Final Technical Report

Submitted to the U.S. GEOLOGICAL SURVEY

By the Seismological Laboratory
CALIFORNIA INSTITUTE OF TECHNOLOGY

Reporting Period:	1 Feb. 2010 – 31 Jan. 2015
Cooperative Agreement No.:	Award No. G10AC00091
C.A. Start Date & End Date:	02/01/2010 – 01/31/2015
Project Web sites:	www.scsn.org and scedc.caltech.edu
Network Code:	CI
Network Name:	Southern California Seismic Network
ANSS Region:	California

Operator Address: California Institute of Technology
Seismo Lab, MC 252-21,
1200 East California Blvd.
Pasadena, CA 91125

Principal Investigators: Robert Clayton
Professor of Geophysics
clay@gps.caltech.edu
(626) 395-6909

Egill Hauksson
Research Professor of Geophysics
hauksson@gps.caltech.edu
(626) 395-6954/(626) 255-0323 (cell)

Government Technical Officer: Elizabeth Lemersal
External Research Support Manager
Earthquake Hazards Program, USGS

Title of Award: Partial Support of Joint USGS-Caltech Southern California Seismic Network

Date: 21 April 2015

This work is sponsored by the U.S. Geological Survey under Contract Award No. G10AC00091. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessary representing the official policies, either expressed or implied of the U.S. Government.

Partial Support of Joint USGS-CALTECH Southern California Seismic Network

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INVESTIGATIONS

This Cooperative Agreement provides partial support for the joint USGS-Caltech Southern California Seismic Network (SCSN) and the Southern California Earthquake Data Center (SCEDC). The purpose is to record and analyze data from earthquakes (including local and regional earthquakes and quarry blasts) during the reporting period. We also generated a database of parametric data and digital seismograms. The primary product derived from the database is a joint USGS-Caltech catalog of earthquakes in the southern California region and the associated waveforms. We maintain the SCSN and SCEDC infrastructures. We also provide rapid response to emergency services, the media, and public inquiries about earthquakes and data for seismological research. All aspects of the operation of the SCSN are done in partnership with the USGS Pasadena Office.

RESULTS

Summary of Network Operations

The SCSN operation of network infrastructure consists of: 1) operating computer and communications hardware/software and other instrumentation for data acquisition at the central site; 2) installation and field maintenance of new and existing digital stations; and 3) population and maintenance of earthquake databases. Caltech and USGS personnel share these operations responsibilities. Because the SCSN is a cooperative project of Caltech and USGS, all the facilities listed below are jointly operated and contribute to the overall project mission.

At present we operate ~353 seismic stations, and record continuous data from another ~129 seismic stations operated by partner networks. These stations are classified as: 1) broadband and strong motion; 2) short period, 3) strong motion, and 4) event triggered NetQuakes. All of the broadband and strong motion stations have local recording. The broadband and short period stations are free field sites that are located away from structures of two or more stories, and preferentially in places with low ambient ground noise (Figure 1).

Many of the strong motion stations are reference sites that differ from traditional free field sites. They are located close to structures of two or more stories or are located near major facilities or near groups of significant structures. We also record data from three University of California borehole strong motion stations located on UC campuses, and four SCEC borehole strong motion stations. The real-time sharing of strong motion data facilitates dual use of the data, for both ground motion measurements and seismological purposes such as earthquake locations.

State of health. The SCSN state of health is monitored using SeisNetWatch. SeisNetWatch can be operated remotely using a regular web browser and field engineers can be notified via paging or email in case problems develop. SeisNetWatch is a good example of how the seismic network community has benefited from SCSN/TriNet development. Initially, it was developed as TriNetWatch and was made available to the community as SeisNetWatch at the request of the USGS/ANSS earthworm group in Golden, Colorado.

Metadata. Full metadata for all digital stations in the SCSN is available, and updated within 1 day of any instrument change. The full metadata are available now from scedc.caltech.edu or www.iris.edu for a subset of stations. Only partial metadata are available for short-period analog stations.

