ANNUAL PROJECT SUMMARY

AWARD NUMBER: 01HQAG0020

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, 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), lind@seismo.berkeley.edu

PROGRAM ELEMENTS: I & II

KEY WORDS: Seismology; Real-time earthquake information

1. INVESTIGATIONS UNDERTAKEN

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, 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 enhance and improve earthquake reporting in northern California. Important areas of activity include:

- ShakeMap operation
- Migration to database environment
- Design and preliminary implementation of new software system

1.1 Current Capabilities

In 1996, the BSL and USGS began collaboration 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. Today, the BSL and USGS system forms the Northern California Management Center (NCMC) of the California Integrated Seismic Network (CISN), which is the California "region" of the ANSS.

The details of the Northern California processing system and the REDI project have been described in past annual reports. In this section, we will describe how the Northern California Management Center fits within the CISN system, detail recent developments, and discuss plans for the future development.

Figure 1 illustrates the NCMC as part of the the CISN communications ring. The NCMC 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 link, with the capability of falling back to the Internet. In addition to the CISN ring, the BSL

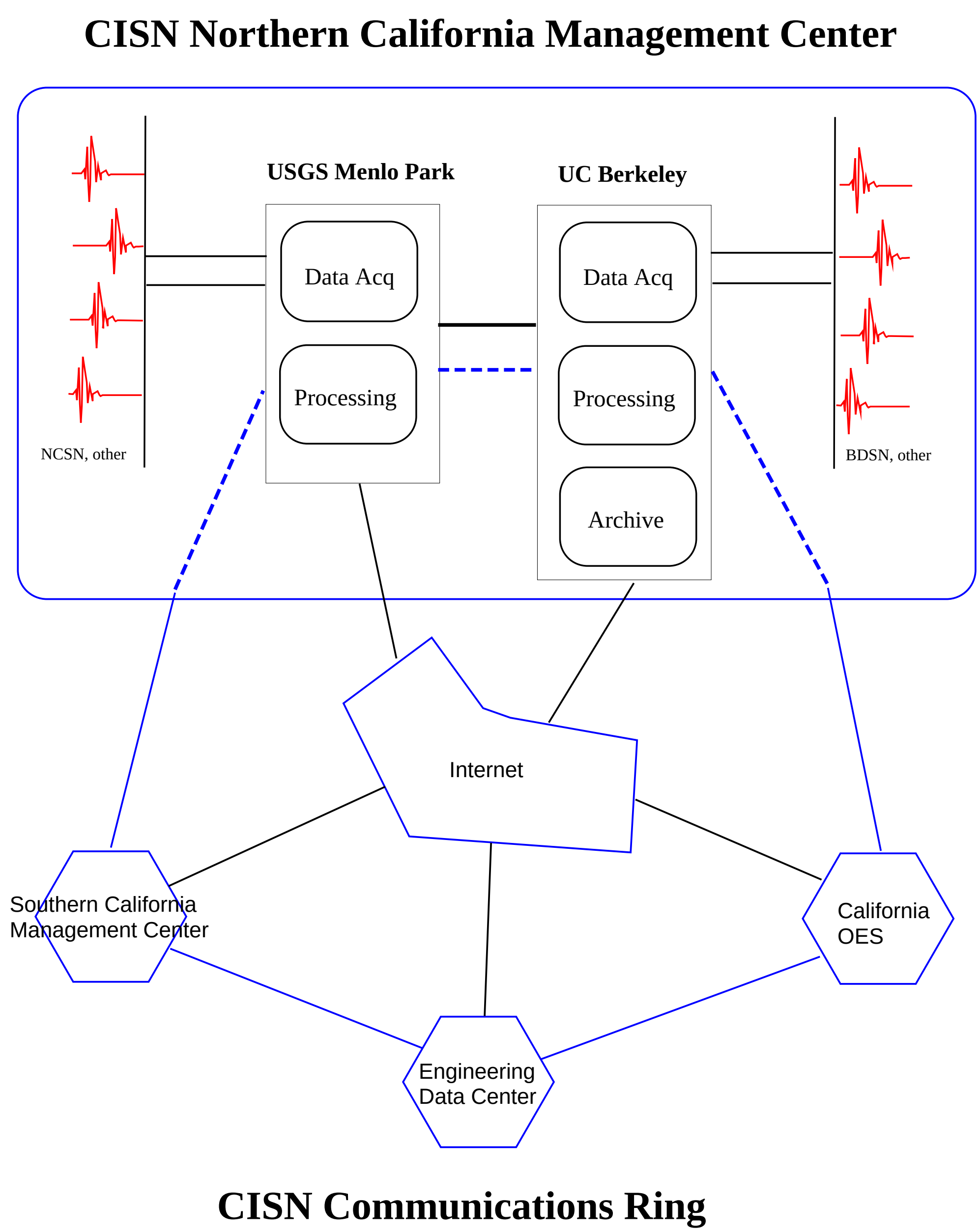

Figure 1: Schematic diagram illustrating the connectivity between the real-time processing systems at the USGS Menlo Park and UC Berkeley, forming the northern California Management Center, and with other elements of the CISN.

