FINAL TECHNICAL REPORT

- AWARD NUMBER: 04HQAG0109
- RECIPIENT: Regents of the University of California
- PRINCIPAL INVESTIGATOR: Barbara Romanowicz
- TITLE: Operation of the joint earthquake notification system in Northern California: Collaboration between UC Berkeley and the USGS Menlo Park
- PROGRAM ELEMENTS: I & II

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TITLE: OPERATION OF THE JOINT EARTHQUAKE NOTIFICATION SYSTEM IN NORTHERN CALIFORNIA:
COLLABORATION BETWEEN UC BERKELEY
AND THE USGS MENLO PARK

P.I.: Barbara Romanowicz, Lind Gee, Margaret Hellweg and Doug Neuhauser
Berkeley Seismological Laboratory, 215 McCone Hall
UC Berkeley, CA 94720-4760
(510) 643-5690, x3-5811 (Fax), barbara@seismo.berkeley.edu
(510) 643-9449, x3-5811 (Fax), peggy@seismo.berkeley.edu

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1. TECHNICAL ABSTRACT

In Northern California, the BSL and the USGS Menlo Park collaborate to provide the timely and reliable earthquake information to the federal, state, and local governments, to public and private agencies, and to the general public. This joint earthquake notification system provides enhanced earthquake monitoring by building on the strengths of the Northern California Seismic Network (NCSN), operated by the USGS Menlo Park, and the Berkeley Digital Seismic Network (BDSN), operated by the UC Berkeley Seismological Laboratory.

During this reporting period, the BSL worked with the USGS Menlo Park to continue operating the UC Berkeley component of the Northern California Earthquake Management Center and continue software development on and begin the transition to a new, more robust system of software for earthquake monitoring initiated during the previous project. The goals of these activities is to enhance and improve earthquake reporting in northern California.

2. CURRENT CAPABILITIES

In 1996, the BSL and USGS began collaborating on a joint notification system for northern and central California earthquakes. The current system merges the programs in Menlo Park and Berkeley into a single earthquake notification system, combining data from the NCSN and the BDSN. Together, the BSL and USGS form the Northern California Earthquake Management Center (NCEMC) of the California Integrated Seismic Network (CISN), which is the California "region" of the ANSS.

Details of the Northern California processing system and the "Rapid Earthquake Data Integration" (REDI) project have been described in past reports. In this section, we will describe how the NCEMC fits within the CISN system, detail developments over the time period of this grant, and discuss plans for the future development.

Figure 1 illustrates the NCEMC as part of the the CISN communications ring. The NCEMC is a distributed center, with elements in Berkeley and Menlo Park. The 35 mile separation between these two centers is in sharp contrast to the Southern California Management Center, where the USGS Pasadena is located across the street from the Caltech Seismological Laboratory. With funding from the State of California, the CISN partners have established a dedicated T1 communications ring, 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 communication link to provide bandwidth for shipping waveform data and other information between their processing systems.

At the NCEMC, we recently took the first, very important step towards a new processing system which will provide maximum independence and redundancy. With this step, the database becomes the primary holder of information, including event-related data, waveform-related data, and station- and instrument-related data. The database is both the repository and source of information for the many interacting elements of the processing system.

After this first step, Figure 2 still represents the system at the NCEMC. Two Earthworm-Earlybird systems in Menlo Park feed two "standard" REDI processing systems at UC Berkeley [*Gee et al.*, 2003]. Until now, events have been reviewed using the CUSP system, originally developed in the 1980s. To remove the dependence on CUSP, the database has been interfaced with the processing components at the BSL, and several new services have been developed. As in the past, one of the Earthworm-Earlybird-REDI systems remains the production or paging system. The other system serves as hot backup and has also been used to test new software before migrating it to the production environment. The Earthworm-Earlybird-REDI systems perform the standard detection, location, estimation of M_d before passing the information to the REDI system. The primary new aspect of this upgraded system is that REDI now enters this information into the database in addition to producing M_L, and M_w, and preparing processed ground motion data. ShakeMaps [*Wald et al.*, 1999] are computed 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 (ShakeMaps that account for finite faulting).