Summary of Changes Implemented in this Reporting Period

The milestones listed below were completed during the reporting period:

SEISMIC STATIONS

- Number of analog stations continues to decrease and is now at 59 (see Table 1).
- Number of NetQuake stations operated remained steady at 82.
- Upgrading of broadband seismometers at 25 sites using UASI funds was completed.
- Installed/upgraded 50 new Q330S, broadband and strong motion stations with UASI funds.
- Installed/upgraded 50 new Basalt, strong motion, and short period stations with UASI funds.
- Moving more sites to cell modem communications and discontinuing frame relay.
- Operation of SIS continues as metadata repository (also see below).
- Continued monthly conference calls between field techs in Pasadena and Menlo Park.
- Continued collaboration with CGS to record real-time data from 4 stations located in Calif. Valley and 5 stations in the greater LA area.

REAL-TIME SYSTEMS OPERATIONS

Seismological Algorithms

- Refined binder configurations to optimize event detection.
- Maintained and used station delays for Hypoinverse locations.
- Mw magnitude updates now sent out automatically within ~6 to 8 minutes for M≥4.0.
- W-phase code running in a research mode to determine near real-time moment tensors.

Data Export

- We export real-time waveforms to ANZA, ATW, CALVO (USGS), CICESE, DWR, USGS (Menlo), PTWC, IRIS/DMC, UCSB and USARRAY/ANF.
- We export picks and HYP to NEIC, Menlo and PTWC.
- Recently we responded to a request to export waveforms to USGS (CalVO) - We now export 21 stations to the USGS California Volcano Observatory (Menlo) as requested by Dr. Mangan for research projects.
- Cloud project. Began installing a real-time processing system on the AWS cloud.

Hardware Upgrades

- Using UASI funds we purchased three new computer servers that will become the next generation Linux real-time AQMS processing systems. Extensive effort was spent in migrating the all the real-time AQMS software to x86 Linux servers. We are exclusively using kickstart for installing Linux OS and puppet for managing configuration parameters to reduce system administration overhead and errors. We are also performing extensive testing of waveforms, picks, locations, magnitudes and origin time comparisons between the new Linux and existing Solaris Real-Time systems. The systems are currently on-line and in the process of being stress-tested. These were brought into production in early 2014.
- Import servers handling data from partner networks changed from old Sun Unix hardware to new Linux hardware - Our import servers that receive waveform data from other network including ANZA, NCSN, CICESE, DWR are now x86-based Linux servers. The Linux servers provide better performance, easier system administration maintenance and allow us to stay updated with the latest software and security patches.
- Import servers handling data flow from SCSN stations moved from Sun Unix to new Linux hardware.
- Clustering cs-import servers - allow cs-import servers to work together and provide failover and

increased availability.

Product Distribution and System Management

- PDL - We have installed PDL on our real-time as well as our post-processing systems and are sending messages to a development PDL server.
- Request tracker - Started using bug tracking and trouble ticketing system called RT (Request Tracker) for all SCSN stations and telemetry, software development, post processing, system administration and data center issues.
- Configuration management - We are also extensively using software called puppet and kickstart to deploy new servers and install and maintain standard configurations.

Robustness

- We have added redundancy between real-time system and post-processing databases via a private Intranet network connection.
- Self-healing telemetry redundancy - We have increased redundancy of our USGS microwave network stations using a T1 between Pasadena and Edwards Air Force Base.
- Improved Network and Server Security - Installing a syslog server, updating security patches on Cisco routers, locking down vulnerabilities like FTP and Telnet, standardizing on password strength and employed 2-factor authentication via duo for secure server access.
- With UASI funds, we upgraded the centralized UPS power system in South Mudd, which provides backup power for all real-time and post-processing servers in the SCSN computer server room room.
- Using NAGIOS (IT infrastructure monitoring software) for monitoring all our servers and network devices.
- Using UASI funds, we purchased a data storage system to hold all log files for our systems, to provide engineering data for troubleshooting and future improvements.
- WildBlue satellite - Setup and tested a satellite-based path for sending redundant PDL messages in case of Caltech IMSS Internet connection outage or slowdown.
- OASIS satellite - This is the satellite-based emergency connection between Pasadena and Sacramento. Helped with restoring and testing telephone and network connection via the OASIS satellite.

DATA-POST-PROCESSING

- Timing and review of detected earthquakes is up to date.
- 2010 El Mayor-Cucapah earthquake sequence backlog almost completed.
- The offshore 14 Dec. 2012 Mw6.3 earthquake was the largest recorded in 2012.
- The March 2013 Anza M4.7 was a significant sequence near Anza.
- The March 2014 La Habra Mw5.1 occurred in the east Los Angeles area.

