Southern California Seismic Network Update

Kate Hutton, Egill Hauksson, John Clinton, Joseph Franck, Anthony Guarino, and Nick Scheckel

Seismological Laboratory, California Institute of Technology

Doug Given and Alan Yong

Pasadena Field Office, U.S. Geological Survey

INTRODUCTION

The authoritative region of the Southern California Seismic Network (SCSN) extends across southern California, from the U.S./Mexico international border to Coalinga and Owens Valley in central California (Figure 1). This area contains almost 20 million inhabitants, including two of the ten largest cities in the United States (Los Angeles and San Diego) and the two largest harbors (Los Angeles and Long Beach) in the nation. SCSN also reports on earthquakes in Baja California, which could potentially cause damage in the U.S. More than fifty earthquakes (not including aftershocks) are felt each year, and an average of 1.5 events per year are potentially damaging (magnitude greater than 5.0). Immediately after a moderate or large earthquake, SCSN provides information about the size, location, and distribution of ground shaking. Emergency managers use this information to coordinate rescue operations, guide inspectors in the search for damage, and satisfy the public's need for information. The historical record of earthquake occurrences in California is important to insurers, geotechnical engineers, and city planners.

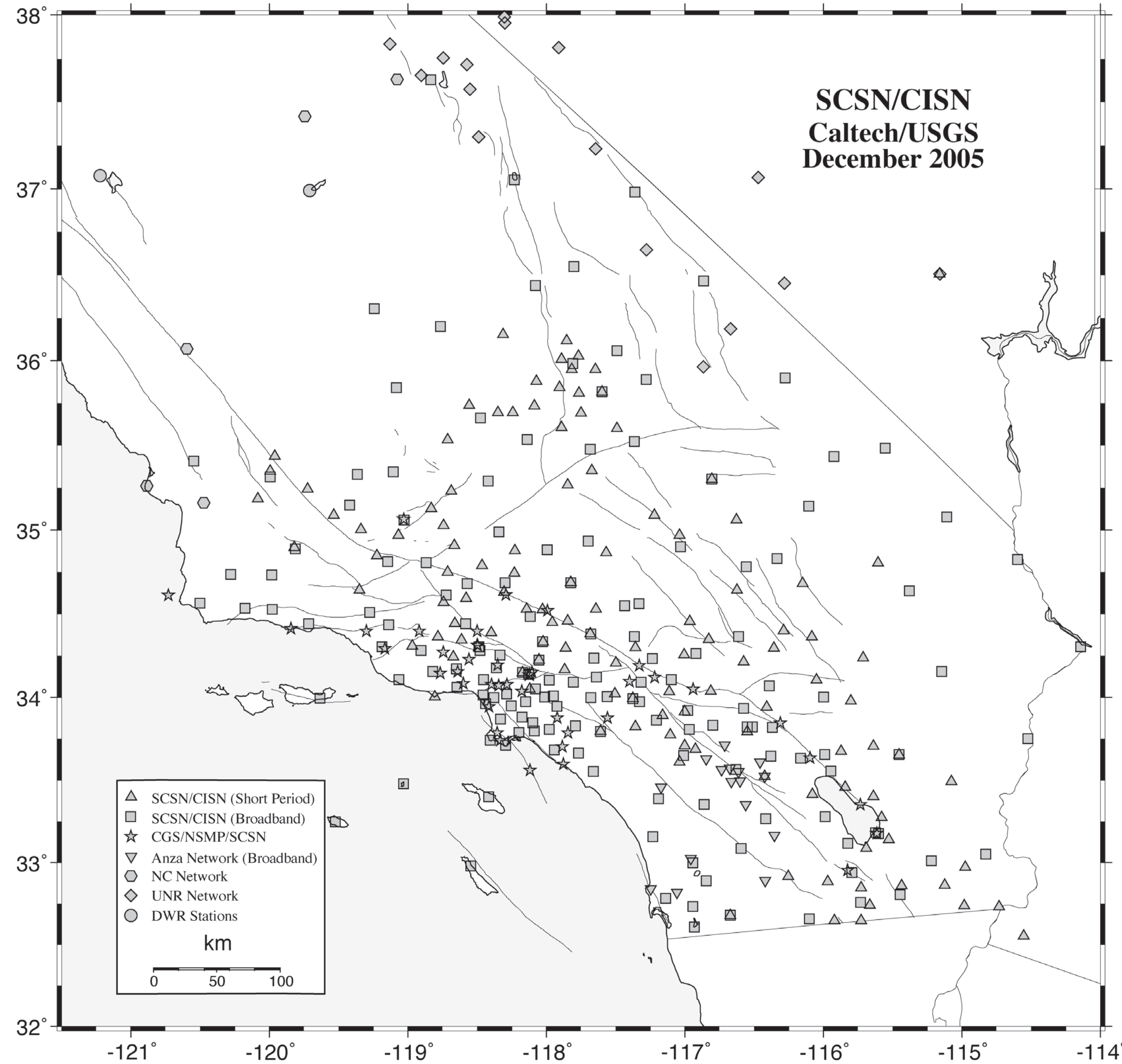
SCSN has maintained and published a catalog of earthquakes complete above about magnitude 3.0 since 1932, and above about magnitude 1.8 since the late 1970's, with relatively consistent magnitudes (mostly M_L) over the whole time period. Digital seismograms are available since the late 1970's, and selected seismograms since 1962 have been scanned.

