Chapter 3

BSL Operations

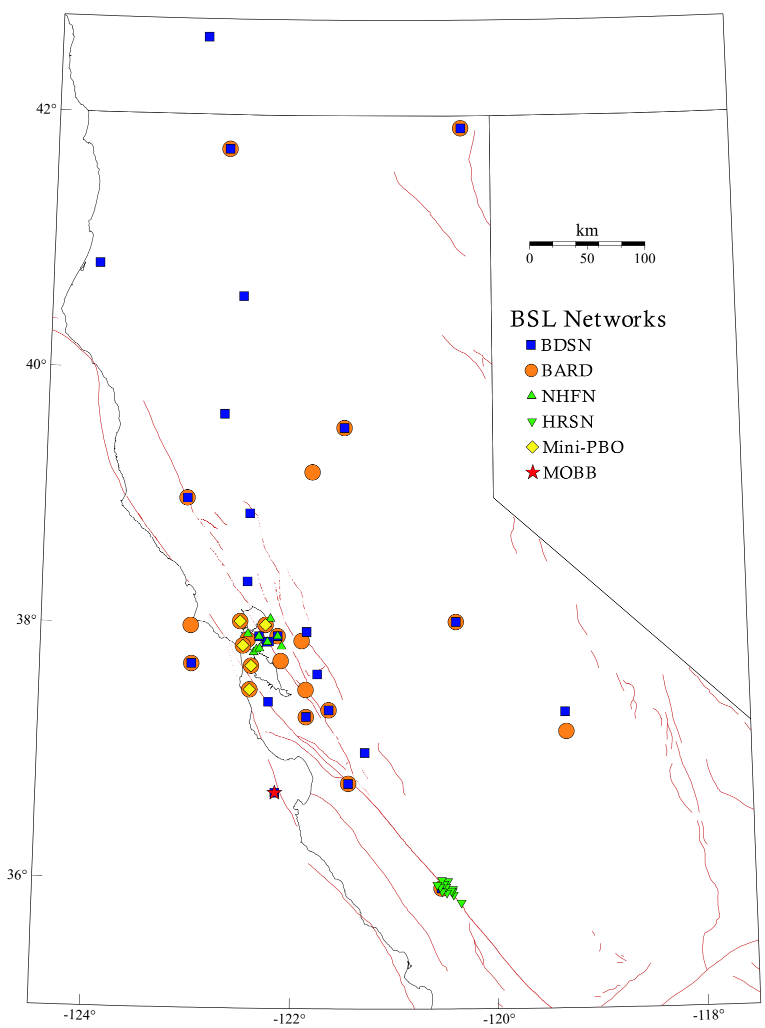

Figure 3.1: Map illustrating the distribution of BSL networks in northern and central California.

3.1. Berkeley Digital Seismic Network

3.1.1 Introduction

The Berkeley Digital Seismic Network (BDSN) is a regional network of very broadband and strong motion seismic stations spanning northern California and linked to UC Berkeley through continuous telemetry (Figure 3.2 and Table 3.1). The network is designed to monitor regional seismic activity at the magnitude 3+ level as well as to provide high quality data for research projects in regional and global broadband seismology.

Since 1991 the BDSN has grown from the original 3 broadband stations installed in 1986-87 (BKS, SAO, MHC) to comprise 27 stations, including an autonomous ocean-bottom seismometer in Monterey Bay (MOBB). We take particular pride in high quality installations, which often involve lengthy searches for appropriate sites away from sources of low-frequency noise, as well as continuous improvements in installation procedures and careful monitoring of noise conditions and problems. Thus, the focus of this year's technical efforts evolved to maintenance and repair, because of aging instruments, the desire for higher data rates, corrosion and outright equipment failure. Considerable engineering and research activities were also involved in a project to develop new electronics for the STS-1 seismometers (see Section 3.7.).

Further expansion of our network to densify the state-of-the-art strong motion/broadband seismic network and the joint earthquake notification system in this seismically hazardous region, one of BSL's long term goals, must be coordinated with other institutions and is contingent on the availability of funding.

Equally important, data quality and the integrity of the established network must be preserved and remain assured despite expansion. The first generation of broadband seismometers installed by BSL have been operating for almost 25 years. At the same time, the first generation of broadband dataloggers are entering their 16th year of service. These will both require continued vigilance and greater time commitment to both repairs and upgrades in the future.

3.1.2 BDSN Overview

Twenty-four of the BDSN sites are equipped with 3 component broadband seismometers and strong-motion accelerometers, and a 24-bit digital data acquisition system or datalogger. Two additional sites (RFSB and SCCB) consist of a strong-motion accelerometer and a 24-bit digital datalogger. The ocean-bottom station MOBB is equipped with a 3 component broadband seismometer. Data from all BDSN stations, except MOBB, are transmitted to UC Berkeley using continuous telemetry. In order to insure against data loss during utility disruptions, each site has a 3-day supply of battery power and is accessible via a dialup phone line. The combination of high-dynamic range sensors and digital dataloggers ensures that the BDSN has the capability to record the full range of earthquake motion for source and structure studies. Table 3.2 lists the instrumentation at each site.

Most BDSN stations have Streckeisen STS-1 or STS-2 three-component broadband sensors (*Wielandt and Streckeisen*, 1982; *Wielandt and Steim*, 1986). A Guralp CMG-3T downhole broadband sensor contributed by LLNL is deployed in a post-hole installation at BRIB. A Guralp CMG1-T is deployed at MOBB. The strong-motion instruments are Kinemetrics FBA-23, FBA-ES-T or MetroZet accelerometers with ± 2 g dynamic range. The recording systems at all sites are either Q330, Q680, Q730, or Q4120 Quanterra dataloggers, with 3, 6, 8, or 9 channel systems. The Quanterra dataloggers employ FIR filters to extract data streams at a variety of sampling rates. In general, the BDSN stations record continuous data at .01, 0.1, 1.0, 20.0 or 40.0, and 80 or 100 samples per second, although some sites send triggered data at the highest sampling rate using the Murdock, Hutt, and Halbert event detection algorithm (*Murdock and Hutt*, 1983) (Table 3.3). In addition to the 6 channels of seismic data, signals from thermometers and barometers are recorded at nearly every site (Figure 3.3).

In parallel with the upgrade of the broadband network, a grant from the CalREN Foundation (California Research and Education Network) in 1994 enabled the BSL to convert data telemetry from analog leased lines to digital frame-relay connections. The frame-relay network uses digital phone circuits that can support 56 Kbit/s to 1.5 Mbit/s throughput. Since frame-relay is a packet-switched network, a site may use a single physical circuit to communicate with multiple remote sites through the use of "permanent virtual circuits". Frame Relay Access Devices (FRADs), which replace modems in a frame-relay network, can simultaneously support multiple interfaces such as RS-232 async ports, synchronous V.35 ports, and ethernet connections. In practical terms, the upgrade to frame relay communication provides faster data telemetry between the remote sites and the BSL, remote console control of the dataloggers, additional services such as FTP and telnet to the dataloggers, data transmission to multiple sites, and the ability to communicate and transmit data from multiple instruments such as GPS receivers and/or multiple dataloggers at a single site. Today, 23 of the BDSN sites use frame-relay telemetry for all or part of their communications system.

As described in Section 3.7., data from the BDSN are

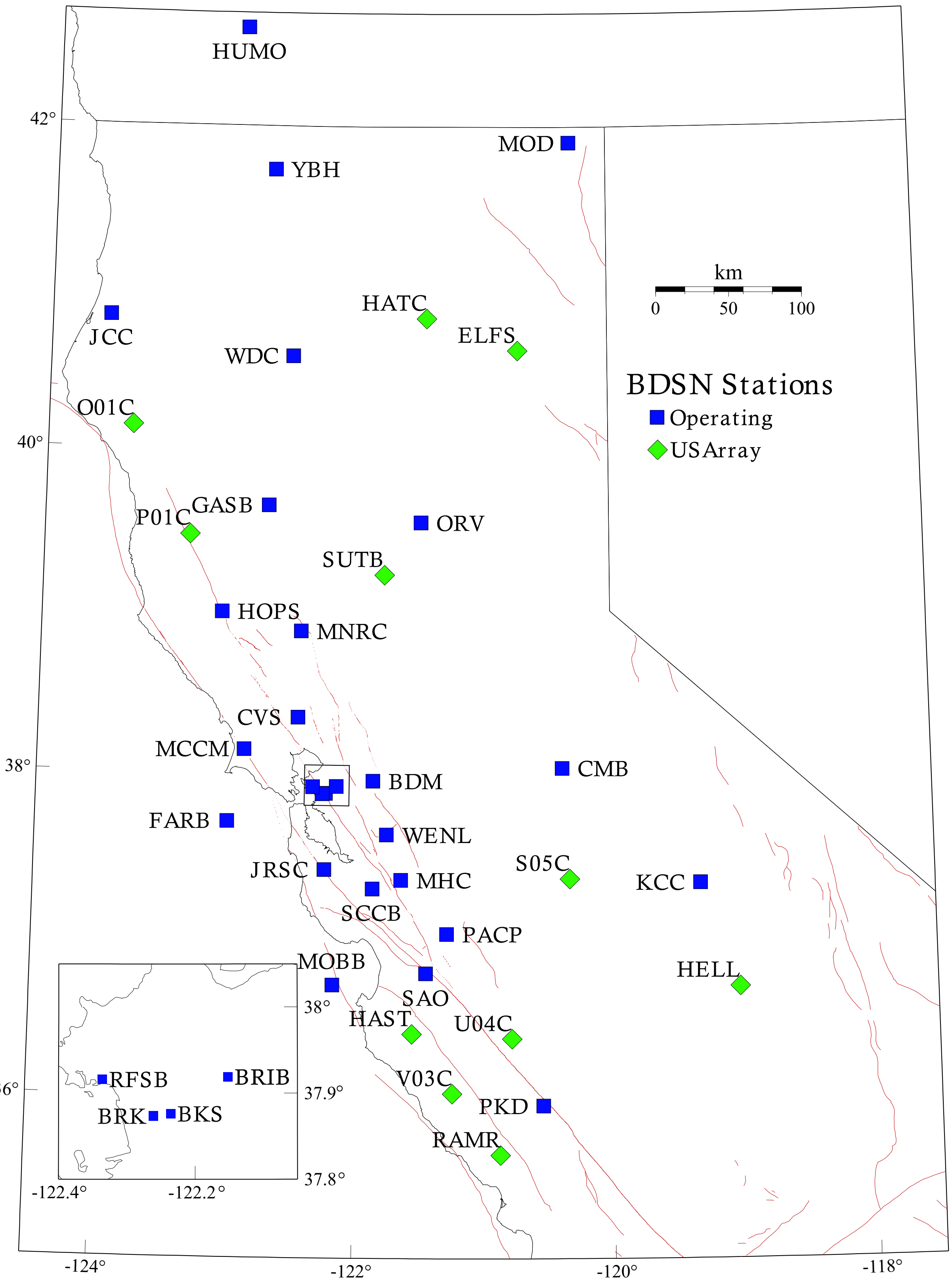

Figure 3.2: Map illustrating the distribution of BDSN stations (squares) in northern and central California. The diamonds indicate sites currently operated by USArray which we are monitoring as perspective future stations.

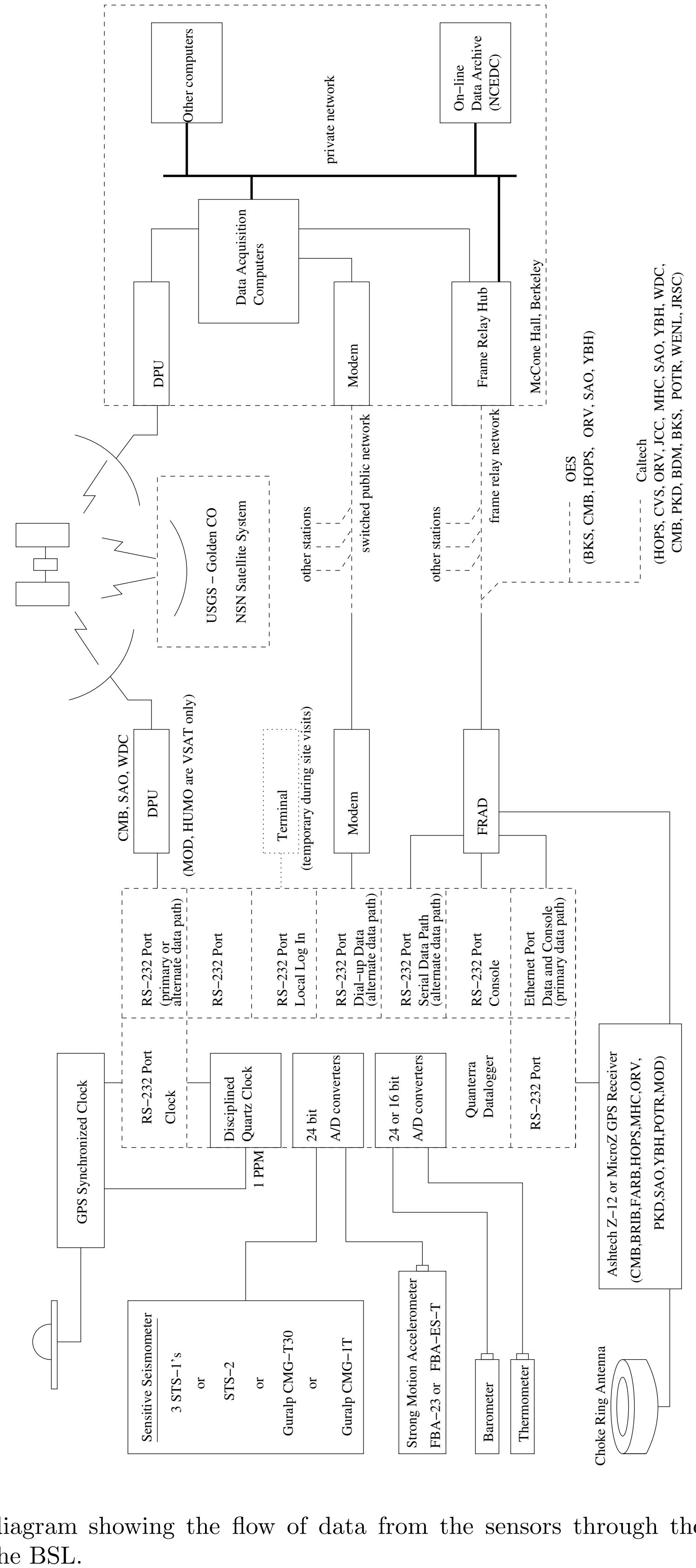

Figure 3.3: Schematic diagram showing the flow of data from the sensors through the dataloggers to the central acquisition facilities of the BSL.

Code	Net	Latitude	Longitude	Elev (m)	Over (m)	Date	Location
BDM	BK	37.9540	-121.8655	219.8	34.7	1998/11 -	Black Diamond Mines, Antioch
BKS	BK	37.8762	-122.2356	243.9	25.6	1988/01 -	Byerly Vault, Berkeley
BRIB	BK	37.9189	-122.1518	219.7	2.5	1995/06 -	Briones Reservation, Orinda
BRK	BK	37.8735	-122.2610	49.4	2.7	1994/03 -	Haviland Hall, Berkeley
CMB	BK	38.0346	-120.3865	697.0	2	1986/10 -	Columbia College, Columbia
CVS	BK	38.3453	-122.4584	295.1	23.2	1997/10 -	Carmenet Vineyard, Sonoma
FARB	BK	37.6978	-123.0011	-18.5	0	1997/03 -	Farallon Island
GASB	BK	39.6547	-122.716	1354.8	2	2005/09 -	Alder Springs
HOPS	BK	38.9935	-123.0723	299.1	3	1994/10 -	Hopland Field Stat., Hopland
HUMO	BK	42.6071	-122.9567	554.9	50	2002/06 -	Hull Mountain, Oregon
JCC	BK	40.8175	-124.0296	27.2	0	2001/04 -	Jacoby Creek
JRSC	BK	37.4037	-122.2387	70.5	0	1994/07 -	Jasper Ridge, Stanford
KCC	BK	37.3236	-119.3187	888.1	87.3	1995/11 -	Kaiser Creek
MCCM	BK	38.1448	-122.8802	-7.7	2	2006/02 -	Marconi Conference Center, Marshall
MHC	BK	37.3416	-121.6426	1250.4	0	1987/10 -	Lick Obs., Mt. Hamilton
MNRC	BK	38.8787	-122.4428	704.8	3	2003/06 -	McLaughlin Mine, Lower Lake
MOBB	BK	36.6907	-122.1660	-1036.5	1	2002/04 -	Monterey Bay
MOD	BK	41.9025	-120.3029	1554.5	5	1999/10 -	Modoc Plateau
ORV	BK	39.5545	-121.5004	334.7	0	1992/07 -	Oroville
PACP	BK	37.0080	-121.2870	844	0	2003/06 -	Pacheco Peak
PKD	BK	35.9452	-120.5416	583.0	3	1996/08 -	Bear Valley Ranch, Parkfield
RFSB	BK	37.9161	-122.3361	-26.7	0	2001/02 -	RFS, Richmond
SAO	BK	36.7640	-121.4472	317.2	3	1988/01 -	San Andreas Obs., Hollister
SCCB	BK	37.2874	-121.8642	98	0	2000/04 -	SCC Comm., Santa Clara
WDC	BK	40.5799	-122.5411	268.3	75	1992/07 -	Whiskeytown
WENL	BK	37.6221	-121.7570	138.9	30.3	1997/06 -	Wente Vineyards, Livermore
YBH	BK	41.7320	-122.7104	1059.7	60.4	1993/07 -	Yreka Blue Horn Mine, Yreka

Table 3.1: Currently operating stations of the Berkeley Digital Seismic Network. Each BDSN station is listed with its station code, network id, location, operational dates, and site description. The latitude and longitude (in degrees) are given in the WGS84 reference frame and the elevation (in meters) is relative to the WGS84 reference ellipsoid. The elevation is either the elevation of the pier (for stations sited on the surface or in mining drifts) or the elevation of the well head (for stations sited in boreholes). The overburden is given in meters. The date indicates either the upgrade or installation time.

acquired centrally at the BSL. These data are used for rapid earthquake reporting as well as for routine earthquake analysis (Section 3.2. and 3.8.). As part of routine quality control (Section 3.7.), power spectral density (PSD) analyses are performed weekly. Figure 3.4 shows a summary of the results for 2006 in comparison with other broadband stations operating in Northern California.

The occurrence of a significant teleseism also provides the opportunity to review station health and calibration. Figure 3.5 displays BDSN waveforms for a M_w 8.1 deep focus earthquake in the Solomon Islands region on April 1, 2007.

BDSN data are archived at the Northern California Earthquake Data Center. This is described in detail in Section 3.6..

Electromagnetic Observatories

In 1995, in collaboration with Dr. Frank Morrison, the BSL installed two well-characterized electric and magnetic field measuring systems at two sites along the San Andreas Fault which are part of the Berkeley Digital Seismic Network. Since then, magnetotelluric (MT) data have been continuously recorded at 40 Hz and 1 Hz and archived at the NCEDC (Table 3.4). At least one set of orthogonal electric dipoles measures the vector horizontal electric field, E, and three orthogonal magnetic sensors measure the vector magnetic field, B. These reference sites, now referred to as electromagnetic (EM) observatories, are co-located with seismographic sites so that the field data share the same time base, data acquisition, telemetry and archiving system as the seismometer outputs.

The MT observatories are located at Parkfield (PKD1, PKD) 300 km south of the San Francisco Bay Area,

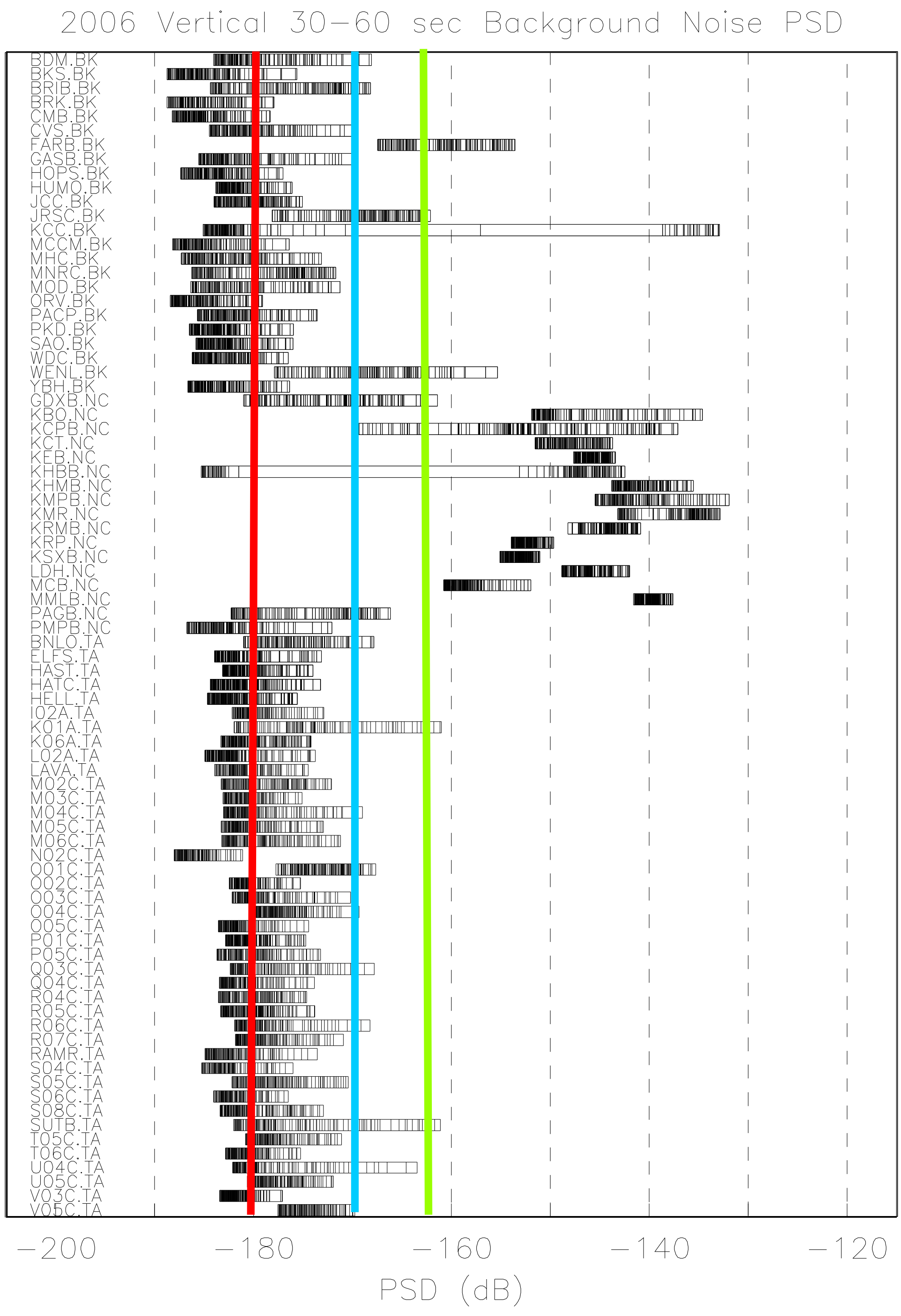

Figure 3.4: PSD noise analysis for vertical components of the broadband stations of the BK, NC and TA networks in Northern California, in the period range from 32-128 sec for the interval 1/1/2006-12/31/2006. The BK and TA stations have much lower noise levels than the NC stations because of the sensors. BRIB (situation in a shallow vault that is prone to tilting) and FARB (located on the Farallon Islands) stand out as sites with high noise levels. KCC is located in a overflow tunnel near a dam. When the water is running, it has high noise levels. HUMO (located in an abandoned mine) stands out as an exceptionally quiet site. The vertical lines indicate the average signal levels of events with M_L 2.5, 3.5 and 4.5, respectively.

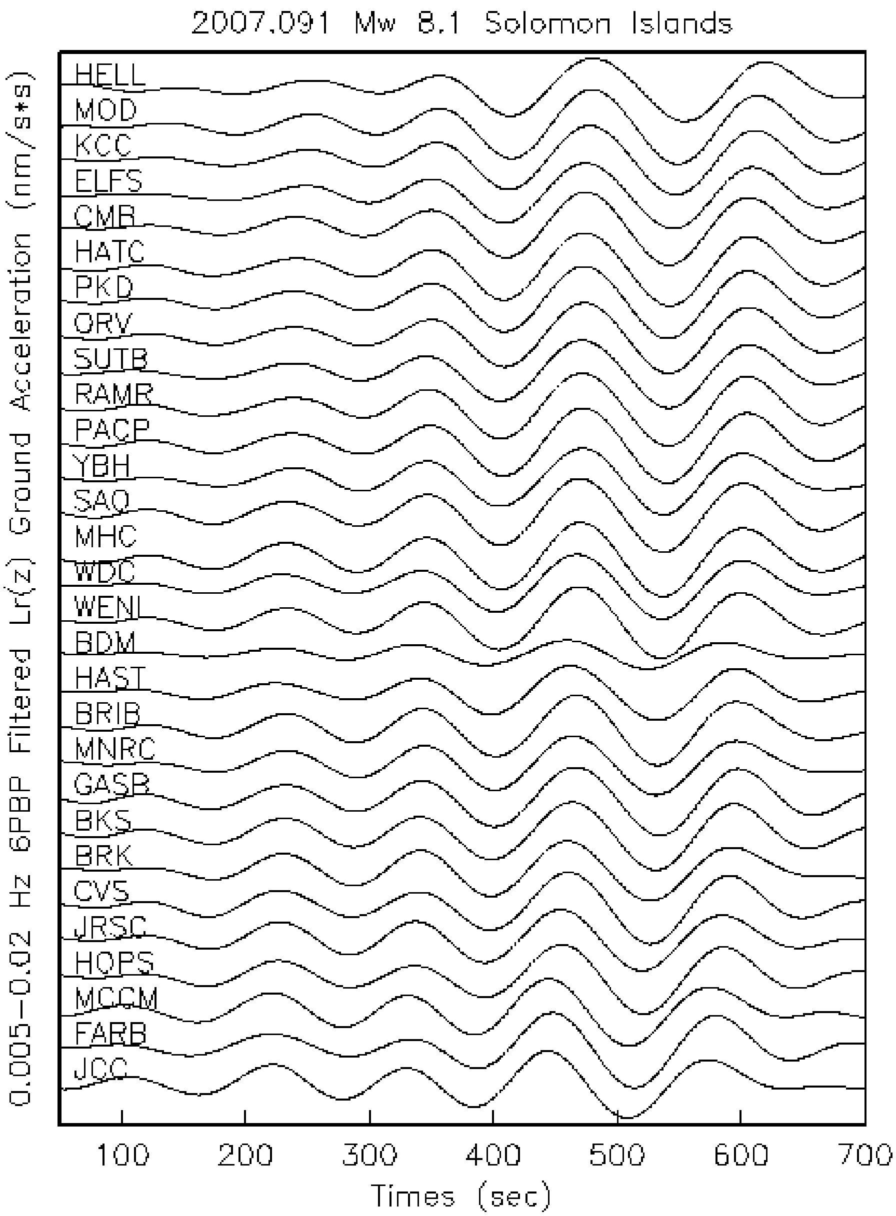

Figure 3.5: $L_R(Z)$ vertical component broadband waveforms recorded across BDSN from the M_w 8.1 teleseism which occurred on April 1, 2007, in the Solomon Islands at 8.48° S, 156.98° E. The traces are deconvolved to ground motion, scaled absolutely, and ordered from bottom to top by distance from the epicenter. For reference, the vertical distance between the traces is equivalent to 500 nm/s^2. The highly similar waveforms recorded across the BDSN provide evidence that the broadband sensors other than BDM are operating within their nominal specifications.

Code	Broadband	Strong-motion	datalogger	T/B	GPS	Other	Telemetry	Dial-up
BDM	STS-2	FBA-23	Q4120	X			FR	
BKS	STS-1	FBA-23	Q980	X		Baseplates	FR	X
BRIB	CMG-3T	FBA-23	Q980		X	Vol. Strain	FR	X
BRK	STS-2	FBA-23	Q680				POTS	
CMB	STS-1	FBA-23	Q980	X	X	Baseplates	FR	X
CVS	STS-2	FBA-23	Q4120	X			FR	
FARB	CMG-3T	FBA-23	Q4120	X	X		R-FR/R	
GASB	STS-2	FBA-ES-T	Q4120	X			R-FR	
HOPS	STS-1	FBA-23	Q980	X	X	Baseplates	FR	X
HUMO	STS-2	FBA-ES-T	Q4120	X			VSAT	X
JCC	STS-2	FBA-23	Q980	X			FR	X
JRSC	STS-2	FBA-23	Q680				FR	X
KCC	STS-1*	FBA-23	Q980	X		Baseplates	R-Mi-FR	X
MCCM	STS-2	FBA-ES-T	Q4120				VSAT	
MHC	STS-1	FBA-23	Q980	X	X		FR	X
MNRC	STS-2	FBA-ES-T	Q4120	X			None	X
MOBB	CMG-1T		GEOSense			Current meter, DPG	None	
MOD	STS-1*	FBA-ES-T	Q980	X	X	Baseplates	VSAT	X
ORV	STS-1	FBA-23	Q980	X	X	Baseplates	FR	X
PACP	STS-2	FBA-ES-T	Q4120	X			Mi/FR	
PKD	STS-2	FBA-23	Q980	X	X	EM	R-FR	X
RFSB		FBA-ES-T	Q730				FR	
SAO	STS-1	FBA-23	Q980	X	X	Baseplates, EM	FR	X
SCCB		MetroZet	Q730		X		FR	
WDC	STS-2	FBA-23	Q980	X			FR	X
WENL	STS-2	FBA-23	Q4120	X			FR	
YBH	STS-1 & STS-2	FBA-23	Q980	X	X	Baseplates	FR	X

Table 3.2: Instrumentation of the BDSN as of 06/30/2007. Except for PKD1, RFSB, SCCB and MOBB, each BDSN station consists of collocated broadband and strong-motion sensors, with a 24-bit Quanterra datalogger and GPS timing. The stations PKD1, RFSB and SCCB are strong-motion only, while MOBB has only a broadband sensor. Additional columns indicate the installation of a thermometer/barometer package (T/B), collocated GPS receiver as part of the BARD network (GPS), and additional equipment (Other) such as warpless baseplates or electromagnetic sensors (EM). The obs station MOBB also has a current meter and differential pressure gauge (DPG). The main and alternate telemetry paths are summarized for each station. FR - frame relay circuit, R - radio, Mi - microwave, POTS - plain old telephone line, VSAT - USGS ANSS satellite link, None - no telemetry at this time. An entry like R-Mi-FR indicates telemetry over several links, in this case, radio to microwave to frame relay. (*) During part of 2006-2007 the STS-1s at these two stations were replaced by STS-2s

and Hollister (SAO), halfway between San Francisco and Parkfield (Figure 3.2). In 1995, initial sites were established at PKD1 and SAO, separated by a distance of 150 km, and equipped with three induction coils and two 100 m electric dipoles. PKD1 was established as a temporary seismic site, and when a permanent site (PKD) was found, a third MT observatory was installed in 1999 with three induction coils, two 100 m electric dipoles, and two 200 m electric dipoles. PKD and PKD1 ran in parallel for one month in 1999, and then the MT observatory at PKD1 was closed.

Data at the MT sites are fed to Quanterra dataloggers, shared with the collocated BDSN stations, synchronized in time by GPS and sent to the BSL via dedicated communication links.

3.1.3 2006-2007 Activities

USArray

The BSL concluded an agreement with IRIS during 2003-2004 to contribute 19 stations of the BDSN to USArray while the experiment is deployed in California. This included 17 existing stations: CMB, CVS, FARB, HOPS, HUMO, JCC, JRSC, KCC, MNRC, MOD, ORV, PACP, PKD, POTR, WDC, WENL, and YBH as well as the two new sites: GASB and MCCM.

The 19 BDSN sites provided USArray with a running start in northern California. In June of 2004, the BSL set

Sensor	Channel	Rate (sps)	Mode	FIR
Broadband	UH?	0.01	C	Ac
Broadband	VH?	0.1	C	Ac
Broadband	LH?	1	C	Ac
Broadband	BH?	20/40	C	Ac
Broadband	HH?	80/100	C	Ac/Ca
SM	LL?	1	C	Ac
SM	BL?	20/40	C	Ac
SM	HL?	80/100	C	Ac/Ca
Thermometer	LKS	1	C	Ac
Barometer	LDS	1	C	Ac

Table 3.3: Typical data streams acquired at BDSN stations, with channel name, sampling rate, sampling mode, and the FIR filter type. SM indicates strong-motion; C continuous; T triggered; Ac acausal; Ca causal. The LL and BL strong-motion channels are not transmitted over the continuous telemetry but are available on the Quanterra disk system if needed. The HH channels are recorded at two different rates, depending on the dataloger type. Q4120s provide 100 sps and causal filtering; Q680/980s provide 80 sps and acausal filtering.

Sensor	Channel	Rate (sps)	Mode	FIR
Magnetic	VT?	0.1	C	Ac
Magnetic	LT?	1	C	Ac
Magnetic	BT?	40	C	Ac
Electric	VQ?	0.1	C	Ac
Electric	LQ?	1	C	Ac
Electric	BQ?	40	C	Ac

Table 3.4: Typical MT data streams acquired at SAO and PKD, with channel name, sampling rate, sampling mode, and FIR filter type. C indicates continuous; T triggered; Ac acausal.

up the software necessary to exchange data with USArray and made modifications to the dataloggers to change the BH sampling rate from 20 Hz to 40 Hz. In this third year of USArray, the BDSN has continued to use the 40 Hz sampling rate for the BH channels.

During the station installation phase for northern and central California, the BSL collaborated with USArray to identify and permit sites that might be suitable as BDSN stations, several at UC reserves and field stations. The stations currently operating at Sutter Buttes, Hat Creek Radio Observatory, Eagle Lake Biological Field Station, Kirkwood Ski Area, Ben Lomond Conservation Camp, and at the summer home of a BSL staff member (M. Hellweg) in the Sierra Nevada foothills were established with support from BSL staff. Data from these sites (Figure 3.2) are being sent directly to the BSL as well as to the Array Network Facility. In addition, the BSL is monitoring data from several other USArray stations to evaluate their performance as possible future BDSN stations when USArray moves on across the country. In particular, noise comparisons are being conducted in different frequency bands for all BDSN and USArray stations in northern California (see Section 3.7. for further details).

Station Upgrades, Maintenance and Repairs

Given the remoteness of the off-campus stations, BDSN data acquisition equipment and systems are designed, configured, and installed so that they are both cost effective and reliable. As a result, the need for regular station visits has been reduced. In 2006-2007 the focus of BSL's technical efforts went toward maintaining and repairing existing instrumentation, stations and infrastructure that was put in place during the early and mid 1990's . While expanding the data acquisition network remains one of the long term goals of BSL, it is equally important to assure integrity of the established network and preserve data quality.

The broadband seismometers installed by BSL are of the first generation and are now approaching 25 years in age. Concurrently, the first generation of broadband dataloggers are now 17 years old. Computer systems are retired long before this age, yet the electronics that form these data acquisition systems are expected to perform without interruption.

SUTB: During 2006-2007, the BSL has received support from the TA for operating permanent stations in northern California. The BSL has provided telemetry for this TA site for the past year and a half. Data are delivered to the BSL datacenter via a radio telemetry link to the BSL station ORV. Beyond the initial setup and deployment, this has involved maintaining the radio telemetry between the seismic site and the radio repeater - a distance of several kilometers. The radios inexplicably lost their connections and control programming several times during the past year. In each instance, they could be reinitialized remotely from Berkeley, and telemetry resumed. Some of this year's support was used for equipment maintenance and to correct telemetry problems. BSL engineers visited both the radio installation and the seismic vault at the TA site, Sutter Buttes (SUTB), many times to maintain and troubleshoot network connectivity.

KCC: At station KCC (Kaiser Creek California) BSL engineers removed the STS-1 seismometers during 2006-2007 and installed an STS-2, and instrument consistent with the specifications of the TA. This provided the opportunity to use the three STS-1 components from Berkeley in the STS-1 electronics upgrade program (REF). During this testing, one of the STS-1 sensors was found to have reduced sensitivity. The instrument was repaired and is scheduled to be reinstalled before the winter of 2007, when the STS-2 is removed.

WENL: The BSL station WENL began operating in 1997. The equipment is installed in a high humidity adit used for storing and aging wine. BSL engineers replaced cables and the STS-2 seismometer this year after a reduction in the instrument's sensitivity (signal levels) was observed. Since WENL was installed, growth and development at the winery caused increases in the background noise levels over the past several years. A search for a suitable replacement site has begun.

HOPS: The BDSN station at Hopland, California, has been operating since October, 1994. The station is located approximately 100 miles northwest of Berkeley. During the current year, BSL engineers visited the station seven times to remove, repair, and replace seismometers and the geodetic GPS (BARD) receiver.

Actual repair of instruments in the field is difficult due to the nature of the sites, lack of test equipment, poor lighting, etc. In most cases, BSL engineers will remove failed equipment and replace it with a working spare in a single trip. The objective is to minimize the station down time. In the case of HOPS, which is close to the BSL, we elected to remove the equipment, return it to the Berkeley lab, repair it, and in at least one case, replace it the following day.

At HOPS, all three components of the STS-1 seismometers were found to have degraded sensitivity. Experience with the site, where similar problems have occurred in the past, led to the suspicion that the insulation on the connectors on the seismometer electronics had broken down. The connectors were replaced.

Later in the year, the prototype of the new STS-1 electronics (MetroZet) was installed at HOPS. As described elsewhere in this report, these electronics have the advantage of swept sign and step calibration functions over the network connection. The field operation of these electronics is currently being evaluated at HOPS.

SAO: At SAO, BSL engineers began rebuilding the seismometer vault in late summer of 2006. The area in front of the vault was excavated and re-graded to improve drainage. A new concrete entrance was poured, and most importantly, a welded steel security door was added. The wooden door it replaced had been broken into on a number of occasions during the past ten years. A second steel door was hung on the outside to create a secure atrium and thermal buffer for the vault. As envisioned, future seismic instruments could be added in this atrium. Backfilling the entrance, final re-grading and cleanup of the site will be completed before the winter of 2007. SAO was built in 1966 and upgraded to first generation Quanterra broadband recording in early 1992.

MCCM: Two site visits were required to MCCM during the 2006-2007 year. During the first of these, a failed 12 vdc power supply was replaced. Later in the year, VSAT telemetry was restored during the second visit. A present, BSL engineers have developed a plan to improve continuous telemetry using digital radio link. Permits have been acquired for the installation of the necessary radios, repeater radios and infrastructure.

YBH: Station YBH was visited three times in the past year. Power at YBH is supplied by the local utility company. In this heavily forested area, it is BSL's obligation to keep the path to the power meter clear of fallen trees. One trip was necessary to remove fallen trees. In a later trip, BSL engineers replaced a failed data acquisition subsystem belonging to the CTBTO. The third trip was also necessary to resolve CTBTO telemetry issues. BSL's YBH station has been providing data to the CTBTO since 2002.

HUMO: BSL engineers visited the station at HUMO once during 2006-2007. This visit was necessary to repair and replace the power supply for the VSAT equipment. HUMO is the BDSN station furthest from Berkeley.

OXMT: The OXMT site has been providing borehole seismic and strain data, as well as geodetic GPS data, since February of 2004. This is a mountaintop site within 6 kilometers of the coast. During the past year, BSL engineers replaced a DC power supply which appeared to have failed due to weather-related problems.

SBRN: The site SBRN is a companion to OXMT and also provides borehole seismic and strain data, as well as geodetic GPS data. The site is within 100 meters of an elementary school. During the past year, the GPS monument and cover were vandalized and subsequently replaced by BSL engineers.

RFSB: BSL engineers made four trips to the Richmond Field Station (RFSB) during the past year. In two instances, the telemetry ports from the data logger were found not to be working, presumably as a result of a power surge or a nearby lightning strike. The other two trips were necessary to investigate and troubleshoot low signal levels on the surface accelerometer. Corroded connectors were found and replaced in each case. The RFSB site is within one kilometer of the San Francisco Bay.

MONB: The MONB site lies on an east/west ridge north of San Jose, California. BSL operates a geodetic GPS and telemetry equipment there. In 2006-2007, BSL engineers installed radio equipment to consolidate data from future sites in the valley below. We expect to add at least one GPS site with data telemetry through MONB in the next year.

SCCB: During October of 2006, BSL engineers replaced the strong motion accelerometer at SCCB. The previous instrument (Kinemetrics FBA-ESP) was rendered unusable when the instrument enclosure was flooded during seasonal rain. A MetroZet accelerometer was installed in its place.

ORV: BSL engineers visited the station at ORV during the past year to replace the back up batteries. The replaced batteries were 15 years old and at end of their manufacturers specified lifetime.

BRIB: In March of 2007, BSL engineers installed a fiber optic local loop (between the telephone company demarcation and the instrument vault) at BRIB. The fiber optic data connections provide the advantage of electrical isolation from the telephone system, while concurrently allowing greater telemetry speeds and additional telemetry paths. This work was undertaken in part to support the Stanford/USGS electro-magnetic and magnetic monitoring equipment which was installed at BRIB during the past year. The Stanford/USGS instruments telemeter data to the BSL data center for archival.