ARCHIVING

- For details, see SCEDC report on page 11

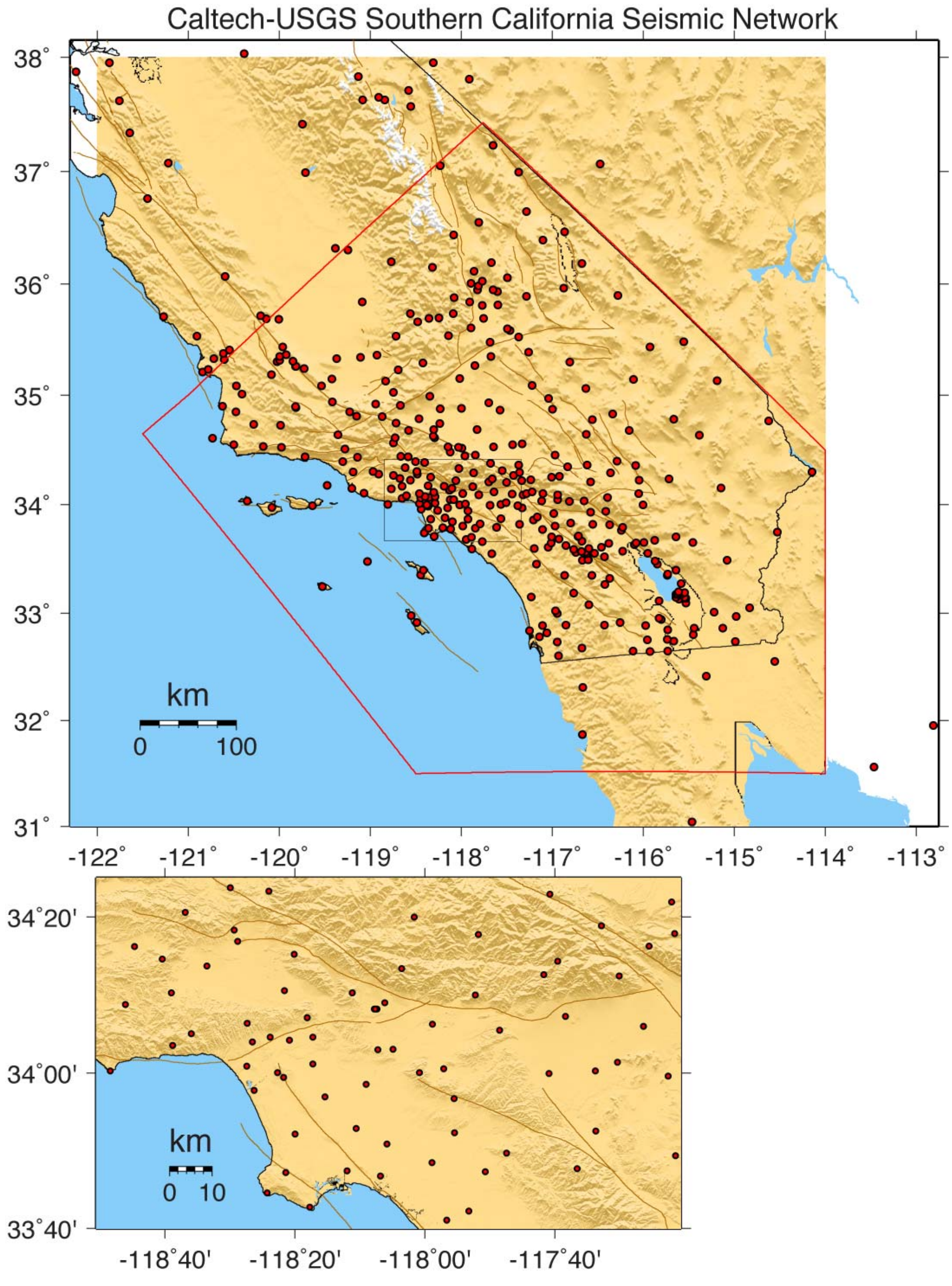

Figure 1. Southern California seismic stations recorded and operated by the SCSN. Not shown are the 82 NetQuake stations. Stations operated by partners in Ensenada Mexico are also shown. We started receiving these data in 2010. One USArray station in Arizona is also included.