Much has changed in SCSN since the last Network Bulletin (Wald *et al.*, 1998) was published, which described changes that took place during 1997. More than half the new stations have modern broadband sensors and strong-motion sensors, and dataloggers with continuous telemetry. Many of the remaining analog stations are digitized on *Earthworm* hubs (Johnson *et al.*, 1995) at field sites and telemetered to the data-processing facility in Pasadena, California. Online and offline data processing has been converted completely from the CUSP (Caltech-USGS Seismic Processing) system to TriNet software (Hauksson *et al.*, 2001). The new TriNet software uses Oracle as the database, and most of the code development was done in C++. Earthquake parametric information and waveforms are normally available to users within a few minutes of the occurrence of an earthquake. To accomplish its mission, SCSN continues to develop and operate a reliable, modern system for earthquake monitoring, archiving, and distribution of information for improved public safety, emergency response, loss mitigation, and scientific research.

SCSN is operated jointly by the Pasadena office of the U.S. Geological Survey and the Seismological Laboratory at the California Institute of Technology. SCSN is a partner of the California Integrated Seismic Network (CISN), which in turn is the California region of the Advanced National Seismic System (ANSS). Signals from more than 370 remote seismic stations in southern California are transmitted via various telemetry paths to central computers at the Seismological Laboratory in Pasadena, where they are processed to yield phases, earthquake locations and magnitudes, archived seismograms, and ultimately data "products" such as ShakeMaps (Wald *et al.*, 1999) and moment-tensor solutions (Clinton *et al.*, 2005). Waveform, phase, and catalog data are archived and distributed by the Southern California Earthquake Data Center (SCEDC). In this paper we summarize the main network developments and the seismicity of the region in recent years.

STATIONS

SCSN now operates 159 digital stations with broadband and strong-motion sensors, 132 (digitized) analog stations with short-period sensors, and 20 digital stations with strong-motion sensors and in a few cases also short-period sensors (Figure 1). Added, deleted, and changed stations for 2004 and 2005 are shown in Table 1. In addition, real-time, continuous data were imported from 16 stations from the Anza area via UC San Diego, 18 stations from the University of Nevada at Reno, 16 stations from the National Strong-Motion Program, and six stations from the California Geological Survey. The short-period stations include five stations from the California Division of Water Resources and six from the Northern California Seismic Network (NCSN). We also received data from 15 stations in



▲ **Figure 1.** Seismic stations recorded by SCSN. Most stations are operated by SCSN, while some are operated by other agencies such as UCSD Anza network, University of Nevada at Reno, and Department of Water Resources.

the U.C. Berkeley Digital Seismic Network, to ensure minimal statewide monitoring capability in case of a major failure of monitoring capability in northern California. Similarly, we export data from 15 SCSN stations to UC Berkeley Seismological Laboratory to provide back-up for southern California.

The 159 broadband stations are each equipped with one of three different types of three-component broadband sensors (long-period corner of 30 s, 120 s, and 360 s), a three-component strong-motion sensor, and a datalogger. Most stations are sampled at 100 sps, the others at 80 sps. The instrument responses are available from http://www.data.scec.org/.