BDM: The Quanterra data logger at Black Diamond Mine (BDM) froze several times during the past year and remained unresponsive. In each case, however, the data logger was rebooted remotely from Berkeley and did not require a site visit. At this time, BSL is permitting with the East Bay Regional Parks to add a geodetic GPS to the other instruments on site. As planned, the monument would be located within 100 meters of the seismometers.

The Monterey Bay Ocean Bottom Seismic Observatory (MOBB)

The Monterey Ocean Bottom Broadband observatory (MOBB) is a collaborative project between the Monterey Bay Aquarium Research Institute (MBARI) and the BSL. Supported by funds from the Packard Foundation to MBARI, NSF/OCE funds and UC Berkeley funds to BSL, its goal has been to install and operate a long-term seafloor broadband station as a first step towards extending the on-shore broadband seismic network in northern California to the seaside of the North-America/Pacific plate boundary, providing better azimuthal coverage for regional earthquake and structure studies. It also serves the important goal of evaluating background noise in near-shore buried ocean floor seismic systems, such as may be installed as part of temporary deployments of "leap-frogging" arrays (e.g. Ocean Mantle Dynamics Workshop, September 2002).

BSL staff put significant effort in the development of procedures to minimize instrumental noise caused by air circulation inside the seismometer package casing (see 2001-2002 and 2002-2003 BSL Annual Reports). These procedures were later applied to the preparation of 3 similar packages destined for installation on the Juan de Fuca plate in the framework of University of Washington's Keck project.

This project follows the 1997 MOISE experiment, in which a three component broadband system was deployed for a period of 3 months, 40 km off shore in Monterey Bay, with the help of MBARI's "Point Lobos" ship and ROV "Ventana" (Figure 3.6). MOISE was a cooperative program sponsored by MBARI, UC Berkeley and the INSU, Paris, France (*Stakes et al.*, 1998; *Romanowicz et al.*, 1999; *Stutzmann et al.*, 2001). During the MOISE experiment, valuable experience was gained on the technological aspects of such deployments, which contributed to the success of the present MOBB installation.

The successful MOBB deployment took place April 9-11, 2002 and the station is currently recording data autonomously (e.g. *Romanowicz et al.*, 2003). It comprises a 3 component very broadband CMG-1T seismometer system, a diffential pressure gauge (DPG, *Cox et al.*, 1984) and a current meter. Data from the DPG are acquired with a sampling rate of 1 sps, and are crucial for the development and implementation of a posteriori noise deconvolution procedures to help counteract the large contribution of infragravity wave noise in the period range 20-200 sec. Procedures for removal of ingravity wave noise as well as signal generated noise have been developed.

Twenty "dives" involving the MBARI ship "Point Lobos" and ROV "Ventana" have so far taken place to exchange dataloggers and battery packages during the time period 04/10/02 to 06/30/07. In February 2004, the N/S component seismometer failed. It was temporarily replaced, from 05/19/04 to 07/09/04, by one of the Keck seismometer packages which was conveniently available at that time. The original seismometer was sent back to Guralp Systems Ltd. for repair and successfully reinstalled on 07/09/04.

The data collection from the broadband seismic system is fairly complete. However, there have been recurring DPG sensor as well as DPG data storage problems in the first two years of the MOBB operation. Well recorded DPG data are available since 03/18/2004.

The MOBB station is located close to the path of the MARS cable (Figure 3.6) which was deployed in the Spring of 2007. The connection of MOBB to the MARS cable will allow continuous, real-time data acquisition from this site. Developing the interface for the connection to MARS is the object of a recently funded NSF project. Work on this project commenced in the summer of 2007.

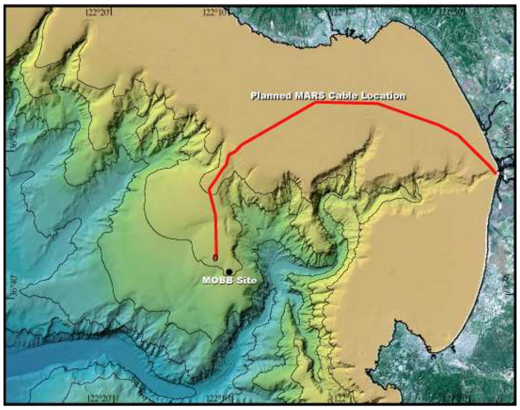

Figure 3.6: Location of the MOBB station in Monterey Bay, California, against seafloor and land topography. The path of the MARS cable is indicated by the solid line.

3.1.4 Acknowledgements

Under Barbara Romanowicz's general supervision, Peggy Hellweg and Doug Neuhauser oversee the BDSN data acquisition operations, and Bill Karavas heads the engineering team. John Friday, Jarrett Gardner, Rick Lellinger and Bob Uhrhammer contribute to the operation of the BDSN. Karl Kappler has been responsible for the operation of the EM observatories. Bill Karavas, Bob Uhrhammer, and Peggy Hellweg contributed to the preparation of this chapter.

The California Governor's Office of Emergency Services provided funding toward the development of sites MCCM and GASB as part of the CISN. The Incorporated Research Institutions in Seismology provided matching funds for the installation of MCCM. The CREST project provided a datalogger for GASB. Earthscope (USArray) provided funds towards telemetry of northern California TA stations through BSL and operation of joint BDSN/USArray stations.

MOBB is a collaboration between the BSL and MBARI, involving Barbara Romanowicz, Bob Uhrhammer, Doug Neuhauser and David Dolenc from the BSL, and Debra Stakes and Paul McGill from MBARI. The MBARI team also includes Steve Etchemendy (Director of Marine Operations), Jon Erickson, John Ferreira, Tony Ramirez and Craig Dawe. The MOBB effort at the BSL is supported by UC Berkeley funds. MBARI supports the dives and data recovery. The MOBB seismometer package was funded by NSF/OCE grant #9911392.

The Earthscope Transportable Array provides support for telemetry and maintenance of the 19 BDSN stations from which the BSL supplies data to the USArray efforts.

3.1.5 References

Cox, C., T. Deaton and S. Webb, A deep-sea differential pressure gauge, *J. Atm. Ocean. Tech., 1*, 237-245, 1984.

Crawford W. C., and S. C. Webb, Identifying and removing tilt noise from low- frequency (<0.1 Hz) seafloor vertical seismic data, *Bull. Seis. Soc. Am., 90*, 952-963, 2000.

Murdock, J., and C. Hutt, A new event detector designed for the Seismic Research Observatories, *USGS Open-File-Report 83-0785,* 39 pp., 1983.

Romanowicz, B., D. Stakes, J. P. Montagner, P. Tarits, R. Uhrhammer. M. Begnaud, E. Stutzmann, M. Pasyanos, J.F. Karczewski, S. Etchemendy, MOISE: A pilot experiment towards long term sea-floor geophysical observatories, *Earth Planets Space, 50,* 927-937, 1999.

Romanowicz, B., D. Stakes, R. Uhrhammer, P. McGill, D. Neuhauser, T. Ramirez and D. Dolenc, The MOBB experiment: a prototype permanent off-shore ocean bottom broadband station, *EOS Trans. AGU*, Aug 28 issue, 2003.

Stakes, D., B. Romanowicz, J.P. Montagner, P. Tarits, J.F. Karczewski, S. Etchemendy, D. Neuhauser, P. McGill, J-C. Koenig, J.Savary, M. Begnaud and M. Pasyanos, MOISE: Monterey Bay Ocean Bottom International Seismic Experiment, *EOS Trans. AGU, 79*, 301-309, 1998.

Stutzmann, E., J.P. Montagner et al., MOISE: a prototype multiparameter ocean-bottom station, *Bull. Seism. Soc. Am., 81*, 885-902, 2001.

Wielandt, E., and J. Steim, A digital very broad band seismograph, *Ann. Geophys., 4*, 227-232, 1986.

Wielandt, E., and G. Streckeisen, The leaf spring seismometer: design and performance, *Bull. Seis. Soc. Am., 72*, 2349-2367, 1982.

Zürn, W., and R. Widmer, On noise reduction in vertical seismic records below 2 mHz using local barometric pressure, *Geophys. Res. Lett., 22*, 3537-3540, 1995.

3.2. California Integrated Seismic Network

3.2.1 Introduction

Advances in technology have made it possible to integrate separate earthquake monitoring networks into a single seismic system as well as to unify earthquake monitoring instrumentation. In California, this effort began in the south with the TriNet Project. There Caltech, the California Geological Survey (CGS), and the USGS combined efforts to create a unified seismic system for southern California. With major funding provided by the Federal Emergency Management Agency (FEMA), the California Governor's Office of Emergency Services (OES), and the USGS, the TriNet project provided the opportunity to upgrade and expand the monitoring infrastructure, combining resources in a federal, state and university partnership. In 2000, the integration effort expanded to the entire State with the formation of the California Integrated Seismic Network (CISN, see 2000-2001 Annual Report). To this end, UC Berkeley and the USGS Menlo Park and Pasadena offices joined forces with Caltech and the CGS. The CISN is now in the seventh year of collaboration and its sixth year of funding from the OES.

3.2.2 CISN Background

Organization

The organizational goals, products, management, and responsibilities of the CISN member organizations are described in the founding MOU and in the strategic and implementation plans. To facilitate activities among institutions, the CISN has formed three management centers:

- Southern California Management Center: Caltech/USGS Pasadena
- Northern California Earthquake Management Center: UC Berkeley/USGS Menlo Park
- Engineering Strong Motion Data Center: California Geological Survey/USGS National Strong Motion Program

The Northern and Southern California Management Centers are operating as twin statewide earthquake processing centers serving information on current earthquake activities, while the Engineering Strong Motion Data Center has the responsibility for producing engineering data products and distributing them to the engineering community.

The Steering Committee, made up of two representatives from each core institution and a representative from OES, oversees CISN projects. The position of chair rotates among the institutions; Jeroen Tromp is currently the chair of the Steering Committee.

An external Advisory Committee represents the interests of structural engineers, seismologists, emergency managers, industry, government, and utilities and provides review and oversight. The Advisory Committee is chaired by Stu Nishenko of Pacific Gas and Electric Company. It last met in August 2006. Agendas from the meetings and the resulting reports may be accessed through the CISN Web site (`http://www.cisn.org/advisory`). The next meeting is planned for September 2007.

The Steering Committee has formed other committees, including a Program Management Group to address planning and coordination, a Strong Motion Working Group to focus on issues related to strong-motion data, and a Standards Committee to resolve technical design and implementation issues.

In addition to the core members, other organizations contribute data that enhances the capabilities of the CISN. Contributing members of the CISN include: University of California, Santa Barbara; University of California, San Diego; University of Nevada, Reno; University of Washington; California Department of Water Resources; Lawrence Livermore National Lab; and Pacific Gas and Electric.

CISN and ANSS

The USGS Advanced National Seismic System (ANSS) is being developed along a regionalized model. Eight regions have been organized, with the CISN representing California. David Oppenheimer of the USGS represents the CISN on the ANSS National Implementation Committee (NIC).

Over the past 8 years, ANSS funding in California has been directed primarily to the USGS Menlo Park to expand the strong-motion instrumentation in the San Francisco Bay Area. As a result, more than 100 sites have been installed or upgraded, significantly improving the data available for ShakeMaps.

As the ANSS moves forward, committees and working groups are being established to address issues of interest. BSL faculty and staff have been involved in several working groups of the Technical Integration Committee, including Doug Dreger, Pete Lombard, Doug Neuhauser, Bob Uhrhammer, and Stephane Zuzlewski.

CISN and OES

The California Governor's Office of Emergency Services has had a long-term interest in coordinated earthquake monitoring. The historical separation between northern and southern California and between strong-motion and weak-motion networks resulted in a complicated situation for earthquake response. Thus, OES has been an advocate of increased coordination and collaboration in California earthquake monitoring and encouraged the development of the CISN. In FY01/02, Governor Gray Davis requested support for the CISN, to be administered through OES. Funding for the California Geological Survey, Caltech and UC Berkeley was made available in spring 2002, officially launching the statewide coordination efforts. Following the first year of funding, OES support led to the establishment of 3-year contracts to the UC Berkeley, Caltech, and the California Geological Survey for CISN activities. The first multi-year award covered activities in 2002-2005. The second year of the three-year contract for 2006-2008 has just been completed. Past CISN-related activities are described in previous annual reports.

3.2.3 2006-2007 Activities

The CISN funding from has OES supported a number of activities at the BSL during the past year.

Collaboration with USArray

In late 2003, the CISN concluded a memorandum of agreement with the Incorporated Research Institutions in Seismology (IRIS) covering the duration of the USArray project in California. As a result, data from 19 stations operated by the BSL and 41 stations operated by Caltech are contributed to USArray's travelling array (TA) during its California deployment. The BSL has also provided accelerometers for use at TA sites which are of interest as future BDSN stations. We monitor the data from these stations in real time, and use the data in ShakeMaps and moment tensors. In addition, data from these TA stations have been included in our development of new parameters that are valid statewide for determining M_L (see Research Study 2.13.). The collaboration between the BSL and USArray is discussed more fully in Sections 3.1. and 3.7., including the telemetry the BSL provides for the two USArray stations RAMR and SUTB. The TA will move out of California during the Fall of 2007.

FEMA Hazard Grant Mitigation Program Funds

The San Simeon and Parkfield earthquakes highlighted the sparseness of high quality instrumentation in northern California, outside of the Bay Area. Although the Parkfield event occurred in a very densely instrumented region, many of accelerometers operated there by the CGS are primarily analog, and the data were not available until several days after the event. Thus, in both these Central California events, the initial ShakeMaps were poorly constrained, because there were few digital instruments in the area with real-time communications.

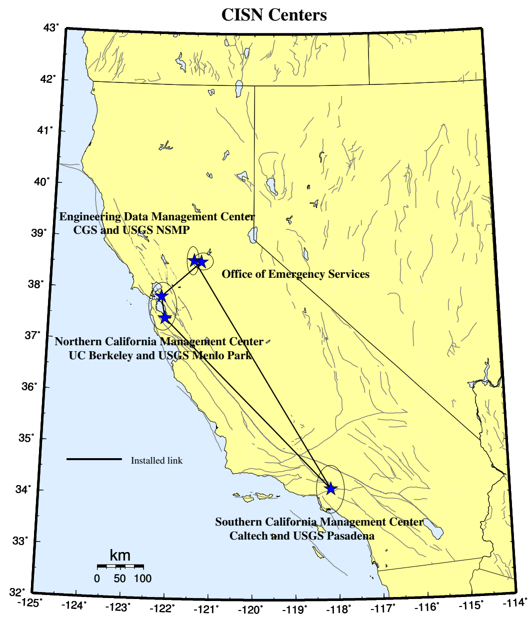

Figure 3.7: Map showing the geographical distribution of the CISN partners and centers. The communications "ring" is shown schematically with installed links (solid lines).

As a result of the San Simeon earthquake and other disasters, FEMA made funds available to OES under the Hazard Grant Mitigation Program (HGMP). The BSL, Caltech, and CGS submitted joint applications for funds to two of these programs, which were funded in August 2005 and May 2006. With funds from these two projects, seismic equipment has been purchased for four new stations, which will be chosen from the USArray TA stations currently deployed in California. One set was installed at the USArray station RAMR near the epicenter of the San Simeon event in September 2007 after the removal of the TA equipment. We monitor and use data from other TA stations in routine processing, and expect to take over HAST, just north of the San Simeon epicenter, and P01C, along the Northern California coast. The fourth site for FEMA equipment remains to be chosen.

Northern California Earthquake Management Center

As part of their effort within the CISN, the BSL and the USGS Menlo Park are implementing the new generation of the northern California joint notification system. Section 3.8. describes the operations of the existing Management Center and reports on the design and implementation progress.

In order to move ahead with plans for restructuring the northern California earthquake monitoring system, the USGS Menlo Park and BSL have been improving their

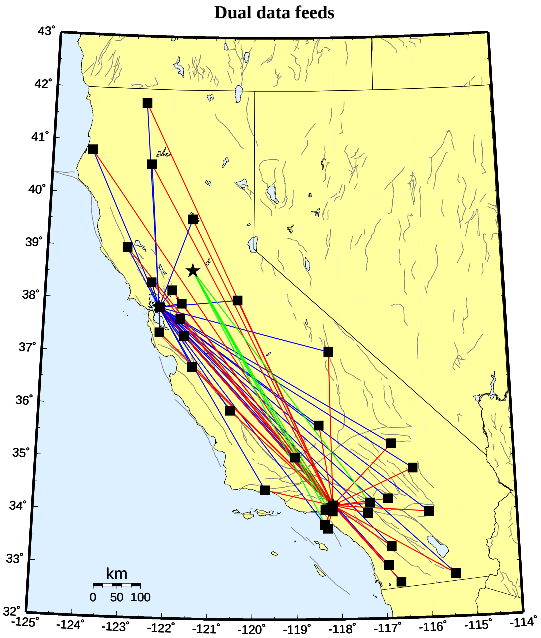

Figure 3.8: Map showing the 30 stations selected to send data directly to the Northern and Southern California processing centers, and the 5 stations that send data directly to the Engineering Data Center and the Southern California processing center.

communications infrastructure. At present, the BSL and the USGS Menlo Park are connected by two dedicated T1 circuits. One circuit is a component of the CISN ring, while the second circuit was installed in 2004-2005 (Figure 3.9) to support dedicated traffic between Berkeley and Menlo Park above and beyond that associated with the CISN.

The installation of the second dedicated T1 between Berkeley and Menlo Park freed up a frame-relay connection deployed by the BSL as part of the CalREN project in mid-1990s. The BSL has reconfigured this frame-relay circuit to serve as a second data acquisition link. BDSN data acquisition is now distributed between two frame-relay T1 circuits, eliminating what had been a single point of failure. An additional Permanent Virtual Circuit (PVC) has also been implemented at each BDSN site so that each station has connections to both T1s. This has improved the robustness of data acquisition at the BSL by providing redundancy in the incoming circuit.

In the long term, the BSL and USGS Menlo Park hope to be connected by high-bandwidth microwave or satellite service. Unfortunately, we have not yet been able to obtain funding for such an additional communication link.

3.2.4 Statewide Integration

BSL staff are involved in many elements of the statewide integration effort. The Standards Committee, chaired by Doug Neuhauser, continues to define and prioritize projects important to the development and implementation of the statewide earthquake processing system and to establish working groups to address them (see minutes from meetings and conference calls at `http://www.cisn.org/standards/meetings.html`).

Dual Station Feeds: Early in the existence of CISN, "dual station feeds" were established for 30 stations (15 in northern California and 15 in southern California) (Figure 3.8). The Northern California Earthquake Management Center (NCEMC) is using data from the Southern California stations to estimate magnitudes on a routine basis. A subset of these stations are being used for the moment tensor inversions, a computation that is sensitive to the background noise level.

Data Exchange: Pick exchange was initiated between the NCEMC and its Southern California counterpart in 2001-2002. The software CISN has developed to produce and exchange the reduced amplitude timeseries has also been completed. Currently, these timeseries are being exchanged at the NCEMC, but not yet statewide. Using a common format, the CISN partners continue to exchange observations of peak ground motion with one another following an event or a trigger. This step increases the robustness of generating products such as ShakeMap, since all CISN partners now exchange data directly with one another. This also improves the quality of ShakeMaps for events on the boundary between northern and southern California, such as the San Simeon earthquake, by allowing all data to be combined in a single map. Finally, this is a necessary step toward the goal of generating statewide ShakeMaps.

The Software Calibration & Standardization: CISN partners are working to standardize the software used for automatic earthquake processing and earthquake review, as well as to calibrate it. Currently, the software implemented in the NCEMC and in Southern California Management Center is very different. During the past year in the NCEMC, we have worked on preparing a version of the Southern California TriNet software software for implementation as CISN Software in the NCEMC.

- Magnitude: Calibrating magnitude estimates has proven to be more difficult than originally anticipated. As described in 2003-2004, evidence indicates that there is a bias between the northern and southern California estimates of local magnitude M_L. Efforts to understand this issue have been hampered by the lack of a good statewide dataset. Bob Uhrhammer has selected data from 180 earthquakes distributed throughout the state and comprising recordings from 976 horizontal components

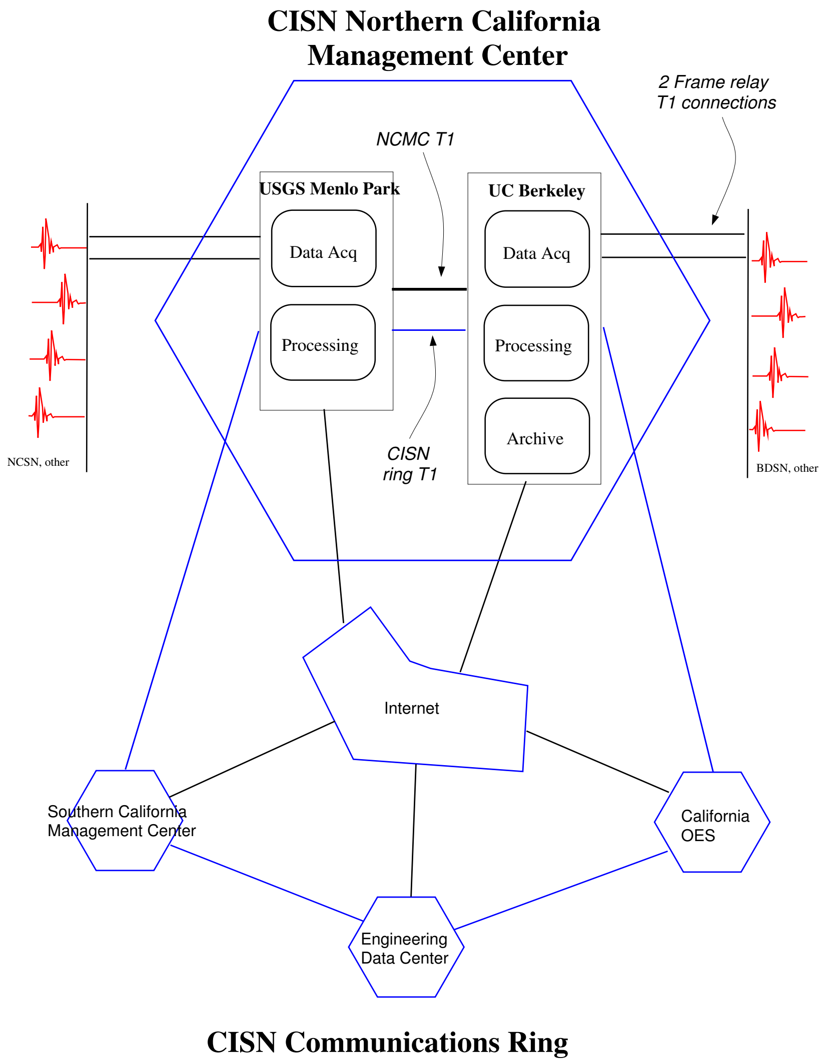

Figure 3.9: Schematic diagram illustrating the connectivity between the real-time processing systems at the USGS Menlo Park and UC Berkeley, forming the northern California Management Center, and with other elements of the CISN.

from the AZ, BK, CI and NC networks (see Research Study 2.13.). In January, we agreed on a $logA_o$ function suitable for statewide use. We are currently determining how to define station-specific corrections for M_L using differences for each station-component that has been recorded for a given event. The primary advantage of using this differencing method is that the results are independent of a reference station. A final component of the magnitude efforts is the determination of a magnitude reporting hierarchy. For the near future, each region will continue to use its own preferences for magnitude reporting.

- ShakeMap: At present, ShakeMaps are generated on 5 systems within the CISN. Two systems in Pasadena generate "SoCal" Shakemaps; 2 systems in the Bay area generate "NoCal" Shakemaps; and 1 system in Sacramento generates ShakeMaps for all of California. The Sacramento system uses QDDS to provide the authoritative event information for northern and southern California.

The dearth of stations in the near source region of the 2003 San Simeon earthquake raised the issues of how to measure the quality of a ShakeMap and how to quantify the uncertainty. A subset of the Working Group has been working on this issue, based on the work of *Hok and Wald* (2003). *Lin et al* (2006) presented progress toward quantifying ShakeMap uncertainty. When the method is validated, we can use this information to determine a grade.

A second goal of this effort was to improve the robustness of ShakeMap generation and delivery by taking advantage of the fact that ShakeMaps are generated in the Bay Area, Pasadena, and Sacramento. Ongoing fforts in this direction will likely be based on the new USGS ShakeMap webpages at the National Earthquake Information Center.

- Location Codes: The CISN adopted a standard for the use of "location" codes (part of the Standard for the Exchange of Earthquake Data (SEED) nomenclature to describe a timeseries based on network-station-channel-location) in the late fall of 2003. USGS and UC Berkeley developers have modified the Earthworm software to support the use of location codes. After the transition at USGS Menlo Park away from the CUSP analysis system to `Jiggle` in late November, 2006, all networks in the CISN implemented location codes in their systems.

- Metadata Exchange: Correct metadata are vital to CISN activities, as they are necessary to insure valid interpretation of data. CISN is working on issues related to their reliable and timely exchange. The CISN Metadata Working Group compiled a list of metadata necessary for data processing and developed a model for their exchange. In this model, each CISN member is responsible for the metadata for its stations and for other stations that enter into CISN processing through it. For example, Menlo Park is responsible for the NSMP, Tremor, and PG&E stations, while Caltech is responsible for the Anza data. At the present time, dataless SEED volumes are used to exchange metadata between the NCEMC and the SCMC. The Metadata Working Group is developing a Station XML format for metadata exchange. This vehicle is expandable, and will probably allow exchange of a more comprehensive set of metadata than dataless SEED volumes, some which may be necessary for other systems, for example in V0 formatted data.

- Standardization: The CISN's focus on standardization of software continues. For example, the BSL and the USGS Menlo Park are adapting the software running at the SCMC for use at the NCEMC and are currently testing its various elements. The adoption of `Jiggle` in northern California in late November 2007, was the first step in the implementation of the new software. Current efforts are directed toward the implementation and testing of the complete system (see Section 3.8.).

CISN Display

CISN Display is an integrated Web enabled earthquake notification system, designed to provide earthquake information for emergency response at 24/7 operations centers. First-responders, organizations with critical lifelines and infrastructure, and emergency responders are invited to register for an account at `http://www.cisn.org/software/cisndisplay.htm`.

The application provides users with maps of real-time seismicity, and automatically provides access to Web-related earthquake products such as ShakeMaps. CISN Display also offers an open source GIS mapping tool that allows users to plot freely available layers of public highways, roads and bridges, as well as private layers of organizational-specific infrastructure and facilities information. The current version of CISN Display is 1.4. Its primary enhancement over the previous version is the development of a kiosk-mode for public display purposes.

Earthquake Information Distribution

The USGS hosted a workshop in October 2004 to develop plans for the installation and use of the EIDS software. Doug Neuhauser and Pete Lombard participated in this workshop, which resulted in a document outlining the steps necessary for the installation and migration of the earthquake notification system from the current Quake Data Distribution Servies (QDDS) to EIDS.

Outreach

Since FY05/06 the CISN Web site (`www.cisn.org`) has been supported by two servers located at Berkeley and Caltech. The Web servers are set up so that the load can be distributed between them, providing improved access during times of high demand. With the increased robustness provided by the new servers, the CISN provides access to certain earthquake products directly from `www.cisn.org`. For example, ShakeMaps are now served directly from the CISN Web site, in addition to being available from several USGS Web servers and the CGS. The design and content of `http://www.cisn.org` continues to evolve. The Web site is an important tool for CISN outreach as well as for communication and documentation among the CISN partners.

The CISN continues to support the dedicated Web site for emergency managers. Following a suggestion from the Advisory Committee, we have designed a Web site to provide personalized access to earthquake information. Known as "myCISN," the Web site is available at `eoc.cisn.org`. Access to the Web site is limited to registered users in order to provide highly reliable access. At present, "myCISN" is a single Web server located at UC Berkeley. However, modifications to the database are underway to allow for multiple servers in the future. A second computer, already purchased, will either be installed in Sacramento or in southern California.

As part of the CISN, the BSL is contributing to efforts to raise awareness of earthquakes and preparedness as the 140 anniversary of the 1868 Hayward Fault earthquake approaches on October 21, 2008. In particular, we will be co-hosting the *Third Conference on Earthquake Hazards in the Eastern Bay Area* as well as organizing and participating in other related activities.

3.2.5 Acknowledgements

CISN activities at the BSL are supported by funding from the Governor's Office of Emergency Services.

Barbara Romanowicz and Peggy Hellweg are members of the CISN Steering Committee. Peggy Hellweg is a member of the CISN Program Management Group, and she leads the CISN project at the BSL with support from Doug Neuhauser. Doug Neuhauser is chair of the CISN Standards Committee, which includes Peggy Hellweg, Pete Lombard and Stephane Zuzulevski as members.

Because of the breadth of the CISN project, many BSL staff have been involved including: John Friday, Jarrett Gardner, Peggy Hellweg, Bill Karavas, Alexei Kireev, Rick Lellinger Pete Lombard, Doug Neuhauser, Charley Paffenbarger, Bob Uhrhammer and Stephane Zuzlewski. Peggy Hellweg contributed to this chapter. Additional information about the CISN is available through reports from the Program Management Committee.

3.2.6 References

Hok, S., and D. J. Wald, Spatial Variability of Peak Strong Ground Motions: Implications for ShakeMap Interpolations, *EOS. Trans. AGU, 84(46)*, F1121, 2003.

Lin, K-W., D. Wald, B. Worden and A.F. Shakal, Progress toward quantifying CISN ShakeMap uncertainty, *Eighth National Conference on Earthquake Engineering, San Francisco, California, April 18-21, 2006.*

3.3. Northern Hayward Fault Network

3.3.1 Introduction

Complementary to the regional broadband network, the Hayward Fault Network (HFN) (Figure 3.10 and Table 3.5) is a deployment of borehole-installed, wide-dynamic range seismographic stations along the Hayward Fault and throughout the San Francisco Bay toll bridges network. Development of the HFN initiated through a cooperative effort between the BSL and the USGS, with support from the USGS, Caltrans, EPRI, the University of California Campus/Laboratory Collaboration (CLC) program, LLNL, and LBNL. The project's objectives included both an initial characterization period followed by longer-term monitoring effort using a backbone of stations from among the initial characterization set. Subsequent funding from Caltrans, however, has allowed for continued expansion of the backbone station set for additional coverage in critical locations.

The HFN consists of two components. The Northern Hayward Fault Network (NHFN) is operated by the BSL and currently consists of 28 stations with various operational status. These include stations located on Bay Area bridges and now at borehole sites of the Mini-PBO (MPBO) project, which were installed with support from NSF and the member institutions of the MPBO project. The NHFN is considered part of the BDSN and uses the network code BK. The Southern Hayward Fault Network (SHFN) is operated by the USGS and currently consists of 5 stations. This network is considered part of the NCSN and uses the network code NC. The purpose of the HFN is threefold: 1) to increase substantially the sensitivity of seismic data to low amplitude seismic signals, 2) to increase the recorded bandwidth for seismic events along the Hayward fault, and 3) to obtain bedrock ground motion signals at the bridges from more frequent smaller earthquakes.

Data with these attributes contribute significantly to a variety of scientific objectives including: a) the investigation of bridge responses to stronger ground motions from real earthquakes, b) obtaining a significantly lower detection threshold for microearthquakes and nonvolcanic tremor signals, c) increasing the resolution of the fault-zone seismic structure (e.g., in the vicinity of the Rodgers Creek/Hayward Fault step over), d) improving monitoring of spatial and temporal evolution of seismicity (to magnitudes approaching $M \sim> -1.0$) that may signal behavior indicative of the nucleation of large damaging earthquakes, e) the investigation of earthquake scaling, physics and related fault processes, f) improving working models for the Hayward fault, and g) using these models to make source-specific response calculations for estimating strong ground shaking throughout the Bay Area.

This chapter is primarily focused on the NHFN and activities associated with the BSL operations.

3.3.2 NHFN Overview

The initial characterization period ended in 1997. During that period, the NHFN sensors provided signals to on-site, stand-alone Quanterra Q730 and RefTek 72A-07 dataloggers, and manual retrieval and download of data tapes was required. Also in that year, the long-term monitoring phase of the project began, involving the installation of 24-bit data acquisition and communication platforms and data telemetery to the BSL archives for a backbone of the initial NHFN stations.

Over the years, CalTrans has provided additional support for the upgrade of two non-backbone sites to backbone operational status and for the addition of several new sites to the monitoring back-bone. These expansion efforts are ongoing. Also since the transition to the long-term monitoring phase, the 5 stations of the MPBO project have been folded into the NHFN.

Of the 28 stations now considered part of the NHFN history, 14 of the stations are currently operational, with telemetered data streams flowing continuously into the BSL's BDSN processing stream with subsquent archival in the Northern California Earthquake Data Center (NCEDC) archive. These include the 5 MPBO sites. Nine of the original 28 are non-backbone stations that have not been upgraded to continuous telemtry. Though collection of data from these sites has been discontinued, their borehole sensor packages are still in place (having been grouted in), and efforts to find funding for upgrade of these sites with Quanterra Q4120, Q730 or Q330 dataloggers and continuous telemetry continues. The remaining 5 sites are in the process of being added to the NHFN backbone. Four of the sites have been drilled and instrumented and are awaiting installation of their electronics and infrastructures. Equipment has been purchased for the 1 remaining site, which is awaiting final land-use agreement from the Regional Parks district and drilling by CalTrans.

Installation/Instrumentation: The NHFN Sensor packages are generally installed at depths ranging between 100 and 200 m, the non-backbone non-operational Dumbarton bridge sites being exceptions with sensors at multiple depths (Table 3.5).

The five former MPBO sites that are now part of the NHFN have 3-component borehole geophone packages. Velocity measurements for the MPBO sites are provided by Mark Products L-22 2 Hz geophones (Table 3.6). All the remaining backbone and non-backbone NHFN sites have six-component borehole sensor pack-

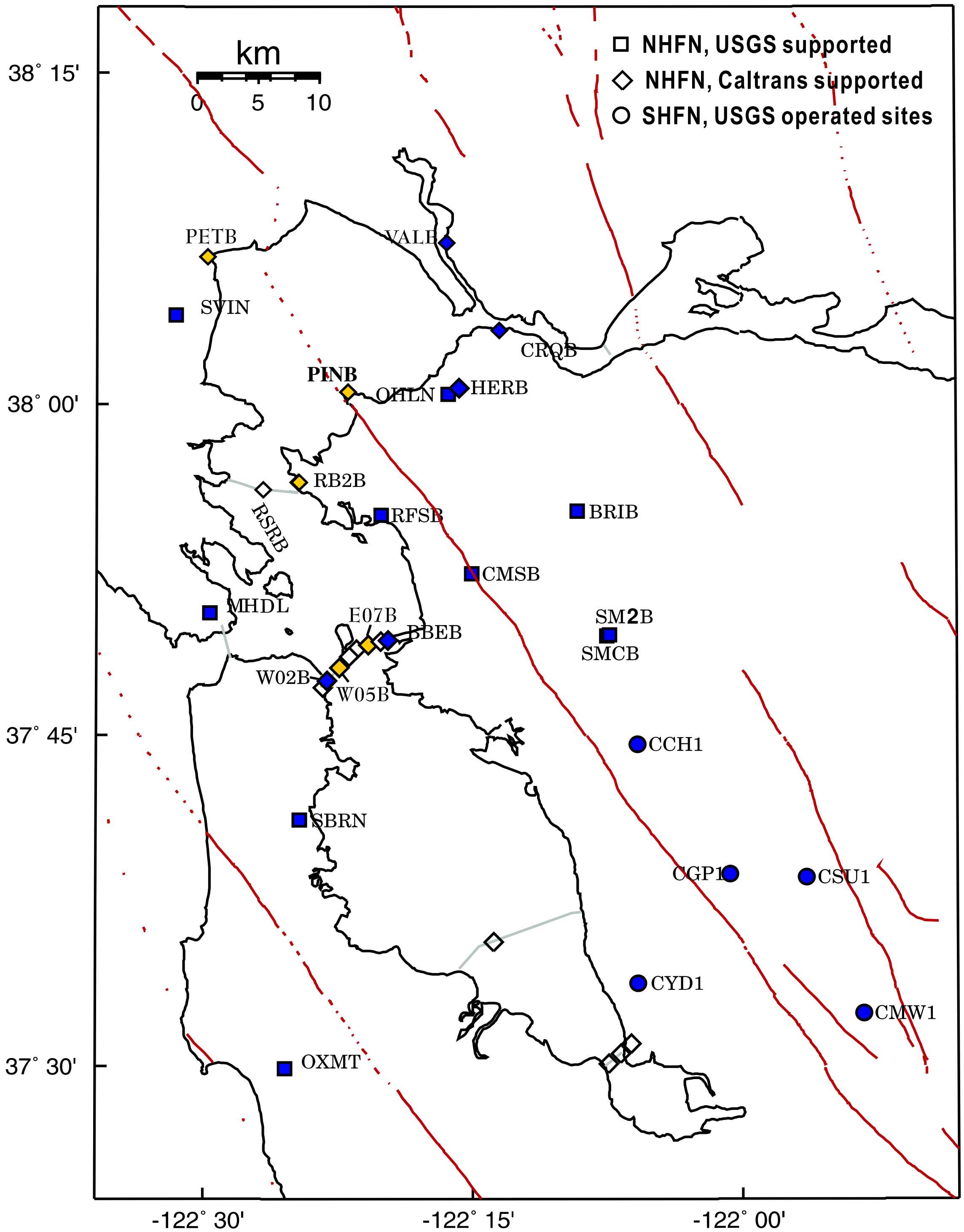

Figure 3.10: Map showing the locations of the HFN stations operated by the BSL (NHFN - squares and diamonds) and the USGS (SHFN - circles). Operational sites are filled blue/black, while sites in progress are yellow/grey. Other instrumented but currently non-operational boreholes are indicated as open symbols.

ages. The six-component packages were designed and fabricated at LBNL's Geophysical Measurement Facility and have three channels of acceleration, provided by Wilcoxon 731A piezoelectric accelerometers, and three channels of velocity, provided by Oyo HS-1 4.5 Hz geophones.

The 0.1-400 Hz Wilcoxon accelerometers have lower self-noise than the geophones above about 25-30 Hz, and remain on scale and linear to 0.5 g. In tests performed in the Byerly vault at UC Berkeley, the Wilcoxon is considerably quieter than the FBA-23 at all periods, and is almost as quiet as the STS-2 between 1 and 50 Hz.

All 14 NHFN backbone sites have Quanterra dataloggers with continuous telemetry to the BSL. Signals from these stations are digitized at a variety of data rates up to 500 Hz at 24-bit resolution (Table 3.7). The dataloggers employ causal FIR filters at high data rates and acausal FIR filters at lower data rates.

Data Rates and Channels: Because of limitations in telemetry bandwidth and disk storage, 8 of the 9 (excluding VALB) six-component NHFN stations transmit one channel of geophone data continuously (i.e., their vertical geophone channels) and an additional 3 channels of triggered data in 90 sec. snippets. A Murdock, Hutt, and Halbert (MHH) event detection algorithm (*Murdock and Hutt*, 1983) is operated independently at each station on 500 sps data for trigger determinations. Because of they are quieter, the 3 triggered channels are taken from the Wilcoxon accelerometers when possible. However, there is a tendency for these powered sensors to fail and in such cases, geophone channels are substituted for the failed accelerometers. Station VALB also transmits data from only 4 channels; however, all channels are transmited continuously. Continuous data for all channels at reduced rates (20 and 1 sps) are also transmitted to and archived at the BSL. The five MPBO sites transmit their 3-component continuous geophone data streams at 100, 20 and 1 sps, which are also archived at BSL.

Station Maintenance

Ongoing network maintenance involves regular inspection of the collected seismic waveform data and spectra for nearby seismic events, and also from noise samples. Other common problems include changes to background noise levels due to ground loops and failing preamps, as well as power and telemetry issues. Troubleshooting and remediation of problems often require a coordinated effort, with a technician at the BSL to examine seismic waveforms and spectra while the field technicians are still on site. BSL technicians and researchers regularly review data and assist in troubleshooting.

The NHFN station hardware has proven to be relatively reliable. Nonetheless, numerous maintenance and performance enhancement measures are still carried out. In particular, when a new station is added to the backbone, extensive testing and correction for sources of instrumental noise (e.g., grounding related issues) and telemetry through-put are carried out to optimize the sensitivity of the station. Examples of maintenance and enhancement measures that are typically performed include: 1) tests on radio links to ascertain reasons for unusually large numbers of dropped packets, 2) trouble shooting sporadic problems with numerous frame relay telemetry dropouts, 3) manual power recycle and testing of hung Quanterra data loggers, 4) replacement of blown fuses or other problems relating to dead channels identified through remote monitoring at the BSL, 5) repair of frame relay and power supply problems when they arise, and 6) correctingtenna problems that arise due to various causes,such as weather or cultural activity.

Quality Control

- PSD and Real Event Displays: Our commonly used quality checks on the performance of the borehole installed network include assessments of the power spectral density (PSD) distributions for background noise and quick checks following large teleseismic and moderate local earthquakes of the data records across the NHFN stations. Shown in Figure 3.11 is such a display for NHFN geophone channels from a recent Bay Area earthquake (20 July 2007, M4.2 Piedmont, CA). It is immediately apparent from this simple display that station MHDL was dead and needed immediate attention.