Table 1: Seismic Stations Operated and/or Recorded by the SCSN in January 2015		
SUMMARY STATISTICS FOR SCSN	**NUMBER**	**SEED VOL.**
Total number of stations operated/continuously recorded	**353/482***	**353****
Total number of channels continuously recorded	**9,176**	
Number of short-period (SP) stations operated/recorded	**59/111**	**59**
Number of broadband (BB/SM) stations operated/recorded	**219/261**	**219**
Number of strong motion stations operated/recorded	75/110***	45
Number of non-analog short period stations only recorded; from EN, NN, NC, and SN networks; includes rotational sensors	0/30	
Total number of triggered NetQuake stations operated/recorded	82/70	83
Number of stations only contributing latent triggered waveforms to the archive; mostly CE and NC waveforms from NCEDC	254	
Number of stations maintained & operated by network	**435******	**383**
Number of stations maintained & operated as part of ANSS	**435**	**383**
Total data volume archived (mbytes/day)	26,134	

*) The 82 triggered NetQuakes stations are not included

**) We produce authoritative SEED volumes for CI-network stations; partner networks such as Anza produce their own SEED volumes

***) May have an additional 4^{th} high-gain short period channel

****) Includes BB/SM, SM, analog, and triggered NetQuake stations

The data in Table 1 (above) shows that the number of stations and channels operated/recorded by the SCSN continues to grow, because of the added NetQuakes and upgrades of analog stations to digital, which increase the number of strong motion stations by 4. However, the number of stations equipped with broadband (BB) and strong motion (SM) sensors remains stable.

Data Management Practices

- *Describe briefly your state of progress toward meeting ANSS data management performance standards (standards 4.1, 4.2, 4.3, 5.1 and 5.2).*

Hutton et al (2010) describe how the SCSN catalog (1932 to present) is generated and curated.

We meet and in some cases exceed the ANSS standards:

4.1 – Waveforms are shipped via earthworm or Seedlink within seconds to partner networks. We have 10 dual feed stations to BDSN.
4.2 – We export amplitudes in near real time to CISN partner networks.
4.3 – Phase picks are shipped via earthworm within seconds to partner networks, including NEIC, NCSS and PTWC.
5.1 – We currently have event-based waveforms available within 8 minutes from origin time. Continuous data is archived hourly, being on average 6 minutes after an hour segment has elapsed.
5.2 – An event bulletin is available within 2 minutes of the origin time of an event. Updates to the catalog are made available within 4-8 seconds of the update to an event.

- *Provide timeliness for importing your data into an ANSS archive.*

Earthquake parameter data is available within minutes after processed by the SCSN RT system. All types of earthquake locations are sent to NEIC. For automated solutions, a lower magnitude threshold of 0.95 is used. For analyzed solutions, there is no lower threshold. Both automated and analyzed solutions have a geographic constraint.
Event waveform data is available for distribution at SCEDC within 7 minutes. All SCSN continuous waveform data is archived as a batch process. For high sample rate data it is 1 hour after acquisition, for low sample rate data it is 24 hours after acquisition, also see SCEDC report on page 11.

Progress on ANSS Integration

Most of the SCSN partnerships and coordination are done through the California Integrated Seismic Network (CISN). We have monthly Program Management Group (PMG) and CISN Standards Group calls. The SCSN imports real-time waveform data from about 129 partner network stations. We export real-time waveforms to NCSN, BDSN, ANZA, UNR, Earrthscope/USArray, CGS, and others.

We view NEIC as our primary backup partner. Two export servers feed near real-time parametric and catalog data to NEIC since August 2010. For ShakeMap backup, we work with CISN partners. We have distributed our ShakeMap generation parameters to UC Berkeley and California Geological Survey (CGS) to facilitate backup generation of ShakeMap. The California Geological Survey (CGS) is now the official backup for California ShakeMap.

Our in-house computer facilities at Caltech and USGS Pasadena Office were upgraded in 2011, which included implementation of the hot-isle/cold-isle concept. We also installed two power sources in our computer room, UPS/generator backed-up campus power and Pasadena City Power. New transfer switches provide seamless transfer between power sources. This has also significantly improved the robustness of our operations.

For all significant earthquakes (either felt or larger than a regionally adopted threshold magnitude), the SCSN coordinates public response with USGS Pasadena Office, USGS Menlo Park, NEIC, SCEC, and CISN partners as quickly as possible.