To transmit the data from the remote sites, we use a mixture of commercial frame-relay service, T1 circuits, microwave communications provided by local utilities, and the Internet. Much of the analog station data are transmitted via analog radio telemetry to one of five remote *Earthworm* digitizer hubs (Johnson *et al.*, 1995), where the signals are digitized and transmitted to Pasadena via frame-relay or Internet telemetry circuits. Signals from other analog stations are transmitted all the way to Pasadena, where they are digitized by an *Earthworm* digitizer, at 100 sps.

DATA PROCESSING

All the digitized waveform data are processed by algorithms on a pair of real-time computers, a primary system and a back-up.

TABLE 1
Additions and Deletions to SCSN in 2004 and 2005

New Stations in 2004 and 2005			
Station	**System**	**Station Name**	**Installation Date**
CE.26903	Strong Motion	OBS Irene, Pt. Arguello	1/20/2005
CI.ARV	Broadband	Arvin	7/9/2004
CI.BLY	Broadband	Blythe	11/17/2004
CI.EDW2	Broadband	Edwards AFB 2	5/4/2004
CI.JRC2	Broadband	Joshua Ridge	1/15/2004
CI.LRL	Broadband	Laurel Mountain	6/18/2004
CI.MUR	Broadband	Murrieta	7/25/2005
CI.NSS2	Quanterra	North Shore Salton Sea	3/17/2004
CI.PMD	Broadband	Palm Desert	5/7/2005
CI.PSD	Broadband	Palm Springs Desert Museum	4/13/2005
CI.PSR	Broadband	Puddingstone Reservoir	4/13/2005
CI.RXH	Broadband	Rock Hill	5/26/2004
CI.SBB2	Broadband	Saddleback Butte 2	10/28/2004
CI.TER	Short Period	Tule Elk Reserve	12/15/2204
CE.14901	Strong Motion	offshore Newport Beach	12/12/2004
NP.286	Strong Motion	Superstition Mountain	4/20/2005
NP.5062	Strong Motion	Salton Sea Wildlife Preserve	6/10/2004
NP.5442	Strong Motion	Oak Glen	10/13/2004
NP.5443	Strong Motion	Thousand Palms	10/13/2004
NP.5444	Strong Motion	Thermal	10/14/2004
NP.5445	Strong Motion	Wheeler Ridge	1/26/2005
Terminated Stations in 2004 and 2005			
Station	**System**	**Station Name**	**Termination Date**
BK.POTR	Broadband	Potrero Hills, Fairfield	2/5/2005
CI.AGA	Broadband	Agave Hill	5/6/2005
CI.ARV	Short Period	Arvin	11/22/2004
CI.BCC	Broadband	Bear Creek Country Club	8/2/2005
CI.EDW	Broadband	Edwards AFB	8/3/2004
CI.JRC	Broadband	Joshua Ridge	1/14/2004
CI.LKL	Broadband	Lake Los Angeles	11/19/2004
CI.NSS	Broadband	North Shore Salton Sea	3/10/2004
CI.SIP	Short Period	Simi Peak	12/13/2005
CI.SMB	Broadband	Santa Maria Base	12/15/2005
CI.SSW	Broadband	Salton Sea Wildlife	6/10/2004
CI.WER	Broadband	Wheeler Ridge	7/9/2004
Stations Name Changes in 2004 and 2005			
Old Station	**New Station**	**Station Name**	**Change Date**
CE.400K	CE.24400	Obregon Park, East Los Angeles	7/15/2004
CE.G405	CE.14405	Rolling Hills Estates	7/15/2004
CE.J732	CE.23732	San Bernardino	7/15/2004
CE.K851	CE.24851	LA, 3rd & La Brea	7/7/2004
CE.K853	CE.24853	LA, Beverly & Virgil	7/15/2004
CI.SPG	CI.SPG2	Springville	12/6/2005
NP.BBA	NP.5398	Burbank Airport	7/15/2004
NP.BBB	NP.5271	Bombay Beach	7/15/2004
NP.BVH	NP.5402	Beverly Hills	7/15/2004
NP.CAB	NP.5404	Calabasas	7/15/2004
NP.FLL	NP.5401	Fillmore	7/15/2004
NP.GRF	NP.141	Griffith Observatory	7/15/2004
NP.JAB	NP.655	Sylmar, Balboa Blvd.	5/16/2004
NP.JGB	NP.655	Sylmar, Balboa Blvd.	5/16/2004
NP.LAX	NP.5399	Los Angeles Airport	7/15/2004
NP.LT2	NP.5030	Littlerock	7/15/2004
NP.OKV	NP.5403	Oak View, Hwy 33	7/15/2004
NP.SSW	NP.5062	Salton Sea Wildlife Refuge	7/7/2004
NP.TCF	NP.5081	Fernwood, Topanga Canyon	7/15/2004