The dense network and Earthworm-Earlybird processing environment of the NCSN ensure rapid and accurate earthquake locations, low magnitude detection thresholds, and first-motion mechanisms for smaller quakes. The high dynamic range data loggers, digital telemetry, and broadband and strong-motion sensors of the combined BDSN/NCSN and REDI analysis software provide reliable magnitude determination, moment tensor estimation, peak ground motions, and source rupture characteristics. Robust preliminary hypocenters continue to become 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).

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. 2005-2006 DEVELOPMENTS

Here we recap some of the important developments in the REDI system during the contract period. Our primary efforts have been directed toward the development and implementation of new Northern California, and eventually CISN-wide, joint notification system. The BSL and the USGS Menlo Park recently completed the first step toward this goal.

3.1 Transition to the new Joint Notification System

Figure 2 illustrates the current organization of the joint USGS-UCB system. As described above, an Earthworm/Earlybird component is tied to a REDI component and the pair form a single ”joint notification system”. Although this approach has functioned reasonably well over the last 8 years, potential problems are posed by the separation of critical system elements across 30 miles of San Francisco Bay. Thus, system we have designed for operation in Northern California, will have a single independent unit operating at the USGS and one at UC Berkeley. Three elements provide the foundation of the design, “network services”, the use of a messaging service to enable

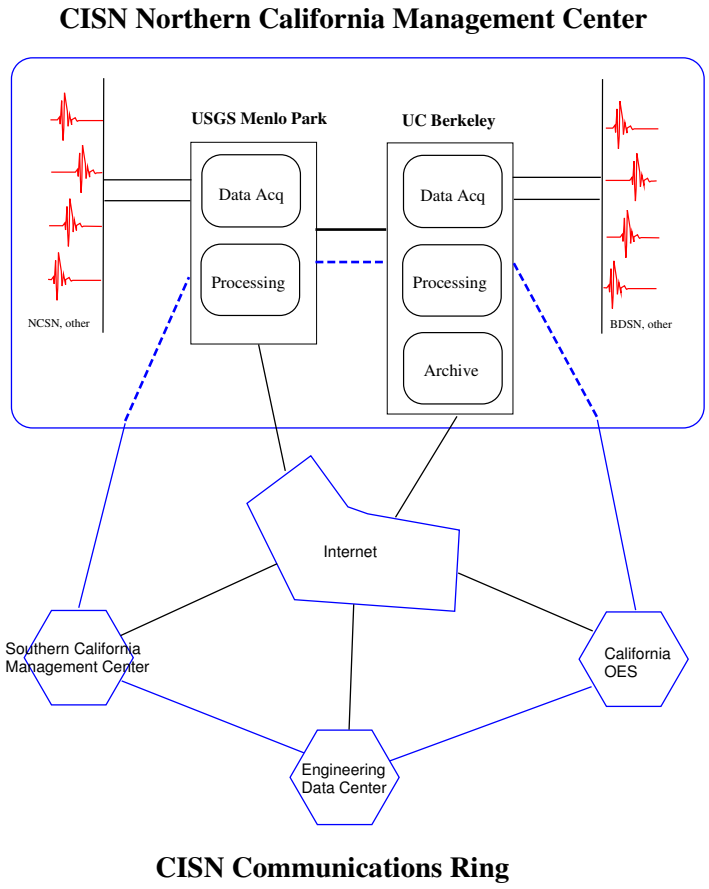

Figure 1: Schematic diagram illustrating the connectivity between the real-time processing systems at the USGS Menlo Park and UC Berkeley, forming the Northern California Management Center, and with other elements of the CISN.