SCSN sends real time picks and origins to NEIC. We send waveforms real-time to NCSN and IRIS. We also export ShakeMap amplitudes to CGS, and NCSN.

In 2013 we setup AQMS system for CICESE including the real-time, post-processing and Database systems. This involved installing the hardware in Pasadena, installing Solaris, building the latest EarthWorm and AQMS software, installing the databases and post-processing servers and software and all the Duty Review webservices setup. This was done at the request of Doug Given, USGS, Pasadena.

Seismicity Summary for Southern California: Nov. 2013 – Jan. 2015

Total number of earthquakes recorded and post-processed by the SCSN during the reporting period, 18,329 (Figure 2; Table 2). The SCSN also recorded 716 quarry blasts. These earthquakes and quarry blasts, that are located inside and just outside of the SCSN reporting region, occurred at a rate of about 42 events per day during the reporting period.

The March 2014 Mw5.1 La Habra earthquake was the largest earthquake that occurred during 2014. It was felt across the Los Angles basin and caused some damage in the Whittier-La Habra region. It was preceded by two foreshocks, the larger of M3.6 at 8:03pm (Figure 2). It ruptured a southwest striking fault that extends from the Whittier fault towards the west Coyote Hills oilfield. This sequence could be associated with the Puente Hills thrust (PHT). The PHT is a blind thrust fault that extends from this region to the north and west towards the City of Los Angeles. It caused the M5.9 1987 Oct. 1 Whittier Narrows earthquake. Previously, the M5.4 2008 Chino Hills earthquake occurred in this region. It caused somewhat stronger shaking in Orange County and across the Los Angeles Basin.