Two earthquake event-detection processing threads operate in parallel. The first thread uses *Earthworm P*-picker/associator/*Hypoinverse* locator algorithms, which detect, locate, and compute magnitudes for the earthquakes. Most earthquakes above magnitude 1.8 are detected in this fashion. A parallel, more sensitive, thread uses the *Earthworm* subnet trigger algorithm, which detects most of the same events, plus a number of smaller events missed by the first thread. Parametric information and waveform files are available immediately on a pair (primary and back-up) of Data Center computer systems for archiving and distribution.

If the real-time system results meet quality control criteria for location and magnitude, earthquake "alarm" notifications are sent to various clients, which include the Quake Data Distribution System (QDDS) that delivers information to the "Recent Earthquake" map Web sites operated by the U.S. Geological Survey, the CUBE (Caltech-USGS Broadcast of Earthquakes notification system), the CISN Display software, and the ShakeMap system. SCSN also distributes e-mail notification directly to critical users, and through a public e-mail subscription list with sign-up available from the http://www.cisn.org/ Web page.

A duty seismologist is on call 24 hours a day and responds when earthquake alarms are issued. The duty seismologist may confirm, modify, or withdraw the alarm. In addition, all phase arrival times, locations, amplitudes, and magnitudes are reviewed by a seismic analyst, usually on the same day, and always within one week.

FOCAL MECHANISMS

SCSN produces both first-motion mechanisms and centroid moment-tensor (CMT) solutions for larger earthquakes (Clinton *et al.*, 2005). The first-motion mechanisms are more reliable for small earthquakes, whereas the moment tensors are more reliable for large (M ≥ 4.0) earthquakes.

Moment Tensors

Automatically generated moment-tensor solutions have recently been added to the suite of real-time products produced by SCSN (Clinton *et al.*, 2005). The moment magnitude, M_w, and moment tensor are both available within minutes for all regional earthquakes with $M_L > 4.0$, and in many cases for events between M_L 3.5–4.0. The method uses the 1D Time-Domain INVerse Code (TDMT INVC) software package developed by Doug Dreger (see Dreger and Helmberger, 1990) for real-time application by the UC Berkeley Seismological Laboratory. The algorithm uses Green's functions for various velocity profiles in southern California to invert the observed three-component broadband waveforms filtered from 10 s–100 s, for three to five stations. Automatic solutions have an assigned quality factor which depends on the number of stations in the inversion and the goodness of fit between synthetic and observed data. Depending on the quality, the M_w and moment tensor may be automatically distributed to users via e-mail, and to QDDS for display on the USGS Recent Earthquakes Web page (http://quake.wr.usgs.gov/recenteqs/latestfault.htm) and CISN Display. The duty seismologists can review the automatically generated solution via a Web interface and determine whether it meets the minimum requirements for an immediate distribution. Different stations may be selected and the inversion rerun to optimize the solution. If a minimum quality factor is attained and the event is in the southern California reporting region, the M_w can become the official SCSN/CISN magnitude. During 2004, however, manual insertion of the M_w was required.

The real-time moment-tensor algorithm has been applied to the SCSN catalog for all regional events with $M_L > 3.5$, and local events with $M_L > 3.0$ since September 1999. The method reliably produces a M_w for local events with $M_L > 3.5$, and moment tensors for $M_L > 4.0$. The algorithm also provides excellent back-up solutions for large events at regional distances, such as in northern California, Nevada, and Baja California.