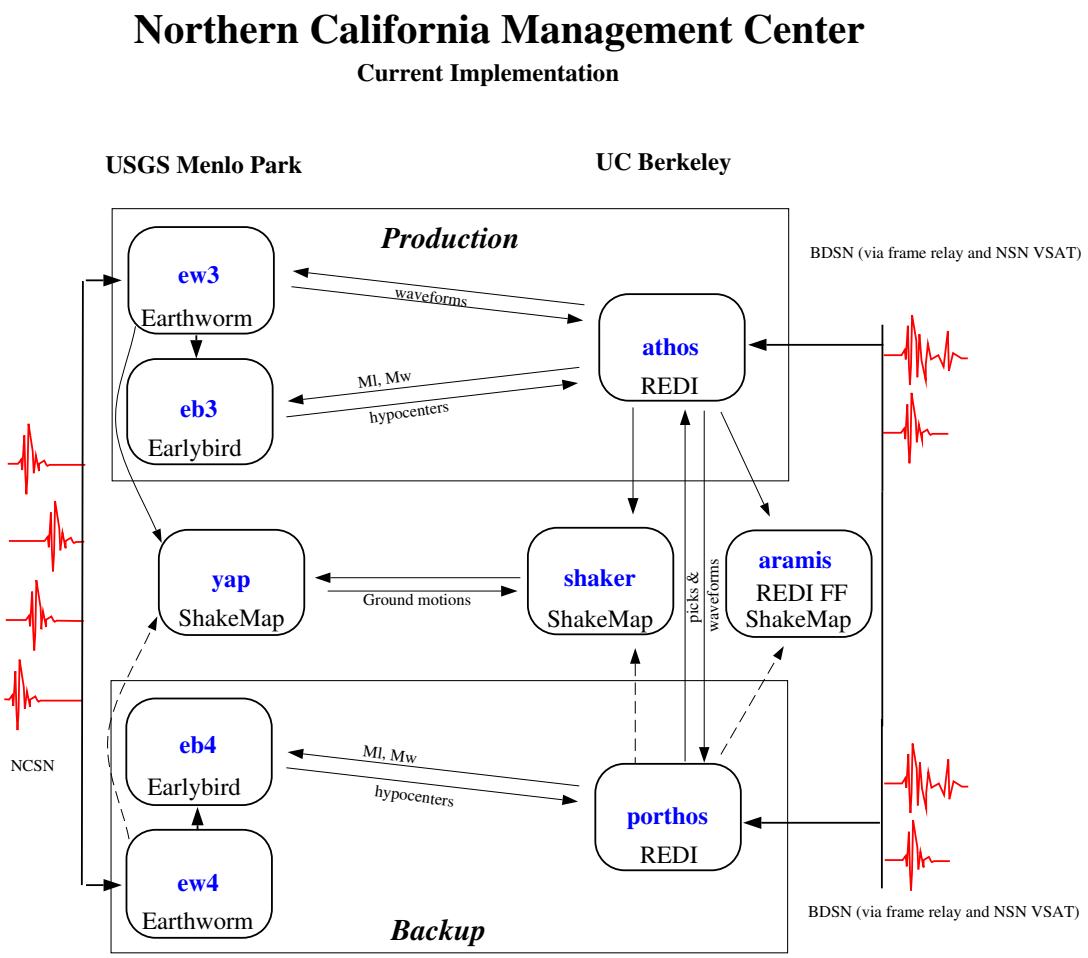

Figure 2: Detailed view of the Northern California processing system, showing the two Earthworm-Earlybird-REDI systems, the two ShakeMap systems, and the finite-fault system.

inter-module communication and the central role of a database in storing and providing the most up-to-date information to modules for processing. The design draws strongly on the experience in Southern California for the development of TriNet (Figure 5). Important modifications have been introduced to allow for local differences (such as different forms of data acquisition). In addition, the BSL and the USGS want to minimize use of proprietary software in the system. The TriNet software used three forms of proprietary software: Talerian Smart Sockets (TSS) for inter-module communication via a ”publish and subscribe” method; RogueWave software for database communication, and Oracle as the database management system. 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. However, with the agreement of Southern California and with shared development effort, we have replaced Smart Sockets with the CISN Messaging System (CMS), and RogueWave.

The concept of network services is schematically illustrated in Figure 4. Certain elements of processing are completed at remote sites and the results are passed via the network to other users, such as the realtime processing systems. Thus, picks, codas and amplitudes can be produced at one location and shared between the UCB and USGS Menlo Park realtime systems, or indeed, state-wide. Four types of network services will be important when the transition is complete: pick