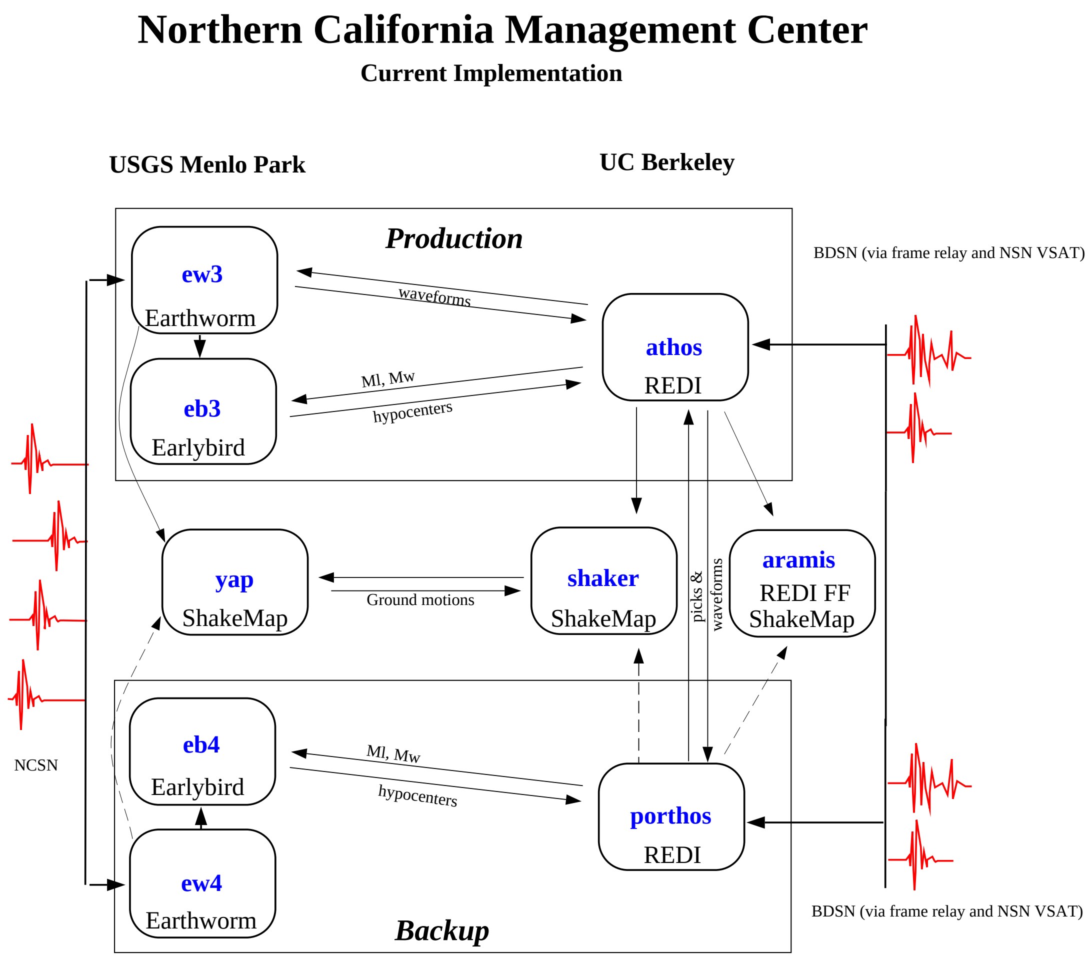

Figure 2: Detailed view of the current Northern California processing system, showing the two Earthworm-Earlybird-REDI systems, the two ShakeMap systems, and the finite-fault system.

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.

Figure 2 provides more detail on the current system at the NCMC. 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 the standard detection, location, estimation of M_d, M_L, and M_w, as well as processing of ground motion data. The computation of ShakeMaps is also performed on two systems, one in Menlo Park and one in Berkeley, as described below. An additional system performs finite-fault processing and the computation of higher level ShakeMaps (ShakeMaps that account for finite faulting).

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 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 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).

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.

2. RESULTS

2.1 Earthquake Monitoring

During FY2002-2003, over 8300 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, 241 events had an M_d greater than 3.0, 84 events had an M_L greater than 3.5, and 1 earthquake with M_L greater than 5 was recorded.

2.1.1 Special Events

In late November 2002, a small swarm of earthquakes occurred near the Calaveras fault in San Ramon. The largest event was a M_w 3.9, with 4 events over M3.5. The pre-Thanksgiving events were felt over a large area - the Community Internet Intensity Map reports approximately 2400 responses for the M3.9. 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.02.11.24/`.

In early February, a small swarm of earthquakes occurred near the Calaveras fault in Dublin. The largest event in this sequence was an M_L4.2, with 3 events of M3.5. In contrast to the events in November, these events occurred sub parallel to the Calaveras fault (Figure 4). As in November, these events were felt over a broad area, although no damage was reported. Because of the attention focused on these earthquakes and the possible implications for the Calaveras fault, the Northern California Management Center ublished an Internet report on the CISN Web page: `http://www.cisn.org/special/evt.03.02.02/`.

2.2 ShakeMap

The BSL and USGS/Menlo Park staff met in August 2002 to discuss how to improve the robustness of ShakeMap operation in northern California. At that time, ShakeMaps in northern California depended on the operation of a single computer, located in Menlo Park. This was in contrast to other earthquake monitoring operations, where 2 parallel systems provide back-up capability should a computer fail. The BSL and USGS Menlo Park agreed to bring up a second ShakeMap system at UC Berkeley, which will be twin or clone of the Menlo Park system.

