuracy is estimated at 3 cm. However, such sites allows maintaining sites by reducing costs of telemetry. RTK messages are converted by an NTRIP server at BSL into RINEX format to be archived.

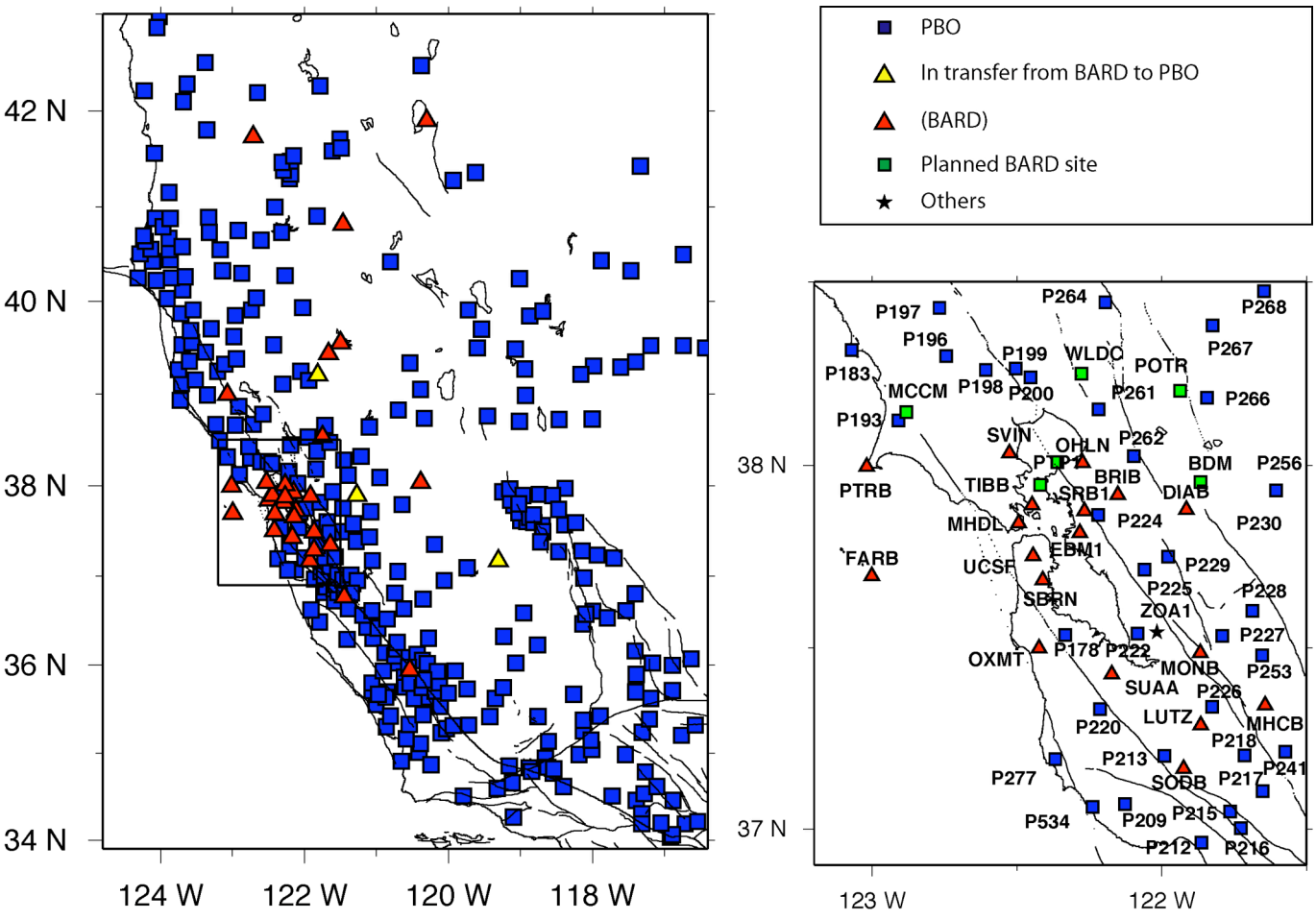
New site installed on SF peninsula: A new site has been installed on the rooftop of UCSF Hospital. This site is hosting a NETRS receiver and is streaming data (RT17 format) every second. This site will be crucial when a large seismic event occurs along the San Andreas fault at the latitude of SFBA.