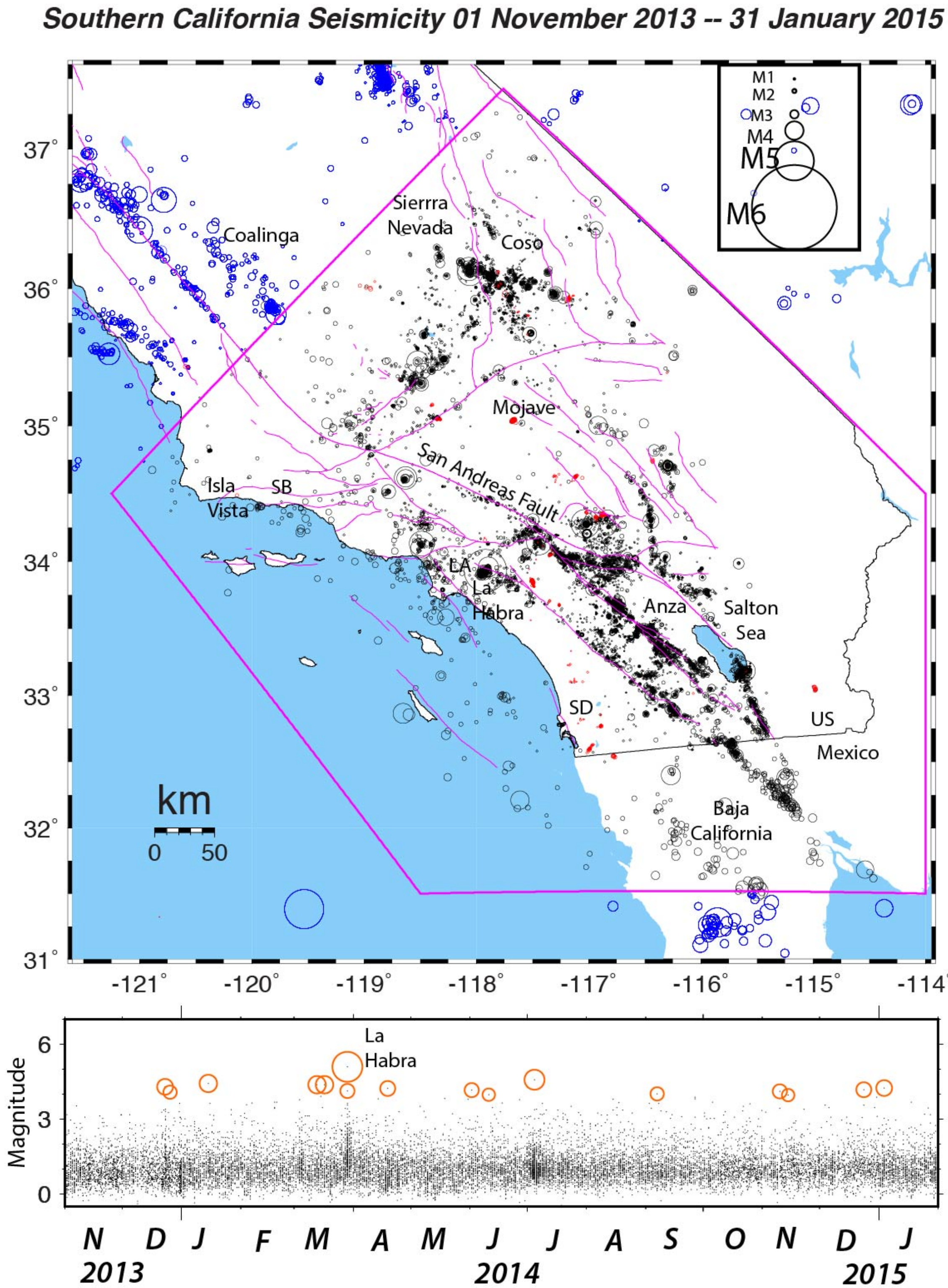

Figure 2. Seismicity recorded by SCSN and archived by SCEDC: 1 November 2013 to 31 January 2015. The black circles are local earthquakes, red circles are quarry blasts, and blue circles are earthquakes recorded but occurred outside the SCSN reporting region. The SCSN reporting region is within the magenta polygon. The magnitude date plot of events in the reporting region shows M≥4.0 local earthquakes as brown circles. LA – Los Angeles; SB – Santa Barbara; SD – San Diego.

Table 2: Summary of earthquake magnitude distribution recorded by SCSN: Feb. 2010 to Jan. 2015					
Mag	**2010/02-2010/11**	**2010/11-2011/10**	**2011/11-2012/10**	**2012/11-2013/10**	**2013/11-2015/01**
Total # Events	27,689	15,980	15,246	17,352	18,329
>2.0	8,901	2,300	1,815	1,419	1,912
>3.0	1,565	330	235	213	327
>4.0	165	38	31	12	35
>5.0	10	1	2	0	2
>7.0	1	0	0	0	0
# of ShakeMaps Generated	288	102	95	60	81

Seismicity Summary for Southern California: 2010/02 to 2015/01

With over 14,000 to more than 41,000 earthquakes recorded per year, the SCSN analyzes and archives at the SCEDC a large quantity of data every year, including catalog listings (time, magnitude, location, and location quality), phase data (arrival times, qualities, and first motions at each station), moment tensors, and seismograms (Figure 3; Table 3). The SCSN data are recorded and processed using the AQMS post processing software system.