The implementation of the second ShakeMap system was completed in early 2003, using one of the new CISN processing computers. Both ShakeMap systems are be driven off the ”production” monitoring system and both are configured to allow distribution of ShakeMaps to the Web and to recipients such as OES. At any one time, however, only one system distributes information.

In parallel, Pete Lombard at the BSL was trained to review ShakeMaps following an earthquake. Since early in 2003, the BSL has been trading the responsibility of ShakeMap production. The key to making a ShakeMap machine take over the production duty is to copy the earthquake database

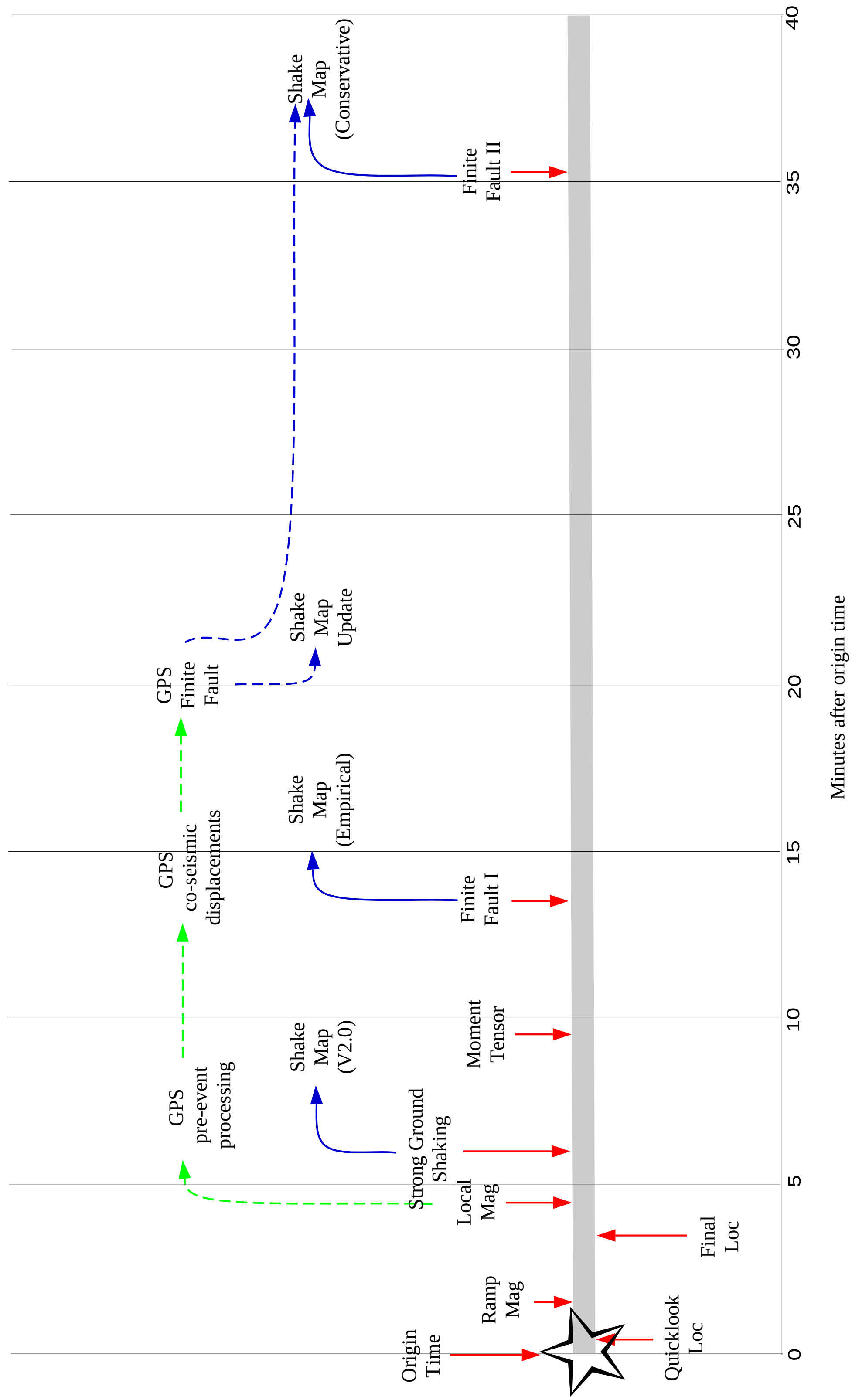

Figure 3: Illustration of the current (solid lines) and planned/proposed (dotted lines) development of real-time processing in northern California. The Finite Fault I and II are fully implemented within the REDI system at UC Berkeley and are integrated with ShakeMap. The resulting maps are still being evaluated and are not currently available to the public.