First-motion Solutions

First-motion lower-hemisphere focal mechanisms are determined for most local earthquakes of $M_L > 2.5$ (Figures 2 and 3). These solutions are posted on the USGS Recent Earthquakes Web page. We used the grid-searching algorithm and computer programs (FPFIT) by Reasenberg and Oppenheimer (1985) to determine the first-motion focal mechanisms. If the epicentral location is within the boundaries of SCSN, the first-motion mechanisms are generally well constrained using the analyst's phases. They are not as well constrained using automatic picks. The average uncertainties in strike, dip, and rake of the focal mechanisms are approximately 10°, 20°, and 30°.

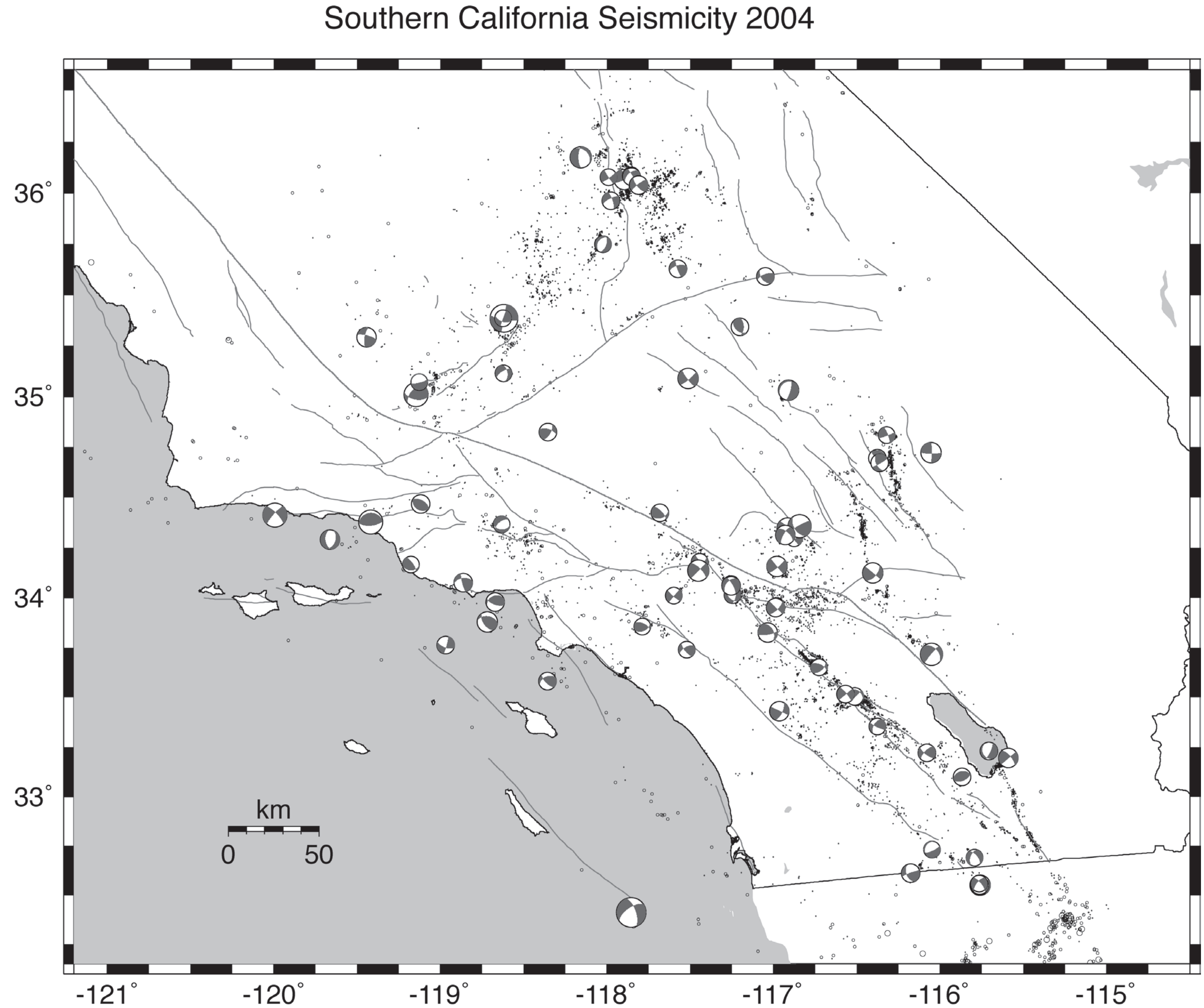
SEISMICITY

Location Practice

All phase picks are reviewed by a seismic analyst. Automatic picks from the real-time system are retained if they are correct and derived from the component with the clearest arrival. All others are replaced or added manually, using a Java-based graphical user interface called Jiggle. The operational standards call for picking all impulsive arrivals and reasonably well constrained ("E2") emergent arrivals. *Hypoinverse* (2002) is used for the locations. For events with nearby stations, distance weighting begins at 80 km, and no stations beyond 120 km are used.

For routine catalog locations (used in the SCEDC searchable catalog at http://www.data.scec.org/catalog_search/date_mag_loc.php), a uniformly layered velocity model (Hadley and Kanamori, 1977) is used. The Hadley-Kanamori velocity model is not appropriate for deep sedimentary basins, such