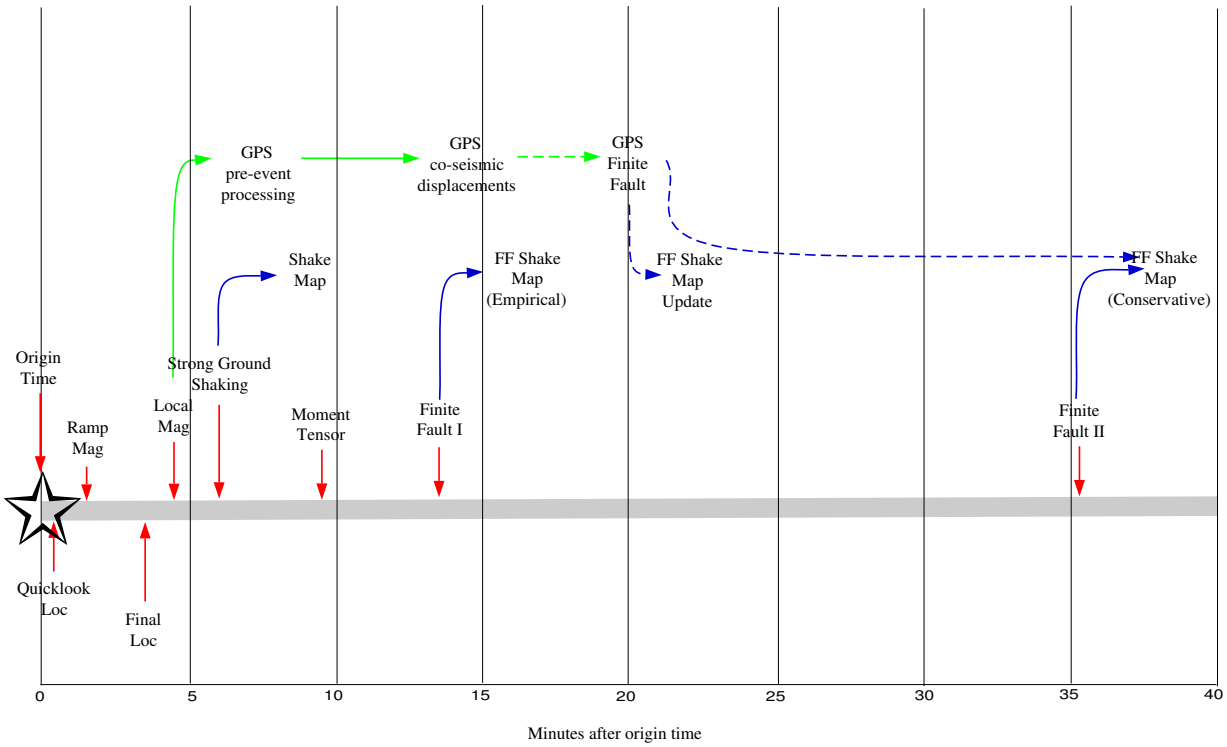

Figure 3: Illustration of the current (solid lines) and planned/proposed (dotted lines) development of real-time processing in Northern California. The Finite Fault I and II are fully implemented within the REDI system at UC Berkeley and are integrated with ShakeMap. The resulting maps may be published after review.

and coda services, waveform services, reduced amplitude data (RAD) services and station trigger services. Software for the RAD services was produced in the previous project period. Programs for the waveform and station trigger services have been developed in the past two years.

Figure 5 schematically shows the goal of our transition: network services preparing information which is distributed to processing systems at several locations. In the case of the NCEMC, redundance will be supplied by complete event processing at both the BSL and USGS Menlo Park. As in the past, one system will be "in production" and the other will be a hot backup.

Since embarking on this project, BSL staff, particularly Pete Lombard, has become extremely familiar with portions of the TriNet software. The BSL is providing essentially all the software development work and database support to implement the new system. We are adapting elements of the TriNet software for Northern California, making adjustments and modifications along the way.

The first important step in the transition to the new unified processing system has been the retirement of the antiquated analysis system used for event review at the USGS, CUSP. CUSP has been an impediment on many counts, among them its inability to accept location codes and interface with the Oracle database. CUSP has been replaced by *jiggle*, the event review graphical user interface (GUI) developed and used in Southern California. *Jiggle* receives and deposits its information from the database. To accomplish this step, the elements of the system currently operating at the BSL have been adapted to communicate with the Oracle database, and a number of new modules have been developed.