CALREF 1.0 release. We are finalizing a manuscript in which we present and analyze the BARD data since 1992. The coordinates and site velocities in the ITRF2000 is available to the public user.

Additionally, we show that asymmetric distribution of deformation across San Andreas fault system can be inferred from the analysis of GPS data , confirming results previously obtained in the rigidity jump across the Bay Area faults using seismic data. We discuss the implications of this finding on the seismic cycle.

Connection with the Bay Area Velocity Unification (BAVU) system. While BARD and PBO networks are dedicated to continuous monitoring, high-rate positioning, and the measurement of long-term plate boundary motion, dense campaign GPS networks provide a higher spatial sensitivity. The BAVU dataset is composed of campaign data collected by USGS, UNAVCO, CALTRANS and academic groups and is able to map the surface strain field at a finer resolution (~5 kilometers). As the campaign measurements are less accurate (troposphere estimates, etc.) than permanent measurements, there is a need to adjust them together. We successfully adjusted the BAVU velocity dataset with the solutions from BARD and GPS sites in southern California. A joint release of BARD and BAVU solutions will be published (under the acronym BAVU 2.0) during the next year.

Figure 1 Map of Geodetic Stations in northern California.



1	BRIB	37.91	237.84	NETRS	T1	1Hz	BDSN	Briones Reservation, Orinda
2	CMBB	38.03	239.61	A-UZ12	FR	1Hz	BDSN	Columbia College, Columbia
3	DIAB	37.87	238.08	A-Z12	FR	1Hz		Mt. Diablo
4	FARB	37.69	236.99	A-Z12	R-FR/R	1Hz	BDSN	Farallon Island
5	EBMD	37.81	237.71	T-5700	R	1Hz		East Bay Mud Headquarter
6	HOPB	38.99	236.92	TR 4000	FR	1Hz	BDSN	Hopland Field Stat.,
7	LUTZ	37.28	238.13	A-Z12	FR	30s		SCC Comm., Santa Clara
8	MHCB	37.34	238.35	A-Z12	FR	1Hz	BDSN	Lick Obs., Mt. Hamilton
9	MHDL	37.84	237.50	NETRS	FR	1Hz	miniPBO	Marin Headland
10	MODB	41.90	239.69	A-UZ12	NSN	15s		Modoc Plateau
11	MONB	37.48	238.13	A-Z12	FR	1Hz		Monument Peak, Milpitas
12	MUSB	37.16	240.69	A-Z12	R-Mi-FR	30s		Musick Mt.
13	OHLN	38.00	237.72	A-UZ12	FR	1Hz	miniPBO	Ohlone Park, Hercules
14	ORVB	39.55	238.49	A-Z12	FR	15s	BDSN	Oroville
15	OXMT	37.49	237.57	A-UZ12	FR	1Hz	Mini-	Ox Mountain
16	PKDB	35.94	239.45	A-Z12	FR	30s	BDSN	Bear Valley Ranch,
17	PTRB	37.99	236.98	A-Z12	R-FR	1Hz		Point Reyes Lighthouse
18	SAOB	36.76	238.55	A-Z12	FR	30s	BDSN	San Andreas Obs., Hollister
19	SBRN	37.68	237.58	A-Z12	FR	1Hz	miniPBO	San Bruno
20	SODB	37.16	238.07	A-Z12	R-FR	30s		Soda Springs, Los Gatos
21	SRB1	37.87	237.73	T-SSE	FR	1Hz		RB building, Berkeley
22	SUTB	39.20	238.17	A-Z12	R-FR	30s	BDSN	Sutter Buttes
23	SVIN	38.03	237.47	A-UZ12	FR	1Hz	Mini-	St Vincents
24	TIBB	37.89	237.55	A-UZ12	R	1Hz		Tiburon
25	UCD1	38.53	238.24	NETRS	WEB	1Hz		UC - Davis
26	YBHB	41.73	237.28	A-Z12	FR	15s	BDSN	Yreka Blue Horn Mine,
27	UCSF	37.75	237.55	NETRS	FR	1Hz		UC-San Francisco, San
Stations with permit requests completed								
28	*BDM1*	*37.95*	*238.13*	*NETRS*			*BDSN*	*Black Diamond Mines Park,*
29	*MCCM*	*38.14*	*237.12*	*NETRS*			*BDSN*	*Marconi Conference Center,*
30	*PTP1*	*38.00*	*237.64*	*NETRS*			*NHFN*	*Point Pinole Regional Park*