  It is also apparent from the buzz underlying the earthquake signal in this display that the grounding schemes for stations SBRN and HERB may be in need of modification. One of the most pervasive problems at NHFN stations is power line noise (60 Hz and its harmonics at 120, 180, and 240 Hz). This noise reduces the sensitivity of the MHH detectors, and at any given station this type of noise source changes over periods of weeks to months, requiring continued vigilance and adaptability of the grounding scheme in order to maintain the desired high sensitivity to low amplitude seismic signals.

- Geophone Calibration Tests: Comparisons of the inferred ground accelerations generated by local earthquakes from co-sited NHFN geophone and accelerometer pairs show that the waveforms generally are quite coherent in frequency and phase response, but that their inferred ground accelerations differ significantly. At times, the amplitudes differ by up to a factor of 2 while the times of the peak amplitudes are identical. This implies that the free period and damping of the geophones are well characterized. However, it also indicates that the generator constant is not accurate (assuming that the

Code	Net	Latitude	Longitude	Elev (m)	Over (m)	Date	Location
VALB	BK	38.1215	-122.2753	-24	155.8	2005/11 - current	Napa River Bridge
PETB	BK	38.1189	-122.5011	-30	113	in progress	Petaluma River Bridge
CRQB	BK	38.05578	-122.22487	-25	38.4	1996/07 - current	CB
HERB	BK	38.01250	-122.26222	-25	217.9	2000/05 - current	Hercules
PINB*	BK	38.0113	-122.3653	tbd	tbd	in progress	Point Pinole
BRIB	BK	37.91886	-122.15179	219.7	108.8	1995/06 - current	BR, Orinda
RFSB	BK	37.91608	-122.33610	-27.3	91.4	1996/01 - current	RFS, Richmond
CMSB	BK	37.87195	-122.25168	94.7	167.6	1994/12 - current	CMS, Berkeley
SMCB	BK	37.83881	-122.11159	180.9	3.4	1997/12 - 2007/06	SMC, Moraga
SM2B	BK	37.8387	-122.1102	200	150.9	2007/06 - current	SMC, Moraga
SVIN	BK	38.03325	-122.52638	-21	158.7	2003/08 - current	MPBO, St. Vincent's school
OHLN	BK	38.00742	-122.27371	-0	196.7	2001/07 - current	MPBO, Ohlone Park
MHDL	BK	37.84227	-122.49374	94	160.6	2006/05 - current	MPBO, Marin Headlands
SBRN	BK	37.68562	-122.41127	4	157.5	2001/08 - current	MPBO, San Bruno Mtn.
OXMT	BK	37.4994	-122.4243	209	194.2	2003/12 - current	MPBO, Ox Mtn.
BBEB	BK	37.82167	-122.32867	-31	150.0	2002/05 - current	BB, Pier E23
E17B	BK	37.82086	-122.33534		160.0	1995/08 - current *	BB, Pier E17
E07B	BK	37.81847	-122.34688	tbd	134.0	1996/02 - current *	BB, Pier E7
YBIB	BK	37.81420	-122.35923	-27.0	61.0	1997/12 - current *	BB, Pier E2
YBAB	BK	37.80940	-122.36450		3.0	1998/06 - current *	BB, YB Anchorage
W05B	BK	37.80100	-122.37370	tbd	36.3	1997/10 - current *	BB, Pier W5
W02B	BK	37.79120	-122.38525	-45	57.6	2003/06 - current	BB, Pier W2
SFAB	BK	37.78610	-122.3893		0.0	1998/06 - current *	BB, SF Anchorage
RSRB	BK	37.93575	-122.44648	-48.0	109.0	1997/06 - current *	RSRB, Pier 34
RB2B	BK	37.93	-122.41	tbd	133.8	2003/07 - current *	RSRB, Pier 58
SM1B	BK	37.59403	-122.23242		298.0	not recorded	SMB, Pier 343
DB3B	BK	37.51295	-122.10857		1.5	1994/09 - 1994/11	DB, Pier 44
					62.5	1994/09 - 1994/09	
					157.9	1994/07 - current *	
DB2B	BK	37.50687	-122.11566			1994/07 - current *	DB, Pier 27
					189.2	1992/07 - 1992/11	
DB1B	BK	37.49947	-122.12755		0.0	1994/07 - 1994/09	DB, Pier 1
					1.5	1994/09 - 1994/09	
					71.6	1994/09 - 1994/09	
					228.0	1993/08 - current *	
CCH1	NC	37.7432	-122.0967	226		1995/05 - current	Chabot
CGP1	NC	37.6454	-122.0114	340		1995/03 - current	Garin Park
CSU1	NC	37.6430	-121.9402	499		1995/10 - current	Sunol
CYD1	NC	37.5629	-122.0967	-23		2002/09 - current	Coyote
CMW1	NC	37.5403	-121.8876	343		1995/06 - current	Mill Creek

Table 3.5: Stations of the Hayward Fault Network. Each HFN station is listed with its station code, network id, location, operational dates, and site description. The latitude and longitude (in degrees) are given in the WGS84 reference frame. The elevation of the well head (in meters) is relative to the WGS84 reference ellipsoid. The overburden is given in meters. The start dates indicate either the upgrade or installation time. The abbreviations are: BB - Bay Bridge; BR - Briones Reserve; CMS - Cal Memorial Stadium; CB - Carquinez Bridge; DB - Dumbarton Bridge; MPBO - mini-Plate Boundary Observatory; RFS - Richmond Field Station; RSRB - Richmond-San Rafael Bridge; SF - San Francisco; SMB - San Mateo Bridge; SMC - St. Mary's College; and, YB - Yerba Buena. The * for station PINB indicates that this station name has been requested but has not yet been approved and may change. The * in the Date column indicates the stations that have recorded data from an earlier period of manually retrieved tapes, but that are currently off-line.

Site	Geophone	Accelerometer	Z	H1	h2	datalogger	Notes	Telem.
VALB	Oyo HS-1	Wilcoxon 731A	TBD	TBD	TBD	Q330		FR
PETB	Oyo HS-1	Wilcoxon 731A	TBD	TBD	TBD	TBD		TBD
CRQB	Oyo HS-1	Wilcoxon 731A	-90	251	341	Q4120		FR
HERB	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	Q4120		FR
PINB	Oyo HS-1	Wilcoxon 731A	TBD	TBD	TBD	TBD		TBD
BRIB	Oyo HS-1	Wilcoxon 731A	-90	79	349	Q4120	Acc. failed, Dilat.	FR
RFSB	Oyo HS-1	Wilcoxon 731A	-90	256	346	Q4120		FR
CMSB	Oyo HS-1	Wilcoxon 731A	-90	19	109	Q4120		FR
SMCB	Oyo HS-1	Wilcoxon 731A	-90	76	166	Q4120	Posthole	FR
SM2B	Oyo HS-1	Wilcoxon 731A	TBD	TBD	TBD	Q4120		FR
SVIN	Mark L-22		-90	298	28	Q4120	Tensor.	FR/Rad.
OHLN	Mark L-22		-90	313	43	Q4120	Tensor.	FR
MHDL	Mark L-22		-90	TBD	TBD	Q4120	Tensor.	FR
SBRN	Mark L-22		-90	347	77	Q4120	Tensor.	FR
OXMT	Mark L-22		-90	163	253	Q4120	Tensor.	FR
BBEB	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	Q4120	Acc. failed	Radio
E17B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present		
E07B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present		
YBIB	Oyo HS-1	Wilcoxon 731A	-90	257	347	None at present	Z geop. failed	FR/Rad.
YBAB	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present		
W05B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present		
W02B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	Q4120		Radio
SFAB	None	LLNL S-6000	TBD	TBD	TBD	None at present	Posthole	
RSRB	Oyo HS-1	Wilcoxon 731A	-90	50	140	None at present	2 acc. failed	FR
RB2B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present	1 acc. failed	
SM1B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present		
DB3B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present	Acc. failed	
DB2B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present		
DB1B	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	None at present	Acc. failed	
CCH1	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	Nanometrics HRD24	Dilat.	Radio
CGP1	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	Nanometrics HRD24	Dilat.	Radio
CSU1	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	Nanometrics HRD24	Dilat.	Radio
CYD1	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	Nanometrics HRD24	Dilat.	Radio
CMW1	Oyo HS-1	Wilcoxon 731A	-90	TBD	TBD	Nanometrics HRD24	Dilat.	Radio

Table 3.6: Instrumentation of the HFN as of 06/30/2007. Every HFN downhole package consists of co-located 3-component geophones and accelerometers, with the exception of MPBO sites which have only 3-component geophones and are also collecting tensor strainmeter data. Six HFN sites (5 of the SHFN and 1 of the NHFN) also have dilatometers (Dilat.). Currently, 14 NHFN sites have Quanterra dataloggers with continuous telemetry to the BSL. The remaining backbone sites are either still being developed with support from Caltrans or are being upgraded to Quanterra dataloggers. The 5 SHFN sites have Nanometrics dataloggers with radio telemetry to the USGS. The orientation of the sensors (vertical - Z, horizontals - H1 and H2) are indicated where known or identified as "to be determined" (TBD).

corresponding ground accelerations inferred from the accelerometers are accurate).

Generally speaking, the accelerometers, being an active device, are more accurate and also more stable than the geophones, so it is reasonable to assume that the most likely reason for the difference is that the assumed generator constants for the geophones are inaccurate. *Rodgers et al.* (1995) describe a way to absolutely calibrate the geophones in situ and to determine their generator constant, free period and fraction of critical damping. The only external parameter that is required is the value of the geophone's inertial mass.

We have built a calibration test box which allows us to routinely perform the testing described by *Rodgers et al.* whenever site visits are made. The box drives the signal coil with a known current step and rapidly switches the signal coil between the

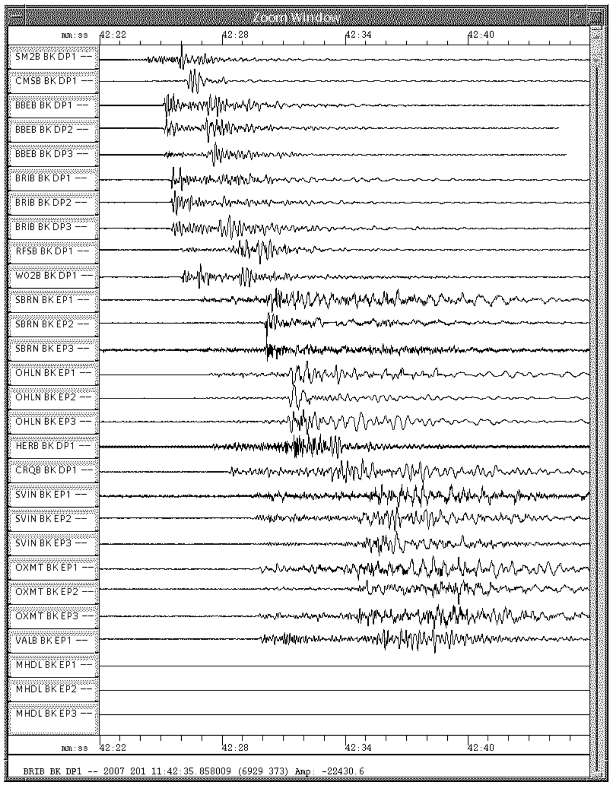

Figure 3.11: Plot of unfiltered P-wave seismograms, recorded on the geophones of the 14 operational NHFN borehole stations for a recent Bay Area earthquake (20 July 2007, M4.2 Piedmont, CA). The stations have been ordered by increasing distance from the event (top to bottom). It is immediately apparent from this simple display that station MHDL was dead and needed immediate attention.

current source and the datalogger input. From this information, expected and actual sensor response characteristics can be compared and corrections applied. Also, changes in the sensor response over time can be evaluated so that adjustments can be made, and pathologies arising in the sensors due to age can be identified. Once a geophone is absolutely calibrated, we also check the response of the corresponding accelerometer.

3.3.3 2006-2007 Activities

In addition to routine maintenance, operations, quality control and data collection, activities of the NHFN project over the past year have also included efforts at ensuring more stable operations and maintenance (O&M) funding support, upgrading and expanding the NHFN and developing procedures to enhance quality control and data analysis.

Sensor	Channel	Rate (sps)	Mode	FIR
Accelerometer	CL?	500.0	T	Ca
Accelerometer	HL?	200.0	C	Ca
Accelerometer	BL?	20.0	C	Ac
Accelerometer	LL?	1.0	C	Ac
Geophone	DP?	500.0	T,C	Ca
Geophone	EP?	200.0	C	Ca
Geophone	EP?	100.0	C	Ca
Geophone	BP?	20.0	C	Ac
Geophone	LP?	1.0	C	Ac

Table 3.7: Typical data streams acquired at NHFN sites, with channel name, sampling rate, sampling mode and FIR filter type. C indicates continuous, T triggered, Ca causal, and Ac acausal. Typically the DP1 continuous channel is archived and the remaining high sample rate data (i.e., CL and DP channels) are archived as triggered snippets. Prior to Sept. 2004, however, only triggered data was archived for all high sample rate channels.

3.3.4 Stable O&M Funding

In past years, support for NHFN O&M has been obtained on a yearly basis through competetive proposals to the USGS's external National Earthquake Hazard Reduction Program (NEHRP) program. Our requests for operating and maintaining a network were at a disadvantage in many regards since they had to compete against other proposals in the program that were focused on research. To help offset this disadvantage, we would also typically propose not only support for O&M but also support for research to be performed using NHFN data. For years the results of our proposal requests were funding grants that were roughly half the requested support and that were barely able to support the O&M of the network, without any moneys left over to do research. The need to compete competitively each year also contributed a significant level of uncertainly to the prospects for continued operation of the NHFN over longer time periods, and long-term planning of enhancement and expansion of the network were difficult.

This year, finally, after several years of negotiation and administrative and operational adaptations, we were able to propose and obtain a 3-year funding grant (cooperative agreement) through the ANSS (Advanced National Seismic System). Though this grant supports O&M for only 9 NHFN stations, it is more stable in the long-term, allowing for long-term planning and action to take place. It has also allowed us to fold the 5 MPBO stations into the network, which provide an excellent complement to the NHFN's borehole seismic coverage of the Bay Area. This year, we have also obtained a 3-year funding agreement with Caltrans for the O&M of 10 additional NHFN stations, bringing the total number of stations with long-term O&M support to 19 (14 currently operational and 5 near operational). We anticipate future long-term O&M support for the new planned NHFN stations to also receive long-term Caltrans support.

3.3.5 Upgrade of SMCB to SM2B

This year, we have completed our agreements with Caltrans and St. Mary's College to replace the post hole installation at St. Mary's College (SMCB) with a deep borehole installation (SM2B). Last year the hole was drilled by Caltrans as a hole of opportunity (i.e., when the schedule of a Caltrans drilling crew had an opening) to a depth of 151 m and a few hundred meters away from the post-hole (SMCB) site. The sensor package was also installed at that time. This year, with assistance from Caltrans and the St. Mary's College grounds crew, the site infrastructure was completed and 79 days of coincident data from both SMCB and SM2B was collected and analysed. SMCB was decommissioned and SM2B data acquisition began on June 26 of this year.

New Installations

As originally conceived, the Hayward Fault Network was to consist of 24 to 30 stations, 12-15 each north and south of San Leandro, managed respectively by UCB and USGS. Due to USGS funding limitations, however, the original plan has been significantly modified. The USGS component, for example, is now limited to 5 stations. With additional Caltrans support, however, development of the NHFN component of the project has continued. Currently, 14 NHFN sites are now operational and 4 more sites should come on-line soon (PETB, RB2B, E07B and W05B) having downhole sensors in place and surface equipment ready for installation. Activation of PETB (expected the 2nd week of October, 2007) and RB2B are planned first, with the addition of W05B and E07B as progress on the Bay-Bridge retrofit project allows.

With Caltrans funding, we have also purchased sensors and instrumentation for 2 additional sites, and Caltrans will provide drilling for these sites as spare drilling crew time becomes available (i.e., holes of opportunity). Permit negotiations for these two sites (PINB, shown in Figure 3.10; and a site at Cal Maritime Academy, not shown) are in their final stages, and the availability of Caltrans drilling is anticipated later this year or early next. We have also been asked by Caltrans to submit a proposal for the addition of 3 more NHFN sites in the coming years, an opportunity we are pursuing with vigor.

Quality Control and Data Analysis

In order to monitor and capture the source spectrum of moderate down to micro-scale earthquakes, it is essential that the NHFN instruments operate at high precision and in an extremely low noise environment. Therefore, the stations record at high sample rate, and their sensors are emplaced in deep boreholes to reduce noise contamination originating in the near surface weathered zone and from cultural noise sources. In addition, the reduction of noise at these stations through vigilant monitoring of actual seismic events plays a central part of our quality control effort.

As mentioned, a key aspect of quality control of the NHFN data is the analysis of actual seismic events. Seismic events of larger magnitude are relatively rare and generally provide more energy at lower frequencies. Hence, in order to provide more frequent real events and quality control in the higher frequency band of the NHFN stations, analysis of recordings from the much more frequent microearthquakes are needed. Because real event analyses are relatively labor intensive and because of inadequate insufficient funding, traditional methods of event analysis have proven financially infeasible. To help circumvent these problems, efforts to develop new and improved analysis techniques are ongoing. We have developed and are currently testing some promising techniques that are particularly well suited to the analysis of similar and repeating microearthquakes. The advantages of similar and repeating event analyses for both quality control and scientific purposes are numerous, and the nature of the seismograms from these types of events make automated, rapid and robust analysis possible.

Towards this end, we are continuing to develop our new pattern scanning recognition scheme to detect, pick, locate and determine magnitudes for small and very small similar events recorded either continuously or from among large volumes of noisy triggered data snippets and our phase coherency method for identification of characteristically repeating events sequences from among groups of similar event multiplets.

Pattern Scanning: The pattern scanning recognition approach we are developing enhances the effective signal to noise for event detection, picking and locating by using the high amplitude information available in the full waveform of earthquake's signals. This is done by using a cross-correlation based scanning approach, which scans known waveform patterns through either continuous or collections triggered event snippets (regardless of the triggered event noise levels). With this approach, continuous or triggered waveform data that does not match selected patterns are ignored while waveforms that approximately match selected reference event patterns are flagged as newly identified earthquakes.

This approach is less comprehensive in that it only detects events that are somewhat similar in waveform character to the reference patterns. However, it can be generalized significantly by increasing the number of event patterns scanned or by using fairly low maximum cross-correlation thresholds for event flagging. Preliminary tests of our scanning code show that scans of 100 distinct event patterns can be scanned through a day's worth of waveform data in 75 minutes on one 900Mhz SPARC cpu when continuous seismic data is used. Scanning through collections of all triggered snippets is substantially faster, in proportion to the inverse fraction of total time spanned by the snippet data.

The approach also provides automated cross-correlation pick alignments that can be used for high precision relative locations and for automated low-frequency spectral ratio determinations for magnitude estimates. Clearly the method has potential for automatically cataloging a large fraction of the more numerous microearthquakes, and, in conjunction with the special attributes of similar event groups, updates of the catalogs in an automated monitoring mode can provide near-real-time microearthquake information that can be a powerful tool for monitoring network performance of real event data. Future plans include development and implementation of an automated similar event scanning and cataloging scheme that will provide real-event data from similar small magnitude events for assessment of network health on a much more frequent basis (every few days).

Perhaps more significantly, the approach can also capture and rapidly catalog some of the most scientifically relevant events (e.g. repeats of characteristically repeating microearthquakes used for deep slip rate monitoring and swarms of similar events typically associated with foreshocks and aftershocks). The approach is also surprisingly good at detecting events over a wide magnitude range. Hence there is clear potential for using patterns from larger aftershocks (e.g. flagged by REDI) to rapidly and automatically develop a high-resolution picture of foreshock and aftershock activity associated with large mainshocks. Tests so far using waveform patterns from an aftershock from the Parkfield magnitude 6 event (2.2Ml) have been able to detect and fully process similar events as low as Ml - 1.2 (a range of 3.4 magnitude units). Testing in this regard is continuing, but clearly the 3.4 magnitude range is a lower bound on the potential magnitude range attainable.

Phase Coherency: In order to enhance even further the resolution and scientific value of the similar events identifed using the pattern scanning approach, we are continuing to refine and test our spectral phase coherency algorithm. This algorithm allows for detailed quantification of the similarities and differences between highly similar Hayward fault events to provide characterization of the subsets of similar events known as characteristically repeating microearthquakes. These subsets form groups or sequences of events that are believed to represent recuring ruptures of the same small patch of fault through time, and, once recongnized, such sequences provide a new dimension of constraint on earthquake physics and deep fault deformation through the recurrence intervals and magnitudes of the events comprising the sequences. The complex spectral phase coherency methodology can be carried out in various frequency bands geared appropriately to the magnitude dependence of frequency for earthquakes and is generally an order of magnitude better in its discrimination power than the simple cross correlation method. The goal of the testing and refinement is ultimately to develop a scheme for rapid and objective discrimination and identification of characteristically repeating microearthquakes sequences down to the lowest magnitude possible (where recurrence times are short and hence temporal resolutions are higher) along the Hayward fault, and to use the information from these sequences to gain a better picture of the time evolution of creep deep in the fault zone.

3.3.6 Acknowledgments

Thomas V. McEvilly, who passed away in February 2002, was instrumental in developing the Hayward Fault Network, and without his dedication and hard work the creation and continued operation of the NHFN would not have been possible.

Under Bob Nadeau's and Doug Dreger's general supervision, Rich Clymer, Doug Neuhauser, Bob Uhrhammer, Bill Karavas, John Friday, and Rick Lellinger all contribute to the operation of the NHFN. Bob Nadeau prepared this chapter.

Support for the NHFN is provided by the USGS through the NEHRP grant program (grant no. 07HQAG0014) and by Caltrans through grant no. 59A0245. Pat Hipley of Caltrans has been instrumental in the effort to continue to upgrade and expand the network. Larry Hutchings and William Foxall of LLNL have also been important collaborators on the project in years past.

3.3.7 References

Rodgers, P.W., A.J. Martin, M.C. Robertson, M.M. Hsu, and D.B. Harris, Signal-Coil Calibration of Electromagnetic Seismometers, *Bull. Seism. Soc. Am., 85*(3), 845-850, 1995.

Murdock, J., and C. Hutt, A new event detector designed for the Seismic Research Observatories, *USGS Open-File-Report 83-0785,* 39 pp., 1983.

3.4. Parkfield Borehole Network (HRSN)

3.4.1 Introduction

The operation of the High Resolution Seismic Network (HRSN) at Parkfield, California began in 1987, as part of the United States Geological Survey (USGS) initiative known as the Parkfield Prediction Experiment (PPE) (*Bakun and Lindh*, 1985).

Figure 3.12 shows the location of the network, its relationship to the San Andreas fault, sites of significance from previous and ongoing research using the HRSN, double-difference relocated earthquake locations from 1987-1998, routine locations of seismicity from August 2002 to July 2003, some preliminary nonvolcanic tremor locations from January 2006 through June 2007, and the epicenter of the 1966 and 2004 M6 earthquakes that motivated much of the research. The HRSN records exceptionally high-quality data, owing to its 13 closely spaced three-component borehole sensors (generally emplaced in the extremely low attenuation and background noise environment at 200 to 300 m depth (Table 3.8), its high-frequency wide bandwidth recordings (0-100 Hz; 250 sps), and its low magnitude detection threshold (below magnitude 0.0 Ml).

Several aspects of the Parkfield region make it ideal for the study of small earthquakes and nonvolcanic tremors and their relationship to tectonic processes and large earthquakes. These include the fact that the network spans the SAFOD (San Andreas Fault Observatory at Depth) experimental zone, the nucleation region of earlier repeating magnitude 6 events and a significant portion of the transition from locked to creeping behavior on the San Andreas fault, the availability of three-dimensional P and S velocity models (*Michelini and McEvilly*, 1991), a long-term HRSN seismicity catalogue (complete to very low magnitudes and that includes at least half of the M6 seismic cycle), a well-defined and simple fault segment, the existence of deep nonvolcanic tremor (NVT) activity, and a relatively homogeneous mode of seismic energy release as indicated by the earthquake source mechanisms (over 90% right-lateral strike-slip).

In a series of journal articles and Ph.D. theses, the cumulative, often unexpected, results of UC Berkeley's HRSN research efforts (see: `http://www.seismo.berkeley.edu/seismo/faq/parkfield_bib.html`) trace the evolution of a new and exciting picture of the San Andreas fault zone responding to its plate-boundary loading, and they are forcing new thinking on the dynamic processes and conditions within the fault zone at the sites of recurring small earthquakes and deep nonvolcanic tremors (*Nadeau and Dolenc, 2005*).

The Parkfield area has also become an area of focus of the EarthScope Project (`http://www.earthscope.org`) through the SAFOD experiment (`http://www.icdp-online.de/sites/sanandreas/news/news1.html`), and the HRSN is playing a vital role in this endeavor. SAFOD is a comprehensive project to drill into the hypocentral zone of repeating M $\sim$ 2 earthquakes on the San Andreas Fault at a depth of about 3 km. The goals of SAFOD are to establish a multi-stage geophysical observatory in close proximity to these repeating earthquakes, to carry out a comprehensive suite of down-hole measurements in order to study the physical and chemical conditions under which earthquakes occur, and to monitor and exhume rock, fluid, and gas samples for extensive laboratory studies (*Hickman et al.*, 2004).

3.4.2 HRSN Overview

1986 - 2001

Installation of the HRSN deep (200-300m) borehole sensors initiated in 1986, and recording of triggered 500 sps earthquake data began in 1987. The HRSN sensors are 3-component geophones in a mutually orthogonal gimbaled package. This ensures that the sensor corresponding to channel DP1 is aligned vertically and that the others are aligned horizontally. Originally a 10 station network, completed in 1988, the HRSN was expanded to 13 borehole stations in 2001, and the original recording systems (see previous BSL Annual Reports) were upgraded to 24 bit acquisition (Quanterra 730s) and 56K frame relay telemetry to UCB. Properties of the sensors are summarized in Table 3.9.

The 3 2001 borehole stations were added, with NSF support, at the NW end of the network as part of the SAFOD project to improve resolution of the structure, kinematics and monitoring capabilities in the SAFOD drill-path and target zones. Figure 3.12 illustrates the location of the drill site, the new borehole sites, and locations of earthquakes recorded by the initial and upgraded/expanded HRSN.

The three newest SAFOD stations have a similar configuration to the original upgraded 10 station network and include an additional channel for electrical signals. Station descriptions and instrument properties are summarized in Tables 3.8 and 3.9. All HRSN Q730 dataloggers employ FIR filters to extract data at 250 and 20 Hz (Table 3.10).

The remoteness of the drill site and new stations required an installation of an intermediate data collection point at Gastro Peak, with a microwave link to the CDF facility. The HRSN stations use SLIP to transmit TCP and UDP data packets over bidirectional spread-spectrum radio links between the on-site data acquisition

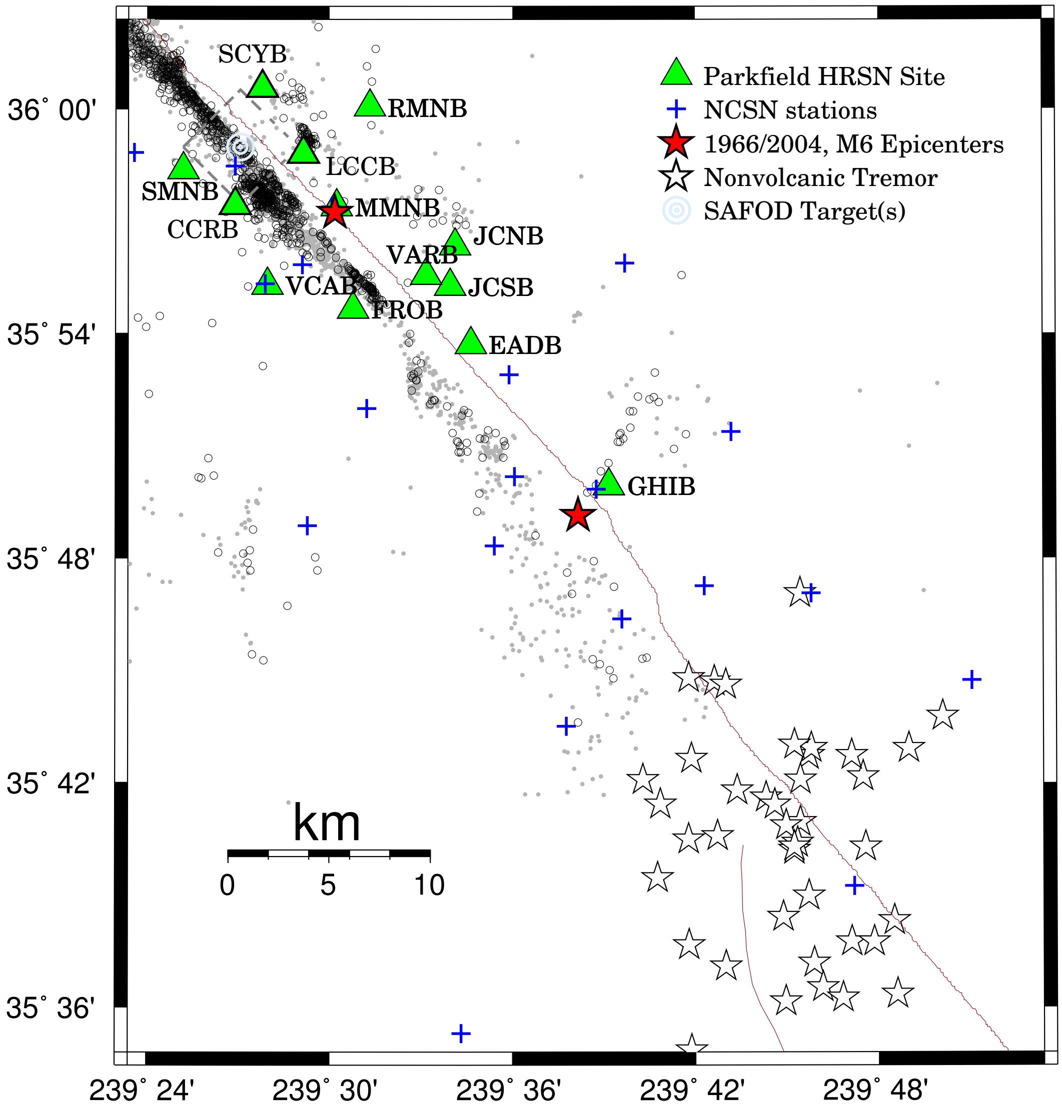

Figure 3.12: Map showing the San Andreas Fault trace and locations of the 13 Parkfield HRSN stations, the repeating M2 SAFOD targets (a 4 km by 4 km dashed box surrounds the SAFOD zone), and the epicenters of the 1966 and 2004 M6 Parkfield main shocks. Also shown are preliminary locations of some recently detected nonvolcanic tremors in the Cholame, CA area (January 2006 to June 2007), routine locations of earthquakes recorded by the expanded and upgraded 13 station HRSN (small open circles) and locations of events recorded by the earlier vintage 10 station HRSN relocated using an advanced 3-D double-differencing algorithm (gray points) applied to a cubic splines interpolated 3-D velocity model (*Michelini and McEvilly*, 1991).

Site	Net	Latitude	Longitude	Surf. (m)	Depth (m)	Date	Location
EADB	BP	35.89525	-120.42286	466	245	01/1988 -	Eade Ranch
FROB	BP	35.91078	-120.48722	509	284	01/1988 -	Froelich Ranch
GHIB	BP	35.83236	-120.34774	400	63	01/1988 -	Gold Hill
JCNB	BP	35.93911	-120.43083	527	224	01/1988 -	Joaquin Canyon North
JCSB	BP	35.92120	-120.43408	455	155	01/1988 -	Joaquin Canyon South
MMNB	BP	35.95654	-120.49586	698	221	01/1988 -	Middle Mountain
RMNB	BP	36.00086	-120.47772	1165	73	01/1988 -	Gastro Peak
SMNB	BP	35.97292	-120.58009	699	282	01/1988 -	Stockdale Mountain
VARB	BP	35.92614	-120.44707	478	572	01/1988 - 08/19/2003	Varian Well
VARB	BP	35.92614	-120.44707	478	298	08/25/2003 -	Varian Well
VCAB	BP	35.92177	-120.53424	758	200	01/1988 -	Vineyard Canyon
CCRB	BP	35.95718	-120.55158	595	251	05/2001 -	Cholame Creek
LCCB	BP	35.98005	-120.51424	640	252	08/2001 -	Little Cholame Creek
SCYB	BP	36.00938	-120.53660	945	252	08/2001 -	Stone Canyon

Table 3.8: Stations of the Parkfield HRSN. Each HRSN station is listed with its station code, network id, location, date of initial operation, and site description. The latitude and longitude (in degrees) are given in the WGS84 reference frame. The surface elevation (in meters) is relative to mean sea level, and the depth to the sensor (in meters) below the surface is also given. Coordinates and station names for the 3 new SAFOD sites are given at the bottom.

Site	Sensor	Z	H1	H2	RefTek 24	RefTek 72-06	Quanterra 730
EADB	Mark Products L22	-90	170	260	01/1988 - 12/1998	12/1998 - 07/1999	03/2001 -
FROB	Mark Products L22	-90	338	248	01/1988 - 12/1998	12/1998 - 07/1999	03/2001 -
GHIB	Mark Products L22	90	failed	unk	01/1988 - 12/1998	12/1998 - 07/1999	03/2001 -
JCNB	Mark Products L22	-90	0	270	01/1988 - 12/1998	12/1998 - 06/2001	03/2001 -
JCSB	Geospace HS1	90	300	210	01/1988 - 12/1998	12/1998 - 07/1999	03/2001 -
MMNB	Mark Products L22	-90	175	265	01/1988 - 12/1998	12/1998 - 06/2001	03/2001 -
RMNB	Mark Products L22	-90	310	40	01/1988 - 12/1998	12/1998 - 07/1999	03/2001 -
SMNB	Mark Products L22	-90	120	210	01/1988 - 12/1998	12/1998 - 06/2001	03/2001 -
VARB	Litton 1023	90	15	285	01/1988 - 12/1998	12/1998 - 07/1999	03/2001 -
VCAB	Mark Products L22	-90	200	290	01/1988 - 12/1998	12/1998 - 06/2001	03/2001 -
CCRB	Mark Products L22	-90	N45W	N45E	-	-	05/2001 -
LCCB	Mark Products L22	-90	N45W	N45E	-	-	08/2001 -
SCYB	Mark Products L22	-90	N45W	N45E	-	-	08/2001 -

Table 3.9: Instrumentation of the Parkfield HRSN. Most HRSN sites have L22 sensors and were originally digitized with a RefTek 24 system. After the failure of the WESCOMP recording system, PASSCAL RefTek recorders were installed. In July of 1999, 6 of the PASSCAL systems were returned to IRIS and 4 were left at critical sites. The upgraded network uses a Quanterra 730 4-channel system. For the three new stations (bottom) horizontal orientations are approximate (N45W and N45E) and will be determined more accurately as available field time permits.

Sensor	Channel	Rate (sps)	Mode	FIR
Geophone	DP?	250.0	T and C	Ca
Geophone	BP?	20.0	C	Ac

Table 3.10: Data streams currently being acquired at each HRSN site. Sensor type, channel name, sampling rate, sampling mode, and type of FIR filter are given. C indicates continuous; T triggered; Ac acausal; Ca causal. "?" indicates orthogonal, vertical, and 2 horizontal components.

systems and the central recording system at the CDF. Six of the sites transmit directly to a router at the central recording site. The other seven sites transmit to a router at Gastro Peak, where the data are aggregated and transmitted to the central site over a 4 MBit/second digital 5.4 GHz microwave link. All HRSN data are recorded to disk at the CDF site.

The upgraded and expanded system is compatible with the data flow and archiving common to all the elements of the BDSN/NHFN and the NCEDC (Northern California Earthquake Data Center), and is providing remote access and control of the system. It has also provided event triggers with better timing accuracy and is also now recording continuous 20 and 250 sps data for all 38 channels of the HRSN, which flow seamlessly into both the USGS automated earthquake detection system and into the Berkeley's NCEDC for archiving and online access to the community. The new system also helps minimize the problems of timing resolution, dynamic range, and missed detections, in addition to providing the added advantage of conventional data flow (the old system recorded SEGY format).

Another feature of the new system that has been particularly useful both for routine maintenance and for pathology identification has been the Internet connectivity of the central site processing computer and the station dataloggers with the computer network at BSL. Through this connection, select data channels and on-site warning messages from the central site processor are sent directly to BSL for evaluation by project personnel. If, upon these evaluations, more detailed information on the HRSN's performance is required, additional information can also be remotely accessed from the central site processing computer at Parkfield. Analysis of this remotely acquired information has been extremely useful for trouble shooting by allowing field personnel to schedule and plan the details of maintenance visits to Parkfield. The connectivity also allows certain data acquisition parameters to be modified remotely when needed, and commands can be sent to the central site computer and dataloggers to modify or restart processes when necessary.

The network connectivity and seamless data flow to the NCEDC also provides near-real-time monitoring capabilities that are useful for rapid evaluation of significant events as well as the network's overall performance level. For example, shown in Figure 3.13 are P-wave seismograms of the M_w 8.1 Solomon Islands earthquake of April 1, 2007 20:39:56 (UTC) (9892 km S54E of Parkfield, CA; depth 10 km) recorded on the DP1 (vertical) channels of the 13 HRSN borehole stations. This event killed 54 people. The seismic data from the quake was telemetered to Berkeley and available for analysis within a few seconds of being recorded by the HRSN. The consistency of the first motions and subsequent arrivals across all the stations of the local HRSN for this global event also show that the entire ensemble of stations for the network was performing well at this time. By routinely performing PSD analysises of the HRSN data, rapid assessment of the HRSN seismometer responses across their wide bandwidth is also easily done and corrective measures applied in a relatively short time-frame.

Data Flow

Initial Processing Scheme. Continuous data streams on all 38 HRSN components are recorded at 20 and 250 sps on disk on the local HRSN computer at the CDF facility. These continuous data are transmitted in near-real-time to the Berkeley Seismological Laboratory (BSL) over a T1 link and then archived at the NCEDC. In addition, in large part in support of the SAFOD experiment taking place at Parkfield, the near-real-time data are being transmitted over the T1 circuit to the USGS at Menlo Park, CA and are also integrated into their NCSN (Norther California Seismic Network) trigger detection scheme to increase the sensitivity of the NCSN in the SAFOD area.

Shortly after being recorded to disk on the central site HRSN computer, event triggers for the individual station data are also determined, and a multi-station trigger association routine then processes the station triggers and generates a list of potential earthquakes. For each potential earthquake that is detected, a unique event identification number (compatible with the NCEDC classification scheme) is also assigned. Prior to the San Simeon earthquake of December 22, 2003, 30 second waveform segments were then collected for all stations and components and saved to local disk as an event gather, and event gathers were then periodically telemetered to BSL and included directly into the NCEDC earthquake database (dbms) for analysis and processing.

Because of its mandate to detect and record very low magnitude events in the Parkfield area, the HRSN is extremely sensitive to changes in very low amplitude seismic signals. As a consequence, in addition to detecting very small local earthquakes at Parkfield, the HRSN also detects numerous regional events and relatively distant and small amplitude nonvolcanic tremor events. For example, spot checks of aftershocks following the M6.5 San

Simeon earthquake of December 22, 2003 using continuous data and HRSN event detection listings have revealed that the overwhelming majority of HRSN detections following San Simeon resulted from seismic signals generated by San Simeon's aftershocks, despite the HRSN's $\sim$ 50 km distance from the events. Data from the California Integrated Seismic Network (CISN) show that there were $\sim$ 1,150 San Simeon aftershocks with magnitudes $>$ 1.8 in the week following San Simeon, and during this same period, the number of HRSN event detections was $\sim$ 10,500 (compared to an average weekly rate before San Simeon of 115 detections). This suggests that, despite the $\sim$ 50 km distance, the HRSN is detecting San Simeon aftershocks well below magnitude 1.

Current Processing. Since the beginning of the network's data collection in 1987, and up until recently, the local and regional events were discriminated based on analyst assessment of S-P times, and only local events with S-P times less than $\sim$ 2.5 sec at the first arriving station were picked and located as part of the HRSN routine catalog. However, because of the networks extreme sensitivity to the large swarm of aftershocks from the San Simeon and M6 Parkfield earthquakes of September 2004 (e.g., in the first 5 months following the San Simeon mainshock, over 70,000 event detections were made by the HRSN system, compared to an average 5 month detection rate of 2500 prior to San Simeon) and because of ever declining funding levels, this approach has had to be abandoned.

The dramatic increase in event detections vastly exceed the HRSN's capacity to process both the continuous and triggered event waveform data. To prevent the loss of seismic waveform coverage, processing of the triggered waveform data has been suspended to allow archiving of the 250 sps continuous data to tape to continue uninterrupted. Cataloging of the event detection times from the modified REDI real-time system algorithm is also continuing, and the continuous 250 sps waveform data is currently being periodically uploaded from the DLT tape archive onto the NCEDC for access to the research community.

Funding to generate catalogs of local events from the 10s of thousands of aftershock detections has not been forthcoming, and, as a consequence, major changes in our approach to cataloging events have had to be implemented, which involves integration of HRSN data into NCSN automated event detection and cataloging (with no analyst review) combined with a high resolution procedure now being developed to automatically detect, pick, locate, and determine magnitudes for similar and repeating events down to very low magnitudes (i.e., below magnitude -1.0Ml). These new schemes are discussed in more detail in the activities section below.