Request card generator: When an event or trigger has been declared, waveforms must be col-

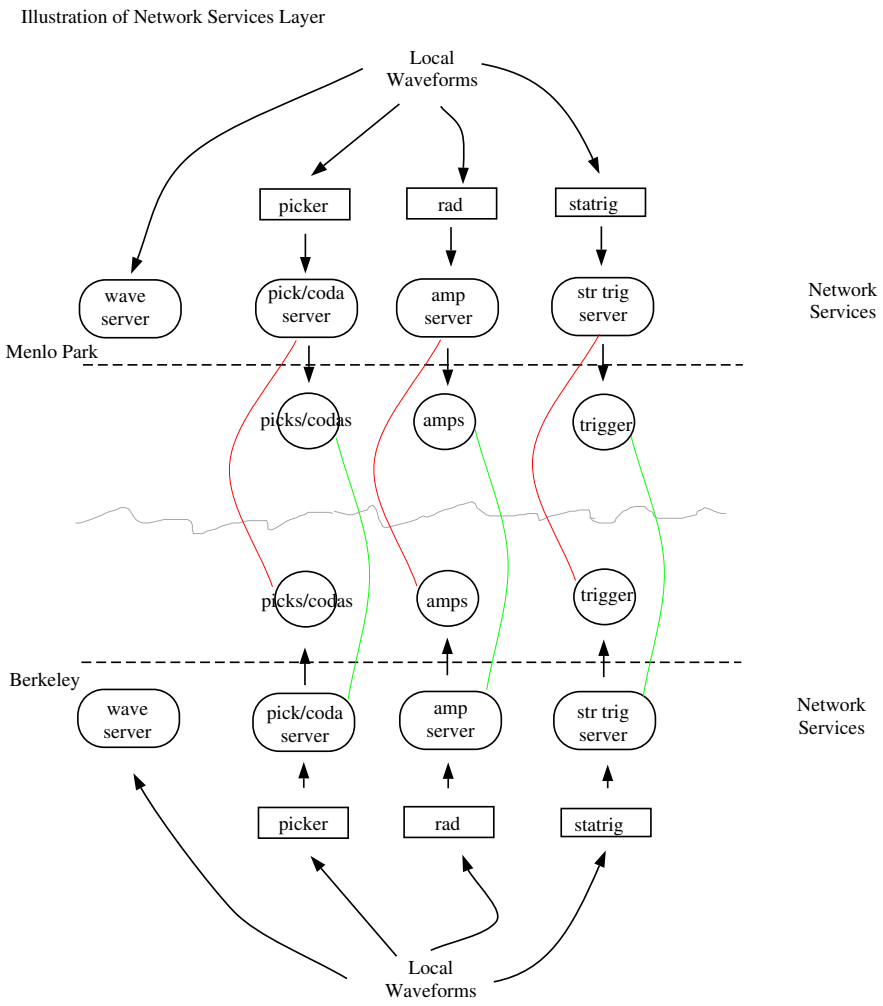

Figure 4: Illustration of the network services layer envisioned as part of the Northern California system, showing the picks/codas, amplitudes, triggers, and waveform services that will form the base of the parallel monitoring systems.

lected, so that it can be reviewed. Rather than simply grabbing all the waveforms for a given time, a *request card* is prepared for each "reasonable" station-network-channel-location (SNCL) that might contribute to the review process. The *request cards* are then processed by the it waveform archiver, which has to know where to look for each particular SNCL waveform. For use in Northern California, modifications were made to the *request card generator*.

Waveform archiver: This process actually retrieves waveforms for future processing and event review. It has to know where to look for waveforms for each SNCL and to persist in collecting waveforms for up to a week, if it has not satisfied the requests initially. It uses *request cards* which define which SNCL and time span, as well as information from the database as to where to find the SNCL's waveform. In Southern California, all waveforms were found in a single *waveserver*. We have modified the *waveform archiver* to enable it to work in the distributed system that is the NCEMC.

Proxy waveserver: In Southern California all waveforms enters processing in the same way, through a single *waveserver*. In Northern California, some data arrives at the BSL, mostly through frame relay links. Other data becomes available at the USGS Menlo Park through *earthworm* waveservers or Nanometrics buffers. Southern California had developed a waveserver to make