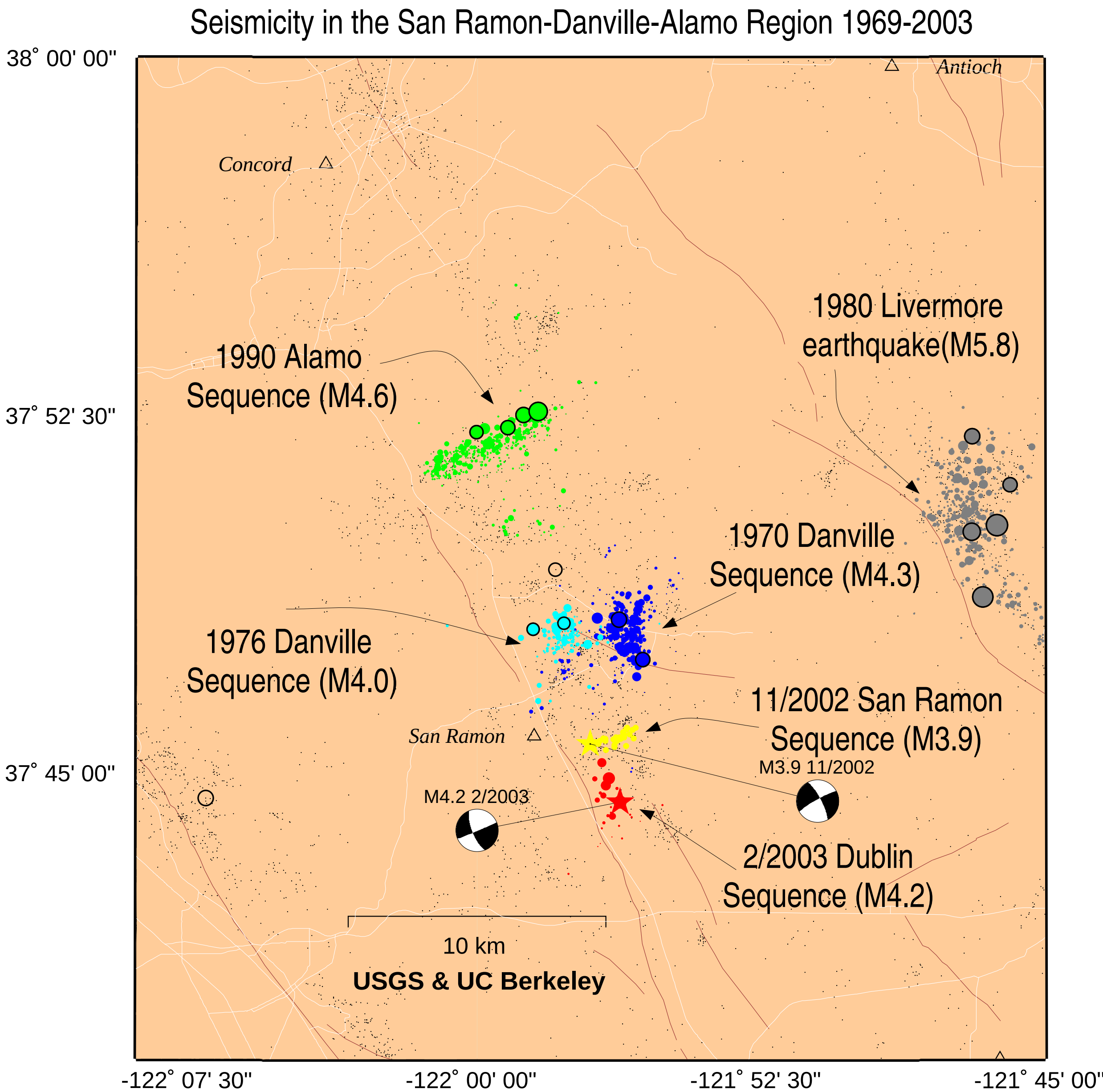

Figure 4: This map illustrates the Feb 2003 Dublin and Nov 2002 San Ramon swarms in the context of historical seismicity. Earthquakes from the USGS catalog 1970-2003 are plotted, with events of M_L ¿= 4.0 plotted with large circles. Events associated with various sequences are plotted in color: 1970 Danville (blue), 1976 Danville (turquoise), 1980 Livermore (grey), and 1990 Alamo (green). Events from the 2002 swarm are plotted in yellow and the events from 2003 are plotted in red.

file from the former production machine to the new production machine. In that way, both machines can produce consistent ShakeMap archive lists.

The BSL has started work on a system to help with review of ShakeMaps. By modifying the program `grind`, we now write logs of the PGA and PGV values from station data, the regression curve, and the limits used by `grind` to flag outlier stations. This data is then plotted on amplitude