as the Los Angeles Basin and the Imperial Valley, where the routine locations are mislocated to varying degrees. Raw locations can be unrealistically deep, with depths up to 30 km or more. The analysts may constrain an earthquake's depth to a reasonable value for the source area, which results in higher RMS values. Although the use of station delays would help account for low-velocity sedimentary layers, we do not use station delays at this time.

We later relocate the events using a three-dimensional velocity model (Hauksson, 2000). These locations are made



▲ **Figure 2.** Seismicity map showing more than 11,000 local earthquakes recorded during 2004. First-motion focal mechanisms are included for most events over M_L 3.0.

available as one of the "alternative catalogs" on the SCEDC Web site (http://www.data.scec.org/).

Magnitude Practice

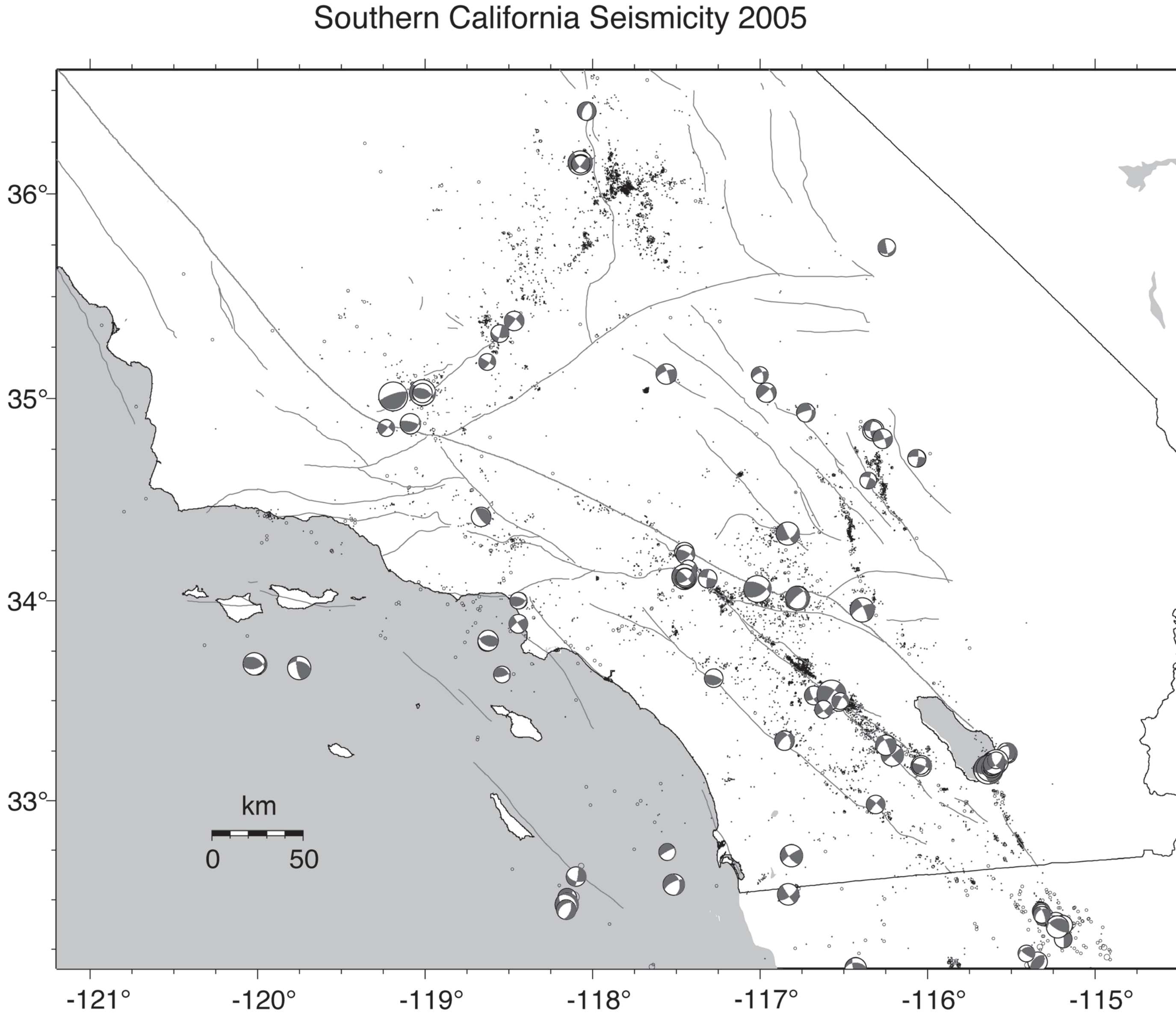
Most earthquakes in our catalog larger than about magnitude 1.8 are assigned M_L (local) magnitudes. Although M_w is computed for most earthquakes with magnitudes 4.0 and larger, during the period of this report, they were used only as the preferred magnitude for 5.0 or larger. The M_L's are based on synthetic Wood-Anderson amplitudes from the broadband horizontal channels (Richter, 1935; see Kanamori *et al.*, 1993). For the smallest earthquakes, too few broadband channels are available to compute M_L; in these cases, the analyst currently inserts a "hand" magnitude (M_h), which is a duration magnitude similar to M_d. Work is currently underway to calibrate duration magnitude M_d for the network.