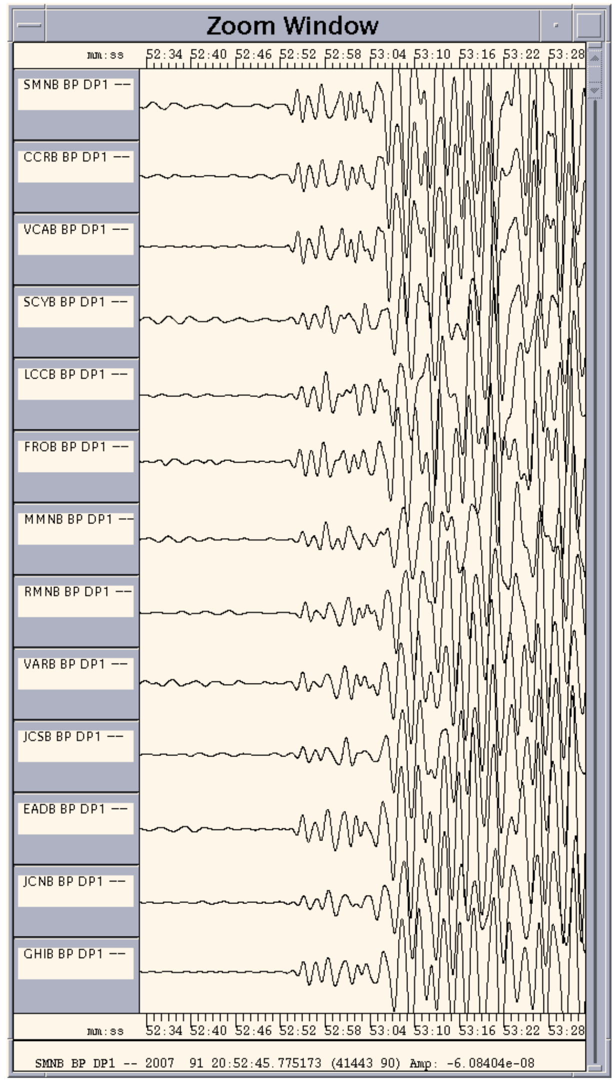

Figure 3.13: Plot of P-wave seismograms of the M_w 8.1 Solomon Islands earthquake of April 1, 2007 20:39:56 (UTC) (9892 km S54E of Parkfield, CA; depth 10 km) recorded on the DP1 (vertical) channels of the 13 HRSN borehole stations. Here vertical component geophone data have been deconvolved to absolute ground velocity, 0.5-5 Hz, BP filtered. All the P waveforms have the same first motions and their subsequent arrivals are highly similar.

3.4.3 2006-2007 Activities

In addition to the routine operations and maintenance of the HRSN (California's first and longest operating borehole seismic network), research into: 1) how to process ongoing similar and repeating seismicity to very low magnitudes, 2) ongoing non-volcanic tremors in the Parkfield-Cholame area, 3) SAFOD related activities and 4) various approaches to lowering operational (primarily landowner fee) costs have been the primary driving forces behind most of the HRSN project's activities this year.

Operations and Maintenance

Routine maintenance tasks required this year to keep the HRSN in operation include cleaning and replacement of corroded electrical connections; grounding adjustments; cleaning of solar panels; re-seating, resodering and replacement of faulty pre-amp circuit cards; testing and replacement of failing batteries; and insulation and painting of battery and datalogger housings to address problems with low power during cold weather. Remote monitoring of the network's health using the Berkeley Seismological Laboratory's SeisNetWatch software is also performed to identify both problems that can be resolved over the Internet (e.g. rebooting of data acquisition systems due to clock lockups) and more serious problems requiring field visits. Over the years, such efforts have paid off handsomely by providing exceptionally low noise recordings of very low amplitude seismic signals produced by microearthquakes (below magnitude 0.0Ml) and non-volcanic tremors.

Reducing Operational costs

The increased scientific activity in the rural Parkfield area due to SAFOD has lead to an increased demand for site access and development on privately owned property and a corresponding increase in access fees charged by private land owners. As a result land use fees paid by the HRSN project have increased dramativally from less than \$1000 annually prior to the SAFOD effort to over \$13,000. This represents over 15% of the entire HRSN budget with no corresponding increase in support from the project's funding agency. To compensate for the increased landowner costs, maintenance efforts have had to be cut back, and network performance has suffered.

To help alleviate the problem, this year we have developed plans to minimize our dependence on access to private lands. This has primarily involved developing alternative telemetry schemes for the HRSN sites in such a way as to minimize the additional effort and equipment needed to implement the schemes. Also central to this effort has been reaching cooperative agreements with other agencies involved in research in the area (i.e., USGS and UNAVCO). Initial field efforts to implement the plan have recently begun and are expected to be completed before the end of summer 2008.

Tremor Monitoring

The HRSN data played an essential role in the discovery of nonvolcanic tremors along the San Andreas Fault (SAF) below Cholame, CA (*Nadeau and Dolenc, 2005*). The location of the Cholame tremors occupies a critical location between the smaller Parkfield ($\sim$ M6) and much larger Ft. Tejon ($\sim$ M8) rupture zones of the SAF. Because the time-varying nature of tremor activity is believed to reflect time-varying deep deformation and presumably episodes of accelerated stressing of faults, and because an anomalous increase in the rate of Cholame tremor activity preceded the 2004 Parkfield M6 by $\sim$ 21 days, we are continuing to monitor the tremor activity observable by the HRSN to look for anomalous rate changes that may signal an increased likelihood for another large SAF event to the SE. Results of monitoring effort are described further in the "Research" section of this report.

Similar Event Catalog

The increased microseismicity rates resulting from the San Simeon M6.5 and Parkfield M6 events and the increased interest in even smaller events in the SAFOD target zone have required new thinking on how to detect and catalog microearthquakes recorded by the HRSN. One action taken to help address this problem has been to integrate HRSN data streams into the NCSN event detection and automated cataloging process (described below). This approach has been successful at discriminating small events in the local Parkfield area from other types of event detections and for providing automated locations of a significantly increased number of small events in the local area (approx. double that of the NCSN network alone). However, the rate of local events from the HRSN sensitized NCSN catalog is still only catching about 1/2 the number of local events previously cataloged by the HRSN, and waveforms for the small events are not typically made available. In addition, unlike the previous HRSN catalog, the additional events added by the NCSN-HRSN integration are not reviewed by an analyst, nor do they generally have magnitude determinations associated with them. In some cases, the selection rules used for the integrated catalog also result in exclusion of events that are otherwise included by the NCSN.

These limitations severely hamper efforts relying on similar and characteristically repeating microearthquakes. They also reduce the effectiveness of research relying on numerous very small magnitude events in the SAFOD zone (e.g. for targeting the SAFOD targets). To help overcome these limitations, we have continued our efforts to develop an automated similar event cataloging scheme based on cross-correlation and pattern scanning of the continuous HRSN data now being

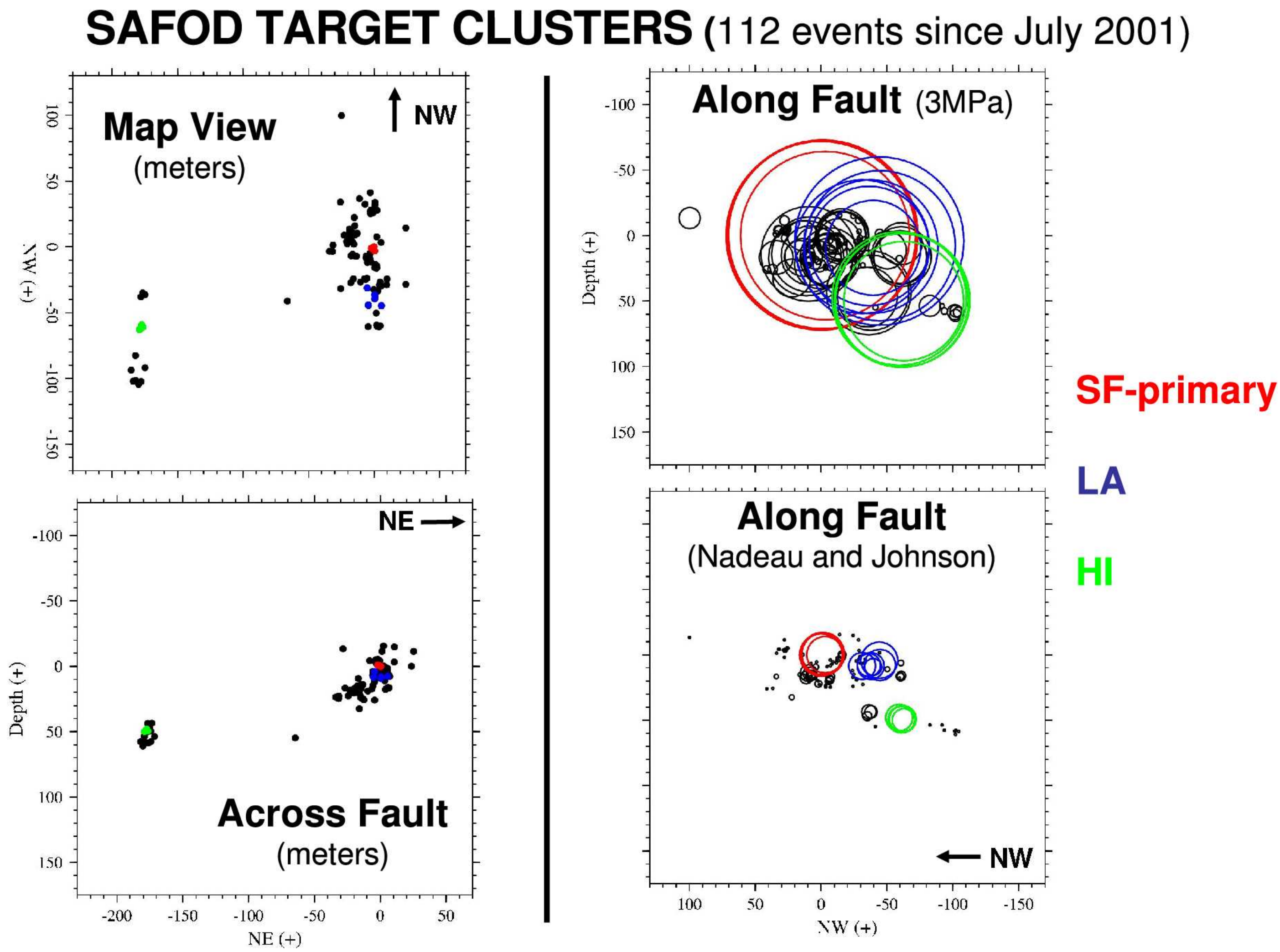

Figure 3.14: Map view (top, left), and across (bottom, left) and along SAF depth sections (top and bottom, right) of double-difference locations resulting from application of the similar event pattern scanning and automated cataloging method using one event from each of the SAFOD HI and SF target sequences as a reference. The magnitudes of the 112 events ranged from 2.2 down to -1.4 Ml. In the across fault sections at the right, inferred circular dimensions of the event ruptures in the SAFOD zone are shown as open circles assuming a 3MPa constant stress-drop model (top) and an increasing stress-drop with decreasing magnitude model inferred from recurrence interval information (*Nadeau and Johnson*, 1998).

archived. The method uses a small number of reference events whose waveforms, picks, locations, and magnitudes have been accurately determined, and it automatically detects, picks, locates and determines magnitudes for events similar to the reference event to the level of accuracy and precision that only relative event analysis can bring.

The similar event detection is also remarkably insensitive to the magnitude of the reference event used, allowing similar events ranging over several magnitude units to be fully cataloged using a single reference event. It also does a remarkably good job even when seismic energy from multiple events is superposed. Once a cluster of similar events has been cataloged, it is a relatively straightforward process to identify characteristically repeating microearthquake sequences within the cluster (frequently a single similar event "cluster" will contain several sequences of repeating events).

Application of the method using two of the SAFOD target events as references is illustrated in Figure 3.14. One reference event is a member of the so-called Hawaii sequence (HI), and one is from the San Francisco sequence (SF), and their magnitudes are ~ 2.1 and 1.8 (respectively). These events were scanned through 5 years of continuous data, and 110 other events occurring within the target region were identified and fully cataloged to high precision. Their magnitudes ranged down to magnitude -1.4 Ml, and in addition to the SAFOD target sequence from which the reference was derived, several other repeating sequences within the 150m zone were also identified (5 of which had not previously been known to exist).

This high level of precision and low magnitude completeness has already proven useful to SAFOD for helping to delineate and constrain the active fault structure in the target zone. It has also proven vital for helping to resolve a long-standing debate in the seismologic community regarding the stress-drop scaling issues (*Dreger et al.*, 2007).

The automated cataloging procedure for similar events is still being refined to capture even smaller events and events over a larger area, as well as for increased processing speed. Eventually, a composite catalog of similar event groups from throughout the HRSN coverage zone is planned.

The approach also holds promise in other applications where automated and precise monitoring of bursts of seismic activity to very low magnitudes is desirable (e.g. in aftershock zones or in volcanic regions) or where automated updates of preexisting repeating sequences and their associated deep slip estimates are desired.

Efforts in Support of SAFOD

An intensive and ongoing effort by the EarthScope component called SAFOD (San Andreas Fault Observatory at Depth) is underway to drill through, sample and monitor the active San Andreas Fault at seismogenic depths and in very close proximity (within a few 10s of km or less) of a repeating magnitude 2 earthquake site. The HRSN data plays a key role in these efforts by providing low noise and high sensitivity seismic waveforms from active and passive sources, and by providing a backbone of very small earthquake detections and continuous waveform data.

As of early September, 2007, SAFOD drilling had penetrated the fault at the HI repeating target sequence and collected core samples both in the presumed rupture zone of the repeating events and in the fault region that presumably creeps and surrounds the repeatedly rupturing HI patch. Future efforts will be focused on attempting to confirm that the drill penetration and coring efforts did indeed hit the target rupture zone and on long-term monitoring of the ongoing chemical, physical, seismologic and deformational properties in the zone (particularly any signals that might be associated with the next repeat of the HI sequence).

HRSN Activities this year have contributed in three principal ways to these and longer-term SAFOD monitoring efforts:

1) In collaboration with the USGS, we have completely integrated the HRSN data streams into the NCSN triggering scheme (described above) to increase the sensitivity of NCSN detection in the SAFOD area. This has effectively doubled the number of small events the target location working group has for constraining the relative location of ongoing seismicity in the target zone.

2) Again in collaboration with the USGS, we have completed a telemetry upgrade begun last year. Now all 39 channels of the HRSN data (both 20 sps and 250 sps data streams) flow directly from Parkfield, through the USGS Parkfield T1 and the NCEMC T1 to the BSL for near-real-time processing and archiving on the web-based NCEDC. This is now providing near immediate access of the HRSN data to the community without the week- or month-long delay associated with the previous procedure of having to transport DLT tapes to Berkeley to upload, and quality check the data. A copy of the 250 sps data stream is also processed for redundancy by the USGS Parkfield Earthworm node.

3) We have also continued to apply our prototype similar event automated catalog approach to the primary, secondary and tertiary SAFOD target zones and to provide the SAFOD event location working group with on-demand precise double-difference and relative magnitude catalogs of ongoing similar event activity in the SAFOD target zone.

During the past year, our SAFOD similar event detections and catalogs have been used by the working group to extract data from the corresponding PASO array, Pilot Hole, NCSN, and mainhole data sets for integration with the HRSN data in order to provide the detailed information that was needed by drill crews for the final targeting of the HI target penetration and coring.

3.4.4 Acknowledgments

Thomas V. McEvilly, who passed away in February 2002, was the PI on the HRSN project for many years. Without his dedication, continued operation of the HRSN would not have been possible. Under Bob Nadeau's and Doug Dreger's general supervision, Rich Clymer, Bob Uhrhammer, Doug Neuhauser, Don Lippert, Bill Karavas, John Friday, Rick Lellinger and Pete Lombard all contribute to the operation of the HRSN. Bob Nadeau prepared this chapter. During this reporting period, operation, maintenance, and data processing for the HRSN project was supported by the USGS, through grant 07HQAG0014.

3.4.5 References

Bakun, W. H., and A. G. Lindh, The Parkfield, California, prediction experiment, *Earthq. Predict. Res., 3*, 285-304, 1985.

Daley, T.M. and T.V. McEvilly, Shear wave anisotropy in the Parkfield Varian Well VSP, *Bull. Seism. Soc. Am., 80*, 857-869, 1990.

Dreger, D., R.M. Nadeau, and A. Morrish, Repeating Earthquake Finite-Source Models: Strong Asperities Revealed on the San Andreas Fault, *Geophys. Res. Lett.*, revised version submitted, 2007.

Hickman, S., M.D. Zoback and W. Ellsworth, Introduction to special section: Preparing for the San Andreas Fault Observatory at Depth, *Geophys. Res. Lett., 31*, L12S01, doi:10.1029/2004GL020688, 2004.

Karageorgi, E., R. Clymer and T.V. McEvilly, Seismological studies at Parkfield. IV: Variations in controlled-source waveform parameters and their correlation with seismic activity, 1987-1994, *Bull. Seismol. Soc. Am., 87*, 39-49, 1997.

Michelini, A. and T.V. McEvilly, Seismological studies at Parkfield: I. Simultaneous inversion for velocity structure and hypocenters using B-splines parameterization, *Bull. Seismol. Soc. Am., 81*, 524-552, 1991.

Nadeau, R.M. and D. Dolenc, Nonvolcanic Tremors Deep Beneath the San Andreas Fault, *SCIENCE, 307*, 389, 2005.

Nadeau, R. M., and L. R. Johnson, Seismological Studies at Parkfield VI: Moment Release Rates and Estimates of Source Parameters for Small Repeating Earthquakes, *Bull. Seismol. Soc. Amer., 88*, 790-814, 1998.

3.5. Bay Area Regional Deformation Network

3.5.1 Introduction

This year was the first of the newly funded BARD NEHRP project for the period 2007-2010. In consequence, this year, the field efforts have been focused on the permitting and preparation of the sites. Additionally, the upgrade to 1Hz of the BARD network has been pursued. The scientific efforts have focused on the processing of the high-rate GPS data in order to include the GPS solutions (static offsets and dynamic waveforms) in the existing monitoring system for the seismic activity in northern California (magnitude determination, moment tensor and Elarms system). Additionally, static solutions have been estimated and will be released in a peer review journal before the end of the year. This year was noteworthy because this was the last year of operation of the PBO installation in the San Francisco Bay Area (SFBA).

3.5.2 BARD overview

Description of the network

The BSL currently maintains and operates 30 BARD stations (twenty-six bi-frequency sites and four L1 sites). The sampling rate varies from 1 to 30 seconds, and the data are transmitted continuously over a serial connection. Most stations use frame relay technology, either alone or in combination with radio telemetry.

Of the 30 sites, ten (BRIB, CMBB, FARB, HOPB, MHCB, ORVB, PKDB, SAOB, SUTB, YBHB) are colocated with broadband seismic stations of the BDSN with which they share continuous frame-relay telemetry to UC Berkeley. These sites use the Quanterra data loggers to store and retrieve the GPS data converted to MiniSEED format (it Perin et al., 1998). The MiniSEED approach provides more robust data recovery from onsite backup on the Quanterra disks following telemetry outages.

Another five stations (SVIN, MHDL, OHLN, OXMT and SBRN) have been installed in the last 3 years in the SFBA and along the Hayward fault as the Berkeley part of a multi-institutional effort funded by the NSF/MRI program to improve strain monitoring in the SFBA using an integrated approach, with significant participation of the USGS/MP (*Murray et al., 2002*). These stations include borehole tensor strainmeters, three-component borehole seismic velocity sensors, downhole pore pressure and tilt sensors, and GPS receivers. This project served as a prototype for the strainmeter installations planned for PBO, which faces many of the same station installation, configuration, and data retrieval issues we have addressed. Consequently, these 5 stations have received the nickname *mini-PBO*. From July 2001 to August 2002, five boreholes were drilled to about 200-m depth and equipped with tensor strainmeters recently developed by CIW and 3-component L22 (velocity) seismometers. For this project, we developed a self-centering GPS antenna mount for the top of the borehole casings, which are mechanically isolated from the upper few meters of the ground, to provide a stable, compact monument that allows access to the top of the borehole casing for downhole maintenance. The 5 GPS receivers were progressively installed and connected to Quanterra 4120 data loggers, which provide backup and telemetry capabilities. The completion of the last station (MHDL), located in the Marin Headlands, took longer because it required AC power, which PG&E installed in December 2005. The site is operational since Sept 1, 2006. In addition, 10-minute interval data, which are retrieved from all the sites by the USGS via a backup GOES satellite system, show that all the sites are successfully measuring strains due to tidal effects and to local and teleseismic earthquakes. The remaining BSL/BARD stations only record C-GPS data. Each BSL/BARD station uses a low-multipath choke-ring antenna, most of which (except the mini-PBO ones discussed above) are mounted to a reinforced concrete pillar approximately 0.5-1.0 meter above the ground level. The reinforcing steel bars of the pillar are drilled and cemented into a rock outcrop to improve long-term monument stability. A low-loss antenna cable is used to minimize signal degradation on the longer cable setups that normally would require signal amplification. Low-voltage cutoff devices are installed to improve receiver performance following power outages. Most stations are equipped with aging Z-12 receivers, which were originally programmed to record data once every 30 s and observe up to 12 satellites simultaneously at elevations down to the horizon. The antennas are equipped with SCIGN antenna adapters and hemispherical domes, designed to provide security and protection from weather and other natural phenomena, and to minimize differential radio propagation delays. The BSL acquired 7 Ashtech MicroZ-CGRS (μZ) receivers with NSF funding for the Mini-PBO project. These have been installed at the mini-PBO stations, and two have been used to replace failing Z12s at other stations (CMBB and MODB). At these sites, the data are collected using only direct serial connections and are susceptible to data loss during telemetry outages.

There is growing interest in collecting higher rates of data for a variety of applications. For example, GPS measurements can accurately track the propagation of earthquake dynamic motions both on the ground (*e.g., Larson et al., 2003*) and in the atmosphere (*e.g., Artru et al.,*

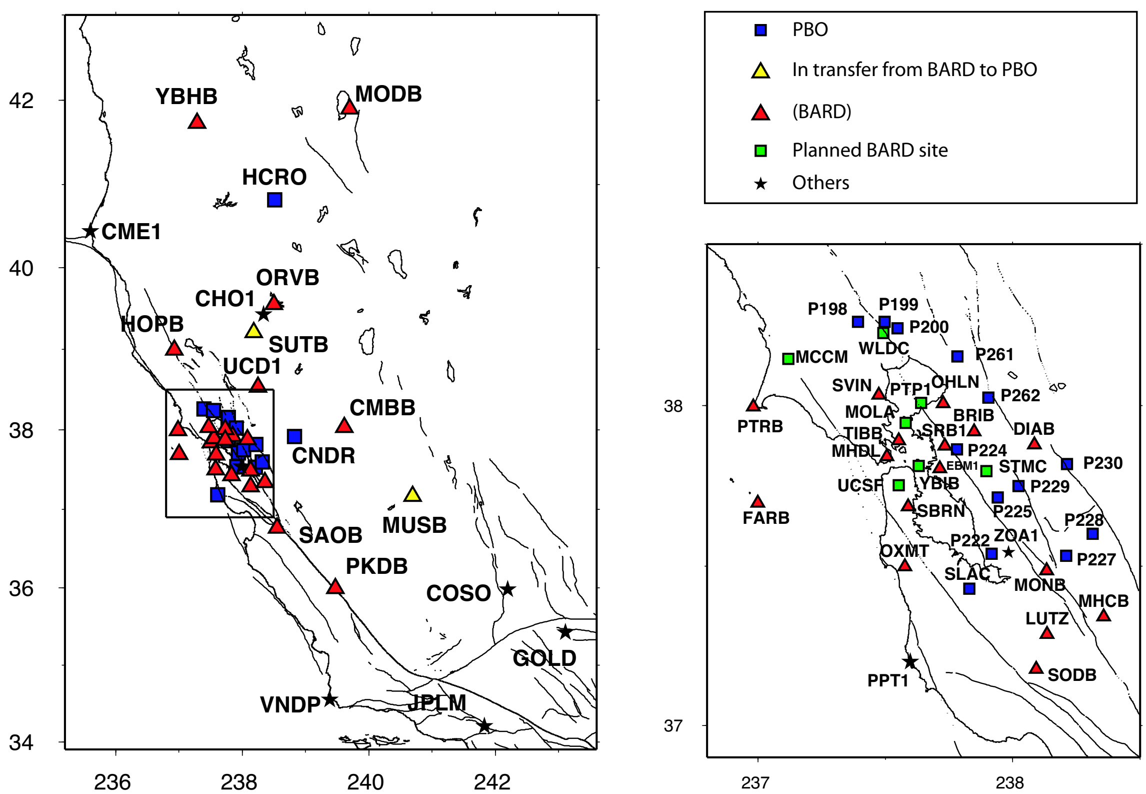

Figure 3.15: Operational BARD stations (dark triangles) in northern California (top) and in the San Francisco Bay area (bottom), including an 18-station network near the Long Valley Caldera (LVC) and a 14-station network near Parkfield (PKFD). In the oblique Mercator projection expected Pacific–North America relative plate motion is parallel to the horizontal. Circled stations use continuous real-time telemetry. The small black triangles near BRIB are the experimental L1 stations. Light triangles are PBO and Nucleus (previously existing continuous stations now part of PBO) stations operating in July 2005.

2001, Ducic et al., 2003), providing complementary information to seismic observations (calibration of integrated acceleration and velocity sensor data) and estimates of earth structure (direct observation of surface wave propagation over the oceans). We started collecting 1 Hz observations at 2 stations (DIAB and MONB) in 2003. In the last year, we have progressively upgraded the telemetry to continuous 1 Hz telemetry at 3 additional stations (BRIB, HOPB and PTRB), where the bandwidth of the existing telemetry system allowed it. At stations collocated with broadband seismic sensors, the seismic data has priority for telemetry, because it is used in the Northern California real-time earthquake notification system (see http://www.cisn.org/ncmc/), making this upgrade more difficult and in general not feasible with the current Z12 receivers because of insufficient data compression. All data collected from BARD/BSL are publicly available at the Northern California Earthquake Data Center (NCEDC; http://www.ncedc.org/bard/).

Between 1993 and 2001, the BSL acquired 29 Ashtech Z-12 and Micro-Z receivers from a variety of funding sources, including from federal (NSF and USGS), state (CLC), and private (EPRI) agencies. The network enhances continuous strain measurements in the Bay Area and includes several profiles between the Farallon Islands and the Sierra Nevada in order to better characterize the larger scale deformation field in northern California (Figure 3.15). During the last two years, 10 NETRS have been purchased via the UNAVCO purchase program. These receivers will help to upgrade the network to full high-rate capabilities. Three receivers are operating today (BRIB, MHDL and DIAB).

The number of continuous GPS stations in northern California is significantly increasing, with over 250 new site installations planned by 2008 as part of the Plate Boundary Observatory (PBO) component of the NSF-funded Earthscope project. UNAVCO and researchers from BARD and the other regional networks, such as SCIGN, BARGEN, and PANGA, are funded by NSF to fold operation and maintenance of about 200 existing stations, which constitute the PBO Nucleus network, into the PBO array by 2008. Two BSL-maintained stations (SUTB and MUSB) are included in the PBO Nucleus network. The other BSL stations are either collocated with seismic instrumentation or are located near the San Andreas Fault where real-time processing of the GPS data for earthquake notification is a high priority. Another 23 northern California stations, including most of the Parkfield network, will be included in the PBO Nucleus, and we are working with UNAVCO to facilitate their transition to UNAVCO control.

BARD Stations

The majority of the BSL BARD stations use a low-multipath choke-ring antenna, most of which are mounted to a reinforced concrete pillar approximately 0.5–1.0 meter above local ground level. The reinforcing steel bars of the pillar are drilled and cemented into a rock outcrop to improve long-term monument stability. A low-loss antenna cable is used to minimize signal degradation on the longer cable setups that normally would require signal amplification. Low-voltage cutoff devices are installed to improve receiver performance following power outages. Most use Ashtech Z-12 receivers that are programmed to record data once every 30 seconds and observe up to 12 satellites simultaneously at elevations down to the horizon. The antennas are equipped with SCIGN antenna adapters and hemispherical domes, designed to provide security and protection from weather and other natural phenomena, and to minimize differential radio propagation delays.

Data from most BSL-maintained stations are collected at 15 or 30-second intervals and transmitted continuously over serial connections (Table 3.5.2). Station TIBB uses a direct radio link to Berkeley, and MODB uses VSAT satellite telemetry. Most stations use frame relay technology, either alone or in combination with radio telemetry. Fourteen GPS stations are colocated with broadband seismometers and Quanterra data loggers (Table 3.2). With the support of IRIS, we developed software that converts continuous GPS data to MiniSEED opaque blockettes that are stored and retrieved from the Quanterra data loggers (*Perin et al.,* 1998), providing more robust data recovery from onsite disks following telemetry outages.

Data from BRIB, CMBB, DIAB, HOPB, MHCB, MHDL, MONB, OHLN, OXMT, PTRB, SBRN, SRB1, SVIN, TIBB and UCD1 in the Bay Area, and 13 stations in the Parkfield region (all but PKDB), are now being collected at 1-second intervals. All high-rate observations collected by these stations are currently available from the NCEDC. Collecting at such high frequency (for GPS) allows dynamic displacements due to large earthquakes to be better measured; however, this 30-fold increase in data can pose telemetry bandwidth limitations. We are planning to convert additional stations to 1-second sampling where possible during the next year. The acquisition of the 5 NETRS bundles will help to complete this project (see Subsection 3.5.3). In the Bay Area, we have converted stations that have sufficient bandwidth and are currently assessing bandwidth issues at other stations. Prior to the September 28, 2004 M6 Parkfield earthquake, data from the Parkfield stations were collected on an onsite computer, written to removable disk once per month, and sent to SOPAC for long-term archiving (decimated 30-sec data is acquired daily via the BSL frame relay circuit). In response to the earthquake, we modified the procedures to download 1-second data converted to compact RINEX format at hourly intervals, which does not significantly impact the telemetry bandwidth.

	Sites	Lat. (deg.)	Lon. (deg)	Receiver	Telem. .	Sampling rate	Collocated Network	Location
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	15 s	BDSN	Farallon Island
5	EBMD	37.81	237.71	T-SSI	R	1Hz		East Bay Mud Headquarter
6	HOPB	38.99	236.92	**TR 4000**	FR	**1Hz**	BDSN	Hopland Field Stat., Hopland
7	LUTZ	37.28	238.13	A-Z12	FR	30 s		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	T-NETRS	FR	1Hz	mini-PBO	Marin Headland
10	MODB	41.90	239.69	A-UZ12	NSN	15 s		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	30 s		Musick Mt.
13	OHLN	38.00	237.72	A-UZ12	FR	1Hz	mini-PBO	Ohlone Park, Hercules
14	ORVB	39.55	238.49	A-Z12	FR	15 s	BDSN	Oroville
15	OXMT	37.49	237.57	A-UZ12	FR	1Hz	mini-PBO	Ox Mountain
16	PKDB	35.94	239.45	A-Z12	FR	30 s	BDSN	Bear Valley Ranch, Parkfield
17	PTRB	37.99	236.98	A-Z12	R-FR	**1Hz**		Point Reyes Lighthouse
18	SAOB	36.76	238.55	A-Z12	FR	30 s	BDSN	San Andreas Obs., Hollister
19	SBRN	37.68	237.58	A-Z12	FR	1Hz	mini-PBO	San Bruno
20	SODB	37.16	238.07	A-Z12	R-FR	30 s		Soda Springs, Los Gatos
21	SRB1	37.87	237.73	T-SSE	FR	1Hz		SRB building, Berkeley
22	SUTB	39.20	238.17	A-Z12	R-FR	30 s	BDSN	Sutter Buttes
23	SVIN	38.03	237.47	A-UZ12	R-FR	1Hz	mini-PBO	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	15 s	BDSN	Yreka Blue Horn Mine, Yreka
27	BDM	37.95	238.13	NETRS			BDSN	Black Diamond Mines Park, Antioch
28	MCCM	38.14	237.12	NETRS			BDSN	Marconi Conference Center, Marshall
29	PTP1	38.00	237.64	NETRS			NHFN	Point Pinole Regional Park
30	UCSF	37.75	237.55	NETRS				UC-San Francisco, San Francisco

Table 3.11: List of the BARD maintained by the BSL. Five models of receiver 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 park more homogeneous. The telemetry types are listed in column 6. FR = Frame Relay, R = Radio, Mi= Microwave, WEB = DSL line. Some sites are transmiting data over several legs with different telemetry. Changes from last year's network table are highlighted in bold typography. **The sites 27 to 30 are in progress. For these 4 sites, the instrumentation is available and permit request procedures have been started.**

Data archival

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. 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 the Federal Aviation Administration (FAA) sites all over 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. This year the volume of GPS data in raw format in the NCEDC storage facility has increased by 30% ($\sim 525 Mb/day$). This trend will continue with the installation of new sites (1Hz) and the conversion of the rest of the 15 sites of BARD.

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 since 1992. The NCEDC continues to archive non-continuous survey GPS data. The initial dataset archived is the survey GPS data collected by the 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 virtually all of the data from 1992 to the present has been archived and is available for distribution. We are also archiving additional high-precision GPS data sets from northern California (mainly Parkfield measurements). Together with graduate students in the department who are now using the GAMIT software to process survey-mode data in the San Francisco Bay area, we are working to combine the survey-mode and C-GPS solutions into a self-consistent velocity field for northern California. The campaign velocity field computed from campaign measurements by UCB and USGS groups has been published by *d'Alessio et al.*, (2005).

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.

3.5.3 2006-2007 Activities

New stations and upgrades

Permit requests: We are in the process of permit agreement 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 retrieved by the EBPARK board during the month of September 2007.

Three sites have been upgraded to 1Hz (BRIB, HOPB, PTRB). The sites BRIB and HOPB are colocated with a broad-band seismometer (BRIB, HOPS) belonging to the BDSN network. The upgrade of these sites is a important step leading to the comparison of the GPS data with seismic records in the Bay Area.

5Hz data in buffer. We started to experiment with the use of 5Hz GPS data during August 2007. Today, the telemetry cost is too high to allow the transmission of these data in real-time. However, some delayed use of these data can occur after manual download, using the existing telemetry for a selection of sites. The storage capacity of NETRS receivers allows storing two days of data recorded at 5Hz.

Real-Time Kinematic (RTK) service In the framework of the collaboration with EBPARK, BSL is distributing RTK corrections at some sites. This experimental project aims at developing collaborations with private actors 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: Ten sites (P181, P222, P224, P225, P227, P228, P229, P230, P262, P256) of the PBO network will be included in the high rate processing under development at Berkeley Seismological Lab. These operations are carried out in close collaboration with East Bay Regional Parks (EBPARK) and East Bay Municipal Water 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 supported by EBPARK and BSL (the Wi-LAN radio for the site P224). All sites will feed a 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.

Upgrade of the EBMD site: This site, operated in collaboration with EBMUD, is streaming RTK messages to Berkeley via a Wi-LAN link to the Space Science Lab. telemetry facility (Figure 3.16). 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 localization (Jim Swanson and Janine Hampton, personnal communication). The RTK system is not able to offer accurate displacements for basic science purposes. The RTK accuracy is estimated to 3 cm instantaneously. For this reason, all the RTK messages are converted by an NTRIP server at BSL.

Parkfield area: In February 2003, the BSL assumed responsibility for data telemetry from a 14-station GPS network in the Parkfield region, in addition to the BSL

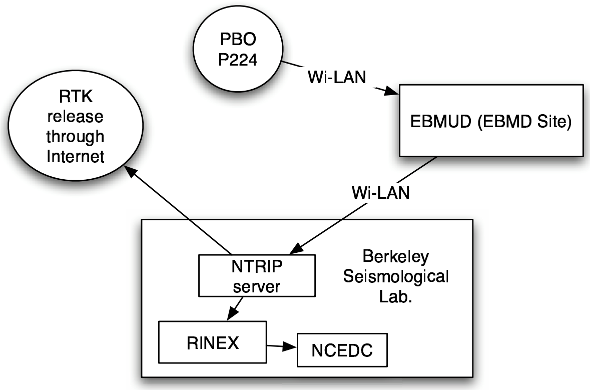

Figure 3.16: Present BSL operations at EBMD site and planned operations between the PBO site P224 and BSL. Since its installation in 2003, the EBMD site had been sending data to BSL using an internet DSL connection. The data collected (Trimble 5700 receiver) are now sent to BSL using a WI-LAN radio connection. The connection represents an upgrade of the quality of the radio link. The data collected here are thus more safely sent to BSL in case of a large seismic event.

station PKDB. Most of these stations were constructed using mini-PBO funding with contributions from the USGS and SCIGN. This project was continued during the year 2006-2007. All the Parkfield GPS sites have 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 sites have not been upgraded to 1Hz, which limits the comparison of data with seismic data. Last year, the site HUNT at Parkfield was upgraded to a Trimble NETRS receiver. We appreciated the good coordination with 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 to be archived at the UNAVCO facility in Boulder.

Replacement and Upgrade of BARD and MPBO GPS receivers: During 2006-2007, geodetic GPS hardware receivers of the BARD and MPBO arrays failed at a number of sites (CMBB, HOPB). Typically these sites had a a crashed receiver that could not be rebooted. Electronics at these sites are twelve to 15 years old.

3.5.4 Data Analysis and Results

CALREF, a stable reference frame for northern California

The BARD dataset has been processed in the ITRF2000 (*Altamimi et al.*, 2002). The solutions (*Houlié and Romanowicz*, in prep) are in good agreement with campaign solutions (BAVU and USGS) previously released (*d'Alessio et al.*, 2005). The new coordinates release of the BARD network includes the presently operating sites and the velocity of the sites already transferred from BSL to PBO during the last two years.

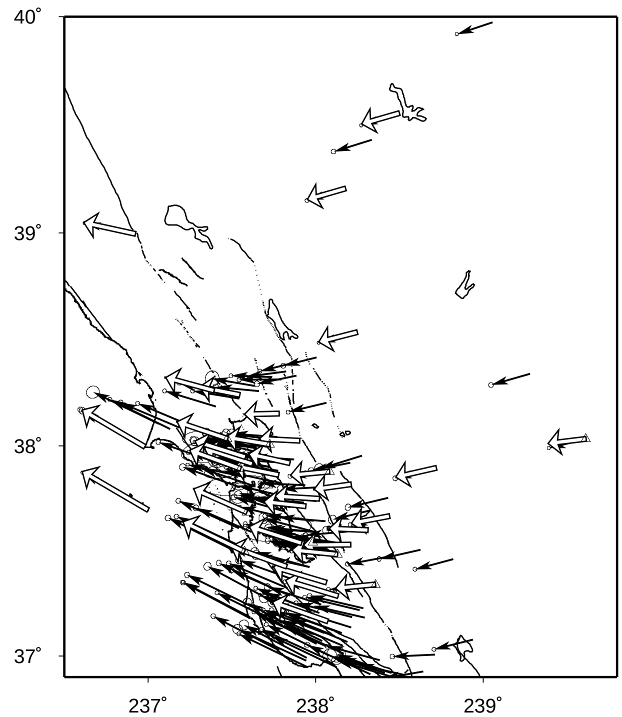

Figure 3.17: Comparison of the BARD solutions (white arrows) with the Bay Area Velocity Unification (BAVU) solutions (black arrows). All the data available at the BSL between 1994 and 2006 have been reprocessed (From *Houlié and Romanowicz,* in prep). BAVU website: http://seismo.berkeley.edu/ burgmann/RESEARCH/BAVU/

All the BARD sites have been processed jointly with IGS sites in California. No *a priori* constraints have been assumed during the processing. All the velocities included in the first release of California Reference Frame (CALREF) are given in Table 3.13. The CALREF will provide velocities and coordinates of sites located in the bay area at specific epochs. Each solution will be associated with error estimations (formal and real). Every surveyor will be able to control the reference site coordinates for a given survey.

BARD products released on the web

A series of products will soon be released on the new BARD website (`http:/www/ncedc.org/bard/`). The list of products released is still under discussion at BSL, but it will include various domains (from time-series (Figure 3.18) to troposphere studies) that can potentially benefit GPS studies and promote collaboration among BSL researchers or others. All products will be updated daily.

Sites	Lon. (deg.)	Lat. (deg.)	dV_e (mm/y)	dV_n (mm/y)
BAY1	197 .293	55 .19	-0 .03	0 .01
GOLD	243 .111	35 .425	1 .20	-0 .11
JPLM	241 .827	34 .205	0 .50	0 .59
PPT1	237 .61	37 .187	0 .82	0.27
VNDP	239 .384	34 .556	-0 .05	-0 .81

Table 3.12: Comparison between previous published values and recomputed values. The adjustment with the ITRF2000 is good. The errors provided here are formal and cannot be qualified as realistic (From *Houlié and Romanowicz,* in prep).