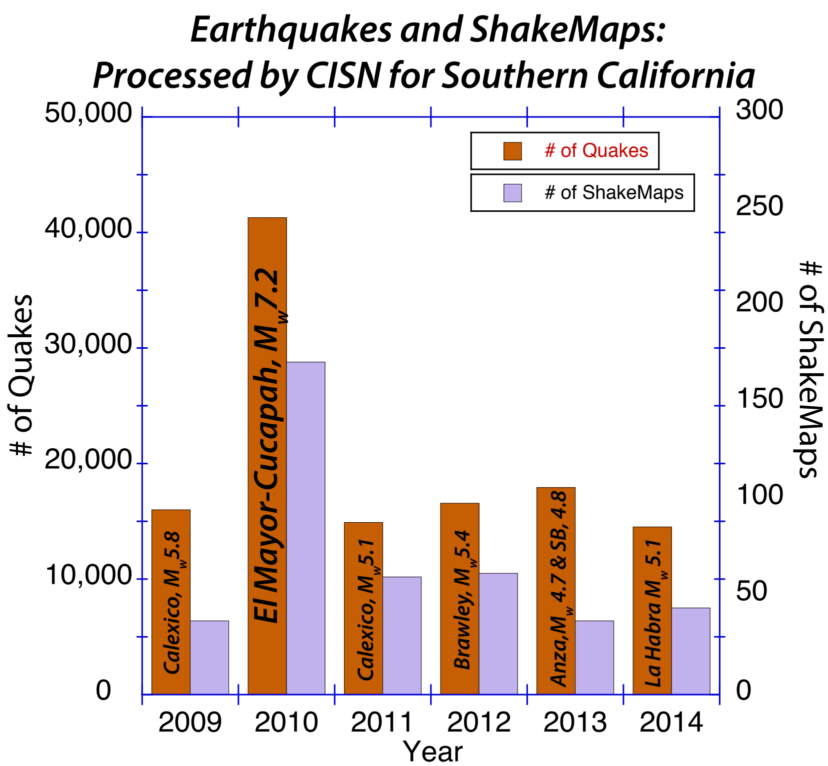

Figure 3. Number of local earthquakes cataloged and ShakeMaps produced by the SCSN and SCEDC. Each bar is labeled with the largest quake recorded that year. The data for 2014 are incomplete. The high number of earthquakes in 2013 relative to ShakeMaps is caused by low detection threshold in the Anza region.

The 2010 Mw7.2 El-Mayor Cucapah earthquake was the largest earthquake to occur during the monitoring period. It was followed by more than 30,000 aftershocks.

The 2012 Brawley earthquake swarm occurred in the Brawley Seismic Zone (BSZ) within the Imperial Valley of southern California. The swarm started near the town of Brawley at 4:30 (UTC) on 26 August, with three events of Mw > 5 occurring within 5 min. The seismic activity picked up again at 11:43 (UTC) and continued at a steady rate. The three largest earthquakes (Mw 5.3, Mw 4.9, and Mw 5.4) in the sequence occurred over a period of 90 min, starting at 19:31 (UTC). The largest (Mw 5.4) earthquake was widely felt across southernmost California, northern Baja California, and western Arizona. The SCSN ShakeMap showed strong to very strong shaking within a 10-km distance of the epicenter.

In December 2012 a Mw6.3 earthquake occurred within oceanic lithosphere of the eastern Pacific plate, about 220 km to the southwest from the closest SCSN seismic station. This earthquake caused weak to moderate ground shaking in the coastal zones of southern California, USA and Baja California, Mexico but the tsunami was negligible. It occurred in an unusual tectonic setting, near a fossil trench that juxtaposes Miocene oceanic lithosphere and submerged, thinned continental lithosphere of the California Continental Borderland. This region is now hundreds of km away from the edge of the Pacific plate. However, it was much closer to the plate boundary earlier in its history, until subduction ceased and the continental material above the subduction zone extended as part of the evolution of the Pacific-North America plate boundary and the transfer of continental slivers to the Pacific plate (Hauksson et al., 2014).

Table 3: Earthquakes of M≥5.0 recorded by the SCSN during the reporting period

#EVID	Mag.	Local date	Local time	Lat.	Long.	Depth	Descriptive location
14607652	7.2	2010/04/04	15:40:42	32 17.2 N	115 17.7 W	10.0	12 km (8 mi) SW of Delta, B.C., MX
10184394	5.3	2010/04/04	15:43:00	32 27.2 N	115 37.9 W	10.0	15 km (9 mi) SSW of Progreso, B.C., MX
31957759	5.7	2010/04/04	15:50:17	32 5.9 N	115 2.9 W	10.0	12 km (7 mi) SSW of Estacion Coahuila, B.C., MX
14607836	5.4	2010/04/04	16:15:14	32 18.0 N	115 15.6 W	10.0	9 km (5 mi) SW of Delta, B.C., MX
14607924	5.4	2010/04/04	16:25:07	32 16.0 N	115 17.6 W	10.0	12 km (8 mi) WNW of Alberto Oviedo Mota, B.C., MX
10148002	5.2	2010/04/04	17:07:07	31 58.7 N	115 8.1 W	10.0	27 km (17 mi) SSW of Estacion Coahuila, B.C., MX
10589037	5.3	2010/04/08	09:44:25	32 9.9 N	115 16.1 W	10.0	12 km (7 mi) SW of Alberto Oviedo Mota, B.C., MX
14745580	5.7	2010/06/14	21:26:58	32 42.3 N	115 54.7 W	9.0	8 km (5 mi) ESE of Ocotillo, CA
10736069	5.4	2010/07/07	16:53:33	33 25.2 N	116 29.3 W	14.0	20 km (13 mi) NE of Warner Springs, CA
14937372	5.1	2011/02/18	09:47:35	32 2.8 N	115 3.7 W	15.0	17 km (11 mi) SSW of Estacion Coahuila, B.C., MX
15199681	5.3	2012/08/26	12:31:23	33 1.0 N	115 33.2 W	8.3	5 km (3 mi) NNW of Brawley, CA
15200401	5.4	2012/08/26	13:57:58	33 1.1 N	115 32.4 W	8.2	4 km (3 mi) NNW of Brawley, CA
15263753	6.3	2012/12/14	02:36:02	31 23.4 N	119 37.7 W	10.0	200 km (124 mi) SW of San Clemente Is.
15472481	5.0	2014/03/04	18:24:24	31 22.9 N	119 32.1 W	6.9	195 km (121 mi) SW of San Clemente Is.
15481673	5.1	2014/03/28	21:09:42	33 55.9 N	117 55.0 W	4.8	2 km (1 mi) NW of Brea, CA