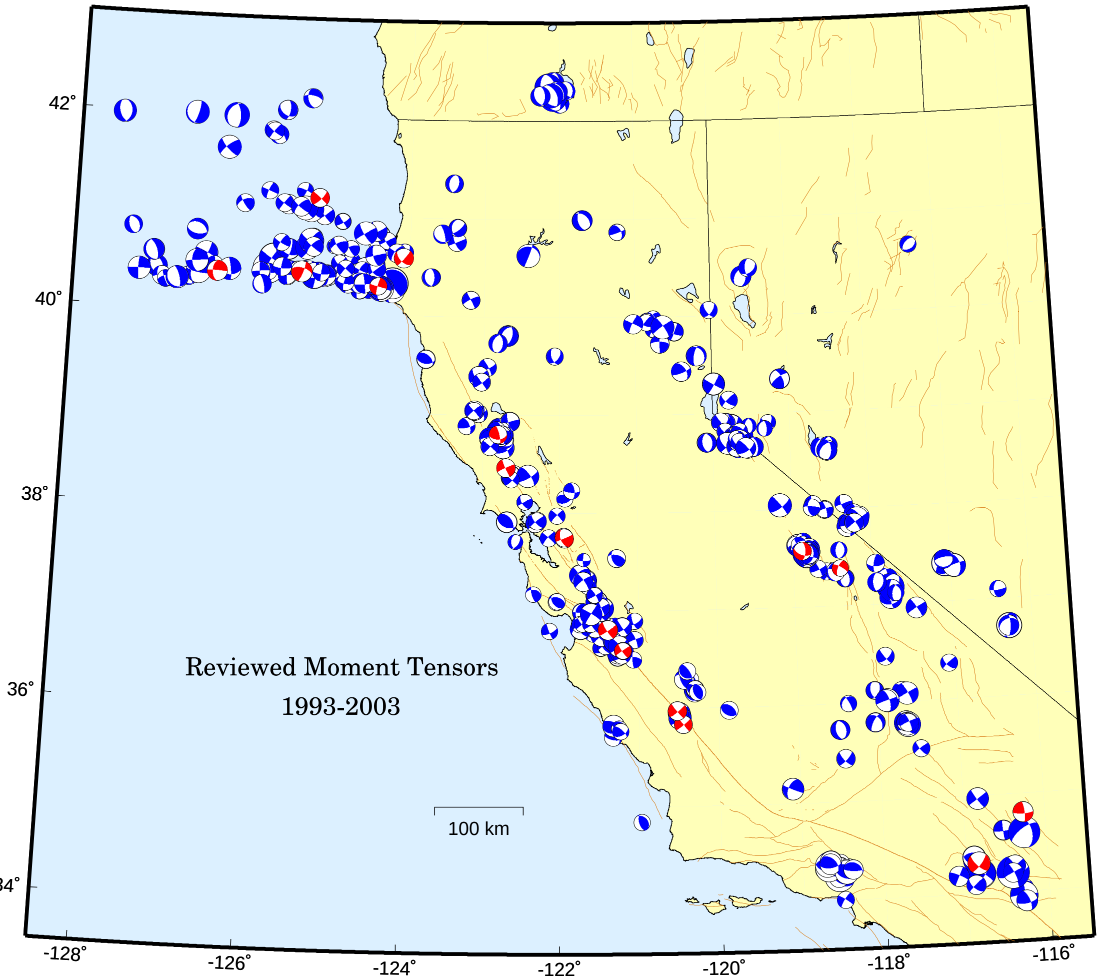

Figure 5: Map comparing the reviewed moment tensor solutions determined by the BSL in the last 10 years (blue) and those from the last fiscal year (red).

vs. distance log-log plots. While this simple plot loses the spatial information available from a map view, it accurately reflects the process that grind uses for flagging stations. And the outlying data are more apparent on the x-y plots. For now, our plotting is done by a crude script running `gnuplot`. We intend at least to change this to use GMT for plotting. And we imagine that some day a pair of "clickable" plots could be presented on an internal Web server for use by ShakeMap reviewers.

2.3 M_w

The REDI system has routinely produced automatic estimates of moment magnitude (M_w) for many years (Figure 5). However, these estimates have not routinely used as the "official" magnitude, due in part to questions about the reliability of the automatic solutions. However, in response to the 05/14/2002 Gilroy earthquake (M_w 4.9, M_L 5.1) and the complications created by the publication of multiple magnitudes, the BSL and USGS Menlo Park have agreed to use automatically determined moment magnitudes, when available, to supplement estimates of local magnitude (M_L). This work was completed in the last year and M_w is now routinely reported when the solution is "good enough".

When is a solution "good enough"? This question has been under review in the last year - both to ensure reliable reporting of M_w in northern California and as part of the CISN-effort to establish rules for a magnitude hierarchy. Figures 6 & 7 illustrate a dataset compiled since the most recent