Earthquakes of Interest

Southern California seismic activity has been quiet over the last few years. The aftershock zones of the 1992 Landers earthquake (M_w 7.3) and the 1999 Hector Mine earthquake (M_w 7.1) are still faintly visible in the seismicity maps (Figures 2 and 3). That of the 1994 Northridge earthquake (M_w 6.7) is barely visible.

During 2004, SCSN detected and processed 11,682 earthquakes, of which 11,499 were located inside the SCSN region. Of these, 1,283 had a magnitude of 2.0 or larger, 127 had a magnitude of 3.0 or larger, and eight were greater than or equal to magnitude 4.0. In addition, we processed 672 quarry and mine blasts.

In 2005, the seismicity was only slightly higher. 12,451 earthquakes were detected and processed, of which 1,650 had a magnitude of 3.0 or larger, 177 had a magnitude of 3.0 or larger, and 27 had a magnitude of 4.0 or larger; 642 quarry and mine



▲ **Figure 3.** Seismicity map showing more than 12,000 local earthquakes recorded during 2005. First-motion focal mechanisms are included for most events over M_L 3.0.

blasts were processed. These seismicity rates are a factor of two lower than the average rate during the 1990's.

Highlights of the 2004 and 2005 seismicity include:

- 15 June 2004 M_w 5.3, 44 miles west-southwest of Coronado (14065544)
- 28 September 2004 M_w 6.0, 9 miles south of Parkfield (51147892)
- 29 September 2004 M_w 5.0, 11 miles north-northwest of Keene (14095628)
- 16 April 2005 M_w 5.2, 13 miles west of Wheeler Ridge (14138080)
- 12 June 2005 M_w 5.2, 6 miles east-southeast of Anza (14151344)
- 1 September 2005 M_w 5.1, 1 mile south of Obsidian Butte (14179736)

"MOLDY OLDIES"

In addition to processing earthquake data as they are recorded, we have made much progress on backlogs of unprocessed or partially processed events from the 1980's and earlier.