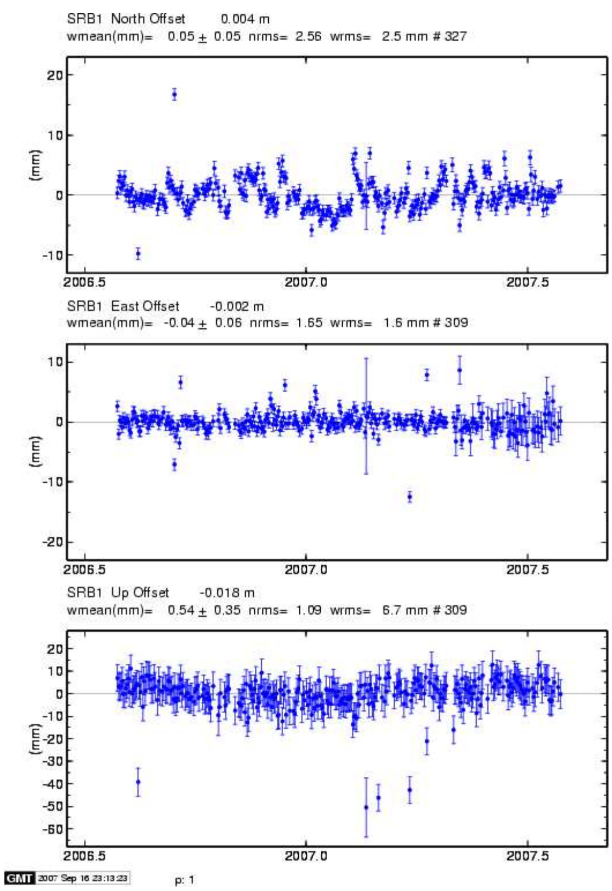

Figure 3.18: Time series of coordinates at the SRB1 site. Each day is processed automatically; then the time series is updated and BARD site coordinates in the ITRF2000 are adjusted.

Troposphere study in southern California and in SFBA

Two distinct troposphere studies have been carried out this year. The first one, in collaboration with Gareth Funning and Roland Bürgmann, focused on the uplift detected above the San Gabriel valley aquifer (Figure 2, Chapter 2) in southern California.

We propose including troposphere estimates from the GPS measurements into SAR data processing (in this case ROIPAC has been used).

Every day a troposphere map is estimated from the BARD dataset in order to increase the GPS accuracy and to correct the SAR scenes acquired in the San Francisco Bay Area. Twice a day, a map of troposphere delay is released for the previous day (See Figure 3.19). The troposphere maps will be released through the new version of the BARD website (see above). The next step of this research on the troposphere is now to manage the meteorological dataset jointly with GPS observations in real-time.

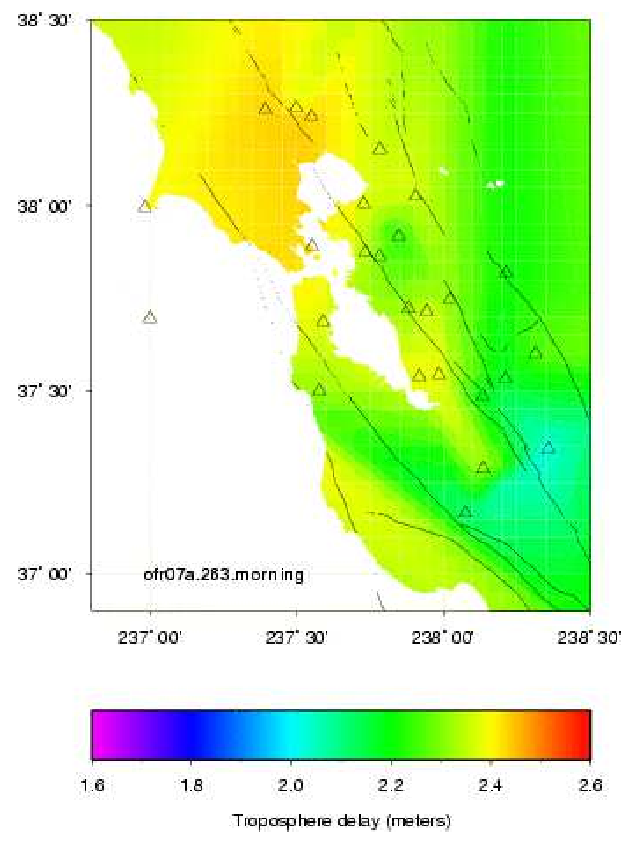

Figure 3.19: Interpolated troposphere delay at the acquisition time (5 am (PDT) of the SAR scene , 2007, Sep. 20th). The zenithal troposphere delay in the SFBA can experience up to 5 cm variation. This lateral troposphere effect can impact the SAR baseline estimation and the ongoing research on the slow creep deformation of the Hayward fault.

2004 Parkfield displacement field update

The Parkfield displacement field associated with the 2004 event has been reprocessed in order to better constrain the slip along the fault. A particular focus was on the near-fault observations. Indeed, as the other geodetic techniques (SAR and LiDAR)

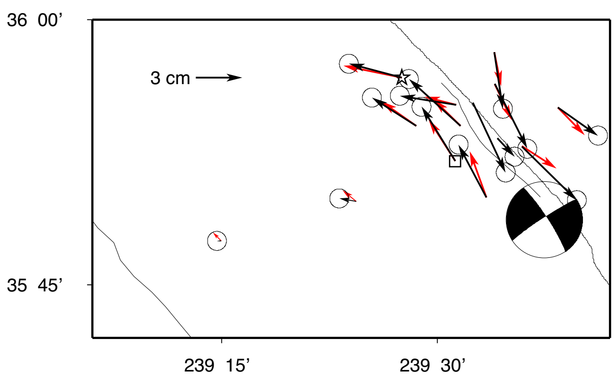

Figure 3.20: Coseismic displacements during the 2004 Parkfield earthquake. The displacement at the CRBT site is less than 3 mm. The displacement observed at PKDB (star) indicates the rupture along the fault is limited in the south.

cannot provide reliable information near the fault due to a lack of coherency, the accuracy of near-fault GPS displacements is crucial. The new computed displacement field will be published in two research articles (*Ahyi and Dreger, in press*, JGR) and (*Houlié, Dreger, and Romanowicz*, in prep.)

3.5.5 Acknowledgements

Since the departure of Mark Murray at the end of 2005, Barbara Romanowicz has overseen the BARD program. Rich Clymer, Bill Karavas, Rick Lellinger, John Friday, Nicolas Houlié and Doug Neuhauser contributed to the operation of the BARD network. The operation of the BARD network is partially supported by funding from the USGS/NEHRP program and funding from the NSF/UNAVCO *PBO nucleus* grant.

3.5.6 References

Altamimi, Z., P. Sillard, and C. Boucher , ITRF2000: A new release of the International Terrestrial Reference Frame for earth science applications, *J. Geophys. Res.,* 107(B10), 2214, doi:10.1029/2001JB000561, 2002

d'Alessio, M. A., I. A. Johanson, R. Bürgmann, D. A. Schmidt, and M. H. Murray, Slicing up the San Francisco Bay Area: Block kinematics from GPS-derived surface velocities, *J. Geophys. Res., 110,* B06403, doi:10.1029/2004JB003496, 2005.

Houlié, N. and Romanowicz, B., CALREF, a stable reference frame for the Northern California, in prep.

Murray, M., Neuhauser D., Gee, L., Dreger, D., Basset, A., and Romanowicz, B., Combining real-time seismic and geodetic data to improve rapid earthquake information , *EOS. Trans. AGU, 83(47),* G52A-0957, 2002.

Perin, B. J., C. M. Meertens, D. S. Neuhauser, D. R. Baxter, M. H. Murray, and R. Butler, Institutional collaborations for joint seismic and GPS measurements, *Seismol. Res. Lett., 69,* 159, 1998.

Romanowicz, B., B. Bogaert, D. Neuhauser, and D. Oppenheimer, Accessing northern California earthquake data via Internet, *EOS Trans. AGU, 75,* 257–260, 1994.

Site	Lon.	Lat	Ve (mm/y)	Vn (mm/y)	σ_e (mm/y)	σ_n (mm/y)	Start
BAY1*	197.29	55.19	-6.3	-25.5	0.0000	0.0000	1996.08
BAY2	197.29	55.19	-5.6	-25.2	0.0400	0.0300	1996.08
BRIB	237.85	37.92	-24.8	5.6	0.0100	0.0100	1993.58
CMBB	239.61	38.03	-22.9	-2.8	0.0100	0.0100	1993.92
CNDR	238.72	37.90	-24.4	-5.5	0.0200	0.0200	1999.27
DIAB	238.08	37.88	-23.7	-2.2	0.0100	0.0100	1998.33
FARB	237.00	37.70	-39.8	23.3	0.0100	0.0100	1994.00
GOLD*	243.11	35.43	-18.2	-5.4	0.0000	0.0000	1989.95
HCRO	238.53	40.82	-18.0	-8.7	0.1400	0.1500	2003.50
HOPB	236.93	39.00	-31.1	6.8	0.0100	0.0100	1995.58
JPLM*	241.83	34.21	-36.6	11.8	0.0000	0.0000	1989.44
LUTZ	238.14	37.29	-31.7	9.5	0.0100	0.0100	1996.33
MHCB	238.36	37.34	-24.2	-2.4	0.0100	0.0100	1996.33
MODB	239.70	41.90	-16.9	-9.1	0.0200	0.0200	1999.83
MOLA	237.58	37.95	-30.5	9.7	0.0100	0.0100	1993.75-2002.22
MONB	238.13	37.49	-27.5	2.7	0.0100	0.0100	1998.50
MUSB	240.69	37.17	-22.3	-4.0	0.0100	0.0100	1997.83
OHLN	237.73	38.01	-26.4	4.4	0.0200	0.0200	2001.83
ORVB	238.50	39.56	-22.7	-6.6	0.0100	0.0100	1996.83
OXMT	237.58	37.50	-36.9	18.0	0.0600	0.0600	2004.12
P181(PBO)	237.62	37.92	-29.0	9.6	0.3800	0.4000	2005.09
P198 (PBO)	237.39	38.26	-29.2	7.9	0.0900	0.1000	2004.77
P200 (PBO)	237.55	38.24	-24.3	4.7	0.2000	0.2200	2005.73
P222 (PBO)	237.92	37.54	-31.5	10.0	0.1100	0.1200	2005.26
P224 (PBO)	237.78	37.86	-26.9	5.5	0.1000	0.1100	2005.25
P225 (PBO)	237.94	37.71	-25.2	2.7	0.0900	0.1000	2005.14
P227 (PBO)	238.21	37.53	-28.6	-0.4	0.5800	0.6300	2006.20
P228 (PBO)	238.31	37.60	-23.5	1.0	0.4300	0.4700	2005.93
P229 (PBO)	238.02	37.75	-26.8	1.6	0.1100	0.1200	2005.29
P230 (PBO)	238.21	37.82	-22.5	-3.1	0.1100	0.1200	2005.15
P261 (PBO)	237.78	38.15	-21.0	-0.5	0.0900	0.1000	2004.50
P262 (PBO)	237.90	38.03	-24.2	1.2	0.1100	0.1200	2005.32
PKDB	239.46	35.95	-43.0	18.7	0.0100	0.0100	1996.67
PPT1*	237.61	37.19	-40.7	22.1	0.0000	0.0000	1996.14
PTRB	236.98	38.00	-37.7	22.2	0.0100	0.0100	1998.58
S300	238.44	37.67	-22.9	-4.4	0.0200	0.0200	1998.48
SAOB	238.55	36.77	-41.4	22.0	0.0100	0.0100	1997.58
SBRN	237.59	37.69	-32.0	14.2	0.0300	0.0300	2003.18
SODA	26.39	67.42	18.7	34.1	0.1400	0.1600	1994.70
SODB	238.07	37.17	-33.1	11.7	0.0100	0.0100	1996.33
SUAA	237.83	37.43	-33.7	12.4	0.0100	0.0100	1994.30
SUTB	238.18	39.21	-23.1	-6.7	0.0100	0.0100	1997.33
SVIN	237.47	38.03	-30.5	10.3	0.0400	0.0400	2003.89
THAL	238.07	37.35	-32.0	9.5	0.2000	0.2200	2003.00
TIBB	237.55	37.89	-30.8	11.2	0.0100	0.0100	1994.42
UCD1	238.25	38.54	-23.1	-6.0	0.0100	0.0100	1996.38
VNDP*	239.38	34.56	-42.2	20.9	0.0000	0.0000	1992.48
YBHB	237.29	41.73	-15.8	-6.7	0.0100	0.0100	1996.75

Table 3.13: CALREF 2006 official velocities. All velocities and estimated errors (σ)are indicated in mm per year. For each site, the relevant time-span and the network are specified. The sites with a star are the sites for which the velocities have been used during the combination of the daily solutions.

3.6. Northern California Earthquake Data Center

3.6.1 Introduction

The Northern California Earthquake Data Center, a joint project of the Berkeley Seismological Laboratory (BSL) and the U.S. Geological Survey at Menlo Park, serves as an online archive for various types of digital data relating to earthquakes in central and northern California. The NCEDC is located at the Berkeley Seismological Laboratory, and has been accessible to users via the internet since mid-1992.

The primary goal of the NCEDC is to provide a stable and permanent archival and distribution center of digital geophysical data for networks in northern and central California. These data include seismic waveforms, electromagnetic data, GPS data, strain, creep, and earthquake parameters. The seismic data comes principally from the Berkeley Digital Seismic Network (BDSN) operated by the Seismological Laboratory, the Northern California Seismic Network (NCSN) operated by the USGS, the Berkeley High Resolution Seismic Network (HRSN) at Parkfield, the EarthScope USArray Transportable Array stations in northern California, the various Geysers networks, and selected stations from adjacent networks such as the University of Reno, Nevada network and the Southern California Seismic Network (SCSN). GPS data are primarily from the Bay Area Regional Deformation (BARD) GPS network and the USGS/Menlo Park GPS surveys. The collection of NCSN digital waveforms dates from 1984 to the present, the BDSN digital waveforms date from 1987 to the present, and the BARD GPS data date from 1993 to the present. The BDSN includes stations that form the specialized Northern Hayward Fault Network (NHFN) and the MiniPBO (MPBO) borehole seismic and strain stations in the SF Bay Region.

The NCEDC also provides support for earthquake processing and archiving activities of the Northern California Earthquake Management Center (NCEMC), a component of the California Integrated Seismic Network (CISN). The CISN is the California regional organization of the Advanced National Seismic Network (ANSS).

3.6.2 2006-2007 Activities

By its nature, data archiving is an ongoing activity. In 2006-2007, the NCEDC continued to expand its data holdings and enhance access to the data. Projects and activities of particular note include:

- Actively participated in the retirement of the NCSN CUSP earthquake review software, which allowed the NCEDC to begin receiving authoritative real-time earthquake data from the NCEMC database into the NCEDC database.

- Implemented real-time waveform collection of earthquake event waveforms for the NCEMC.

- Supported the NCEMC earthquake analysis by providing real-time access to earthquake parameters and waveforms from the NCEDC for the CISN Jiggle earthquake review software.

- Implemented software and procedures to read and archive continuous NCSN seismograms from tapes for 2001-2005, and began processing the NCSN data tapes.

These activities and projects are described in detail below.

3.6.3 Data Collections

The bulk of the data at the NCEDC consists of waveform and GPS data from northern California. Figure 3.21 shows the geographic distribution of data archived by the NCEDC. Figure 3.22 shows the relative proportion of each data set at the NCEDC. The total size of the datasets archived at the NCEDC is shown in Table 3.14. Figure 3.23 shows the amount of data for each year that is archived at the NCEDC.

3.6.4 BDSN/NHFN/MPBO Seismic Data

Archiving current BDSN (Section 3.1.), NHFN (Section 3.3.), and Mini-PBO (Section 3.3.) (all stations using the network code BK) seismic data is an ongoing task. These data are telemetered from 47 seismic data loggers in real-time to the BSL, where they are written to disk files, used for CISN real-time earthquake processing, and delivered in real-time to the DART (Data Available in Real Time) system on the NCEDC, where they are immediately available to anyone on the internet. In September 2004, the NCEDC began to archive continuous high frequency data (80 Hz and 100 Hz) from all of the BDSN broadband, strong motion, and strainmeter sensors. Previously, 20 Hz and lower rate data channels were archived continuously, and high frequency data was archived only for events. In early 2006, the NCEDC started to receive all of the BK stations in real-time and make them available to users through the DART. All timeseries data from the Berkeley networks continue to be processed and archived by an NCEDC analyst using *calqc* in order to provide the highest quality and most complete data stream to the NCEDC.

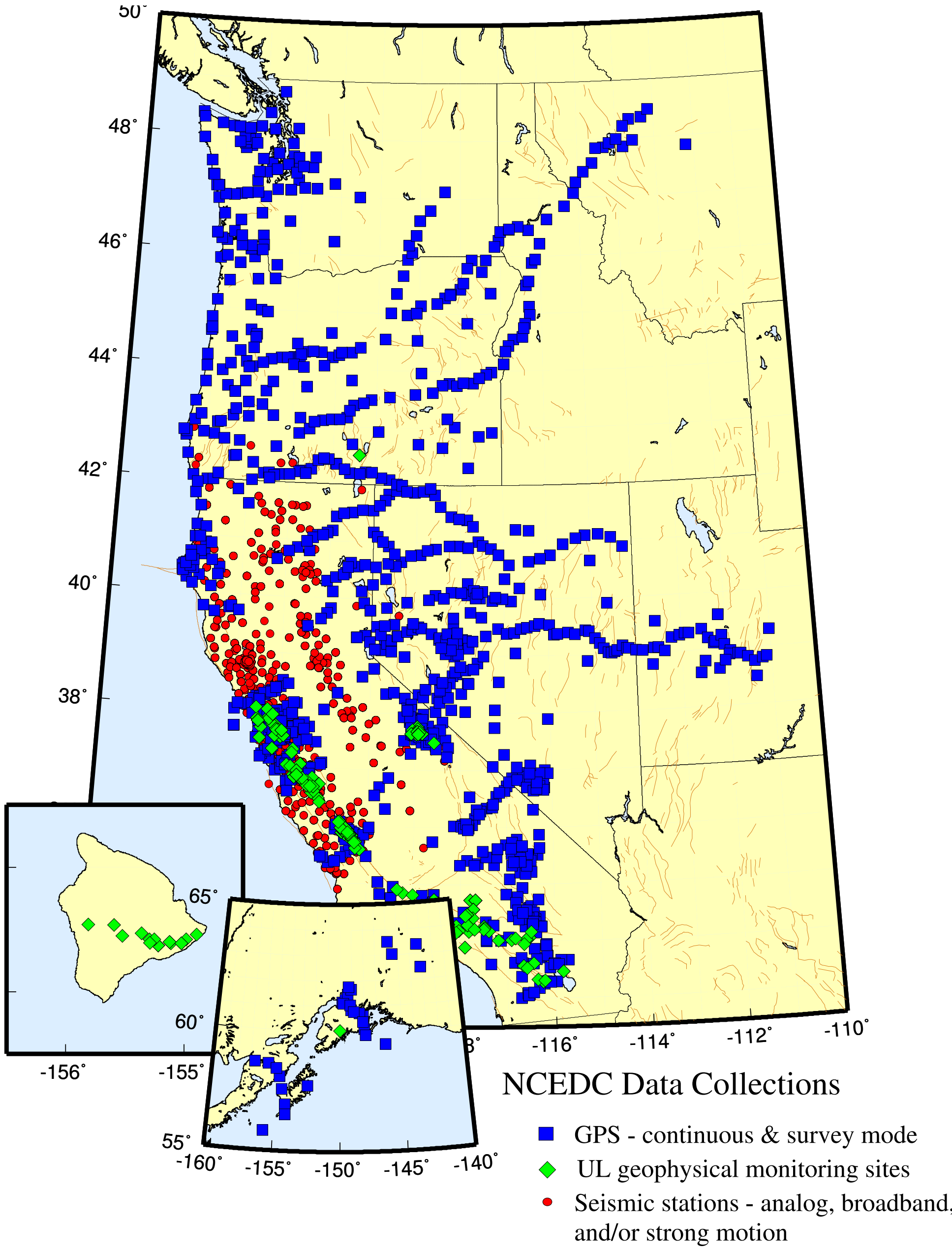

Figure 3.21: Map showing the location of stations whose data are archived at the NCEDC. Circles are seismic sites; squares are GPS sites, and diamonds are the locations of USGS low-frequency experiments.

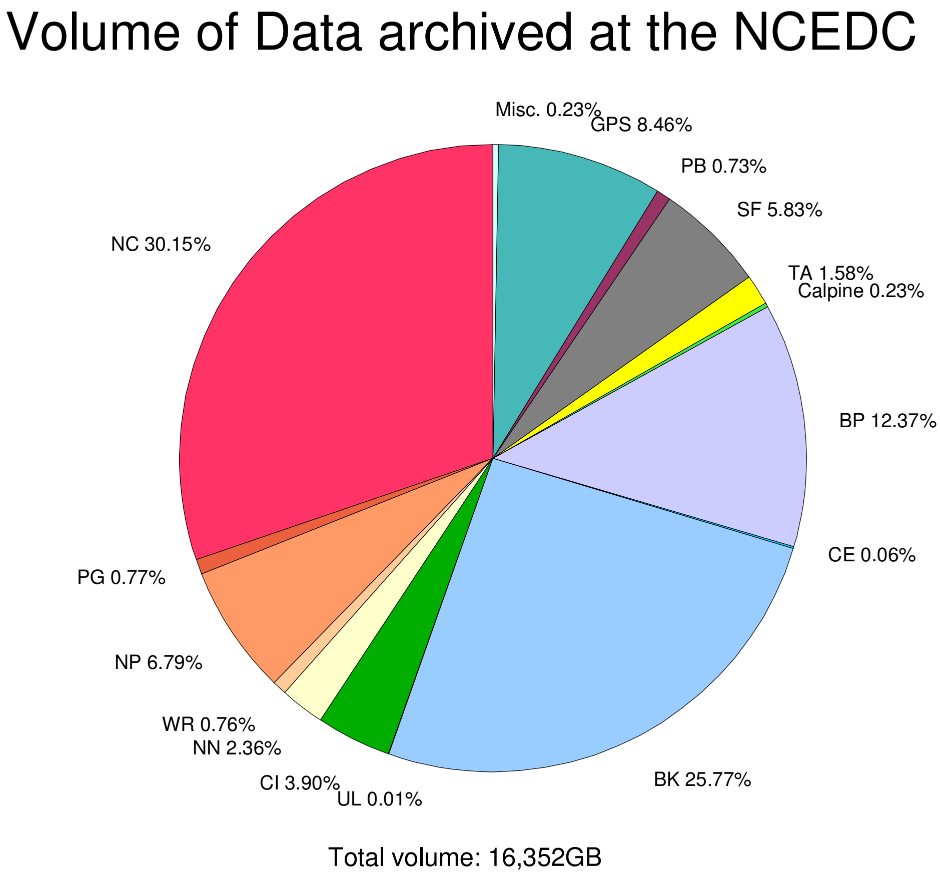

Figure 3.22: Chart showing the relative proportion of each data set at the NCEDC.

Data Type	GBytes
BDSN/NHFN/MPBO (broadband, electric and magnetic field, strain) waveforms	4,215
NCSN seismograms	6,300
Parkfield HRSN seismograms	2,023
BARD GPS (RINEX and raw data)	1,383
UNR Nevada seismograms	386
SCSN seismograms	638
Calpine/Unocal Geysers region seismograms	38
EarthScope SAFOD seismograms	954
EarthScope USArray seismograms	258
EarthScope PBO strain waveforms	119
USGS low frequency geophysical waveforms	2
Misc data	37
Total size of archived data	16,352

Table 3.14: Volume of Data Archived at the NCEDC by network

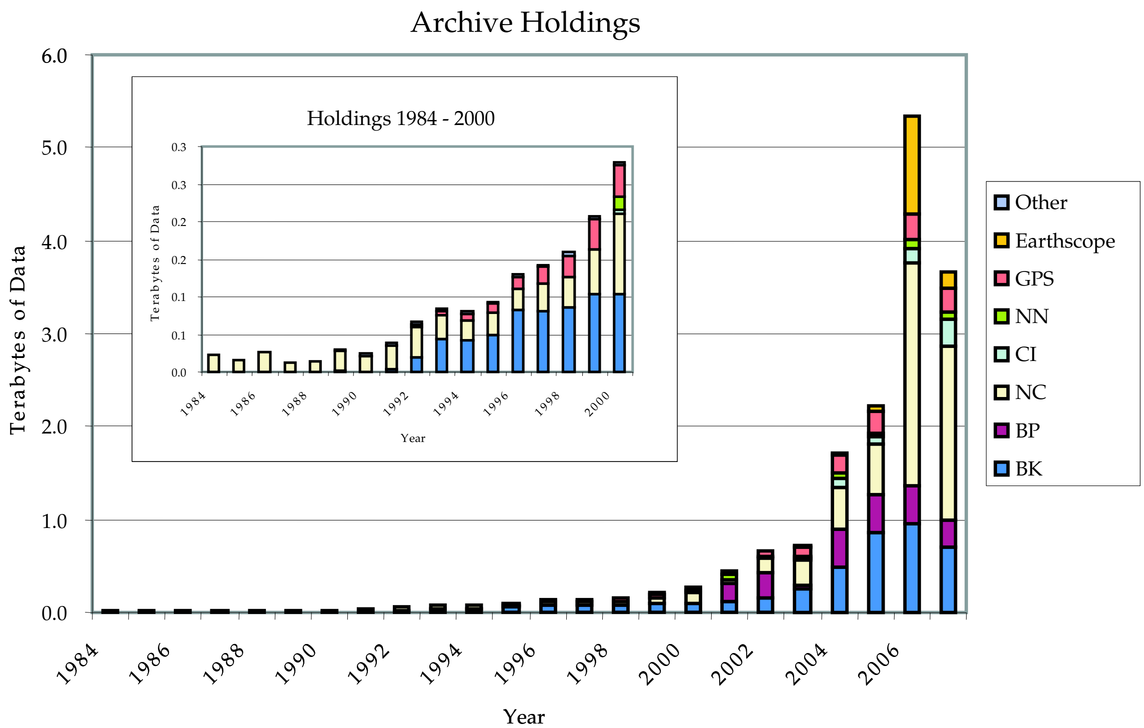

Figure 3.23: Figure showing the total volume of data archived at the NCEDC, broken down by data year.

NCSN Seismic Data

NCSN continuous waveform data are sent in real-time to the NCEDC via the internet, and are made available to users in real-time through the NCEDC DART. NCSN event waveform data, as well as data from all other real-time BSL and collaborating networks, are automatically collected by the NCEMC waveform archiver and stored at the NCEDC for event review and analysis and for distribution to users. All NCSN and NCEMC data are archived in MiniSEED format.

The NCEDC also maintains a list of historic teleseismic events recorded by the NCSN, since these events do not appear in the NCSN catalog.

A description of the successive improvements in the acquisition of NCSN data, leading to the acquisition of complete NCSN waveform data in early 2006, can be found in the 2005-06 BSL annual report. We are currently working on completing the waveform data collection by reading and archiving NCSN seismograms from tapes for the period 2001-2005.

Parkfield High Resolution Seismic Network Data

The history of upgrades to the acquisition and archival of HRSN data can be found in the 2005-06 BSL Annual Report.

In early 2006, the NCEDC started to receive the HRSN 20 Hz data and a subset of the 250 Hz data in real-time for distribution through the DART. The NCEDC continued to archive continuous 250 Hz and 20 Hz data streams from the HRSN tapes written in Parkfield and processed at the NCEDC. In early 2007, the BSL established a radio telemetry link from the HRSN recording center at the California Department of Forestry (CDF) in Parkfield to Carr Hill, and started to telemeter all HRSN continuously to Carr Hill. These data are fed into the NCSN backup Earthworm system at Carr Hill, and are also routed through the USGS Parkfield and the NCEMC T1 between USGS/MP and the BSL for real-time processing by the NCEMC earthquake processing system. The data are also made available to users through the NCEDC DART, and are continuously archived at the NCEDC.

EarthScope USArray Transportable Array

EarthScope began installing broadband stations for the Transportable Array component of USArray in California in 2005. The NCEDC started acquiring telemetered continuous data from the northern California and surrounding stations as they were installed, and is archiving these data to support users working with northern California seismic data. These data are made available to users using the same data request methods as all other continuous data waveform data at the NCEDC. The Transportable Array stations have a limited operational timespan of 18 to 24 months, after which they will be relocated to new sites across the country. Data from these stations are delivered to the NCEDC as they are received by the BSL for distribution through the DART.

EarthScope Plate Boundary Observatory (PBO) strain data

The NCEDC is one of two funded archives for PBO EarthScope borehole and laser strain data. Strain data are collected from all of the PBO strain sites and are processed by UNAVCO. MiniSEED data are delivered to the NCEDC using SeedLink, and raw and XML processed data are delivered to the NCEDC using Unidata's Local Data Manager (LDM). The MiniSEED data are inserted into the NCEDC DART, and are subsequently archived from the DART. UNAVCO provides EarthScope funding to the NCEDC to help cover the processing, archiving, and distribution costs for these data.

EarthScope SAFOD

The NCEDC is designated as the primary archive center for the SAFOD event data, and will also process the continuous SAFOD data. Starting in July 2002, scientists from Duke University successfully installed a three component 32 level downhole-seismic array in the pilot hole at the EarthScope SAFOD site in collaboration with Steve Hickman (USGS), Mark Zoback (Stanford University) and the Oyo Geospace Engineering Resources International (GERI) Corporation. High frequency event recordings from this array have been provided by Duke University for archiving at the NCEDC. We converted data from the original SEG-2 format data files to MiniSEED, and have developed the SEED instrument responses for this data set. Continuous 4 KHz data from SAFOD are written to tape at SAFOD, and are periodically sent to the BSL to be converted, archived, and forwarded to the IRIS DMC. SAFOD EarthScope funding to the NCEDC is to cover the processing, archiving, and distribution costs for these data. A small subset of the continuous SAFOD data channels are also incorporated into the NCSN, are available in real-time from the NCEDC DART, are archived at the NCEDC, and are forwarded to the IRIS DMC.

UNR Broadband data

The University of Reno in Nevada (UNR) operates several broadband stations in western Nevada and eastern California that are important for northern California earthquake processing and analysis. Starting in August 2000, the NCEDC has been receiving and archiving continuous broadband data from four UNR stations. The data are transmitted in real-time from UNR to UC Berkeley, where they are made available for CISN real-time earthquake processing and for archiving. Initially, some of the stations were sampled at 20 Hz, but all stations are now sampled and archived continuously at 100 Hz.

The NCEDC installed Simple Wave Server (SWS) software at UNR, which provides an interface to UNR's recent collection of waveforms. The SWS is used by the NCEDC to retrieve waveforms from UNR that were missing at the NCEDC due to real-time telemetry outages between UNR and UC Berkeley.

In early 2006, the NCEDC started to archive continuous data from the UNR short-period stations that are contributed to the NCSN. Both the broadband and short-period UNR stations contributed to the CISN are available in real-time through the NCEDC DART.

Electro-Magnetic Data

The NCEDC continues to archive and process electric and magnetic field data acquired at several UC Berkeley sites. The BSL operates both magnetic and electric field sensors at PKD and SAO. Through a collaboration with Dr. Simon Klemperer at Standord University, we acquire magnetic and electric field channels at BSL sites JRSC and BRIB, and magnetic field channels at site MHDL. The three magnetic field channels and either two or four electric field channels are digitized at 40 Hz, 1 Hz, and 0.1 Hz, and are telemetered in real-time along with seismic data to the Berkeley Seismological Laboratory, where they are processed and archived at the NCEDC in a similar fashion to the seismic data.

Using programs developed by Dr. Martin Fullerkrug at the Stanford University STAR Laboratory (now at the University of Bath), the NCEDC has computed and archived magnetic activity and Schumann resonance analysis using the 40 Hz data from this dataset. The magnetic activity and Schumann resonance data can be accessed from the Web. This processing was halted in mid 2005 due to problems with the code and will be resumed when the problems have been identified and corrected.

The NCEDC also archives data from a low-frequency, long-baseline electric field project operated by Dr. Steve Park of UC Riverside at site PKD2. These data are acquired and archived in an identical manner to the other electric field data at the NCEDC.

GPS Data

The NCEDC continues to archive GPS data through the BARD (Bay Area Regional Deformation) network of continuously monitored GPS receivers in northern California (Section 3.5.). The NCEDC GPS archive now includes 67 continuous sites in northern California. There are approximately 50 core BARD sites owned and operated by UC Berkeley, USGS (Menlo Park and Cascade Volcano Observatory), LLNL, UC Davis, UC Santa Cruz, Trimble Navigation, and Stanford. Data are also archived from sites operated by other agencies including East Bay Municipal Utilities District, the City of Modesto, the National Geodetic Survey, and the Jet Propulsion Laboratory.

In addition to the standard 15 second or 30 second continuous GPS datastream, the NCEDC is now privately archiving high-rate 1 Hz continuous GPS data from the 14 stations in Parkfield and from 10 BARD stations. The high-rate Parkfield data are collected by UNAVCO as part of the PBO Nucleus. The Parkfield data are available via anonymous FTP from the NCEDC but are currently not included in the GPS Seamless Archive (GSAC), since the GSAC does not currently handle both high-rate and low-rate data from the same site and day.

The NCEDC continues to archive non-continuous survey GPS data. The initial dataset archived is the survey GPS data collected by the 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 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 virtually all of the data from 1992 to the present has been archived and is available for distribution.

Geysers Seismic Data

The Calpine Corporation currently operates a microseismic monitoring network in the Geysers region of northern California. Prior to 1999 this network was operated by Unocal. Through various agreements, both Unocal and Calpine have released triggered event waveform data from 1989 through 2000 along with preliminary event catalogs for the same time period for archiving and distribution through the NCEDC. This dataset represents over 296,000 events that were recorded by Calpine/Unocal Geysers network, and are available via research accounts at the NCEDC.

The Lawrence Berkeley Laboratory (LBL), with funding from the California Energy Commission, operates a 22 station network in the Geysers region with an emphasis on monitoring seismicity related to well water injection. The earthquake locations and waveforms from this network are sent to the NCEDC, and the locations are forwarded to the NCSN so that they can be merged into the NCSN earthquake catalog. The LBL Geysers waveforms will be available at the NCEDC after the NCSN catalog has been migrated from flat files to the database. In 2007 the NCSN installed an Earthworm system at the Geysers to receive continuous LBL Geysers data, and this system provides event waveforms in real-time for the NCEMC earthquake procssing and the NCEDC event archives.

USGS Low Frequency Data

Over the last 30 years, the USGS at Menlo Park, in collaboration with other principal investigators, has collected an extensive low-frequency geophysical data set that contains over 1300 channels of tilt, tensor strain, dilatational strain, creep, magnetic field, and water level as well as auxiliary channels such as temperature, pore pressure, rain and snow accumulation, and wind speed. In collaboration with the USGS, we assembled the requisite information for the hardware representation of the stations and the instrument responses for many channels of this diverse dataset, and developed the required programs to populate and update the hardware database and generate the instrument responses. We developed the programs and procedures to automate the process of importing the raw waveform data and convert it to MiniSEED format. Since these data are delivered to the NCEDC on a daily basis and immediately archived, these data are not inserted into the NCEDC DART.

We have currently archived timeseries data from 887 data channels from 167 sites, and have instrument response information for 542 channels at 139 sites. The waveform archive is updated on a daily basis with data from 350 currently operating data channels. We will augment the raw data archive as additional instrument response information is assembled by the USGS for the channels and will work with the USGS to clearly define the attributes of the "processed" data channels.

SCSN/Statewide seismic data

In 2004 the NCEDC started to archive broadband and strong motion data from 15 SCSN (network CI) stations that are telemetered to the Northern California Management Center (NCEMC) of the California Integrated Seismic Network (CISN). These data are used in the prototype real-time state-wide earthquake processing system and also provide increased coverage for northern California events. Since the data are telemetered directly from the stations in real-time to both the SCSN and to the NCEMC, the NCEDC archives the NCEMC's copy of the data to ensure that at least one copy of the data will be preserved.

In early 2006, the NCEDC started to continuously archive all of the selected SCSN short-period stations that are contributed to the NCSN. All of these data are available in real-time from the NCEDC DART.

Earthquake Catalogs

Northern California: The NCEDC provides searchable access to both the USGS and BSL earthquake catalogs for northern and central California. The "official" UC Berkeley earthquake catalog begins in 1910 and runs through 2003, and the "official" USGS catalog begins in 1966. Both of these catalogs are archived and available through the NCEDC, but the existence of 2 catalogs has caused confusion among both researchers and the public.

In late 2006, the NCEMC begun to archive and distribute a single unified northern California earthquake catalog in real-time to the NCEDC through database replication from the NCEMC's real-time systems. The NCEDC has developed and is testing the required programs that will be used to enter all previous NCSN catalog data into the NCEDC database. We will then merge the BSL catalog with the NCEMC catalog to form a single unified northern California catalog from 1910 to the present. The BSL and the USGS have spent considerable effort over the past years to define procedures for merging the data from the two catalogs into a single northern and central California earthquake catalog in order to present a unified view of northern California seismicity. The differences in time period, variations in data availability, and mismatches in regions of coverage all complicate the task.

Worldwide: The NCEDC, in conjunction with the Council of the National Seismic System (CNSS), produced and distributed a world-wide composite catalog of earthquakes based on the catalogs of the national and various U.S. regional networks for several years. Each network updates their earthquake catalog on a daily basis at the NCEDC, and the NCEDC constructs a composite world-wide earthquake catalog by combining the data, removing duplicate entries that may occur from multiple networks recording an event, and giving priority to the data from each network's *authoritative region*. The catalog, which includes data from 14 regional and national networks, is searchable using a Web interface at the NCEDC. The catalog is also freely available to anyone via ftp over the internet.

With the demise of the CNSS and the development of the Advanced National Seismic System (ANSS), the NCEDC was asked to update its Web pages to present the composite catalog as a product of the ANSS. This conversion was completed in the fall of 2002. We continue to create, house, distribute, and provide a searchable web interface to the ANSS composite catalog, and to aid the regional networks in submitting data to the catalog.

3.6.5 NCEDC Operations

In 2005, the NCEDC relocated its archive and distribution system from McCone Hall to a new state-of-the-art computer facility in a new seismically braced building on the Berkeley campus. The facility provides seismically braced equipment racks, gigabit ethernet network, air conditioning, and power conditioning. The entire facility is powered by a UPS with generator backup.

The currently installed NCEDC facilities consist of a mass storage environment hosted by a Sun V240 host computer, a 100 slot LTO-2 tape library with two tape drives and a 20 TByte capacity, and 40 TBytes of RAID storage, all managed with the SAM-FS hierarchical storage management (HSM) software. A dual processor Sun Ultra 60 provides Web services and research account access to the NCEDC, a dual Sun 280R processor provide data import and export services, and a Sun Ultra 450 computer is used for quality control procedures. Two AIT tape libraries are used to read NCSN continuous data tapes. A 64-bit Linux system hosts a database dedicated to providing data to external users. Two Sun Opteron processors provide additional data processing support for the NCEDC.

The hardware and software system is configured to automatically create multiple copies of each timeseries file. The NCEDC creates an online copy of each file on online RAID, a second copy on LTO-2 tape which is stored online in the tape libraray, and a third copy on LTO-2 tape which is stored offline and offsite. All NCEDC data are online and rapidly accessible by users.

The NCEDC operates two instances of its Oracle database, one for internal operations and one for external use for user data queries and data distribution programs. The databases are synchronized using multi-master replication.

Data Quality Control

The NCEDC developed a GUI-based state-driven system *calqc* to facilitate the quality control processing that is applied to the continuously archived data sets at the NCEDC.

The quality control procedures for these datasets include the following tasks:

- data extraction of a full day of data,
- quickcheck program to summarize the quality and stability of the stations' clocks,
- determination if there is missing data for any data channel,
- provided procedures to retrieve missing data from the stations and incorporate it into the day's data,
- optional creation of multi-day timeseries plots for state-of-health data channels,
- optional timing corrections for data,
- optional extraction of event-based waveforms from continuous data channels,
- optional repacking of MiniSEED data,
- creating waveform inventory entries in the NCEDC database,
- publishing the data for remote access on the NCEDC.

Calqc uses previously developed programs to perform each function, but it provides a graphical point-and-click interface to automate these procedures, and to provide the analyst with a record of when each process was started, whether it executed correctly, and whether the analyst has indicated that a step has been completed. *Calqc* is used to process all data from the BDSN network, and all continuous broadband data from the NCSN, UNR, SCSN, and HRSN networks that are archived by the NCEDC. The remainder of the continuously archived data are automatically archived without any analyst interaction.

3.6.6 Database Development

Due to restrictions imposed by the USGS/MP NCSN CUSP event analysis system, the NCSN's authoritative catalog, phase data, amplitude, and coda readings were stored in flat files, rather than the NCEDC database. However, the NCEDC worked closely with the Northern California Earthquake Management Center (NCEMC) of the CISN to develop procedures allowing the USGS/MP to replace the CUSP analysis system with *jiggle*, the analysis tool developed by the SCSN, and to deliver earthquake parametric data in real-time to the NCEDC database. We developed the database tools to insert the NCEMC earthquake parametric information into databases in the real-time earthquake analysis systems, and extensively tested database replication between the NCEMC databases and the NCEDC database.

Starting in December 2006, the NCSN retired the CUSP system, and real-time earthquake parameters from the NCEMC has been inserted directly into the NCEMC and NCEDC databases, and reviewed with the *jiggle* analysis software. In collaboration with the NCSN, we developed the programs and procedures necessary to migrate the 1967-2006 NCSN catalog into the CISN parametric schema and have been performing quality control procedures on the data prior to entering the catalog into the database. During this time, we have continued to create flat-file hypoinverse files from the new data in the database in order to provide users with a single view of the entire NCSN catalog. Once the historic NCSN catalog has been entered into the database, the NCEDC will serve catalog and parametric searches from the database.