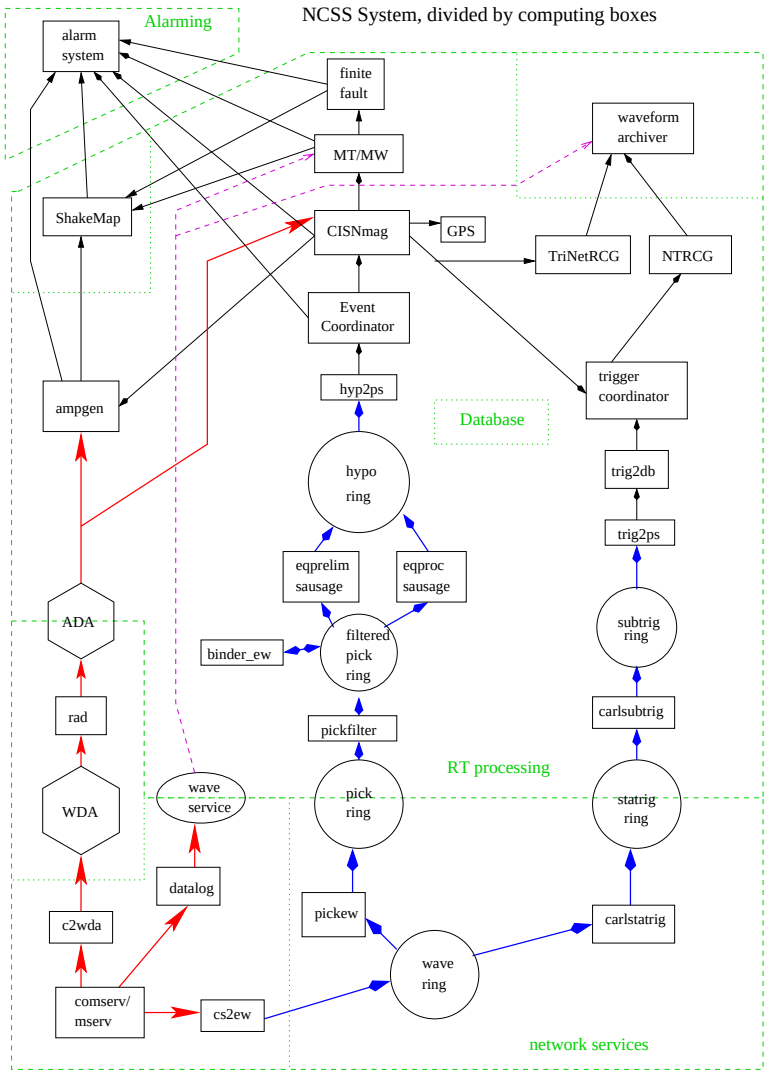

Figure 5: Illustration of the modules that will make up the monitoring system in Northern California, showing communication between modules and the database. Earthworm modules will continue to provide picking, triggering, association, and location capabilities; TriNet modules will be used to calculate magnitude, generate amplitudes, and coordinate between events and triggers; REDI modules will calculate moment tensors and finite faults; and ShakeMap.

waveform data available for collection when an event has been declared. We have written a *proxy waveserver*, which provides a uniform front end for access by the *waveform archiver*. It can currently provide access to the various data types in the NCEMC, however it can also be adapted to serve waveforms from other types of services.

In addition to the new modules or to the extensive modifications necessary in these three cases, the BSL has invested extensive work in preparing and managing the Oracle databases for their new role in the realtime analysis system. A large number of perl scripts were written to configure the database properly for use with *jiggle* and the *waveform archiver*. The NCEMC is now using Oracle databases jointly with the Northern California Earthquake Data Center and exchanging information

among themselves. Database replication is of ultimate importance in maintaining correct and up-to-date information. Stephane Zuzulewski has expended considerable effort in setting up the the database replication and supporting the USGS Menlo Park database efforts as well. He has also developed procedures to import and export hypoinverse information and format from the database.

More information on the Northern California software development efforts is available at `http://www.cisn.org/ncmc/`.

3.2 Move of REDI computers and support equipment to 2195 Hearst

Until 2005-2006, both the BSL staff monitoring routine data acquisition, and the computers and connectivity to acquire, process, and archive the data were situated in McCone Hall. There the BSL has facilities designed to provide air conditioning, 100-bit switched network, and reliable power with UPS and generator. In the past, however, problems have occurred with both the air conditioning and the power backup systems. During 2005-2006, the computers and telemetry equipment associated with data collection and archival were moved to the new campus computer facility in 2195 Hearst Avenue. This facility is more robust than McCone Hall. It was constructed to current seismic codes, and 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. All data acquisition and real-time earthquake processing computers, as well as the data archive and distribution computers. Following the computer move, all telemetry equipment (5 T1s lines, dedicated leased phone circuit to our paging service, dialin/dialout modems, as well as various radio and VSAT communication equipment) were also transferred to the new location over the course of several months. The final elements were moved in February, 2006. During the transition, the private network used for seismic data acquisition and earthquake processing was temporarily bridged between McCone Hall and 2195 Hearst using an encrypted tunnel across the campus backbone network.