- *1932–1978:* All earthquakes on the phase cards were entered into the CUSP system, relocated, and transferred to the SCEDC database. Some events (close aftershocks) not on the phase cards have yet to be inserted, and some of the data need to be checked for quality and completeness. This period, however, is searchable, and the phase data are available online.

- *1979–1980:* All available waveform, phase, and hypocenter data were loaded into a test database, where we are currently relocating events and sorting out multiple copies.
- *1981, 1983:* A complete list of events is available in the database. Wood-Anderson amplitudes still need to be incorporated, so some magnitudes may change.
- *1982, 1984–present:* Only minor changes have been made, particularly in the Joshua Tree and Landers aftershock sequences. In particular, some magnitudes incorrectly estimated to be over M3 have been revised. This work continues.

FOR FURTHER INFORMATION

The data, including catalog search capability, phases, waveforms, and the instrument response characteristics, are available through the Southern California Earthquake Data Center (http://www.data.scec.org/).

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REFERENCES

Clinton, J. F., E. Hauksson, and K. Solanki (2005). Automatically generated moment tensor solutions for southern California: Robustness of the Mw magnitude scale and style of faulting, *Bulletin of the Seismological Society of America* (submitted).

Dreger, D. S. and D. V. Helmberger (1990). Broadband modeling of local earthquakes, *Bulletin of the Seismological Society of America* **80**, 1,162–1,179.

Hadley, D. and H. Kanamori (1977). Seismic structure of the Transverse Ranges, California, *Geological Society of America Bulletin* **88**, 1,469–1,478.

Hauksson, E. (2000). Crustal structure and seismicity distribution adjacent to the Pacific and North American plate boundary in southern California, *Journal of Geophysical Research* **105**, 13,875–13,903.

Hauksson, E., P. Small, K. Hafner, R. Busby, R. Clayton, J. Goltz, T. Heaton, K. Hutton, H. Kanamori, J. Polet, D. Given, L. M. Jones, and D. Wald, (2001). Southern California Seismic Network: Caltech/USGS element of TriNet 1997–2001, *Seismological Research Letters* **72**, 697–711.

Johnson, C. E., A. Bittenbinder, B. Boegart, L. Dietz, and W. Kohler (1995). Earthworm: A flexible approach to seismic network processing, *IRIS Newsletter* **XIV**(2), 1–4.

Kanamori, H., J. Mori, E. Hauksson, T. H. Heaton, L. K. Hutton, and L. M. Jones (1993). Determination of earthquake energy release and M_L using TERRAscope, *Bulletin of the Seismological Society of America* **83**, 330–346.

Klein, F. W. (2002). *User's Guide to HYPOINVERSE-2000, a Fortran Program to Solve for Earthquake Locations and Magnitudes*, U.S. Geological Survey Open-File Report 02-171.

Reasenberg, P. and D. Oppenheimer (1985). *FPFIT, FPPLOT and FPPAGE: Fortran Computer Programs for Calculating and Displaying Earthquake Fault-plane Solutions*, U.S. Geological Survey Open-File Report 85-739, 109 pp.

Richter, C. F. (1935). An instrumental earthquake scale, *Bulletin of the Seismological Society of America* **25**, 1–31.

Wald, D. J., J. W. Dewey, and V. Quitoriano (2000). Community Internet Intensity Maps: Examples from California earthquakes (abstract), *Seismological Research Letters* **71**, 267.

Wald, D. J., V. Quitoriano, T. H. Heaton, H. Kanamori, C. W. Scrivner, and C. B. Worden (1999). TriNet "ShakeMaps": Rapid generation of peak ground motion and intensity maps for earthquakes in southern California, *Earthquake Spectra* **15**, 537–556.

Wald, L. A., L. M. Jones, S. Schwarz, and L. K. Hutton (1998). The 1997 Southern California Seismic Network Bulletin, *Seismological Research Letters* **69**, 532–549.

Seismological Laboratory
California Institute of Technology
Pasadena, CA 91106
(K.H., E.H., J.C., J.F., A.G., N.S.)
kate@gps.caltech.edu

Pasadena Field Office
U.S. Geological Survey
525 S. Wilson Avenue
Pasadena, CA 91106
(D.G., A.Y.)