During 2002-2004, the NCEDC and NCSN jointly developed a system consisting of an extensive spreadsheet containing per-channel information that describes the hardware of each NCSN data channel and provides each channel with a SEED-compliant channel name. This spreadsheet, combined with a limited number of files that describe the central-site analog digitizer, FIR decimation filters, and general characteristics of digital acquisition systems, allows the NCSN to assemble its station history in a format that the NCEDC can use to populate the hardware tracking and instrument response database tables for the NCSN.

The NCEDC instrument response schema represents full multi-stage instrument responses (including filter coefficients) for the broadband data loggers. The hardware tracking schema represents the interconnection of instruments, amplifiers, filters, and data loggers over time, and is used to describe all of the UC Berkeley and USGS stations and channels archived at the NCEDC. All NCSN event waveform and continuous timeseries data has been converted from CUSP and Earthworm format to MiniSEED, and is available along with the UC Berkeley data and data from the other networks archived at the NCEDC in full SEED format.

The NCEDC has developed XML import and export procedures to provide better maintenance of the hardware tracking information and resulting instrument responses for stations in our database. When changes are made to either existing hardware or to station configurations, we export the current view in XML format, use a GUI-based XML editor to easily update the information, and import the changes back into the database. When adding new stations or hardware, we can easily use information from existing hardware or stations as templates for the new information. This allows us to treat the database as the authoritative source of information, and to use off-the-shelf tools such as the XML editor and XML differencing programs as part of our database maintenance procedures.

Additional details on the joint catalog effort and database schema development may be found at `http://www.ncedc.org/db`

3.6.7 Data Distribution

The NCEDC continues to use the World Wide Web as a principal interface for users to request, search, and receive data from the NCEDC. In fall 2005 the NCEDC acquired the domain name *ncedc.org*. The NCEDC's Web address is now `http://www.ncedc.org/`

Earthquake Catalogs

The NCEDC provides users with searchable access to northern California earthquake catalogs and to the ANSS world-wide catalog via the web. Users can search the catalogs by time, magnitude, and geographic region, and can retrieve either hypocenter and magnitude information or a full set of earthquake parameters including phase readings, amplitudes, and codas. Moment tensor results are now being added to the NCEMC California earthquake catalog.

Station Metadata

In addition to the metadata returned through the various data request methods, the NCECD provides dataless

SEED volumes and SEED RESP files for all data channels archived at the NCEDC. The NCEDC currently has full SEED instrument responses for 8462 data channels from 1379 stations in 14 networks. This includes stations from the California Geological Survey (CGS) strong motion stations that will contribute seismic waveform data for significant earthquakes to the NCEDC and SCEDC.

SeismiQuery

We have ported and installed the IRIS *SeismiQuery* program at the NCEDC, which provides a common interface to query network, station, and channel attributes and query the availability of archived timeseries data. We have provided both IRIS and the SCEC Data Center with our modified version of *SeismiQuery*.

DART (Data Available in Real Time)

The DART (Data Available in Real Time) represents the first step in NCEDC's effort to make current and recent timeseries data from all networks, stations, and channels available to users in real-time. The NCEDC developed DART in December 2005 to provide a mechanism for users to obtain access to real-time data from the NCEDC. All real-time timeseries data streams delivered to the NCEDC are placed in MiniSEED files in a web-accessible directory structure. The DART waveforms can be accessed by web browsers or http command-line programs such as *wget*, a *FISSURES* waveform server, and a Berkelely-developed Simple Wave Server (SWS) which provides programmatic access to the DART data by specified SEED channel and time interval. We will be providing users with a client program to retrieve data from the SWS in the near future. The DART currently provide assess to the most recent 30 days of data.

We are using the Freeorb software, an enhanced version of the open-source orb software developed by the IRIS-funded Joint Seismic Project (JSP), as the primary method for delivering real-time data to the NCEDC and into the DART. The freeorb package implements an object ring buffer (ORB) and orbserver, which provides a reliable storage ring buffer and an interface for orb client programs to read, write, and query the orbserver. Orbserver clients running at the NCEDC computer connect to remote orbservers at the BSL and USGS/Menlo Park, retrieve the MiniSEED timeseries data records, and write them to daily channel files in the NCEDC DART. Strain data from the EarthScope PBO network are delivered to the NCEDC using SeedLink, and are inserted into the DART using a similar SeedLink client program.

The NCEDC developed an automated data archiving system to archive data from the DART on a daily basis. It allows us to specify which stations should be automatically archived, and which stations should be handled by the NCEDC's Quality Control program *calqc*, which allows an analyst to review the waveforms, retrieve missing data from stations or waveservers that may have late-arriving, out-of-order data, and perform timing corrections on the waveform data. The majority of data channels are currently archived automatically from the DART.

NetDC

In a collaborative project with the IRIS DMC and other worldwide datacenters, the NCEDC helped develop and implement *NetDC*, a protocol which will provide a seamless user interface to multiple datacenters for geophysical network and station inventory, instrument responses, and data retrieval requests. The *NetDC* builds upon the foundation and concepts of the IRIS *BREQ_FAST* data request system. The *NetDC* system was put into production in January 2000, and is currently operational at several datacenters worldwide, including NCEDC, IRIS DMC, ORFEUS, Geoscope, and SCEDC. The *NetDC* system receives user requests via email, automatically routes the appropriate portion of the requests to the appropriate datacenter, optionally aggregates the responses from the various datacenters, and delivers the data (or ftp pointers to the data) to the users via email.

STP

In 2002, the NCEDC wrote a collaborative proposal with the SCEDC to the Southern California Earthquake Center, with the goal of unifying data access between the two data centers. As part of this project, the NCEDC and SCEDC are working to support a common set of 3 tools for accessing waveform and parametric data: *SeismiQuery*, *NetDC*, and *STP*.

The *Seismogram Transfer Program* or *STP* is a simple client-server program, developed at the SCEDC. Access to *STP* is either through a simple direct interface that is available for Sun or Linux platforms, or through a GUI Web interface. With the direct interface, the data are placed directly on a user's computer in several possible formats, with the byte-swap conversion performed automatically. With the Web interface, the selected and converted data are retrieved with a single ftp command. The *STP* interface also allows rapid access to parametric data such as hypocenters and phases.

The NCEDC has continued work on *STP*, working with the SCEDC on extensions and needed additions. We added support for the full SEED channel name (Station, Network, Channel, and Location), and are now able to return event-associated waveforms from the NCSN waveform archive.

EVT_FAST

In order to provide Web access to the NCSN waveform before the SEED conversion and instrument response for the NCSN has been completed, the NCEDC implemented *EVT_FAST*, an interim email-based waveform request system similar to the *BREQ_FAST* email request system. Users email *EVT_FAST* requests to the NCEDC and request NCSN waveform data based on the NCSN event id. Initially the NCSN waveform data was converted to either SAC ASCII, SAC binary, or AH format, and placed in the anonymous ftp directory for retrieval by the users. *EVT_FAST* event waveforms can now also be provided in MiniSEED format, and are now named with their SEED channel names.

FISSURES

The *FISSURES* project developed from an initiative by IRIS to improve earth scientists' efficiency by developing a unified environment that can provide interactive or programmatic access to waveform data and the corresponding metadata for instrument response, as well as station and channel inventory information. *FISSURES* was developed using CORBA (Common Object Request Broker Architecture) as the architecture to implement a system-independent method for the exchange of this binary data. The IRIS DMC developed a series of services, referred to as the *Data Handling Interface (DHI)*, using the *FISSURES* architecture to provide waveform and metadata from the IRIS DMC.

The NCEDC has implemented the *FISSURES Data Handling Interface (DHI)* services at the NCEDC, which involves interfacing the DHI servers with the NCEDC database schema. These services interact with the NCEDC database and data storage system, and can deliver NCEDC channel metadata as well as waveforms using the *FISSURES* interfaces. We have separate *FISSURES DHI* waveform servers to serve archived and DART data stream. Our *FISSURES* servers are registed with the IRIS *FISSURES naming services*, which ensures that all *FISSURES* users have transparent access to data from the NCEDC.

GSAC

Since 1997, the NCEDC has collaborated with UNAVCO and other members of the GPS community on the development of the *GPS Seamless Archive Centers (GSAC)* project. This project allows a user to access the most current version of GPS data and metadata from distributed archive locations. The NCEDC is participating at several levels in the *GSAC* project: as a primary provider of data collected from core BARD stations and USGS MP surveys, and as a wholesale collection point for other data collected in northern California. We helped to define database schema and file formats for the *GSAC* project, and have produced complete and incremental monumentation and data holdings files describing the data sets that are produced by the BARD project or archived at the NCEDC so that other members of the *GSAC* community can provide up-to-date information about our holdings. Currently, the NCEDC is the primary provider for over 138,000 data files from over 1400 continuous and survey-mode monuments. The data holdings records for these data have been incorporated into the *GSAC* retailer system, which became publicly available in late 2002.

In addition, the NCEDC is archiving and distributing high-rate 1 Hz GPS data from 10 BARD stations in addition to the normally sampled 15 second or 30 second data. These high-rate data are currently available only to UCB and USGS/MP researchers as we develop the appropriate techniques for processing these data.

3.6.8 Acknowledgements

The NCEDC is a joint project of the BSL and the USGS Menlo Park and is funded primarily by the BSL and the USGS. Additional funding for the handling and archiving of the EarthScope PBO and SAFOD data is provided through subawards from the respective NSF EarthScope projects.

Doug Neuhauser is the manager of the NCEDC. Stephane Zuzlewski, Rick McKenzie, Mario Aranha, Nicolas Houlie, Bob Uhrhammer, and Peggy Hellweg of the BSL and David Oppenheimer, Hal Macbeth, and Fred Klein of the USGS Menlo Park contribute to the operation of the NCEDC. Doug Neuhauser, Peggy Hellweg and Stephane Zuzlewski contributed to the preparation of this section.

3.7. Data Acquisition and Quality Control

3.7.1 Introduction

Stations from the networks operated by the BSL transmit data continuously to the BSL facilities on the UC Berkeley campus for analysis and archival. In this chapter, we describe activities and facilities which pertain to the individual networks described in Sections 3.1., 3.3. and 3.4., including procedures for data acquisition and quality control, and sensor testing capabilities and procedures. Some of these activities are continuous from year to year and have been described in prior BSL annual reports. In this section, we describe changes or activities which are specific to 2006-2007.

3.7.2 Data Acquisition Facilities

Before 2005-2006, both the BSL staff monitoring routine data acquisition and the computers and facilities to acquire, process and archive the data were located in McCone Hall. Since 2006, the computers and telemetry equipment associated with data acquisition reside in the new campus computer facility at 2195 Hearst Avenue. This building was constructed to current "emergency grade" seismic codes, and is expected to be operational even after a M 7 earthquake on the nearby Hayward Fault. The hardened campus computer facility within was designed with special attention for post-earthquake operations. The computer center contains state-of-the art seismic bracing, UPS power and air conditioning with generator backup, and extensive security and equipment monitoring. With the move of many BSL and NCEDC operations servers to the campus computer center, the generator power and air conditioning resources in the BSL server room in 237 McCone better match our needs for the infrastructure remaining in McCone Hall. The BSL generator is maintained by Physical Plant Capital Services and was run without load twice monthly.

3.7.3 Data Acquisition

Central-site data acquisition for data from the BDSN/NHFN/MPBO networks is performed by two computer systems in the 2195 Hearst Avenue data center (Figure 3.24). These acquisition systems also collect data from the Parkfield-Hollister electromagnetic array and for the BARD network. A third system is used primarily for data exchange with the USNSN and transmits data to the USNSN from HOPS, CMB, SAO, WDC, HUMO, MOD, MCCM, and YBH. Data acquisition for the HRSN follows a more complicated path, as described in Section 3.4.. During the year, we also collected data from US-Array travelling array stations deployed in Northern and Central California from the orb-server of the Anza Network Facility at the University of California San Diego.

The BSL uses the program `comserv` developed by Quanterra for central data acquisition. This program receives data from a remote Quanterra data logger, and redistributes the data to one or more comserv client programs. The comserv clients used by REDI include `datalog`, which writes the data to disk files for archival purposes, `cdafill`, which writes the data to the shared memory region for REDI analysis, and other programs such as the seismic alarm process, the DAC480 system, and the feed for the Memento Mori Web page (Figure 3.25).

The two computers performing data acquisition also serve as REDI processing systems and hold the databases now used by these systems for storing earthquake information. In order to facilitate REDI processing, each system maintains a shared memory region that contains the most recent 30 minutes of data for each channel used by the REDI analysis system. All REDI analysis routines first attempt to use data in the shared memory region, and will only revert to retrieving data from disk files if the requested data is unavailable in the shared memory region.

Each BDSN datalogger that uses frame relay telemetry is configured to enable data transmission simultaneously to two different computers over two different frame relay T1 circuits to UCB. However, the BSL normally actively enables and uses only one of these data streams from each station at any given time. The `comserv` client program `cs2m` receives data from a comserv and multicasts the data over a private ethernet. The program `mcast`, a modified version of Quanterra's `comserv` program, receives the multicast data from `cs2m`, and provides a comserv-like interface to local comserv clients. This allows each REDI system to have a comserv server for every station, and each of the two systems has a complete copy of all waveform data.

We have extended the multicasting approach to handle data received from other networks such as the NCSN and UNR. These data are received by Earthworm data exchange programs, and are then converted to MiniSEED and multicast in the same manner as the BSL data. We use `mserv` on both REDI computers to receive the multicast data, and handle it in an identical fashion to the BSL MiniSEED data.

In 2006, the BSL established a real-time data feed of all BSL waveforms between the BSL acquisition systems and the NCEDC computers using the open source Free-orb software. This allows the NCEDC to provide near-real-time access to all BSL waveform data through the

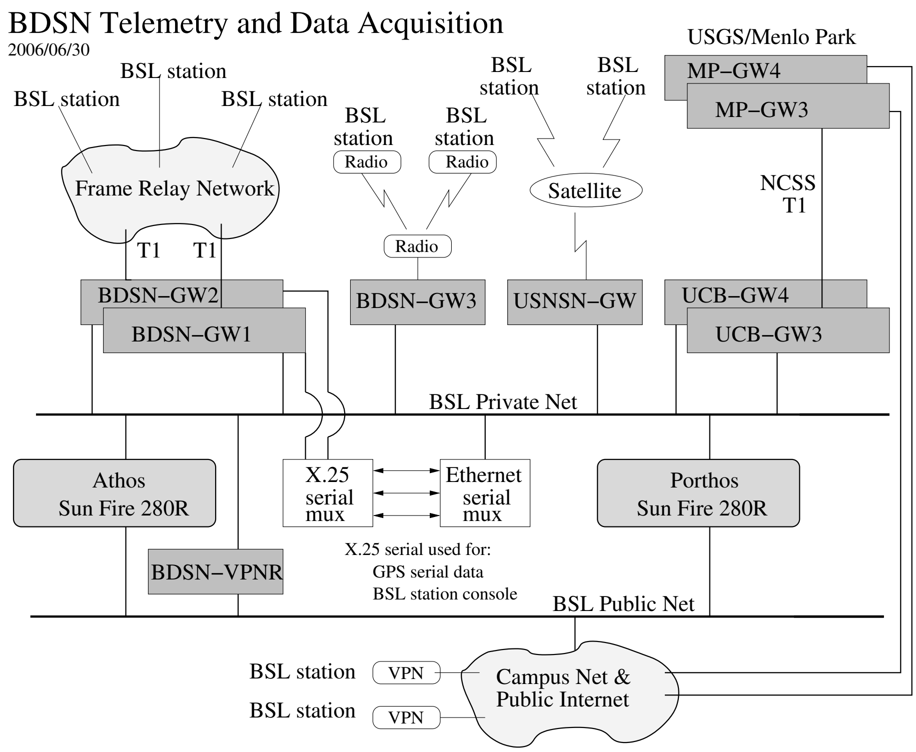

Figure 3.24: Data flow from the BDSN, NHFN, MPBO, HRSN, and BARD network into the BSL central processing facility.

NCEDC DART (Data Availabile in Real Time) system.

3.7.4 Seismic Noise Analysis

BSL seismic data are routinely monitored for state-of-health. An automated analysis is computed regularly to characterize the seismic noise level recorded by each broadband seismometer.

PSD Noise Analysis

The estimation of the Power Spectral Density (PSD) of the ground motion recorded at a seismic station, as documented in the 2000-2001 BSL annual report (`http://seismo.berkeley.edu/annual_report/ar00_01/`), provides an objective measure of background seismic noise characteristics over a wide range of frequencies. When used routinely, the PSD algorithm also provides an objective measure of seasonal and secular variation in the noise characteristics and aids in the early diagnoses of instrumental problems. A PSD estimation algorithm was developed in the early 1990's at the BSL for characterizing the background seismic noise and as a tool for quality control. As presently implemented, the algorithm sends the results via email to the engineering and some research staff members and generates a bar graph output which compares all the BDSN broadband stations by components. A summary of the results for 2006 is displayed in Figure 3.4. We also use the weekly PSD results to monitor trends in the noise level at each station. Figures showing the analysis for the current year are produced. These cumulative PSD plots are generated for each station and show the noise level in 5 frequency bands for the broadband channels. These plots make it easier to spot certain problems, such as failure of a sensor. In addition to the station-based plots, a summary plot for each channel is produced, comparing all stations. These figures are presented as part of a noise analysis of the BDSN on the WWW at `http://www.seismo.berkeley.edu/seismo/bdsn/psd/`.

PDF Noise Analysis

In addition to the PSD analysis developed by Bob Uhrhammer, the BSL has implemented the Ambient Noise Probability Density Function (PDF) analysis system developed by *McNamara and Buland* (2004). This system does its noise analysis over all the data of a given time period (week or year), including earthquakes, calibration pulses, and cultural noise. This is in contrast to Bob Uhrhammer's PSD analysis, which looks at only the quietest portion of data within a day or week. Pete Lombard of the BSL extended the McNamara code to cover a larger frequency range and support the many different types of sensors employed by the

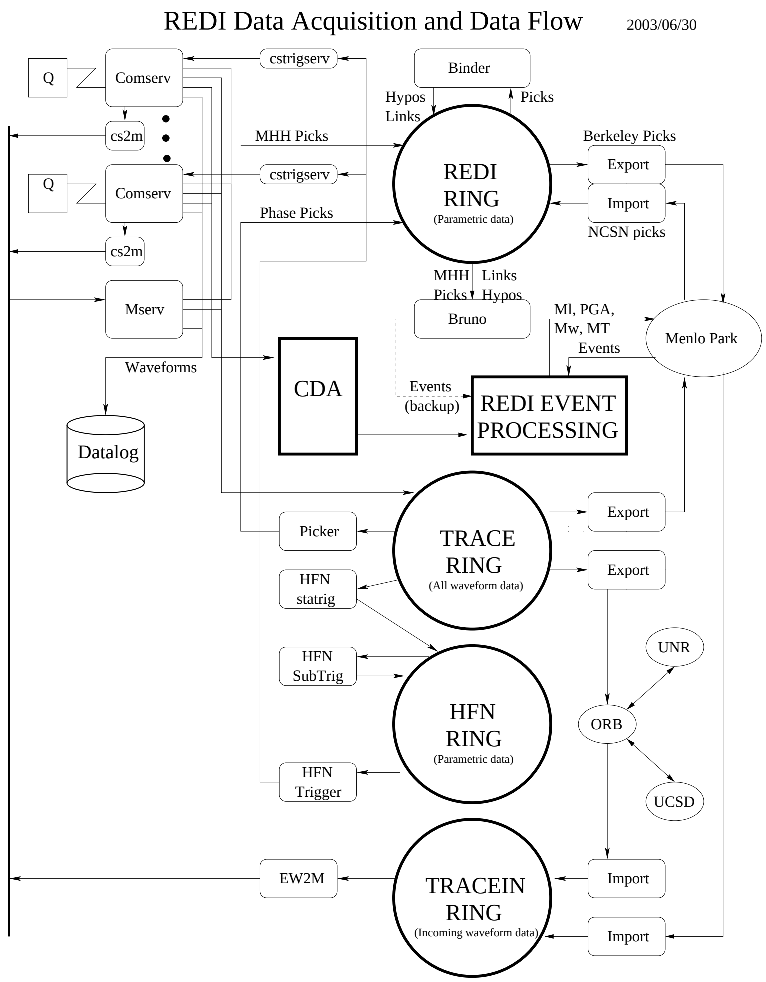

Figure 3.25: Dataflow in the REDI processing environment, showing waveform data coming in from the Quanterra data loggers (Q) into `comserv`. From comserv, data are logged to disk (via `datalog`), distributed to other computers (`mserv`), fed into the CDA for REDI processing, and spooled into a trace ring for export.

BSL. Besides the originally supported broadband sensors, our PDF analysis now includes surface and borehole accelerometers, strain meters, and electric and magnetic field sensors. These enhancements to the PDF code, plus a number of bug fixes, were provided back to the McNamara team for incorporation in their work. The results of the PDF analysis are presented on the web at `http://www.ncedc.org/ncedc/PDF/`. One difficulty with using these plots for review of station quality is that it is necessary to look at data from each component separately. To provide an overview, we have developed summary figures for all components in two spectral bands, 30 - 60 s and 0.125 - 0.25 s. Figure 3.26 shows these overviews for 2006. As the processing takes place shortly after the data arrives at the datacenter, data gaps may be present (white areas) in these plots. Most of these gaps have been filled by retrieving data from the stations.

3.7.5 Sensor Testing Facility

The BSL had set up an Instrumentation Test Facility in the Byerly Seismographic Vault in order to systematically determine and compare the characteristics of up to eight sensors at a time. The test equipment consists of an eight-channel Quanterra Q4120 high-resolution data logger and a custom interconnect panel that provides isolated power and preamplification, when required, to facilitate the connection and routing of signals from the sensors to the data logger with shielded signal lines. A GPS rebroadcaster has also been installed, so that all data loggers in the Byerly vault operate on the same time base. Upon acquisition of data at up to 200 samples-per-second (sps) from the instruments under test, PSD analysis, coherence analysis and additional ad hoc analysis algorithms are used to characterize and compare the performance of each sensor. Tilt tests and seismic signals with a sufficient signal level above the background

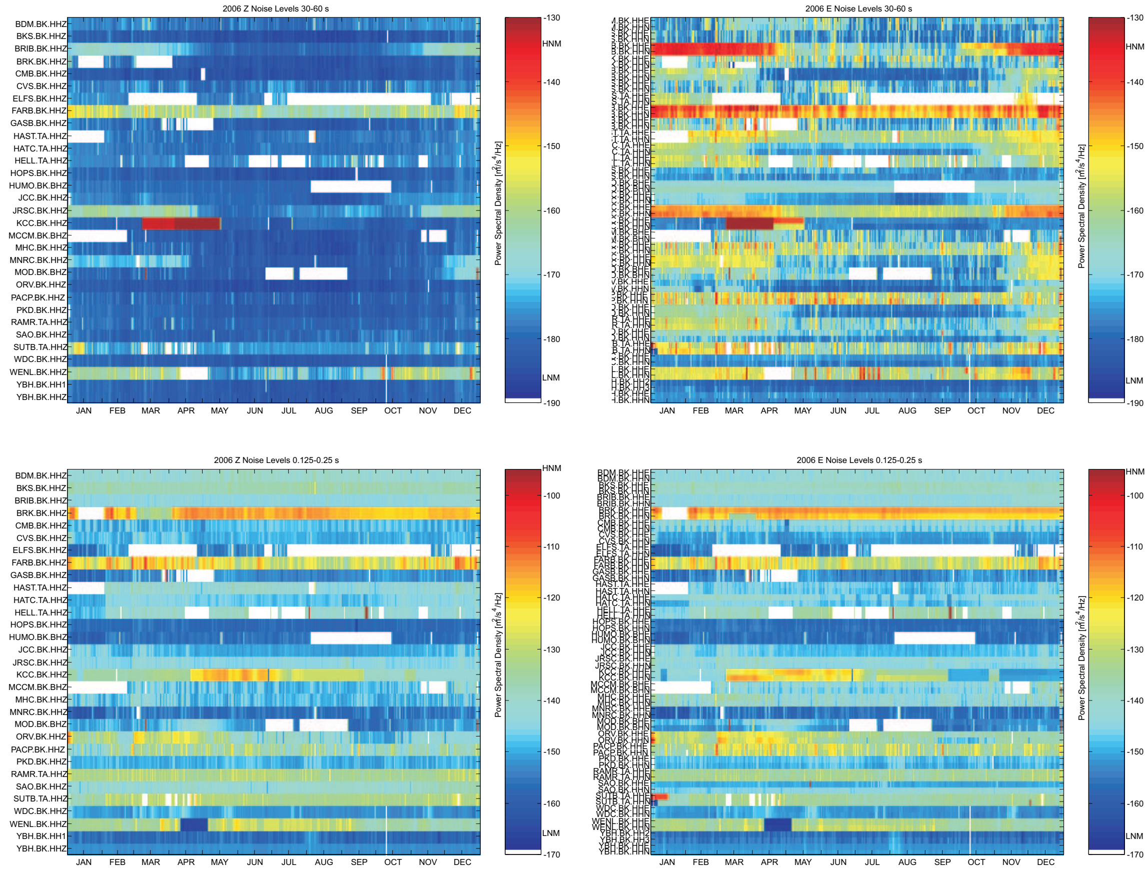

Figure 3.26: Noise overview taken from the PDF analysis for 2006 for BDSN stations. The top row shows daily minimum noise levels for the vertical (left) and horizontal (right) stations in the band 30 - 60 s. The lower row shows corresponding values in the band 0.125 - 0.25 s. White areas indicate times when realtime data are missing. Most such gaps have been filled in the datacenter archive by retrieving the data from the datalogger. The high noise level for KCC in the spring shows when water is running past the seismometers through the tunnel.

seismic noise are also used to verify the absolute calibration of the sensors. A simple vertical shake table is used to assess the linearity of a seismic sensor. The sensor testing facility of the BSL is described in detail in the BSL 2001-2002 Annual Report (available on-line at `http://www.seismo.berkeley.edu/`).

3.7.6 STS-1 Electronics Development

The STS-1 seismometer is currently the principal very broad-band (VBB) seismometer used in global or regional seismic networks operated by members of the Federation of Digital Broad-Band Seismograph Networks (FDSN). It is widely viewed as the finest VBB sensor in the world. Unfortunately, many of the STS-1's, which were manufactured and installed 10-20 years ago, are encountering both operational failures and age-related degradation. This problem is exacerbated by the fact that sensors are no longer being produced or supported by the original manufacturer, G. Streckeisen AG. In a first step towards assuring continued high quality of VBB data for decades to come, we have developed and tested new electronics and methods for mechanical repair for the STS-1 very broadband seismometer. A primary goal of this effort was to develop a fully-tested, modern electronics module that will be a drop-in replacement for the original electronics. This new electronics design addresses environmental packaging problems that have led to operational errors and failures in the existing instruments. This effort also provided the opportunity to implement a set of electronic improvements that will make the installation and operation of the sensors more efficient. Metrozet developed the first prototype new electronics for the STS-1, while the BSL engineering staff prepared a test-bed at the Byerly Vault (BKS) and developed the capability to simultaneously test 6-8 STS-1 components. BSL staff then tested and analysed results from successive versions of the electronics.

The first generation prototype electronics did not include centering or calibration functionality. The second generation prototype included remote centering functionality as well as calibration functions. After some observations and refinements, this generation of electronics was operated on two seismometers concurrently and successfully run through the swept and stepped calibration functions on four seismometers. During this final phase, the Metrozet electronics included the ability to initiate and operate the calibrations via a network (ethernet) connection. Most of the calibration testing was performed remotely from Metrozet's Southern California office over the BSL network. Metrozet was able to remotely log into the Berkeley network, establish a connection to the test bed in the Byerly seismic vault, and initiate control of the seismometer, including remote centering and calibration functions.

In the final stage of the project, once the BSL tests were completed and the development appeared complete and satisfactory, the new electronics were finally tested at the Albuquerque Seismological Laboratory's seismic vault, which is located in a quieter environment than BKS. The new electronics are currently being field tested at the BDSN broadband station HOPS.

Data Logger Calibration

Prior to the tests on the new STS-1 electronics, the Instrumentation Test Facility eight-channel Quanterra Q4120 data logger (serial number 103064) was operated in the BDSN for 8 years. In July 2004, it was repaired, and the calibration was checked by the factory. At the beginning of these tests, the sensitivity, noise floor and crosstalk of the data logger were checked using a reference signal applied first simultaneously and then sequentially to all channels, with the non-driven channels terminated. The relative sensitivities of the data logger channels were checked by applying a high-level (19.8 V peak-to-peak) 1 Hz square wave signal simultaneously to all channels. The signal level on each channel was measured and the relative signal levels were compared to the sensitivities on the factory calibration sheet. The results are given in Table 3.15. The sensitivities of four of the channels have not changed by more than $\pm 0.01\%$ from the factory calibration values. Of the remaining four channels, three changed by less than $\pm 0.3\%$ and the fourth changed by -0.8%.

The Q4120 data logger contains two 4-channel digitizer modules (HH1-HH4 and HH5-HH8). The inter-channel cross-talk was checked by connecting each of the channels in sequence with the high amplitude (20 V P-P) 1 Hz square-wave signal while terminating the other seven channels. The observed cross-talk signal on all channels is below the 2.38 μV quantization level of the Q4120 data logger. The cross-talk is thus more than 138.5 dB below the drive signal level. A check of the phase coherence between channels was performed by driving channel HH1 with a 20 V P-P 1 Hz square wave while terminating channels HH2-HH8 with 1k resistors. Spectral phase coherence analysis of the signal between selected channels (HH1-HH2, HH3-HH4, HH5-HH6, and HH7-HH8) shows that there is an inter-channel coherent phase comb present with peaks at 1 Hz and its odd harmonics, on channels within the same digitizer module, when HH1 is driven. At the same time, channels HH5-HH8, which are on a different digitizer module, exhibit no significant inter-channel phase coherence structure.

Seismometer Acquisition and Alignment

After the data logger was calibrated, it was necessary to establish a stable seismometer subsystem test bed. Nine different STS1 instruments (six horizontal, and three vertical instruments) from a variety of sources were used. These sensors came from among the available BDSN sensors, from surplus sensors on loan from the Gräfenberg Array and from IGPP, UC San Diego. The instruments were set up and leveled, and the outputs to the Q4120 data logger were compared quantitatively. The sensors were systematically inspected and checked for nominal operation, and the ones that performed the best were selected for the testing procedures and installed in the test bed. The horizontal instruments were aligned along a single axis, toward the East, enabling coherency comparisons and evaluations. Misalignment of less than one degree across the six horizontal instruments caused unacceptable variances in signal coherency. It took a week to resolve these differences by rotating the individual instruments. Alignment of the vertical instruments was much easier. Only after all alignment incoherences were resolved were the new Metrozet electronics evaluated against the original Streckeisen factory electronics. The broadband STS-1 sensors listed in Table 3.16 were utilized during the testing procedures.

Sensor Testing Timeline

The performance testing at BSL occurred in stages, with most work being performed between July 2006 and January 2007. The calibration of the data logger took over three weeks due to a number of back-to-back system failures, including the power supply, and dead data channels. During three weeks in August 2006, the initial six STS-1's (four horizontal, two vertical) were set-up as near identical (baseplates, cables, bell jars etc.) as possible.

It was during this portion of the testing that sensor to sensor coherency issues arose. The vertical sensors showed high levels of coherency, while the slightest misalignment of the horizontal instruments caused unacceptable incoherence in the horizontal instruments. All

Channel	Factory DU/V	P-P counts	Est P-P volts	Deviation %
1	403640	8012274	19.850050	-0.29
2	435388	8689678	19.958469	-0.83
3	437149	8651000	19.789591	+0.01
4	422829	8365690	19.785043	+0.01
5	420706	8314894	19.764144	+0.14
6	430613	8548404	19.851709	-0.30
7	438570	8680904	19.793657	-0.01
8	434817	8600236	19.778978	+0.01

Table 3.15: Quanterra Q4120 Calibration Check. Deviation is relative to the median inferred drive level of 19.791624 Volts.

Serial Number	Component	Source	Note
9	V	GRF	1
13	V	GRF	1
14	H	GRF	1
18	H	GRF	1
unknown	V	GRF	1
18718	H	IGPP/UCSD	2, 3
29201	H	BSL	4, 7
29212	H	BSL	4, 7
38502	V	BSL	3, 4, 7
38505	V	BKS Reference	3, 5
39010	H	BSL	4
39039	H	IGPP/UCSD	2, 3, 6, 7
48530	H	BSL	3, 4
48531	H	BKS Reference	3, 5
109112	V	BSL	4, 7
109124	V	BSL	4, 7

Table 3.16: STS-1 sensors. Notes: 1 - Gräfenberg (GRF) sent five seismometers total; three vertical, and two horizontal sensors. These BB instruments were some of the earliest produced by Streckeisen. While the sensors themselves are nearly identical to the later VBB instrument Streckeisen produced, the connector and electronics are sufficiently different that these were not used as part of the response test bed. These instruments were extremely useful in evaluation of the hinges, manufacture and assembly of these instruments. Gräfenberg also provided shielding, vacuum enclosures, and warpless base plates that were used. 2 - IGPP/UCSD sent two horizontal seismometers. 3 - These sensors were shipped from Streckeisen as 20 sec BB seismometers and later upgraded to 360 sec VBB seismometers. 4 - BSL provided STS-1 seismometers. 5 - These co-sited BKS STS-1's in the Byerly Seismic Vault are used as reference. 6 - Sensor was shipped with a mismatched Streckeisen electronics box (s/n 6824). 7 - These STS-1's were ultimately selected and used in the test bed.

possible causes for the incoherence were investigated and documented during the next 3-4 weeks. Possible causes included system timing, grounding, vacuum levels, and the seismometers themselves. Over a period of a week, the horizontal instruments were rotated slightly until the coherence began to improve in a predictable fashion.

Thus, seven weeks after BSL began to work on this project, the first meaningful tests of the Metrozet electronics began. Each set of electronics was paired with each of the seismometers in succession, with the pairing lasting at least twenty four hours. Approximately three weeks after this initial rotation through the seismometers was completed, Metrozet produced the second set of prototype electronics. Progress continued in similar two to three week increments until January of 2007, at which time the new electronics and calibration systems had been paired with and evaluated on seven different STS1 seismometers.

Coherence and Power Spectral Density

An algorithm "scn_psd" to calculate the signal Power Spectral Density (PSD), the noise PSD and the coherence

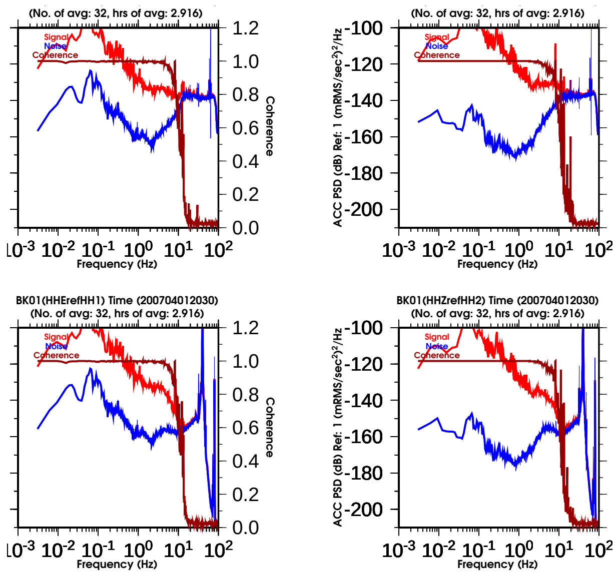

Figure 3.27: Results for two vertical component STS-1's (HHZ and HH2) and two horizontal component STS-1's (HHE and HH1) in the presence of a large seismic signal. The event is a Me 8.1 earthquake which occurred 87.9 degrees WSW of Berkeley at 20:39 UT on 2007/04/01. Shown are the signal PSD (red), the noise PSD (blue) and the coherence (brown) for each sensor. In all tests, the corresponding BKS STS-1's are used as the reference signals in the analysis. In the presence of large seismic signals, the coherence is typically close to unity at all frequencies below the 5 Hz high-frequency corner of the BKS reference STS-1's. Note the relatively high noise PSD level on the horizontal components in the vicinity of 0.1 Hz. This is due to a slight misalignment of the sensitive axes of the horizontal components. Several time consuming trial and error iterations in aligning the horizontal components are required to lower the horizontal component noise PSD. Three continuous hours of 200 Hz data are used by the scn_psd algorithm. scn_psd parses the data into 32 non-overlapping samples, applies a hanning window, corrects for the effects of the hanning window, scales the data to ground motion, calculates the FFT, and stores the resulting complex spectral values for each sample. At each frequency, the RMS signal PSD is calculated from the average of the complex spectral values, coherence is calculated from the averaged complex spectral cross product, and the RMS noise PSD is then determined from the product of the signal PSD and (1 - coherence). The method is described in detail in Gardner (1992).

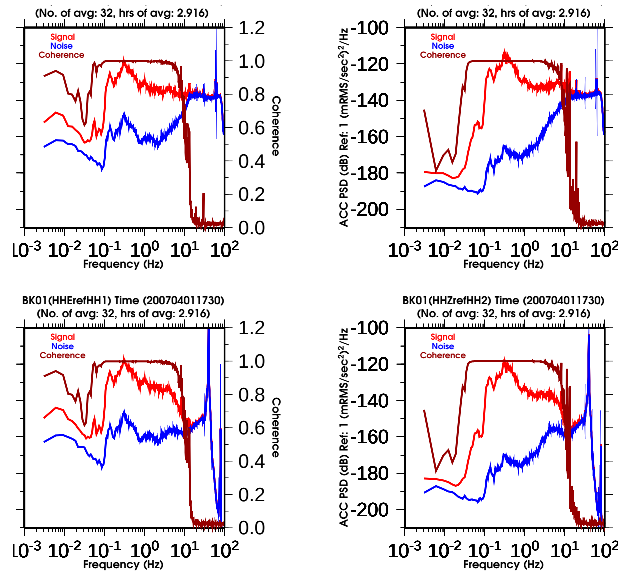

Figure 3.28: Results for the STS-1's in the presence of background noise. The traces are the same as in Figure 3.27. The lower and upper frequencies at which the coherence degrades from near unity varies among the sensors. Coherence bandwidth is a measure of the performance of the sensors.

between sensors has been developed as a tool for quantifying the performance differences between the seismic sensors under test. Two sample results of the algorithm are shown. Figure 3.27 shows the results for four seismometers in the case of a large seismic event and Figure 3.28 shows the results for four seismometers in the case of background noise.

Seismometer Frequency Response

Algorithms were developed to determine the free period (T_s) and fraction of critical damping (h_s) and to determine the high-frequency corner (f_g) and fraction of critical damping (h_g) parameters by measuring the frequency response of the seismometer to known stimuli. The free period (T_s) and fraction of critical damping (h_s), which describe the low-frequency response, were determined via a grid search for the maximum variance reduction between the observed response and the theoretical time series response to a 40-1100 second period swept sine wave. The high-frequency corner (f_g) and fraction of critical damping (h_g), which describe the high-frequency response, were determined via a grid search for the maximum variance reduction between the observed response and the theoretical phase response to a 0.5-40 Hz stepped sine wave. Both of these stimuli are generated by the Metrozet E300 electronics as well as output to the STS-1 calibration coils, and they can be remotely invoked. Figure 3.29 shows an example of the observed and theoretical time series response to the swept sine wave stimulus, and Figure 3.30 shows an example of the observed and theoretical phase response to the stepped sine wave stimulus.

Comp	S/N	Streckeisen BRB V/(m/s)	Streckeisen LP V/(m/s^2)	Metrozet BRB V/(m/s)	Metrozet LP V/(m/s^2)	Percent Change
Z	109114	2452	83.4	2386	80.5	-2.7
N	29219	2284	77.4	1984	66.9	-13.1
E	29215	2304	78.0	1993	67.0	-13.5

Table 3.17: Comparison of the sensitivities of the HOPS STS-1's with Streckeisen and with Metrozet electronics. The Streckeisen sensitivities were obtained from the factory calibration sheets supplied with each seismometer. The Metrozet sensitivities were calculated using the STS-1 Calibration Software Applet supplied by Metrozet.

Comp	T_s	h_s	f_g	h_g	C
Z	360.08	0.6768	15.00	0.371	0.00939
N	362.93	0.6889	16.28	0.328	0.00909
E	388.37	0.9920	16.29	0.343	0.00844

Table 3.18: HOPS STS-1 calibration results.

Field Testing at BDSN Station Hopland (HOPS)

On June 7, 2007, a Metrozet STS-1-E300-10-005 electronics box was installed in place of the Streckeisen factory supplied electronics boxes on the three STS-1 broadband seismometers operating at HOPS. As a result of this change, the flat pass band sensitivities of the STS-1 BRB and LP outputs changed as shown in Table 3.17.

As described in the previous section, the frequency responses of the three STS-1 seismometers with Metrozet E300 electronics were determined from their measured responses to swept sine and stepped sine stimuli. The results are listed in Table 3.18.

The constant "C" in Table 3.18 is an empirically derived scaling factor which scales the stimulus signal so that the calculated times series best agrees with the observed time series in a least-squares sense. "C" is proportional to the product of the calibration coil generator constant, the flat passband velocity sensitivity of the seismometer and the sensitivity of the data logger. This and other tests allowed the development of recommendations for the use of the new remote calibration procedures provided with the Metrozet E300 electronics.