4. 2005-2006 EARTHQUAKE MONITORING

During the time period of this contract, over 60,000 events were processed by the joint notification system in northern California. Most of these events were small earthquakes, although a number represent mislocated teleseisms, microwave glitches, or other blown events. Of the total, 434 events had an M_d greater than 3.0, 73 events had an M_L greater than 3.5, and 2 earthquakes with M_L greater than 5 were recorded, including the June 15, 2005 earthquake offshore of Cape Mendocino.

Below we describe some of the interesting events - earthquakes and others - that occurred during this time period, emphasizing, where appropriate, the lessons learned.

4.1 2005 M_w 7.2 Offshore of Cape Mendocino earthquake

On June 15, 2005, at 02:50:54 UTC a major earthquake occurred off the coast of Northern California, 146 km West of Crescent City, at 41.329N, 125.863W. The Earthworm-REDI system detected and located this event, however its epicenter was far enough from the coast to be outside our area of responsibility. The quake occurred in the middle of the Gorda Plate to the west of the sea-floor expression of the Cascadia Subduction Zone. It was widely felt along the Northern California - southern Oregon coast line, although only light shaking occurred. Nonetheless, the REDI system produced an initial estimate of the fault rupture, which Doug Dreger reviewed and published. This quake, which produced a M6.7 aftershock is similar in pattern and location to the 1980 M7.2 Eureka earthquake. The Northern California Management Center put together an Internet report on the sequence and posted it on the CISN Web page: `http://www.cisn.org/special/evt.05.06.15/`

4.2 2006 Glen Ellen earthquake

In the early evening hours of August 2, 2006, the residents of the greater San Francisco Bay area were surprised by a quake of M_w 4.4. This event, which occurred at 20:08:13 PDT, just 5 km W of Glen Ellen, CA, was felt widely. More than 17,000 people from Chico, CA, to Hollister, CA, filled out "did you feel it" reports `http://www.cisn.org/shakemap/nc/shake/40187964/intensity.html`.

This event also provides an example of the efforts the BSL is investing in a project currently being implemented in the CISN to assess earthquake early warning algorithms. The ElarmS algorithm is undergoing off-line testing, as software is developed to enable realtime tests. For each event in Northern California with M3.0 or greater, the algorithm runs ten minutes after the origin time, using all available data. For each second of data after the first station triggers, it produces an "AlertMap". These maps, which intentionally look like ShakeMaps, show the expected shaking intensity estimated by Elarms on the basis of the data it has received until then. Figure 6 shows how the AlertMaps for the Glen Ellen quake develop as data from more stations becomes available. The AlertMaps produced more than three seconds after the first seismic station detected the P-wave arrival are essentially identical to the actual ShakeMap produced for this event (lower right).