Table 1.1: List of the BARD stations maintained by the BSL. Five receiver models are operating now: Trimble 4000 SSE (T-SSE), Trimble 4000 SSI (T-SSI), Trimble NETRS, (T-NETRS), Ashtech Z12 and Ashtech Micro Z (A-UZ12). The replacement of the Ashtech Z12 by Trimble NETRS will make the receiver array more homogeneous. The telemetry types are listed in column 6. FR = Frame Relay, R = Radio, Mi= Microwave, WEB = DSL line, NSN= US National Seismic Network (VSAT: satellite telemetry). Some sites are transmitting data over several legs with different telemetry. Changes from the last year network table are highlighted in bold. The sites 28 to 30 are in progress. For these 3 sites, the instrumentation is available and permit request procedures have been completed.

Data Management Practices:

Permanent network dataset at NCEDC. The Northern California Earthquake Data Center (NCEDC), operated jointly by the BSL and USGS, archives all permanent-site GPS data currently being collected in northern California (excluding PBO data that are archived at PBO Boulder facility). In the past months, and due to the transition to PBO, some sites are not present in the NCEDC archive (PPT1 for instance). All the sites available will be archived as in the past. We archive data from the Federal Aviation Administration (FAA) sites all along the west pacific coast (the closest one is ZOA1). Data importation and quality assurance are automated, although some manual correction of unusual data problems is still required. All the data provided are prepared to be integrated into GSAC system. This year the volume of GPS data in raw format in the NCEDC storage facility has increased by 30% (525Mb/day). This trend will continue with the installation of new sites and the conversion of the rest of the 15 sites of BARD to 1Hz operation .

Campaign mode dataset. As part of the activities funded by the USGS through the BARD network, the NCEDC has established an archive of the 7000+ survey-mode occupations collected by the USGS or CALTRANS since 1992. The NCEDC continues to archive non-continuous survey GPS data. The initial dataset archived is the survey GPS data collected by USGS Menlo Park for northern California and other locations. The NCEDC is the principal archive for this dataset. Significant quality control efforts were implemented by the NCEDC (Romanowicz et al., 1994) to ensure that the raw data, scanned site log sheets, and RINEX data are archived for each survey. All of the USGS MP GPS data has been transferred to the NCEDC and all of the data available from 1992 to the present have been archived and is available for distribution through NCEDC web server. We are also archiving additional high-precision GPS data sets from northern California (mainly Parkfield measurements).

Parkfield area: In February 2003, the BSL assumed responsibility for data telemetry from a 13-station GPS network in the Parkfield region, in addition to the BARD station PKDB. Most of these stations were constructed using “mini-PBO” funding from the NSF MRI program, with contributions from the USGS and SCIGN. All the Parkfield GPS sites have now been transferred to the PBO network except the PKDB site, which remains a BSL/BARD site, as it is collocated with a long-term BDSN station. The PKDB site has not yet been upgraded to 1Hz, due to telemetry bandwidth limitations. This year, most of the sites at Parkfield were upgraded to a Trimble NETRS receiver. We appreciated the good coordination with Plate Boundary Observatory (PBO) (Freddy Blume) and San Diego teams during this last upgrade. Today, BSL is still in charge of the creation of the RINEX format files. These files are then downloaded daily by the PBO team and archived at the UNAVCO facility in Boulder.