Conclusions

The coherence analysis and the calibration analysis results are evidence that the Metrozet prototype E300 STS-1 electronics are working and that they can successfully replace the original Streckeisen electronics boxes. The new electronics also has the added advantages that it is web accessible and that it has built-in step and sinusoidal calibration stimuli which can be invoked remotely. Another advantage of the new electronics is that the high frequency corner is nominally 15 Hz while the Streckeisen high-frequency corner is 10 Hz.

3.7.7 Acknowledgements

Doug Neuhauser, Bob Uhrhammer, Peggy Hellweg, Pete Lombard, Rick McKenzie and Cyndy Bresloff are involved in the data acquisition and quality control of BDSN/NHFN/MBPO data. Development of the sensor test facility and analysis system was a collaborative effort of Bob Uhrhammer, Tom McEvilly, John Friday, and Bill Karavas. IRIS and DTRA provided, in part, funding for and/or incentive to set up and operate the facility, and we thank them for their support. Bob Uhrhammer, Peggy Hellweg, Pete Lombard, Doug Neuhauser, and Barbara Romanowicz contributed to the preparation of this chapter. The STS-1 project is funded by the NSF through the IRIS/GSN program (IRIS Subaward Agreement number 388). This is a collaborative project with Tom VanZandt of Metrozet, LLC (Redondo Beach, CA).

3.7.8 References

Ekström, G. and M. Nettles, `http://www.seismology.harvard.edu/~ekstrom/Projects/WQC.html`, 2005.

Gardner, W. A., A unifying view of coherence in signal processing, Signal Processing, 29, p. 113-140, 1992.

Ingate, S. et al, Workshop Report from Broadband Seismometer Workshop, Lake Tahoe, CA, `http://www.iris.edu/stations/seisWorkshop04/report.htm`, 2004.

McNamara, D. and R. Buland, Ambient Noise Levels in the Continental United States *Bull. Seism. Soc. Am.*, 94, 4, 2004.

Scherbaum, Frank. Of Poles and Zeros: Fundamentals in Digital Seismology, Volume 15 of Modern Approaches in Geophysics, G. Nolet, Managing Editor, Kluwer Academic Press, Dordrecht, xi + 257 pp., 1996.

Tapley, W. C. and J. E. Tull, SAC - Seismic Analysis

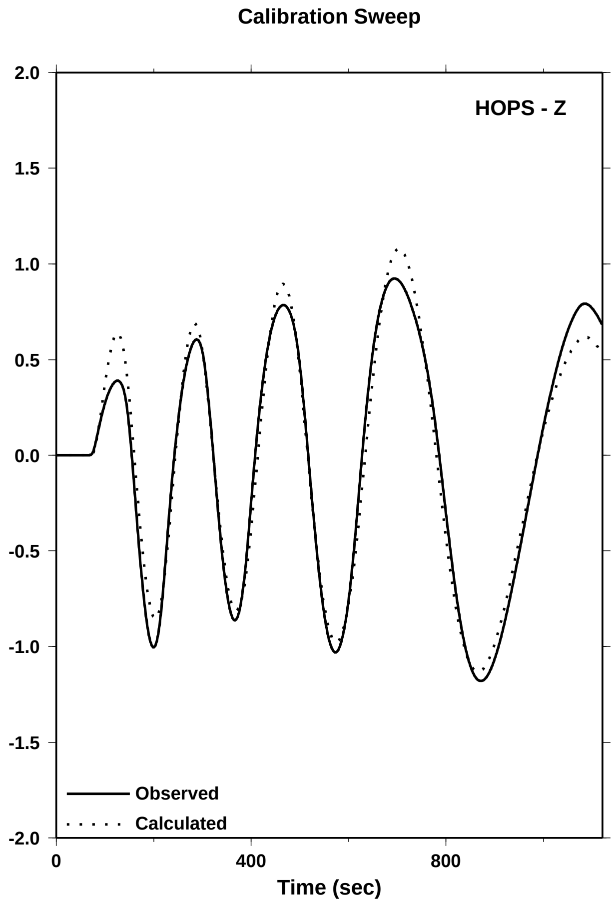

Figure 3.29: Plot of the HOPS STS-1 vertical seismometer observed time series response (solid line) and the corresponding theoretical time series response (dashed line). The best fitting theoretical response was determined via an adaptive migrating grid search to find the T_s and h_s which maximizes the variance reduction. The best fit was obtained for $T_s = 360.08$ seconds and $h_s = 0.6768$ critical.

Code: Users Manual, *Lawrence Livermore National Laboratory*, Revision 4, 388 pp., March 20, 1992.

Wielandt, E. and G. Streckeisen, The leaf spring seismometer: design and performance, *Bull. Seis. Soc. Am., 72*, 2349-2367, 1982.

Wielandt, E. and Steim, J. M., A digital very broad band seismograph, *Annales Geophysicae*, 4 B(3), 227-232, 1986.

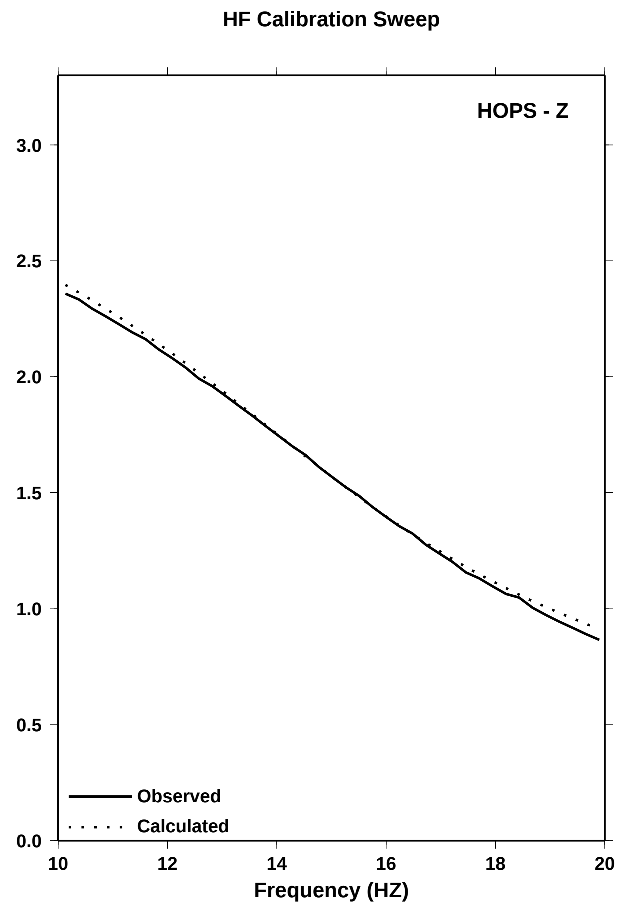

Figure 3.30: Plot of the HOPS STS-1 vertical seismometer observed phase response (solid line) and the corresponding theoretical phase response (dashed line). The best fitting theoretical response was determined via an adaptive migrating grid search to find the f_g and h_g which maximizes the variance reduction. The best fit was obtained for $f_g = 14.998$ Hz and $h_g = 0.371$ critical.

3.8. Northern California Earthquake Monitoring

3.8.1 Introduction

Routine analysis of the data produced by BSL networks begins as the waveforms are acquired by computers at UC Berkeley, and ranges from automatic processing for earthquake response to analyst review for earthquake catalogs and quality control.

Starting in the mid 1990s, the BSL invested in the development of the hardware and software necessary for an automated earthquake notification system (*Gee et al.*, 1996; 2003a) called the Rapid Earthquake Data Integration (REDI) project. This system provides rapid determination of earthquake parameters: near real-time locations and magnitudes of northern and central California earthquakes, estimates of the rupture characteristics and the distribution of ground shaking following significant earthquakes, and tools for the rapid assessment of damage and estimation of loss. In 1996, the BSL and USGS began collaborating on a joint notification system for northern and central California earthquakes. This system merges the programs in Menlo Park and Berkeley into a single earthquake notification system, combining data from the NCSN and the BDSN. Today, the joint BSL and USGS system forms the Northern California Earthquake Management Center (NCEMC) of the California Integrated Seismic Network (Section 3.2.), and development is proceeding on the next generation of earthquake reporting software based on Southern California's Trinet system.

With partial support from the USGS, the BSL has also embarked on the development and assessment of a system to warn of imminent ground shaking in the seconds after an earthquake has initiated but before strong motion begins at sites that may be damaged (Research Study 2.17.).

3.8.2 Northern California Earthquake Management Center

The details of the Northern California processing system and the REDI project have been described in previous annual reports. In this section, we describe how the Northern California Earthquake Management Center fits within the CISN system.

Figure 3.9 in Section 3.2. illustrates the NCEMC as part of the the CISN communications ring. The NCEMC is a distributed center, with elements in Berkeley and in Menlo Park. The 35 mile separation between these two centers is in sharp contrast to the Southern California Earthquake Management Center, where the USGS Pasadena is located across the street from the Caltech Seismological Laboratory. As described in Section 3.2., the CISN partners are connected by a dedicated T1 communications link, with the capability of falling back to the Internet. In addition to the CISN ring, the BSL and the USGS Menlo Park have a second dedicated communications link to provide bandwidth for shipping waveform data and other information between their processing systems.

Figure 3.31 provides more detail on the current system at the NCEMC. At present, two Earthworm-Earlybird systems in Menlo Park feed two "standard" REDI processing systems at UC Berkeley. One of these systems is the production or paging system; the other is set up as a hot backup. The second system is frequently used to test new software developments before migrating them to the production environment. The Earthworm-Earlybird-REDI systems perform standard detection and location, and estimate M_d, M_L, and M_w, as well as processing ground motion data. The computation of ShakeMaps is also performed on two systems, one in Menlo Park and one in Berkeley. An additional system at the BSL performs finite-fault processing and computes higher level ShakeMaps.

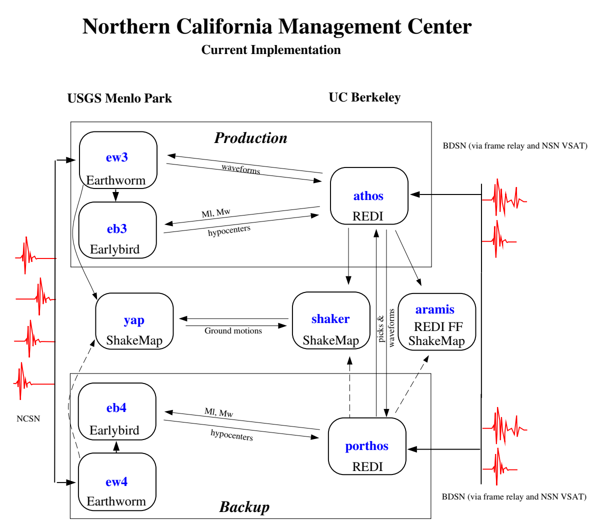

Figure 3.31: Detailed view of the current Northern California processing system, showing the two Earthworm-Earlybird-REDI systems, the two ShakeMap systems, and the finite-fault system.

The dense network and Earthworm-Earlybird processing environment of the NCSN provides rapid and accurate earthquake locations, low magnitude detection thresholds, and first-motion mechanisms for small quakes. The high dynamic range data loggers, digital telemetry, and broadband and strong-motion sensors of the BDSN along with the REDI analysis software provide reliable magnitude determination, moment tensor estimation, peak ground motions, and source rupture characteristics. Robust preliminary hypocenters are available about 25 seconds after the origin time, while preliminary coda magnitudes follow within 2-4 minutes. Estimates of local magnitude are generally available 30-120 seconds later, and other parameters, such as the peak ground acceleration and moment magnitude, follow within 1-4 minutes (Figure 3.32).

Earthquake information from the joint notification system is distributed by pager/cellphone, e-mail, and the WWW. The first two mechanisms "push" the information to recipients, while the current Web interface requires interested parties to actively seek the information. Consequently, paging and, to a lesser extent, e-mail are the preferred methods for emergency response notification. The *recenteqs* site has enjoyed enormous popularity since its introduction and provides a valuable resource for information whose bandwidth exceeds the limits of wireless systems and for access to information which is useful not only in the seconds immediately after an earthquake, but in the following hours and days as well.

3.8.3 2006-2007 Activities

System Development

As part of ongoing efforts to improve the monitoring systems in northern California and to unify the processing systems within the CISN, the BSL and the USGS Menlo Park made progress in the development of the next generation of the northern California joint notification system of the Northern California Seismic System (NCSS). Figure 3.31 illustrates the current organization of the system. Although this approach functions reasonably well, there are potential problems associated with the separation of critical system elements by ~35 miles of San Francisco Bay.

Since FY01/02 we have been working to design and implement the software for Northern California operations so that identical, complete systems operate independently at the USGS and UC Berkeley. When CISN started, independently developed systems for monitoring earthquakes operated in Southern and Northern California, Trinet and Earthworm/REDI, respectively. Each of these systems has its strengths and weaknesses, and a choice had to be made. The current design for the new Northern California system draws strongly on the development of TriNet in Southern California (Figure 3.33), with modifications to allow for local differences (such as very different forms of data acquisition and variability in network distribution). In addition, the BSL and the USGS want to minimize use of proprietary software in the system. One exception is the database program. As part of the development of the Northern California Earthquake Data Center, the USGS and BSL have worked extensively with Oracle databases, and extending this to the real-time system is not viewed as a major issue.

During the last few years, BSL staff members, particularly Pete Lombard, have become extremely familiar with portions of the TriNet software. We have continued to adapt the software for Northern California, making adjustments and modifications along the way. For example, Pete Lombard has adapted the TriNet magnitude module to northern California, where it is now running on a test system. Pete made a number of suggestions on how to improve the performance of the magnitude module and has worked closely with Caltech and the USGS/Pasadena on modifications.

The BSL and the USGS Menlo Park have implemented a system to exchange "reduced amplitude timeseries." One of the important innovations of the TriNet software development is the concept of continuous processing (*Kanamori et al.*, 1999). Waveform data are constantly processed to produce Wood Anderson synthetic amplitudes and peak ground motions. A program called `rad` produces a reduced timeseries, sampled every 5 secs, and stores it in a memory area called an "Amplitude Data Area" or ADA. Other modules can access the ADA to retrieve amplitudes to calculate magnitude and ShakeMaps as needed. The BSL and the USGS Menlo Park have collaborated to establish the tools for ADA-based exchange. As part of the software development in northern California, a number of modules have been developed.

Event Review with `Jiggle`

`CUSP` was finally retired as the event review system in the NCEMC in late November, 2006. `CUSP` was initially developed in Southern California during the late 1970s - early 1980s and has been used to time earthquakes for a number of years in Northern California. However, the `CUSP` system became increasingly outdated, as it relied on obsolete hardware. The primary responsibility for the programming and development necessary has rested on BSL staff. They implemented the `RequestCardGenerator` (a module that decides which channels to archive, given a particular earthquake), a waveform archiving module, and `Jiggle` (the earthquake timing interface) within the Northern California system. The entry of all parameteric earthquake data from real-time processing into the Oracle database and the preparation of station and instrument metadata for insertion into the database were important prerequisites for the transition. The NCEMC and SCMC collaborated on modifications to `Jiggle` for use in Northern California, such as the computation of M_d.

M_L and M_w

The REDI system has routinely produced automatic estimates of moment magnitude (M_w) for many years. However, wary of complications caused by the publication of multiple magnitudes, these estimates were not

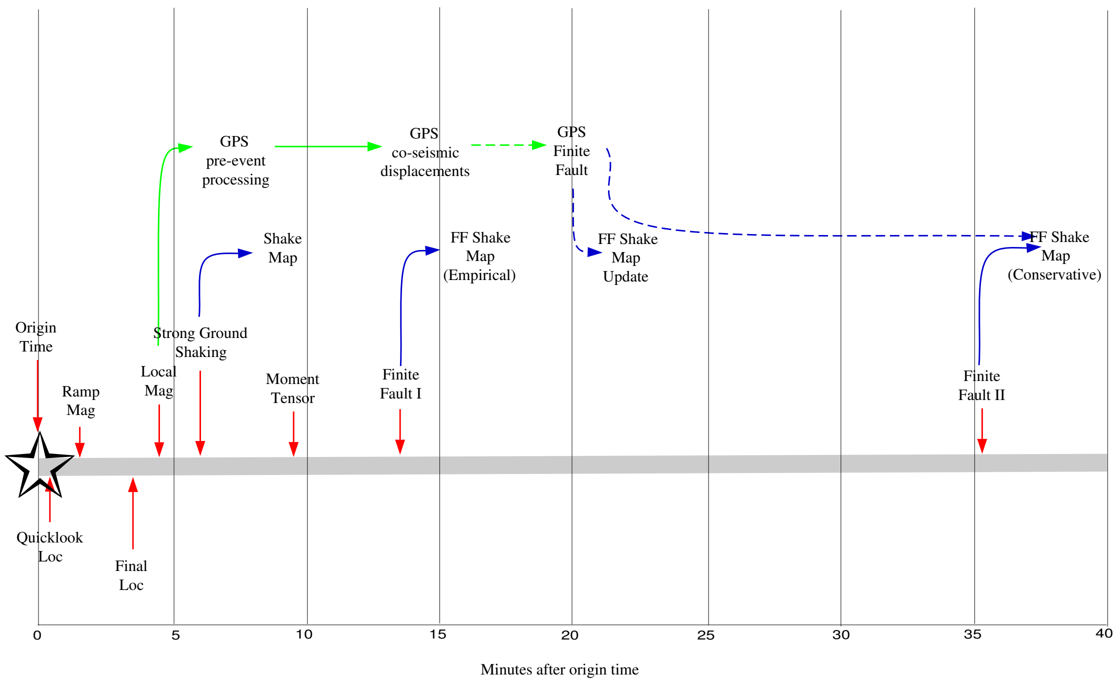

Figure 3.32: Illustration of the current (solid lines) and planned/proposed (dotted lines) development of real-time processing in northern California. The Finite Fault I and II are fully implemented within the REDI system at UC Berkeley and are integrated with ShakeMap. The resulting maps are still being evaluated and are not currently available to the public.

routinely used as the "official" magnitude until after the 05/14/2002 Gilroy earthquake (M_w 4.9, M_L 5.1). Since then, solutions that meet a minimum quality criterion are automatically reported (a variance reduction of 40% or higher). This criterion appears to work very well and screens out events contaminated by teleseisms. Over the last few years, nearly all events over 4.5 have met this criterion, as have a number of events in the M3.5-4.5 range. As part of the effort to establish a statewide magnitude reporting hierarchy, we have looked more closely at the estimates of M_w (*Gee et al.*, 2003b; 2004) and the comparison between M_w and M_L.

Two methods of determining regional moment tensor (RMT) solutions were originally part of the REDI system - the complete waveform modeling technique (CW) of *Dreger and Romanowicz* (1994) and the surface wave inversion (SW) of *Romanowicz et al.* (1993). In FY05/06, processing for the SW algorithm was discontinued, however CW moment tensors continue to be calculated, reviewed and reported. Comparison between the results of the CW method and other regional moment tensor studies in northern California and the western United States show excellent agreement in the estimate of seismic moment and M_w.

As we transition toward statewide reporting of earthquake information, a comparison of magnitudes calculated for Southern and Northern California becomes important. We have collected a set of events recorded well by digital broadband and and strong motion stations of the Northern California (NC), Berkeley (BK) and Southern California (CI) networks and are assessing the computation of local magnitude for each station. Reseacrh Study 2.13. reports on these activities.

3.8.4 Routine Earthquake Analysis

In fiscal year 2006-2007, more than 23,000 earthquakes were detected and located by the automatic systems in northern California. This compares with over 30,000 in 2005-2006 and 38,800 in 2004-2005. Many of the large number of events in 2004-2005 are aftershocks of the 2004 Parkfield earthquake. The number of events continues to remain high, because we now receive and process data from a network of seismometers in the Geysers, a region with a high level of small magnitude seismicity. Of the more than 23,000 events, over 208 had preliminary magnitudes of three or greater. Thirty one events had M_L greater than 4. The largest event recorded by the system occurred on 26 February 2007 with M_w5.4. This earth-

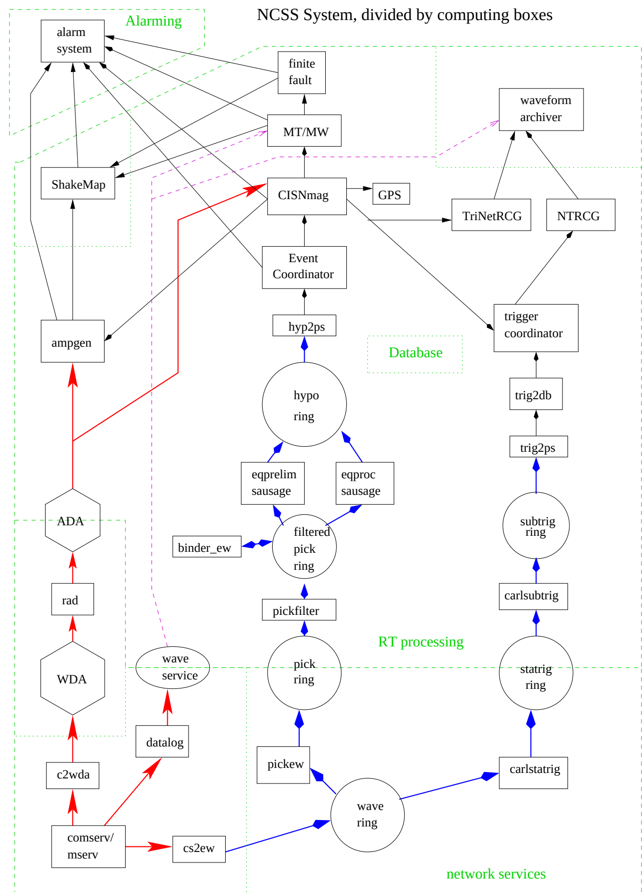

Figure 3.33: Schematic diagram of the planned NCSS system. The design combines elements of the Earthworm, TriNet, and REDI systems

quake, as well as the five events with the next largest magnitudes, occurred off the coast of northernmost California.

As described in the 2003-2004 Annual Report, the BSL staff are no longer reading BDSN records for local and regional earthquakes (as of March 2004). This decision was in part intended to reduce duplication of effort between Berkeley and Menlo Park.

The BSL continues to focus on the unique contributions that can be made from the broadband network. From July 2006 through June 2007, BSL analysts reviewed more than 40 earthquakes in northern California and adjoining areas of magnitude 3.2 and higher. Reviewed moment tensor solutions were obtained for 37 of these events (through 6/30/2007). Figure 3.34 and Table 3.19 display the locations of earthquakes in the BSL moment tensor catalog and their mechanisms.

Seismic Background Noise PSD in Northern and Central California

The density and distribution of broadband seismic stations located in Northern and Central California increased during the past few years, with two new BK stations and additional broadband seismic stations installed as the USArray transportable array completes its station coverage in the region. One design goal of the transportable network has been to complement the existing BDSN broadband stations and cover the region with an average interstation spacing of ∼70 km. We have been using data from the USArray TA stations and monitoring station quality through the analysis of the seismic background noise PSD level observed at the transportable stations. This is, in part, so that we can choose the best sites to continue occupying after the transportable array moves out of the region, in order to improve the coverage of the BDSN network. Based on this analysis as well as criteria such as ownership and access to power and

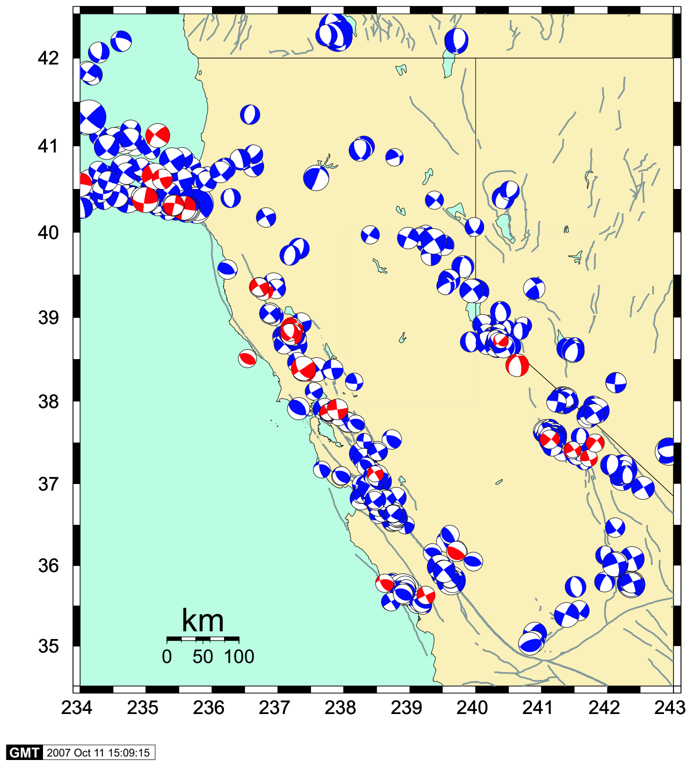

Figure 3.34: Map comparing reviewed moment tensor solutions determined by the BSL from past years (blue) with those from the fiscal year 2006-2007 (red).

telemetry, seven stations have been selected for upgrade to permanent sites within the next 18 months. These are: V04C (RAMR), HAST, P01C and S04C, as well as HATC, HELL and SUTB (see Figure 3.2.

3.8.5 Acknowledgements

Peggy Hellweg oversees the REDI system and directs the routine analysis. Peter Lombard and Doug Neuhauser contribute to the development of software. Rick McKenzie, Doug Dreger, Aimin Cao, Sean Ford, Aurelie Guilhem, Ayhi Kim, Ved Lekic, Junkee Rhie, Dennise Templeton, and Akiko Toh contribute to the routine analysis of moment tensors. Peggy Hellweg, Doug Neuhauser and Bob Uhrhammer contributed to the writing of this chapter. Partial support for the development and maintenance of the REDI system is provided by the USGS. The facilities of the IRIS Data Management System, and specifically the IRIS Data Management Center, were used by Bob Uhrhammer for access to the TA network (USArray) waveform and metadata required in the noise comparison study.

3.8.6 References

Dreger, D., and B. Romanowicz, Source characteristics of events in the San Francisco Bay region, *USGS Open File Report 94-176*, 301-309, 1994.

Gee, L., J. Polet, R. Uhrhammer, and K. Hutton, Earthquake Magnitudes in California, *Seism. Res. Lett., 75(2)*, 272, 2004.

Gee, L., D. Neuhauser, D. Dreger, M. Pasyanos, R. Uhrhammer, and B. Romanowicz, The Rapid Earthquake Data Integration Project, *Handbook of Earthquake and Engineering Seismology*, IASPEI, 1261-1273, 2003a.

Gee, L., D. Dreger, G. Wurman, Y, Gung, B. Uhrhammer, and B. Romanowicz, A Decade of Regional Moment Tensor Analysis at UC Berkeley, *Eos Trans. AGU, 84(46)* , Fall Meet. Suppl., Abstract S52C-0148, 2003b.

Gee, L., D. Neuhauser, D. Dreger, M. Pasyanos, B. Romanowicz, and R. Uhrhammer, The Rapid Earthquake Data Integration System, *Bull. Seis. Soc. Am., 86,* 936-945,1996.

Pasyanos, M., D. Dreger, and B. Romanowicz, Toward real-time estimation of regional moment tensors, *Bull. Seis. Soc. Am., 86,* 1255-1269, 1996.

Romanowicz, B., D. Dreger, M. Pasyanos, and R. Uhrhammer, Monitoring of strain release in central and northern California using broadband data, *Geophys. Res. Lett., 20,* 1643-1646, 1993.

Location	Date	UTC Time	Lat.	Lon.	MT Depth	M_l	M_w	Str.	Dip	Rake	Mo
Offshore of Fort Ross	7/6/2006	20:43:24	38.508	-123.463	5	3.7	3.7	4.69E+21	295	46	84
Petrolia	7/19/2006	11:41:43	40.281	-124.426	30	4.7	5	3.53E+23	102	83	173
Glen Ellen	8/3/2006	3:08:12	38.363	-122.589	5	4.7	4.4	5.64E+22	256	86	19
Bishop	9/7/2006	1:38:59	37.31	-118.284	8	3.6	3.4	1.86E+21	342	86	158
Willits	9/26/2006	20:56:13	39.31	-123.217	8	3.9	3.9	9.52E+21	333	61	-171
Petrolia	10/17/2006	20:53:18	40.55	-126	11	4.9	4.8	2.03E+23	277	85	-166
Geysers	10/20/2006	17:00:08	38.867	-122.7873	5	4.5	4.6	9.88E+22	254	68	-39
Geysers	10/20/2006	23:31:39	38.867	-122.783	5	4.5	3.8	6.50E+21	240	55	-65
Petrolia	10/24/2006	14:26:43	40.403	-125.066	5	4	4.4	4.50E+22	99	85	182
Willits	11/9/2006	8:38:13	39.355	-123.285	8	4	4	1.49E+22	336	87	172
Willits	11/10/2006	5:05:56	39.357	-123.282	8	3.7	3.7	4.69E+21	329	90	-167
Paso Robles	11/30/2006	4:06:40	35.631	-120.754	8	4.7	3.8	5.33E+21	245	89	7
Coalinga	12/16/2006	6:14:05	36.174	-120.292	5	4.3	4.2	2.16E+22	299	71	89
Petrolia	12/17/2006	15:13:40	40.392	-125.023	5	3.9	4.3	3.57E+22	274	90	-159
Bishop	12/19/2006	15:21:42	37.493	-118.188	5	4	3.7	4.33E+21	221	86	-27
Berkeley	12/21/2006	3:12:28	37.86	-122.237	8	3.7	3.6	2.85E+21	49	80	-14
Berkeley	12/23/2006	6:49:57	37.862	-122.237	11	3.7	3.6	2.82E+21	139	89	-153
Berkeley	12/23/2006	17:21:15	37.861	-122.235	11	3.5	3.4	1.63E+21	148	86	-169
Glen Ellen	1/12/2007	11:27:50	38.391	-122.615	11	3.8	3.7	3.27E+23	236	89	34
Bishop	1/17/2007	14:01:08	37.408	-118.531	5	4	3.6	3.66E+21	37	83	17
Morgan Hill	1/17/2007	17:43:22	37.12	-121.523	8	3.5	3.4	1.38E+21	328	89	-159
Petrolia	1/24/2007	13:42:52	40.312	-124.584	18	3.7	4.4	5.05E+22	187	85	25
San Simeon	2/20/2007	16:46:13	35.78	-121.382	8	3.7	3.7	4.96E+21	151	59	137
Berkeley	2/24/2007	23:46:15	37.865	-122.241	11	3.4	3.3	1.15E+21	154	88	-176
Ferndale	2/26/2007	12:19:54	40.647	-124.864	8	5	5.4	1.48E+24	60	89	-4
Lafayette	3/2/2007	4:40:00	37.901	-122.098	14	4.4	4.2	2.77E+22	82	89	-1
Bridgeport	3/9/2007	3:17:32	38.428	-119.367	11	5	4.7	1.29E+23	349	65	-114
Petrolia	4/5/2007	22:54:29	40.311	-124.578	18	3.8	4.1	1.93E+22	12	88	18
Ferndale	4/7/2007	23:55:03	40.616	-124.753	18	3.7	4.1	2.00E+22	256	78	21
Geysers	4/24/2007	21:08:28	38.796	-122.794	5	4.4	4.4	4.62E+22	342	82	-160
Geysers	4/30/2007	15:51:28	38.82	-122.823	5	3.1	3.7	3.89E+21	136	58	-133
Markleeville	4/30/2007	21:57:32	38.72	-119.62	5	3.5	3.1	5.66E+20	226	87	47
Petrolia	5/9/2007	7:50:05	40.376	-125.014	11	5	5.2	7.81E+23	188	85	24
Bishop	5/26/2007	8:04:12	37.416	-118.525	8	3.5	3.3	1.24E+21	59	81	10
Mammoth	6/12/2007	7:22:36	37.5425	-118.8677	11	3.6	3.6	3.14E+21	140	82	-143
Mammoth	6/12/2007	7:23:43	37.539	-118.876	14	5.1	4.6	9.96E+21	310	82	172
Offshore of McKinleyville	6/25/2007	2:32:25	41.1155	-124.825	18	5	5	3.36E+23	128	84	160

Table 3.19: Moment tensor solutions for significant events from July 1, 2006 through June 30, 2007 using a complete waveform fitting inversion. Epicentral information is from the UC Berkeley/USGS Northern California Earthquake Management Center. Moment is in dyne-cm and depth is in km.

3.9. Outreach and Educational Activities

3.9.1 Introduction

The BSL is involved in a variety of outreach activities ranging from lectures to lab tours and educational displays. Recorded information on current earthquake activity is updated regularly on our information tape (510-642-2160). Additional basic information on earthquakes and seismic hazards for northern and central California, as well as other information seismology and our research, can be found on an extensive set of web pages.

3.9.2 Highlights of 2006-2007

This year's Lawson Lecture introduced the Parkfield segment of the San Andreas Fault to the wider community. Andy Michaels of the United States Geological Survey in Menlo Park spoke about "Parkfield 2004: Lessons from the Best-Recorded Earthquake in History". This section of the fault, currently the target of the "San Andreas Fault Observatory at Depth" drilling project, has been the object of intense research since the Parkfield Earthquake Prediction Experiment began in the mid-1980s. Then, the goal was to acquire high-quality measurements close to, and in advance of, a large earthquake. This goal was finally met when the September 28, 2004, magnitude 6, Parkfield, California, earthquake finally occurred on the San Andreas fault in the middle of the dense and diverse network of instruments designed by the scientists for the Parkfield Earthquake Prediction Experiment. The resulting data reveal aspects of the earthquake process never before seen, providing important insights into earthquake processes, prediction, and the hazards assessments that underlie important policies such as building codes.

3.9.3 On-Going Activities

Tours and Presentations

As every year, tours and presentations formed an important part of BSL's public relations activities. Each month, several groups, ranging from middle-school students to scientists and engineers, tour our laboratory under the guidance of a graduate student or a member of the staff.

The BSL hosted several special groups during 2006-2007. The geology class from Bishop Stopford School in England made its annual stop for a tour of the laboratory and the Hayward Fault. Several classes at different grade levels received tours. In addition, BSL graduate students visited local elementary, middle and high schools to talk about earthquakes and how we measure them. In addition to the tours, Drs. Romanowicz, Allen, Dreger, Hellweg, and Uhrhammer presented talks on earthquakes and related phenomena to public groups and the media.

Open House

The BSL participated in *CalDay* this year. The attendance for the open house was, as always, good. The visitors learned about UC Berkeley's role in earthquake monitoring, watched a streaming feed of earthquake data, jumped up and down to "make a quake," played with the earthquake machine, made P and S-waves with springs, learned about earthquake preparedness, and were given sample seismograms. The BSL also co-sponsored lectures with the Earth and Planetary Science department on "Geology of the Berkeley and East Bay Hills", "Geology of San Francisco Bay Area" and "Why do Volcanoes Erupt Explosively."

Educational Displays

The BSL continues to make REDI earthquake data available to certain schools, universities, colleges, and museums for educational displays. Participating organizations receive a REDI pager and the Qpager software to display the earthquake information. The Qpager program maps the previous seven days of seismicity, with each earthquake shown as a dot. The size of the dot indicates the magnitude of the event, while the color of the dot indicates its age. These educational displays have been installed at UC Berkeley (McCone Hall, Earthquake Engineering Research Center, LHS), California Academy of Sciences, CSU Fresno, CSU Northridge, CSU Sacramento, Caltech, College of the Redwoods, Fresno City College, Humboldt State University, San Diego State University, Sonoma State University, Stanford University (Blume Engineering Center, Department of Geophysics), UC Davis, UC Santa Cruz, UC San Diego, and USC. For the past three years, middle schools of the San Francisco Unified School District have participated in the program.

In addition to the seismicity displays, the BSL provides local waveform feeds for helicorders at visitor centers associated with BDSN stations (CMB and MHC). Organizations such as LHS, KRON, and KPIX receive feeds from BKS via dedicated phone lines for display, while the USGS Menlo Park uses data from CMB for display in the lobby of the seismology building. The BSL has also loaned a seismometer and helicorder display to the San Leandro Unified School District for their use in science classes.

WWW

We continue to maintain and update our presence on the WWW. The webpages are intended to provide a source of earthquake information for the public. They also present information about the networks we operate, including station profiles. This benefits the research community as well. The BSL web pages publicize seminar schedules, advertise courses, and describe our research, as well as our operations. They offer updates on recent earthquake activity, details on Bay Area seismicity and hazards, and links to other earthquake and earth science servers. We also use the WWW server to distribute information internally among BSL personnel, with such details as the computing and operational resources, rosters, and schedules for various purposes.

Earthquake Research Affiliates Program

The UC Berkeley Earthquake Research Affiliates (ERA) Program is an outreach project of the BSL, the Department of Earth and Planetary Science, and the Earthquake Engineering Research Center. The purpose is to promote the support of earthquake research while involving corporations and governmental agencies in academic investigation and education activities such as conferences and field trips. The ERA program provides an interface between the academic investigation and practical application of earthquake studies.

3.9.4 Acknowledgements

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Glossary of Common Acronyms

Table 3.20: Standard abbreviations used in this report.

Acronym	Definition
AGU	American Geophysical Union
ANSS	Advanced National Seismic System
BARD	Bay Area Regional Deformation
BDSN	Berkeley Digital Seismic Network
BSL	Berkeley Seismological Laboratory
BSS	Berkeley Seismographic Station
CISN	California Integrated Seismic Network
CGS	California Geological Survey
CLC	Campus Laboratory Collaboration
CNSS	Council of the National Seismic System
CSRC	California Spatial Reference Center
DART	Data Available in Real Time
DRC	Disaster Resistent California
EM	Electromagnetic
EPRI	Electric Power Research Institute
EERI	Earthquake Engineering Research Institute
FBA	Force Balance Accelerometer
FEMA	Federal Emergency Management Agency
FIR	Finite Impulse Response
FRAD	Frame Relay Access Device
GPS	Global Positioning System
GSAC	GPS Seamless Archive Center
HFN	Hayward Fault Network
HRSN	High Resolution Seismic Network
IGS	International Geodetic Service
IMS	International Monitoring System
InSAR	Interferometric Synthetic Aperture Radar
IRIS	Incorporated Research Institutions for Seismology
ISC	International Seismological Center
ISTAT	Integrating Science, Teaching, and Technology
JPL	Jet Propulsion Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
MBARI	Monterey Bay Aquarium Research Institute
MHH	Murdock, Hutt, and Halbert
MOA	Memorandum of Agreement
MOBB	Monterey Ocean Bottom Broadband observatory
MOISE	Monterey Bay Ocean Bottom International Seismic Experiment
MPBO	Mini-Plate Boundary Observatory
MRI	Major Research Initiative

continued on next page

Table 3.20: *continued*

Acronym	Definition
MRE	Major Research Equipment
MT	Magnetotelluric
NCEDC	Northern California Earthquake Data Center
NCEMC	Northern California Earthquake Management Center
NCSN	Northern California Seismic Network
NCSS	Northern California Seismic System
NEHRP	National Earthquake Hazards Reduction Program
NEIC	National Earthquake Information Center
NHFN	Northern Hayward Fault Network
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NSMP	National Strong Motion Program
NSF	National Science Foundation
NSN	National Seismic Network
OES	California Governer's Office of Emergency Services
ORU	Organized Research Unit
PBO	Plate Boundary Observatory
PEER	Pacific Earthquake Engineering Center
PH	Pilot Hole
PMG	CISN Program Management Group
PPE	Parkfield Prediction Experiment
PREM	Preliminary Reference Earth Model
PSD	Power Spectral Density
QDDS	Quake Data Distribution System
REDI	Rapid Earthquake Data Integration
RTK	Real Time Kinematic Data
SAF	San Andreas Fault
SAFOD	San Andreas Fault Observatory at Depth
SAR	Synthetic Aperture Radar
SCEC	Southern California Earthquake Center
SCEDC	Southern California Earthquake Data Center
SCIGN	Southern California Integrated GPS Network
SCMC	Southern California Management Center
SCSN	Southern California Seismic Network
SEED	Standard for the Exchange of Earthquake Data
SEM	Spectral Element Method
SHFN	Southern Hayward Fault Network
SIO	Scripps Institutions of Oceanography
SNCL	Station Network Channel Location
SSA	Seismological Society of America
STP	Seismogram Transfer Program
UCB	University of California at Berkeley
UNAVCO	University NAVSTAR Consortium
UNR	University of Nevada, Reno
UrEDAS	Urgent Earthquake Detection and Alarm System
USGS	United States Geological Survey

Appendix I Publications, Presentations, and Panels 2006-2007

Publications

Allen, R.M., The ElarmS earthquake early warning methodology and its application across California. In "Earthquake Early Warning Systems", P. Gasparini, G. Manfredi, J. Zschau (Eds), p. 21-44, Springer, ISBN-13 978-3-540-72240-3, 2007.

Banerjee, P., F. F. Pollitz, B. Nagarajan, and R. Bürgmann (2007), Coseismic slip distributions of the 26 December 2004 Sumatra-Andaman and 28 March 2005 Nias earthquakes from GPS static offsets, *Bull. Seism. Soc. Am.*, 97, S86-S102.

Benetatos, C., D. Dreger, and A. Kiratzi (2007). Complex and segmented rupture associated with the 14 August 2003 Mw 6.2 Lefkada, Ionian Islands, Earthquake, *Bull. Seism. Soc. Am.*, 97, 35-51.