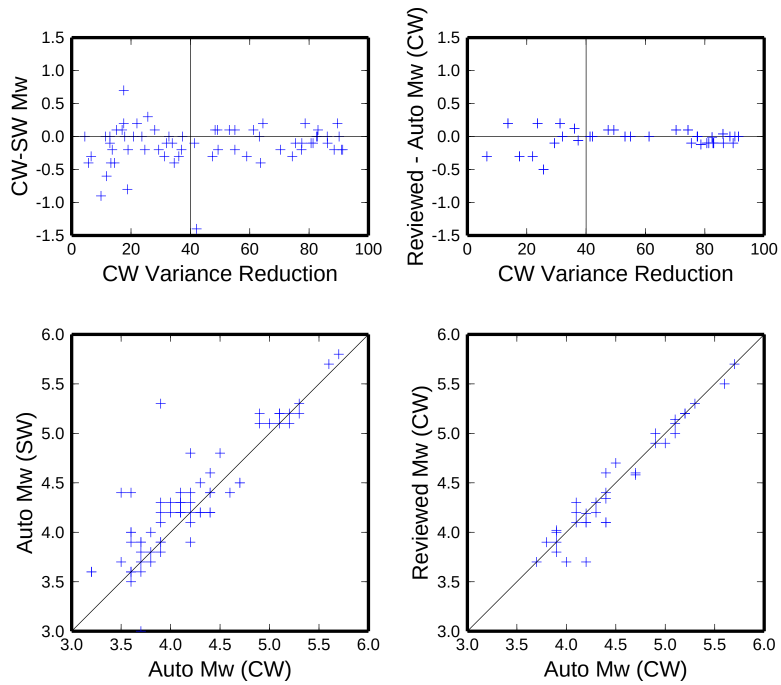

Figure 6: Left: Left: Comparison of the two regional estimates of moment magnitude – the complete waveform (CW) and the surface wave (SW) methods – from the last year of REDI results and a few older events rerun through the system. As observed in *Pasyanos et al., 1996*, the estimates of moment from the surface wave inversion are larger than the complete waveform inversion. Right: Comparison of the estimates of M_w from automatic and reviewed complete waveform solutions.

modification of the moment tensor software. The dataset indicates that the estimate M_w from the complete waveform inversion is quite robust for when a variance reduction of 40% or higher is obtained. In general, earthquakes of M4.5 and higher almost always achieve that level of variance reduction. Under the current rules, the Northern California Management Center always reports M_w if the variance reduction is 40% or better.

We have also looked at comparisons between our regional estimate of M_w and the moment magnitudes determined by Harvard as part of the Centroid Moment Tensor project. Figure 8 illustrates the regional M_w compared with the CMT M_w, along with comparisons between the NEIC estimates of M_w, m_b, M_s and the CMT M_w. This dataset spans approximately 60 events in the western US and good agreement between the regional and global methods is observed, although there appears to be a systematic difference in the estimates of approximately 0.08 - 0.09 magnitude units, with the CMT estimate being higher.

2.4 Version Numbers/Quake Data Delivery System

In the last year, the BSL and the USGS Menlo Park completed the software modifications necessary to track version numbers in the processing system. Version numbers are important for identifying the latest (and therefore hopefully the best) hypocenter and magnitude for an earthquake. Because both Menlo Park and Berkeley can be a source of earthquake information, it was critical to design a common versioning system. The modifications enabled the BSL to begin contributing solutions to QDDS, increasing the robustness of data distribution in northern California. At the present time, the USGS Menlo Park distributes solutions to 2 of the 3 QDDS hubs and the BSL distributes solutions to 2 of the 3 hubs (that is, 2 hubs receive notices from either the USGS or the BSL and 1 hub receives notices from both). This implementation should allow information to be

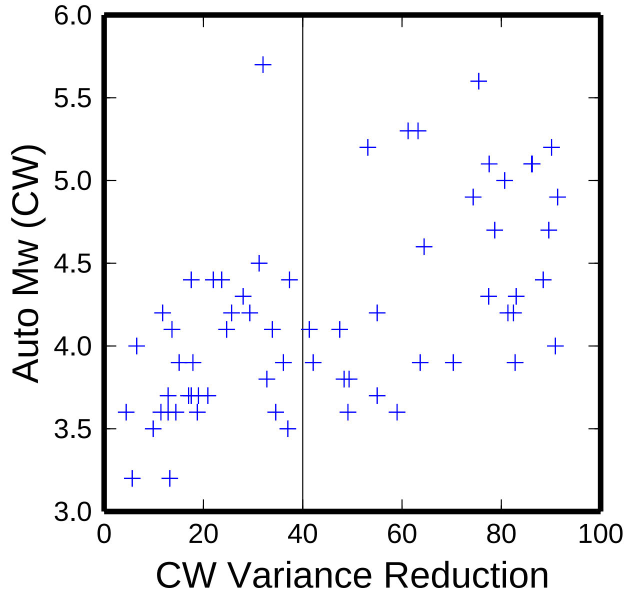

Figure 7: Results from the last year of complete waveform moment tensor inversions in the REDI system, with a few older events. With one exception, all events of M4.5 and higher achieved a variance reduction of 40%; approximately one third of the smaller events achieved the same level.

distributed in the case of Internet shutdown of the Department of Interior (as occurred in December 2001 - see `http://www.cisn.org/news/doi.html`).

2.5 Database Implementation

During the past year, the BSL completed modifications to implement a database within real-time system. At this point, the database is used as a storage system, supplementing the flat files that have been the basis of the REDI system. The modified software has now been installed on both REDI platforms and is operating well.

This is the first step toward the migration of the real-time environment from the flat files currently in use in northern California to a database centric model and provides the key to better integration of the Berkeley and Menlo Park operations as well as a more seamless operation between real time and the archive. Our efforts to design and develop this system are described in the next section. Users can access the database results through a searchable interfaces at the the Northern California Earthquake Data Center: `http://quake.geo.berkeley.edu/db/Search/PI/dbselect.html`

2.6 System Development

As part of ongoing efforts to improve the monitoring systems in northern California, the BSL and the USGS Menlo Park have begun to plan for the next generation of the northern California joint notification system.

Figure 2 illustrates the current organization of the two systems. 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 7 years, there are a number of potential problems associated with the separation of critical system elements by 30 miles of San Francisco Bay.