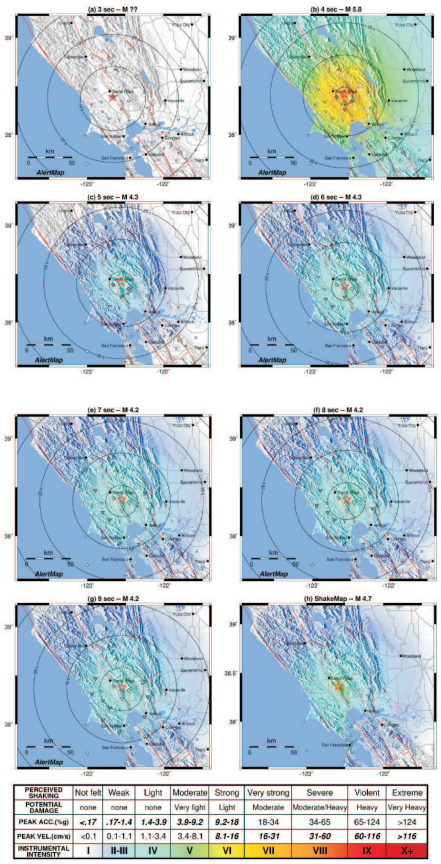

Figure 6: "AlertMap" output from the automatic ElarmS offline processing for the Auguts 2, 2006, M_L 4.7, M_w 4.4 Glen Ellen earthquake. The AlertMap shows the predicted MMI output every second. This changes as additional stations report elevated levels of ground motion. The image on the lower right is the actual ShakeMap for this event. The AlertMaps produced three seconds after the first seismic station detected the P-wave arrival and following are essentially identical to this ShakeMap.

4.3 2006 Hayward Fault sequence

If they occur in densely populated areas, small earthquakes often appear to excite more attention than stronger events. Thus, a sequence of M 3.5 events around Christmas 2006 brought many email and web queries about the earthquake hazard along the Hayward Fault. These quakes are located in a cluster approximately 1 mile SE of the Berkeley campus (7). This is a relatively active pocket of seismicity near Berkeley's border with Piedmont. In the past 30 years, more than 100 earthquake within a mile of this sequence have had magnitudes of 2.0 or larger, with 10 of them exceeding a magnitude 3.0. The current spate of activity in this sequence began on December 20, with a magnitude 3.5 event, however they appear to represent normal Hayward Fault activity.

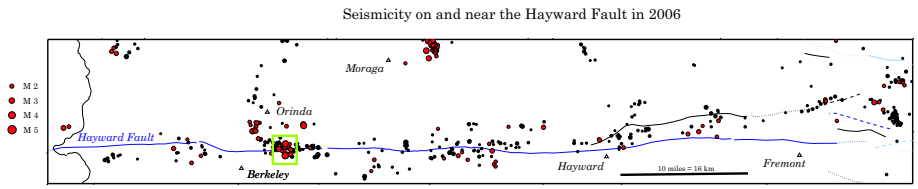

Figure 7: Earthquake activity along the Hayward Fault from 2000 - 2005 (dots) and 2006 (red). The box marks the location of the active pocket.

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6. NON-TECHNICAL ABSTRACT

This project focuses on the development and implementation of hardware and software for the rapid assessment of earthquakes. The Berkeley Seismological Laboratory collaborates with the USGS Menlo Park to monitor earthquakes in Northern California and to provide rapid notification to public and private agencies for rapid response and assessment of earthquake damage. In the project period, we integrated the use of databases into the real-time processing system, and began to implement software to which has been developed to upgrade the Northern California Seismic System to improved robustness. We moved the BSL realtime acquistion and processing equipment to an earthquake-safe environment.

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9. DATA AVAILABILITY

Data and results from the REDI project are available at the Northern California Earthquake Data Center (*//www.ncedc.org*) For additional information on the REDI project, contact Margaret Hellweg at 510-643-9449 or peggy@seismo.berkeley.edu.

Annual Non-Technical Summary

AWARD NUMBER: 04HQAG0109

OPERATION OF THE JOINT EARTHQUAKE NOTIFICATION SYSTEM IN NORTHERN CALIFORNIA:
Collaboration between UC Berkeley
and the USGS, Menlo Park

Barbara Romanowicz, P.I., Lind Gee, Margaret Hellweg and Doug Neuhauser
Berkeley Seismological Laboratory, 215 McCone Hall
UC Berkeley, CA 94720-4760
(510) 643-5690, x3-5811 (Fax), barbara@seismo.berkeley.edu
(510) 643-9449, x3-5811 (Fax), peggy@seismo.berkeley.edu

PROGRAM ELEMENTS: I & II

KEY WORDS: Seismology; Real-time earthquake information

INVESTIGATIONS UNDERTAKEN

This project focuses on the development and implementation of hardware and software for the rapid assessment of earthquakes. The Berkeley Seismological Laboratory collaborates with the USGS Menlo Park to monitor earthquakes in Northern California and to provide rapid notification to public and private agencies for rapid response and assessment of earthquake damage. In the project period, we integrated the use of databases into the real-time processing system, and began to implement software to which has been developed to upgrade the Northern California Seismic System to improved robustness. We moved the BSL realtime acquistion and processing equipment to an earthquake-safe environment.