BARD data at NGS. Data from five of our sites (HOPB, MHCB, CMBB, OHLN, YBHB) are sent to the National Geodetic Survey (NGS) in the framework of the CORS (Continuous Operating Reference Stations) project (http://www.ngs.noaa.gov/ CORS/). The data from these five sites are also distributed to the public through the CORS ftp site.

NTRIP system in collaboration with EBPARK. Streaming data from the EBMD site (operated in collaboration with East Bay Municipal Utility District (EBMUD)), and in the future, from collaborative sites with EBPARK, are available on the internet. As the cost of this development is supported by EBPARK, BSL is working on an MOA, in order to define the use and the availability of the streamed data to users (commercial, private or academic, and governmental).

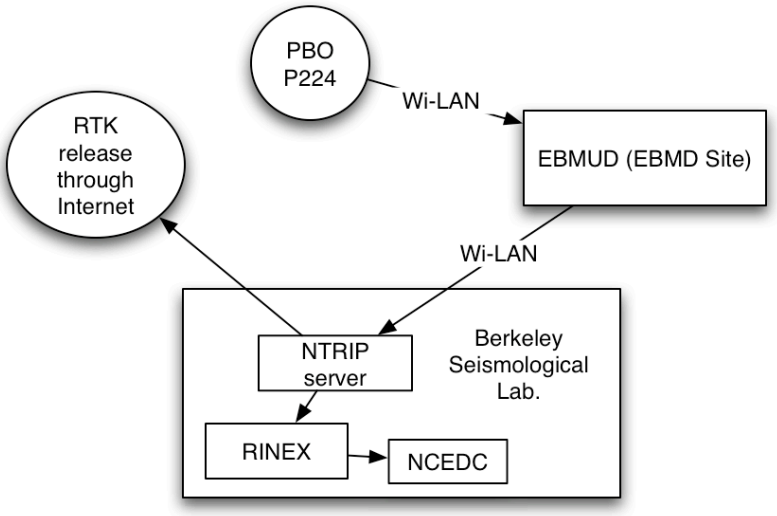


Figure 2: Present BSL operations at EBMD site and planned operations between the PBO site P224 and BSL. Since its installation in 2003, the EBMD site has been sending data to BSL using an internet DSL connection. The data collected (Trimble 5700 receiver) are now sent to BSL using a WI-LAN radio connection. This new connection represents an upgrade of the quality of the communication link, which is important in anticipation of a large seismic event.

Continuity of Operations and Response Planning:

Robust communication in case of earthquake. The BSL operates a robust communication system using Frame Relay (FRAD) and land-based phone lines. The Ashtech Z12 receivers are connected to a Quanterra digitizer allowing the storage of three days of data on-site. For these receivers, data are thus not stored inside the receiver but in the Quanterra. For the new receivers (NETRS), we programmed 10 days of on-site storage at 1Hz and 3 days on-site storage for 5Hz data. In case of telemetry failure between the lab and some sites, the time available to retrieve the data is thus equal to three days.

BSL/USGS/PBO MOU's: We are working on MOU's with the USGS Menlo Park and PBO/UNAVCO. The former establishes the framework for real time GPS data exchange between BSL and USGS/Menlo Park, and integration of the GPS data in the real time earthquake notification system in northern California in a robust and redundant manner. The

latter establishes the framework for real time acquisition of high rate data from GPS sites installed by PBO.

Problems or Concerns Encountered

Ashtech Z12 failure. During this past year, we faced unexplained failures of many of the Z12 receivers. The replacement of the internal batteries may be the solution to some of these failures. We are actively working on this issue with Adrian Borsa (USGS-Pasadena). In parallel, we requested from UNAVCO 14 operational Ashtech Z12 receivers in order to support our operations during the upgrade of the network (replacement of the Z12 by NETRS).

Telemetry issues. The development of high-rate BARD data acquisition is currently limited by the funding available for telemetry. Currently, the telemetry cost of high rate GPS is supported by BSL at those sites which are colocated with seismic instrumentation via existing telemetry, therefore at no extra cost, and several other sites have benefited from available internet lines.