Recognizing this, we intend to redesign the Northern California operations so that a single independent system operates at the USGS and at UC Berkeley. Figure 9 illustrates the overall con-

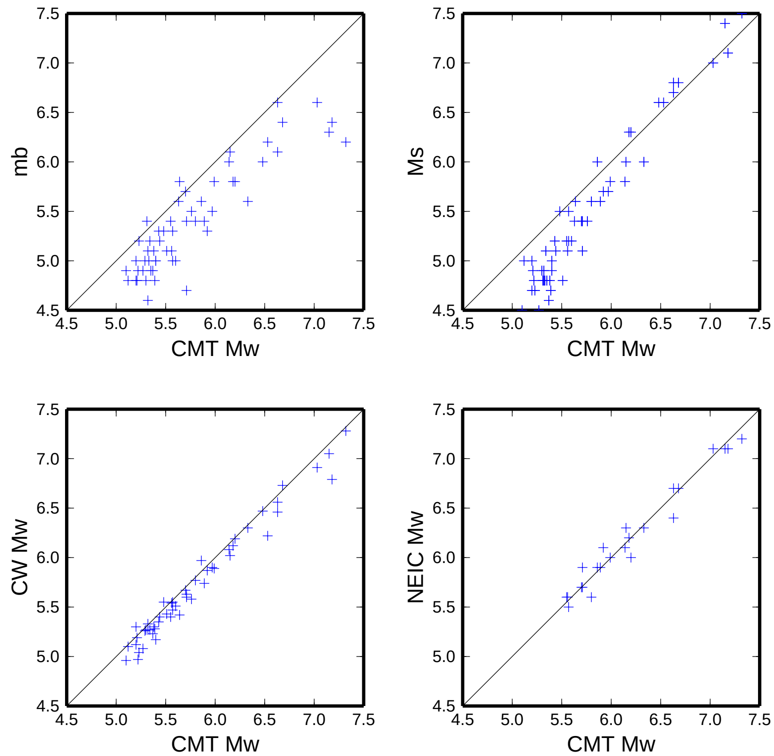

Figure 8: Comparison of several magnitudes with the M_w estimates determined from the Harvard Centroid Moment Tensor project. Lower left: Regional M_w from the reviewed solutions of the BSL; lower right: Global M_w from NEIC; upper left: m_b from NEIC; upper right: M_s from NEIC.

figuration. In FY01/02, our discussions proceeded to the stage of establishing specifications and determining the details required for design. However, in the last year, most of the development effort focused on CISN activities and specific plans for the "next generation" Northern California system were put on hold. This enforced wait provided the opportunity for some ideas to mature and the current plans for the NCMC are somewhat different from those envisioned in 2001.

The current design draws strongly on the experience in Southern California for the development of TriNet (Figure 10), with some modifications to allow for local differences (such as very 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 uses 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, we did take the opportunity to review options for replacing Smart Sockets and RogueWave with Southern California, resulting in joint agreement on replacement packages and shared development effort.

In the last year, BSL staff, particularly Pete Lombard, have become extremely familiar with portions of the TriNet software. We have begun 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 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. One of the recent discoveries with the magnitude module was related to differences in the use of time bases in the

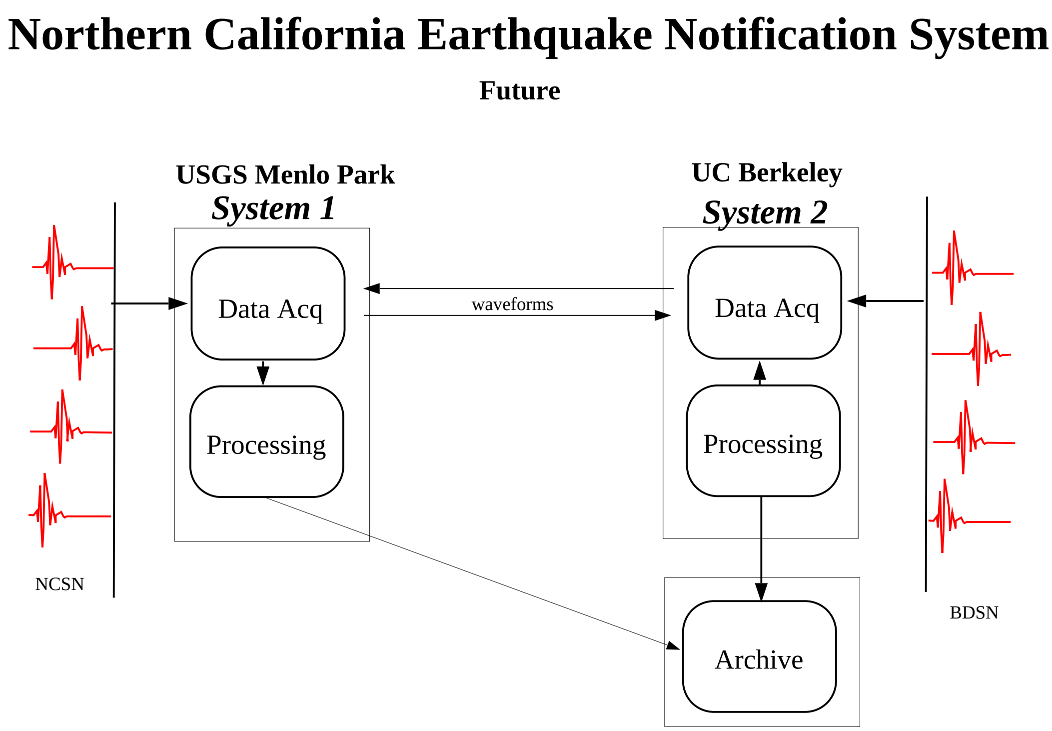

Figure 9: Future design of the Northern California Earthquake Notification System. In contrast with the current situation (Figure 2), the system is being redesigned to integrate the Earthworm/Earlybird/REDI software into a single package. Parallel systems will be run at the Berkeley and Menlo Park facilities of the Northern California Operations Center.

database schema between northern and southern California.