Cao, A., and B. Romanowicz, Locating scatterers in the mantle using array analysis of PKP precursors from an earthquake doublet. *Earth. Planet. Sci. Lett., 255, 22-31, 2007.*

Cao, A., and B. Romanowicz, Test of the innermost inner core models using broadband PKIKP travel time residuals. *Geophys. Res. Lett*, 34, L08303, 2007. doi:10.1029/2007GL029384

Cao, A., Y. Masson, and B. Romanowicz, Short wavelength topography on the Inner Core Boundary. *Proc. Natl. Acad. Sci. U.S.A*, 104, 31-35, 2007.

Cammarano, F. and B. Romanowicz, Insights into the nature of the transition zone from physically constrained inversion of long period seismic data, *PNAS*, 104, 9139-9144

Chen, K. H., R. M. Nadeau, and R.-J. Rau (2007), Towards a universal rule on the recurrence interval scaling of repeating earthquakes?, *Geophys. Res. Lett.*, 34, L16308, doi:10.1029/2007GL030554.

Dolenc, D., B. Romanowicz, R. Uhrhammer, P. McGill, D. Neuhauser, and D. Stakes, Identifying and removing noise from the Monterey ocean bottom broadband seismic station (MOBB) data, *Geochem. Geophys. Geosys.*, 8, Q02005, doi:10.1029/2006GC001403, 2007.

Freed, A. M., R. Bürgmann, E. Calais, and J. T. Freymueller (2006), Stress-dependent power-law flow in the upper mantle following the 2002 Denali, Alaska, earthquake, *Earth Planet. Sci. Lett.*, 252, doi:10.1016/j.epsl.2006.1010.1011.

Freed, A. M., S. T. Ali, and R. Bürgmann (2007), Evolution of stress in Southern California for the past 200 years from coseismic, postseismic and interseismic stress changes, *Geophysical Journal International*, 169, doi: 10.1111/j.1365-1246X.2007.03391.x.

Funning, G J, R Burgmann, A Ferretti, F Novali and A Fumagalli, 2007, Creep on the Rodgers Creek fault from a 10 year PS-InSAR dataset, *Geophys. Res. Lett.*, in press.

Funning, G J, B Parsons and T J Wright, 2007, Fault slip in the 1997 Manyi, Tibet earthquake from linear elastic modelling of InSAR displacements, *Geophys. J. Int.*, 169, 988–1008.

Handy, M. R., G. Hirth, and R. Bürgmann (2007), Continental fault structure and rheology from the frictional-to-viscous transition downward, in Tectonic Faults: Agents of Change on a Dynamic Earth, edited by M. R. Handy, et al., pp. 139-181, MIT Press, Cambridge, MA.

Hellweg, M. and D. Seidl (2006): The contingency table - a powerful tool of multivariate statistics. In Eds. H.M. Mader, S.G. Coles and C.B. Conner, *Statistics in Volcanology*, Special Publications of IAVCEI, Geological Society of London, 1, 105-113.

Houlié, N. and Montagner, J-.P., Hidden Dykes detected on Ultra Long Period (ULP) seismic signals at Piton de la Fournaise volcano, 261, 1-2, 10.1016/j.epsl.2007.04.018, *Earth Planetary Science Letters* (2007).

Jackson, J., M Bouchon, E Fielding, G Funning, M Ghorashi, D Hatzfeld, H Nazari, B Parsons, K Priestley, M Talebian, M Tatar, R Walker and T Wright, 2006, Seismotectonic, rupture process and earthquake hazard aspects of the 26 December 2003 Bam earthquake, *Geophys. J. Int.*, 166, 1270-1292.

Johnson, K. M., R. Bürgmann, and K. Larson (2006), Frictional properties on the San Andreas fault near Parkfield, California, inferred from models of afterslip following the 2004 earthquake, *Bull. Seism. Soc. Am.*, 96, 321-338.

Johnson, K., G. Hilley, and R. Bürgmann (2007), Influence of lithosphere viscosity structure on estimates of fault slip rate in the Mojave region of the San Andreas fault system, *Journal of Geophysical Research*, 112, doi:10.1029/2006JB004842.

Lockman, A.B. and R.M. Allen. Magnitude-period scaling relations for Japan and the Pacific Northwest: Implications for earthquake early warning. *Bull. seism. Soc. Am.* 97 (1), 140-150, doi: 10.1785/0120040091, 2007.

Malagnini, L., P. Bodin, K. Mayeda, A. Akinci, Unbiased moment-rate spectra and absolute site effects in the Kachachh Basin, India, from the analysis of the aftershocks of the 2001 Mw 7.6 Bhuj earthquake, *Bull. Seismol. Soc. Am., 96*, doi:10.1785/0120050089, 2006.

Malagnini, L., K. Mayeda, R. Uhrhammer, A. Akinci, and R.B. Herrmann, A regional ground motion excitation/attenuation model for the San Francisco region, *Bull. Seism. Soc. Am., 97*, 843-862, doi:10.1785/0120060101, 2007.

Marone, F. and B. Romanowicz, On the depth distribution of azimuthal anisotropy in the continental upper mantle, *Nature*, 447, 198-201, 2007.

Marone, F. and B. Romanowicz, Non-linear crustal corrections in high-resolution waveform seismic tomography, *Geophys. J. Int.*, 170, 460-467, 2007.

Marone, F., Y. C. Gung and B. Romanowicz, High resolution 3D radial anisotropic structure of the North American upper mantle from inversion of surface waveform data, *Geophys. J. Int.*, in press; online: doi: 10.1111/j.1365-246X.2007.03465.x, 2007.

Mayeda, K., L. Malagnini, W.R. Walter, A new spectral ratio method using narrow band coda envelopes: Evidence for non-self-similarity in the Hector Mine sequence, *Geophys. Res. Lett., 34, L11303* doi:10.1029/2007GL030041, 2007.

Morasca, P., K. Mayeda, R. Gök, W.S. Phillips, L. Malagnini, 2-D coda and direct wave tomography in northern Italy, *Geophys. J. Int.* (in press)

E Nissen, B Emmerson, G J Funning, A Mistrukov, B Parsons, D P Robinson and T J Wright, 2007, Combining InSAR and seismology to study the 2003 Siberian Altai earthquakes - dextral strike-slip and anticlockwise rotations in the northern India-Eurasia collision zone, *Geophys. J. Int.*, 169, 216-232.

Nolet, G., R.M. Allen and D. Zhao, Mantle plume tomography, *Chemical Geology* 241, 248-263, doi: 10.1016/j.chemgeo.2007.01.022, 2007.

Olson, E.L., and R.M. Allen. Is earthquake rupture deterministic? (Reply) *Nature*, 442, E6, doi:10.1038/nature04964, 2006.

Phillips, W.S., R.J. Stead, G.E. Randall, H.E. Hartse and K. Mayeda, Source effects from broad area network calibration of regional distance coda waves, *Scattering of Short Period Waves in the Heterogeneous Earth*, H. Sato and M.C. Fehler, Editors (in press)

Pollitz, F., R. Bürgmann, and P. Banerjee (2006), Postseismic relaxation following the great 2004 Sumatra-Andaman earthquake on a compressible self-gravitating Earth, *Geophysical Journal International*, 167, doi: 10.1111/j.1365-1246X.2006.03018.x.

Rhie, J., D. S. Dreger, R. Bürgmann, and B. Romanowicz (2007), Slip of the 2004 Sumatra-Andaman earthquake from joint inversion of long period global seismic waveforms and GPS static offsets, *Bull. Seism. Soc. Am.*, 97, S115-S127.

Rolandone, F., D. S. Dreger, M. H. Murray, and R. Bürgmann (2006), Coseismic Slip Distribution of the 2003 Mw 6.5 San Simeon earthquake, California, determined from GPS measurements and seismic waveform data, *Geophys. Res. Lett.*, 33, doi:10.1029/2006GL027079.

Romanowicz, B. and B. Mitchell (2007) Q in the Earth from crust to core, Treatise of Geophysics, Vol. 1, to be published by Elsevier, in press.

Ryder, I., B Parsons, T J Wright and G J Funning, Post-seismic motion following the 1997 Manyi (Tibet) earthquake: InSAR observations and modelling, *Geophys. J. Int.*, 169, 1009–1027, 2007.

Simons, F.J., B.D.E. Dando and R.M. Allen. Automatic detection and rapid determination of earthquake magnitude by wavelet multiscale analysis of the primary arrival. *Earth Planet. Sci. Lett.* 250, 214-223, doi:10.1016/j.epsl.2006.07.039, 2006.

Sol, S., A. Meltzer, R. Bürgmann, R. D. van der Hilst, R. King, Z. Chen, P. Koons, E. Lev, Y. P. Liu, B. P. K. Zeitler, X. Zhang, J. Zhang, and B. Zurek, Geodynamics of the southeastern Tibetan plateau from seismic anisotropy and geodesy, *Geology*, 35, 563-566, 2007.

Tullis, T. E., R. Bürgmann, M. Cocco, G. Hirth, G. C. P. King, O. Oncken, K. Otsuki, J. R. Rice, A. Rubin, P. Segall, S. A. Shapiro, and C. A. J. Wibberley, Rheology of Fault Rocks and Their Surroundings, in Tectonic Faults: Agents of Change on a Dynamic Earth, edited by M. R. Handy, et al., pp. 183-204, MIT Press, Cambridge, MA., 2007

Walter, W. R., K. Mayeda, R. Gök, A. Hofstetter, The scaling of seismic energy with moment: Simple models compared with observations, Earthquakes: Radiated Energy and the Physics of Faulting, *AGU Geophysical Monograph Series, 170*, 2006.

Walter, W.R., K. Mayeda, L. Malagnini, and L. Scognamiglio, Regional body-wave attenuation using a coda source normalization method: Application to MEDNET records of earthquakes in Italy, *Geophys. Res. Lett., 34, L10308*, doi:10.1029/2007GL029990, 2007.

Wu, Y-.M., H. Kanamori, R.M. Allen and E. Hauksson, Determination of earthquake early warning parameters, tau-c and Pd, for southern California. *Geophys. J. Int.*, 241, 248-263 doi: 10.1016/j.chemgeo.2007.01.022, 2007.

Wurman, G., R.M. Allen and P. Lombard, Toward earthquake early warning in northern California, *J. Geophys. Res. 112*, B08311, doi:10.1029/2006JB004830, 2007.

Presentations

SAFER (Seismic Early Warning for Europe) Kickoff Meeting, Capri, Italy, July, 2006

Allen, R.M. Toward earthquake early warning for California.

High Lava Plains Workshop, Bend, Oregon, July, 2006

Allen, R.M. and M. Xue. The origins of the Newberry hotspot.

SCEC Annual Meeting, Palm Springs, CA, September, 2006

Allen, R.M. and G. Wurman. Earthquake early warning in northern California.

Allen, R.M. Subduction and upwelling in Cascadia: Development of a velocity model for the Pacific Northwest. (California 3D Velocity Model Workshop)

Montessus de Balore Conference in Santiago de Chile, November, 2006

Romanowicz, B., "Real -time seismology at UC Berkeley" (invited)

American Geophysical Union, 2006 Fall Meeting, San Francisco, CA, December 11-15, 2006

Brudzinski, M.R. and R.M. Allen. Segmentation in Episodic Tremor and Slip All Along Cascadia. *Eos Trans. AGU, 87*(52), Fall Meet. Suppl., Abstract T53G-05, 2006.

Cammarano, F. and B. Romanowicz, Physically constrained inversion of long-period seismic waveforms: Insights on the nature of the transition zone *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract S41E-05, 2006

Cao, A. and B. Romanowicz, Array analysis of small-scale mantle heterogeneity using PKP precursors from doublets *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract S43A-1355, 2006

Chen, K.H., R.M. Nadeau, R. Rau, Evidence of off-fault deep creep from repeating seismicity along the northern Longitudinal Valley Fault in Taiwan *EOS Trans. AGU*, 87, Fall Meet. Suppl., Abstract, T31F-07, 2006

Dando, B., F.J. Simons and R.M. Allen. Automatic detection and rapid determination of earthquake magnitude by wavelet multiscale analysis of the primary arrival. *Eos Trans. AGU, 87*(52), Fall Meet. Suppl., Abstract S11B-02, 2006.

Dreger, D. and J. Rhie, A source representation of microseisms constrained by HV spectral ratio observations *EOS Trans. AGU*, 87(52), Fall Meeting Suppl., Abstract S23D-0200.

Escalante, C., F. Cammarano, N. De Koker, A. Piazzoni, Y. Wang, F. Marone, C. Dalton, and B. Romanowicz, Seismic velocity gradients across the transition zone *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract U21A-0808, 2006

Ford, S.R., D.S. Dreger, W.R. Walter, Full moment tensor analysis of Western US explosions, earthquakes, collapses, and volcanic events using a regional waveform inversion *EOS Trans. AGU*, 87(52), Fall Meeting Suppl., Abstract S43A-1352.

Ford, S.R., V. Lekic, B.A. Romanowicz, and A. To, Analysis of Multiply Core-reflected Shear-waves from the M6.7 Kiholo Bay Earthquake *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract S51F-1794, 2006

Funning, G.J., R. Bürgmann, A. Ferretti, F. Novali, and A. Fumagalli, Creep on the faults of the Northern San Francisco Bay Area documented by PS-InSAR *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract G52A-03, 2006

Goltz, C., D.L. Turcott, S. Abaimov and R.M. Nadeau, Universal Recurrence Time Statistics of Characteristic Earthquakes, *EOS Trans. AGU*, 87, Fall Meet. Suppl., Abstract, NG41A-03, 2006.

Hellweg, M, J. Boatwright, H. Bundock, H. Haddadi, and P. Lombard, Reality check: Using the 1906 Simulations to Assess Performance of Northern California Networks *Eos Trans. AGU, 87*(52), Fall Meet. Suppl., Abstract S51B-1272.

Houlié, N. and B. Romanowicz, B, CALREF, a stable reference frame for the Northern California *Eos Trans. AGU, 87*(52), Abstract G43A-0982, 2006.

Kim, A., and D. Dreger (2006). Rupture process of the 2004 Parkfield earthquake from near-fault seismic and geodetic data, *EOS Trans. AGU*, 87(52), Fall Meeting Suppl., Abstract S23C-0166, 2006

Komorowski, J., N. Houlié, C.M. Kasereka, H. Ciraba, Early detection of eruptive dykes revealed by Normalized Difference Vegetation Index (NDVI) on Nyiragongo and Etna volcanoes: Implications for dyke wedge emplacement, monitoring, and risk assessment. *Eos Trans. AGU, 87*(52), Abstract T41B-1573, 2006.

Larsen, S., D. Dreger, and D. Dolenc, Simulations of the 1906 San Francisco earthquake and scenario earthquakes in Northern California, *Eos Trans., AGU*, 87 (52), Fall Meet. Suppl., Abstract S51B-1269, 2006.

Lekic, V. and B. Romanowicz, Applying the spectral element method to model 3D attenuation in the upper mantle, *EOS Trans AGU* 87 (52) Fall Meeting Suppl. Abstract S51A-1257, 2006.

Lekic, V., Reif, C., Dziewonski, A. M., Sheehan, A., and van Summeren, J., Seismic Constraints on Slab Interaction With the Transition Zone *Eos Trans., AGU*, 87 (52), Fall Meet. Suppl., Abstract U21A-0809, 2006.

Masson, Y., A. Cao, and B. Romanowicz, Test of innermost inner core models using broadband absolute PKIKP travel time residuals *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract U43A-0843, 2006

Marone, F. and B. Romanowicz, 3D radial and azimuthal anisotropic structure of the North American upper mantle *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract S53A-1295, 2006

Neuhauser, D, L. Dietz, P. Lombard, F. Klein, S. Zuzlewski, W. Kohler, M. Hellweg, J. Luetgert, D. Oppenheimer, and B. Romanowicz, The Northern California Earthquake Management System: A Unified System From Realtime Monitoring to Data Distribution *Eos Trans. AGU, 87*(52), Fall Meet. Suppl., Abstract S11A-0198.

Nissen, E., B. Emmerson, G. Funning, A. Mistrukov, B. Parsons, D. Robinson, E. Rogozhin, and T. Wright, Studying the 2003 Siberian Altai earthquakes with InSAR and seismology - Dextral strike-slip and anticlockwise rotations in the Northern India-Eurasia Collision Zone. *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract T43D-1660, 2006

Novali, F., G.J. Funning, R. Bürgmann, A. Ferretti, and C. Giannico, ASF RADARSAT data reveal rates and mechanisms of contemporary surface deformation in the San Francisco Bay Area *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract H24C-04, 2006

Panning, M.P., F. Marone, A. Kim, Y. Capdeville, P. Cupillard, Y. Gung, B. Romanowicz, Improvements in mode-based waveform modeling and application to Eurasian velocity structure *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract S51A-1254, 2006

Porritt, R.W., R. Allen, R. Nadeau, and M. Brudzinski, Automated Search for Tremor in Parkfield and the Bay Area, CA. *Eos Trans. AGU, 87*(52), Fall Meet. Suppl., Abstract T41A-1549, 2006.

Rhie, J., V. Lekic, and B. Romanowicz, An assessment of surface wave and normal mode spheroidal Q models by forward modeling of Rayleigh waves, *EOS Trans AGU* 87 (52), Fall Meeting Suppl. Abstract, S23D-0201, 2006.

Rodgers, A. Petersson, S. Nilsson, B. Sjogreen, and K. McCandless, Broadband waveform modeling to evaluate the USGS seismic velocity model for the San Francisco Bay Area *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract S51B-1270, 2006

Romanowicz, B., A. Cao, and Y. Masson, Short wavelength topography on the inner core boundary *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract U41D-04, 2006

Scognamiglio, L., E. Tinti, A. Michelini, L. Malagnini, and D.S. Dreger, Near real-time regional moment tensor estimation using Italian broadband stations *EOS Trans. AGU*, 87(52), Fall Meeting Suppl., Abstract S31B-0197.

Taira, T., P.G. Solver, F. Niu, and R.M. Nadeau, Direct Detection of Temporal Variations in Seismic Scatterers at Seismogenic Depth Attributed to the 2004 Parkfield earthquake *EOS Trans. AGU*, 87, Fall Meet. Suppl., Abstract S23C-0185, 2006.

Templeton, D. and R. Nadeau, R. Bürgmann, Distribution of slip at the juncture of the San Andreas and Calaveras Faults from repeating earthquakes *EOS Trans. AGU*, 87, Fall Meet. Suppl., Abstract, S31A-0173, 2006.

To, A. and B. Romanowicz, Constraints on lateral S wave velocity gradients around the Pacific superplume *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract S51C-1288, 2006

Wurman, G., R.M. Allen, and P. Lombard, Toward earthquake early warning in Northern California *Eos Trans. AGU 87*, Fall Meet. Suppl., Abstract S42C-07, 2006.

Xue, M. and R.M. Allen, The fate of the Juan de Fuca Plate, *Eos Trans. AGU, 87(52)*, Fall Meet. Suppl., Abstract S51D-06, 2006.

USGS/NEHRP Annual Workshop on Earthquake Hazards, Menlo Park, CA, January 18-19, 2007

Allen. R.M., M. Hellweg, A. Kireev, P. Lombard, D. Neuhauser, and G. Wurman, Earthquake early warning in Northern California

Bürgmann, R., G. funning, and N. Houlié, Space geodetic constraints on fault slip rates and the distribution of aseismic slip on Bay Area faults

Bürgmann, R., G. Funning, G. Hilley, A. Ferretti, and F. Novali, Active uplift and thrust-fault strain accumulation rates from PS-InSAR and GPS data

Hellweg, M., The Orinda Events

Hellweg, M., P. Lombard, J. Boatwright, H. Bundock, and H. Haddadi, Using 1906 simulations to assess performance of Northern California networks

Houlié, N. and B. Romanowicz, the BARD Continuous GPS Network: Monitoring Active Deformation and Strain Accumulation in Northern California and the San Francisco Bay Area

Kim, A. and D. Dreger, Determination of Finite-Source Parameters: ShakeMap Applications

Romanowicz, B., D. Neuhauser, D. Oppenheimer, F. Klein, H. Macbeth, Operation of the NCEDC

Romanowicz, B., M. Hellweg, P. Lombard, D. Neuhauser, D. Oppenheimer, L. Dietz, and F. Klein, Operation of the joint earthquake notification system in Northern California

Uhrhammer, R., M. Hellweg, P. Lombard, K. Hutton, E. Hauksson, A. Walter, and D. Oppenheimer, Recalibrating M_L for CISN

2007 Earthscope Annual Meeting, Monterey, California, March 27-30, 2007.

Allen, R.M. and M. Xue. Convective interactions in the mantle beneath the Pacific Northwest: The fate of the Juan de Fuca plate.

Hellweg, M., D. Dreger and B. Romanowicz, Regional Moment Tensors in Northern California: Adding Data from USArray Stations

Marone, F. and B. Romanowicz, 3D radial and azimuthal anisotropic structure of the North American upper mantle

Nadeau, R.M. (Invited), Effect of Parkfield Earthquake on Tremor Activity Below the San Andreas Fault Near Cholame, CA, EarthScope National Meeting, March 27-30, 2007, Monterey, CA.

Nadeau, R.M. and K.H. Chen, A Microseismic View of the Immediate SAFOD Target Zone, POSTER, EarthScope National Meeting, March 27-30, 2007, Monterey, CA.

Uhrhammer, R., M. Hellweg, B. Romanowicz and P. Lombard, Assessment of Station Performance: Noise levels at BDSN, TA and NC.

Neuhauser, D., L. Dietz, P. Lombard, F. Klein, S. Zuzlewski, W. Kohler, M. Hellweg, J. Luetgert, D. Oppenheimer and B. Romanowicz, The Northern California Earthquake Management System: A Unified System From Realtime Monitoring to Data Distribution.

101st Annual Meeting of the Seismological Society of America, Kona, Hawaii, April 11-13, 2007

Bürgmann, R., A.M. Freed, and T.A. Herring, Probing the Rheology of the Upper Mantle Using Far-field GPS Transients Following the 1999 Hector Mine, California Earthquake, *Seism. Res. Lett., 78(2), 299,* 2007

Dreger, D.S., E. Tinti, and A. Cirella, Slip Velocity Function Parameterization for Broadband Ground Motion Simulation *Seism. Res. Lett., 78(2), 308,* 2007

Dolenc, D., D. Dreger, and S. Larsen, Simultaneous inversion of the teleseismic, local, and microseism observations for the velocity structure within the Santa Clara Valley basins, *Seism. Res. Lett., 78(2), 310,* 2007.

Dolenc, D., B. Romanowicz, and W.S.D. Wilcock, Observations of infragravity Waves at the Endeavour ocean bottom broadband station (KEEB)*Seism. Res. Lett., 78(2), 261,* 2007

Ellsworth, W., L. Dietz, S. Hickman, G. Jensen, W. Kohler, J. Luetgert, C. Weiland, M. Zoback, E. Davis, R. Krug, E. Samson, M. Aranha, D. Neuhauser, R. Uhrhammer, V. Oye, G.F.Z. Prevedel, and M. Zumberge, The San Andreas Fault Observatory at Depth: Monitoring Earthquakes and Fault Movement Inside the Fault *Seism. Res. Lett., 78(2), 266,* 2007

Ford, S.R., D.S. Dreger, and W.R. Walter, Full Moment Tensor Analysis of Nevada Test Site Explosions and Earthquakes, and Western US Collapses and Volcanic Events Using a Regional Waveform Inversion, *Seism. Res. Lett., 78(2), 240,* 2007

Freymueller J.T., A. Freed, E. Calais, and R. Bürgmann, Denali Earthquake Postseismic Deformation: Implications for Postseismic Mechanisms *Seism. Res. Lett., 78(2), 299,* 2007

Hellweg, M., Complexity at Small Magnitudes: Earthquakes in the Orinda Sequence *Seism. Res. Lett., 78(2), 285,* 2007

Johanson, I.A., R.M. Nadaeu, D. Templeton, and R. Buürgmann, Heterogeneous Creep at San Juan Bautista from GPS, InSAR and Repeating Aarthquakes *Seism. Res. Lett., 78(2), 289,* 2007

Kim, A., D.S. Dreger, and S. Larsen, Broadband Modeling of 3D Velocity Structure in the San Francisco Bay Area *Seism. Res. Lett., 78(2), 257,* 2007

Nadeau, R.M., Borehole Seismic Observations of Deep Fault Deformation Associated with the 2004 Parkfield Mainshock: Nonvolcanic Tremor and Repeating Micro-earthquakes *Seism. Res. Lett., 78(2), 266,* 2007

Neuhauser, D.S., S. Zuzlewski, R. Uhrhammer, N. Houlié, M. Aranha, B. Romanowicz, F. Klein, L. Dietz, S. Silverman, and D. Oppenheimer, Diverse Geophysical Data Available through the Northern California Earthquake Data Center *Seism. Res. Lett., 78(2), 283,* 2007

Sammis, C.G., R.L. Biegel, and L.R. Johnson, Effect of Rock Damage on Seismic Waves generated by Explosions *Seism. Res. Lett., 78(2), 240,* 2007

Wurman, G., R.M. Allen, P. Lombard, D. Neuhauser, A. Kireev, and M. Hellweg, Real-time implementation of ElarmS for earthquake early warning in northern California *Seism. Res. Lett., 78(2), 241,* 2007

Computational Geosciences Symposium (DOE office of BS), Gaithersburg, MD, May 3-4, 2007

Romanowicz, B. "Towards regional tomography of South East Asia using the Spectral Element Method" (invited)

American Geophysical Union, 2007 Spring Meeting, Acapulco, Mexico, May 2007

Houlié, N., B. Romanowicz and M. Hellweg, A Contribution to Mitigating Seismic Risk in the Bay Area: The Bay Area Regional Deformation (BARD) GPS Network, *Eos Trans. AGU,88*(23), Jt. Assem. Suppl., Abstract G43A-03.

B. Romanowicz, D. Dreger, D. Neuhauser, W. Karavas, M.Hellweg, R. Uhrhammer, P. Lombard, J. Friday, R. Lellinger, J. Gardner, R. McKenzie and C. Bresloff, The Berkeley Digital Seismic Network. *Eos Trans. AGU, 88*(23), Jt. Assem. Suppl., Abstract S33C-03.

Hellweg, M., D. Given, E. Hauksson, D. Neuhauser, D. Openheimer and A. Shakal, The California Integrated Seismic Network, *Eos Trans. AGU, 88*(23), Jt. Assem. Suppl., Abstract S33C-07.

SAFER (Seismic Early Warning for Europe) Meeting, Athens, Greece, June, 2007

Allen, R.M. Toward earthquake early warning for California.

Gordon Research Conference, Mt. Holyoke MA, June 2007

Allen, R.M. and M. Xue. The Fate of the Juan de Fuca plate: Implications for a Yellowstone plume head.

Cammarano,F. and B. Romanowicz, L. Stixrude and C. Lithgow-Bertelloni, Thermal and compositional models of the upper mantle as constrained by long period seismic waveforms and mineral physics data

Cao, A. and Barbara Romanonicz, Array analysis of small-scale mantle heterogeneity using PKP precursors from doublet

Lekic, V. and B. Romanowicz, Applying the Coupled Spectral Element Method to Tomography: Crustal Effects

Speaking Engagements

Allen, R.M. "Earthquake early warning in California: Current development and future plans.", Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy, July 2006.

Allen, R.M. "CISN Earthquake Early Warning: Real-time testing of algorithms statewide.", California Integrated Seismic Network Advisory Board Meeting, August 2006.

Allen, R.M. "Warning before shaking: Rapid hazard assessment across California." Institut de Physique du Globe de Paris, January 2007.

Allen, R.M. "Segmentation in episodic tremor and slip along the length of the Cascadia forearc." Institut de Physique du Globe de Paris, January 2007.

Allen, R.M. "Earthquake?" College of Letters and Sciences Faculty Forum, UC Berkeley, CA, February 2007.

Allen, R.M. "Passive source seismology: Resolvable scales using various techniques." GeoSwath Workshop, Boise, Idaho, April 2007.

Allen, R.M. "Episodic tremor and slip along the length of Cascadia: Observations and implications for seismic hazard." National Earthquake Prediction Evaluation Council, Portland, OR, May 2007.

Allen, R.M. "Earthquake early warning: Current progress and future prospects." Advanced National Seismic System Steering Committee, Salt Lake City, UT, June 2007.

Bürgmann, R., "Geodetic Imaging of Lithosphere Rheology", IGP, Paris, January 8, 2007

Bürgmann, R., "Active Tectonics of the San Francisco Bay Area", Konferenz der Geologische Vereinigung, Potsdam, Germany, September 29, 2006

Dolenc, D. "Monterey Bay Broadband Seismic Observatory: Observation and Removal of Long-period Noise", Geological Sciences Seminar, University of Minnesota, Duluth, March 29, 2007

Dreger, D., R. Nadeau and A. Morrish "Kinematic modeling of the SAFOD target events", EarthScope National Meeting, Monterey, California, March 27-30, 2007. (Invited)

Funning, G., "Aseismic creep on the Hayward-Rodgers Creek fault zone" Crustal deformation in the Bay Area meeting, UC Berkeley, June 8, 2007

Funning, G., "Space geodesy in the Bay Area: surface deformation, fault kinematics and creep" Earthquake Hazards Seminar, US Geological Survey, Menlo Park, CA, April 18, 2007

Funning, G., "Studying surface defor-mation and fault creep in the Bay Area using satellite radar measurements" UC Berkeley, Berkeley Seismological Laboratory Seminar, Nobember 14, 2006

Funning, G., "Surface deformation monitoring in the Bay Area using space-based radar", Department of Civil Engineering, Geo-Engineering Seminar, UC Berkeley, November 8, 2006

Hellweg, M. "Below Zero: Scaling and Complexity in Small Earthquakes"; Physics Colloquium, Universidad del Valle, Cali, Colombia, September 28, 2006

Hellweg, M. "Listening Carefully: Learning from Earthquakes", Northern California Chapter of the "Achievement Awards for College", Francisca Club, San Francisco, CA, March 5, 2007

Hellweg, M. "Earthquakes in and around Orinda, CA", Orinda Historical Society, Orinda, CA, March 21, 2007

Hellweg, M. "Earthquakes in our backyard", North Pleasanton Rotary Club, Pleasanton, CA, June 15, 2007

Houlie, N. "Tracking magma volumes on active basaltic volcanoes.", UC Santa Cruz (seminar), June 1, 2007

Mayeda, K. "Why do we have earthquakes, and what do seismologists do?", Head-Royce School 6th Grade, Oakland, CA, March 2, 2007

Nadeau, R.M., "Nonvolcanic Tremor Deep Beneath the San Andreas Fault near Cholame", California, University of California, Berkeley Seismological Laboratory, Summer Tremor Activity Seminar, July 13, 2006. (Invited)

Nadeau, R.M., "Monitoring the SAFOD Target Earthquakes – Nov 2, 2006 Repeat of the NW (San Francisco) M2 sequence", Berkeley Seismological Laboratory, Earthquake of the Week, Berkeley, California, November 3, 2006.

Nadeau, R.M., Internal structure of the targets: relative locations, SAFOD Earthquake Target Location Workshop, San Francisco, CA, December 12, 2006.(Invited)

Romanowicz, B., "Elastic and anelastic waveform tomography at global and continental scales" Paris workshop on IPGP/BSL collaboration, Paris, January 8-10, 2007

Romanowicz, B., "The Earth's hum: bridging the gap between seismology and oceanography", B.Jardetsky Lecture, Lamont, September 22, 2006:

Romanowicz, B. "Contraintes sismologiques sur la structure et la déformation au Tibet", Lecture at Collège de France, France, February 7, 2007

Romanowicz, B., "Le bourdonnement de la terre: interactions dynamiques entre l'atmosphère, les océans et la terre solide", Université Paul Sabatier, Toulouse, France, February 2, 2007

Romanowicz, B., "Tomographie élastique et anélastique à l'échelle globale et continentale", Ecole Normale Supréieure, Lyon, France, April 25, 2007

Romanowicz, B., "Short Period topography on the inner core boundary", Ecole Normale Supréieure, Lyon, France, April 25, 2007

Romanowicz, B., "Structure anisotrope, et dynamique du manteau à l'échelle continentale", Ecole Normale Supréieure, Paris, France May 29th, 2007

Romanowicz, B., "The earth's hum: bridging the gap between seismology and oceanography", Department of Geophysics, Utrecht University, the Netherlands, June 5, 2007

Romanowicz, B., "Structure anisotrope, et dynamique du manteau à l'échelle continentale" Université Joseph Fourier, Grenoble (LGIT), June 21, 2007

Romanowicz, B., "Structure anisotrope, et dynamique du manteau à l'échelle continentale" Université Blaise Pascal, Strasbourg, France, June 25, 2007

Romanowicz, B., "The earth's hum: bridging the gap between seismology and oceanography", Department of Geophysics, ETH, Zurich, June 27, 2007

Romanowicz, B., "Towards large scale tomography using the Spectral Element Method", 4th SPICE workshop, held in Cargèse, Corsica, May 18-19, 2007 (invited)

Uhrhammer, R. A., "Earthquakes and the Hayward Fault", Alameda County Emergency Operations Center, Dublin, CA, January 3, 2007.

Uhrhammer, R. A., "Seismology", North Bay Amateur Radio Association, Mare Island Museum, March 26, 2007.

Uhrhammer, R. A., "Seismology Update", West Berkeley Lions Club, Spengers Restaurant, Berkeley, CA, March 23, 2007.

Panels and Professional Service

Richard M. Allen

Briefed National Earthquake Prediction Evaluation Council, May 2007.
Briefed Advanced National Seismic System Steering Committee, June 2007.
U.S. participant in the European Commission project "Seismic Early Warning Across Europe,"
June 2006 to June 2009.

Roland Bürgmann

Associate Editor, Bulletin of the Seismological Society of America
Corresponding Editor, Eos
Editorial Board, Earth and Planetary Science Letters
Member, UNAVCO Nominations Committee
Member, WinSAR Nominations Committee
Elected member, SSA Board Of Directors
Chair, EarthScope PBO Standing Committee
2007 EarthScope Annual Meeting Organizing Committee
Member, Tectonics Observatory at Caltech Review Committee
Member, UC Berkeley Graduate Fellowship Committee
Member of the AAAS, AGU, GSA, and SSA

Douglas S. Dreger

COSMOS Board of Directors
Golden Gate Bridge Instrumentation Committee

Margaret Hellweg

Member, CISN Program Management Committee
Member, CISN Standards Committee
Member, CISN Steering Committee
Member, CISN Outreach Committee
Member, 1868 Commemoration Committee
Member, 1868 Commemoration Executive Committee
Member, IASPEI/IAVCEI Joint Commission on Volcano Seismology

Douglas S. Neuhauser

Chair, Standards Group, California integrated Seismic network (CISN)
Acting Member, CISN Program management CDommittee

Robert M. Nadeau

Member, SAFOD target event location working group
Member, UNAVCO Strategic Planning Committee

Barbara Romanowicz

Member Advisory Committee to College de France, Paris (COSS)
Member, Conseil d'administration of Institut de Physique du Globe in Paris
Member, Conseil Scientifique, Institut de Recherche pour le Développement
Member, National Earthquake Prediction Evaluation Council
Member, Advisory committee, Geophysical Institute, Univ. of Alaska, Fairbanks
Member, Cooperative Institute for Deep Earth Research (CIDER) Steering Committee
CIDER 2006 Summer program - lead member of organizing team - July 16- Aug 4, 2006, Santa Barbara, CA
Member, Fellows Committee, AGU
Reviewing Editor for Science
Member, BESR (Board on Earth Sciences and Resources)
Member, CISN Steering Committee

Robert A. Uhrhammer

Member, International Association of Seismology and Physics of the Earths Interior, Working Group on Magnitudes
Member, California Integrated Seismic Network, Magnitude Working Group
Member, American National Seismic System, Technical Integration Committee, Working Group D, Seismic Instrumentation

Appendix II Seminar Speakers 2006-2007

JAMIE RECTOR
UC Berkeley
Earth and Planetary Science
"What is Q?"
Tuesday, August 29, 2007

ARCHIE PAULSON
UC Berkeley
"Inference of the Earth's Mantle Viscosity from Post-Glacial Rebound"
Tuesday, September 5, 2006

FELIX HERMANN
University of British Columbia
Earth and Ocean Sciences
"Stable Seismic Recovery with Curvelets"
Tuesday, September 5, 2006

JOE DUFEK
UC Berkeley
Earth & Planetary Science
"Self-organization in turbulent multiphase flow: integrating the dynamics and deposits of volcanic eruptions"
Tuesday, September 19, 2006

DAVID DOLENC
UC Berkeley
Earth & Planetary Science
"Results from two studies in seismology: I. Seismic observations and modeling in the Santa Clara Valley, CA, II. Observations and removal of the long-period noise at the Monterey ocean bottom broadband station (MOBB)"
Tuesday, September 26, 2006

JESSE LAWRENCE
IGPP
UC San Diego
"What Can Body Waves Tell Us About the Mantle Transition Zone?"
Tuesday, October 5, 2006

CHARLIE SAMMIS
Department of Earth Science
USC
"Dynamic Triggering of Microearthquakes by P- and S-waves from the 1999 Chi-Chi, Taiwan Earthquake"
Tuesday, October 10, 2006

JUNKEE RHIE
UC Berkeley
Earth & Planetary Sciences
"Excitation of Earth's Incessant Free Oscillations by Atmosphere-Ocean-Seafloor Coupling"
Tuesday, October 17, 2006

CHRIS FULLER
UC Berkeley
Berkeley Seismological Laboratory
"Subduction-thrust Seismicity and the Structure of Accreting Margins"
Tuesday, October 24, 2006

HEIDI KUMZA
UC Berkeley
"Support Vector machines for Geophysical Inversion"
Tuesday, October 31, 2006

GEORGE ZANDT
University of Arizona
Department of Geosciences
"Lower Crustal Seismic Anistropy: Evidence for Mega Low-Angle Shear-Zones, Crust-Mantle Decoupling, and Delamination"
Tuesday, November 7, 2006

GARETH FUNNING
UC Berkeley
Berkeley Seismological Laboratory
"Studying Surface Deformation and Fault Creep in the Bay Area using Satellite Radar Measurements"
Tuesday, November 14, 2006

EMILY BRODSKY
UC Santa Cruz
Earth & Planetary Sciences
"Triggering Earthquakes Dynamically"
Tuesday, November 21, 2006

CHRISTINE REIF
UC Santa Cruz
Earth & Planetary Sciences
"What can seismic tomography really say about the temperature, composition, and mineralogy of the lowermost mantle?"
Tuesday, November 28, 2006

STEFANO GRESTA
University of Catania
"The 2002 eruption of Mount Etna: seismological constraints on the eruptive mechanism"
Tuesday, September 5, 2006

SEOK GOO SONG
Stanford University
"A unified source model for the 1906 San Francisco Earthquake"
Tuesday, December 19, 2006

JULIET BIGGS
University of Oxford
Department of Earth Sciences
"InSAR observations of the Denali fault earthquake cycle"
Tuesday, January 23, 2007

TAKUJI YAMADA
Boston University
Department of Earth Sciences
"Stress drop, radiated seismic energy, and rupture speed of microearthquakes: Analysis of borehole seismograms in the vicinity of the source region in a South African gold mine"
Tuesday, January 30, 2007

MARGARET BOETTCHER
USGS, Menlo Park
"A synoptic model of slip on oceanic ridge transform faults- insights from earthquakes and laboratory experiments"
Tuesday, February 6, 2007

DENNISE TEMPLETON
UC Berkeley
Berkeley Seismological Laboratory
"Exotic Seismic Sources: A look at non-double-couple earthquakes and identically repeating events"
Tuesday, February 13, 2007

KEVIN MAYEDA
UC Berkeley
Berkeley Seismological Laboratory
"Broadband applications of coda waves to source, site, and path effects"
Tuesday, February 20, 2007

JIM RICE
Harvard University
Earth and Planetary Sciences
"Aseismic transients in subduction zones: What physical basis?"
Tuesday, February 27, 2007

SAEKO KITA
USGS, Menlo Park
"Existence of a seismic belt in the upper plane of the double seismic zone extending in the along-arc direction at depths of 70-100 km beneath NE Japan"
Tuesday, March 6, 2007

GERMAN PRIETO
UC San Diego
IGPP
"Confidence intervals for earthquake source parameters"
Tuesday, March 13, 2007

AKIKO TO
UC Berkeley
Berkeley Seismological laboratory
"What we have learned about the D" layer in and around the Pacific superplume"
Tuesday, March 20, 2007

CHEN JI
UC Santa Barbara
Department Earth Science
"Very broadband studies of large earthquakes"
Tuesday, April 3, 2007

ALLAN RUBIN
Princeton University
Geosciences
"Theoretical earthquake nucleation, with implications for slow slip events and more"
Tuesday, April 17, 2007

ANDY MICHAEL
USGS, Menlo Park
"The Parkfield 2004 earthquake: lessons from the best-recorded quake in history"
Tuesday, April 24, 2007
2007 Lawson Lecture

STEPHEN MORRIS
UC Berkeley
Department of Mechanical Engineering
"The implications of (seismically) small density differences for mantle dynamics"
Tuesday, May 1, 2007

SUSAN HOUGH
USGS, Pasadena
"California's biggest historical earthquake"
Tuesday, May 8, 2007

Berkeley Seismological Laboratory
Organizational Chart
2006-2007 *(as of June 2007)*