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

2.7 References

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, 2003.

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.

3. 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 past year we improved the robustness of the computation of ShakeMaps through the establishment of parallel ShakeMap system at the BSL, began to use databases in our real-time processing system,

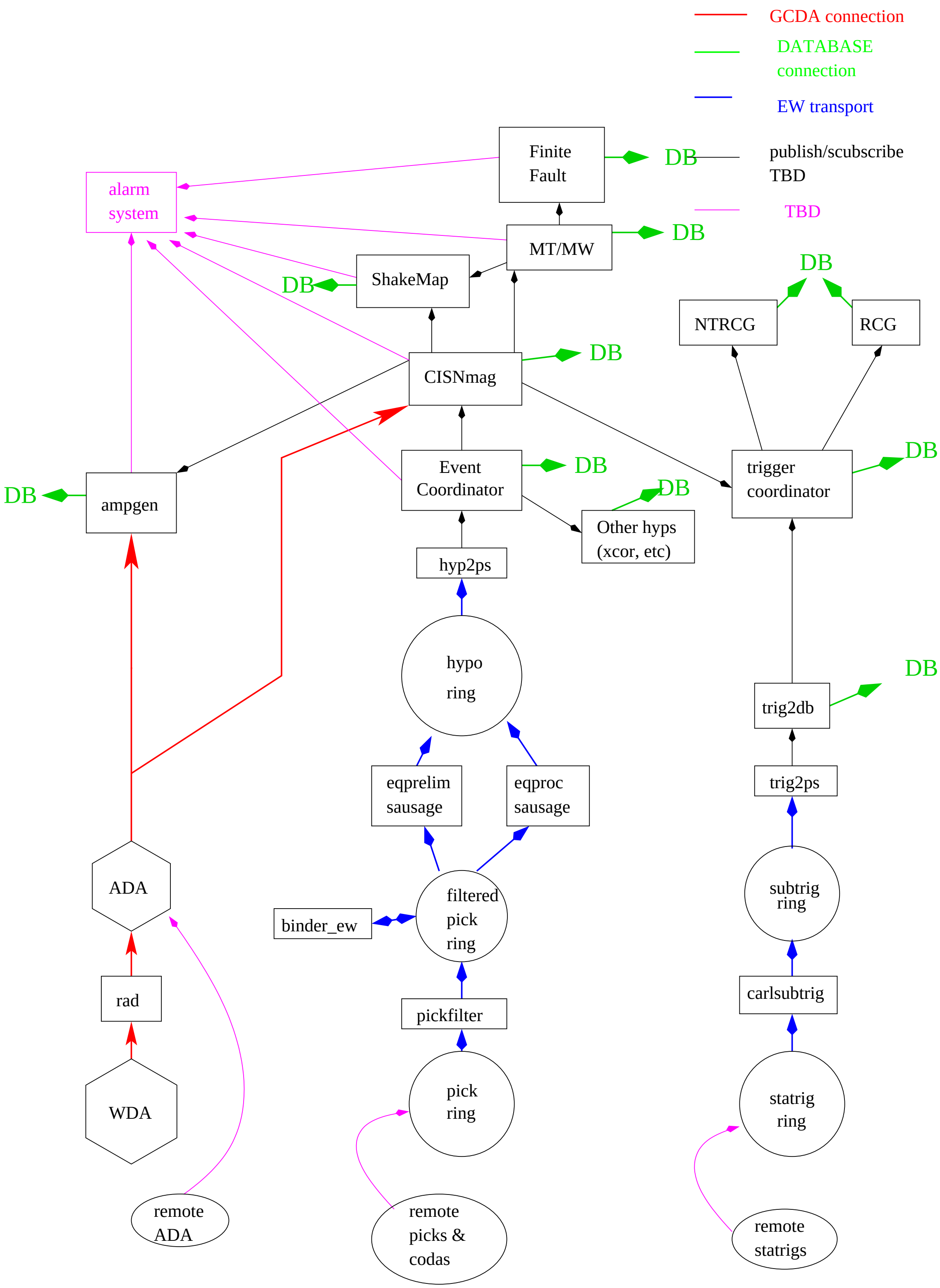

Figure 10: Current "view" of modules making up the new Northern California Earthquake Notification System.

and began the design and development of software to improve the Northern California Seismic System.

4. REPORTS PUBLISHED

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, 2003.

5. MEETING PRESENTATIONS

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

6. DATA AVAILABILITY

Data and results from the REDI project are available at the Northern California Earthquake Data Center (*//www.quake.geo.berkeley.edu*) For additional information on the REDI project, contact Lind Gee at 510-643-9449 or lind@seismo.berkeley.edu.

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