The Southern California Earthquake Data Center

southern california earthquake data center

Data Processing and Production of Earthquake Information

We carried out the following activities:

- We are in the process of loading the entire SCSN catalog into ComCat. We have done a trial load of all events in the catalog into the development server.
- We utilized PDL Product Client to help transfer of earthquake products within our own system. This helps simplify our own scripts that previously needed ssh permissions to other servers to move data to another server.
- Continued adding features to Station Information System (SIS) to meet ANSS/ARRA requirements.
- We continue work developing web services. We have made FDSN compliant station and waveform web services in addition to Web STP, which gives event triggered data.
  - Web STP: SCEDC phase data, continuous waveform time series, triggered waveform time series in mSEED, SAC, ascii formats.
  - Dataselect: continuous waveform time series in mSEED
  - Station: metadata for waveform time series
- Provided database support for RSNs' using AQMS.

Data Archiving

- The Data Center is implementing the Continuous Wave Buffer (CWB) to manage its waveform archive. This software was developed and currently in use at NEIC. We believe successful implementation will simplify and streamline waveform archival, and thus allow the SCEDC to maximize the completeness of its waveform archives. We ran a number of stress tests to ensure CWB would keep up with a high event rate in a sequence. Dave Ketchum provided modifications to the software so it could accept multi-casted waveform data from our acquisition systems and so our software could retrieve data directly from it in mseed format. We have installed the software on two of our production servers. One set of our production applications that use current waveform data retrieve it from the CWB. We plan to install the CWB software on our back up system. We also are currently migrating our waveform archive into the CWB system and porting our software that access historical waveforms to CWB.
- The SCEDC has moved the static content of its website http://scedc.caltech.edu to Amazon Web Service S3 buckets. This move helps us more efficiently use computer resources.
- We have started using Puppet for configuration management of our servers. This should lead to fewer server misconfigurations in our system.
- Working on archiving near real-time GPS data in collaboration with JPL and UCSD, with NASA funding.

Station Information System (SIS) Development

Accomplishments:

- Formed an active TIC which meets monthly to guide development.
- Developed a working functional specifications document and regularly update it based on TIC input.
- Revised database schema to:
  - Provide enhanced equipment and response tracking capability
  - Include user profiles to facilitate ease of sharing SIS among multiple RSNs
  - Accommodate broad station categories, leaving ample room for inclusion of GPS and strong motion networks in the future.
- Fully integrated the Nominal Response Library (NRL) and developed a plan for working with the IRIS DMC for sensor and digitizer response updates.
- Defined naming standards for sensors, loggers, and units.
- Completed SIS user guide, and continually update to reflect changes.
- Revised ExtStationXML format which is an extension of FDSN StationXML to facilitate importing existing station data into SIS. Added ability to describe multi-site seismic installations. To our knowledge, this is the first time a metadata format has been created that describes both equipment and channel response.
- Developed a writer and loader to ExtStationXML. Users can now batch load into SIS using this format.
- Developed a writer for FDSN StationXML.
- Developed forms to enter equipment information and assign response to seismic equipment.
- Developed forms to configure loggers for single site and multi-site seismic installations.
- Developed forms to record field actions for both single site seismic installations and multi-site seismic installations.
- Developed ability for user to publish metadata for a site in ExtStationXML and FDSN StationXML formats in the SIS file server and use the IRIS converter to convert into dataless SEED.
- **SIS v2.0 is now in production starting Dec 1, 2014**. Migrated users of SIS v1.0 into SIS v2.0. South Carolina Seismic Network hand entered their data using the UI and are using it in production. Lamont Doherty are entering their data into production.
- Held 4 WebEx tutorials for regional seismic networks. The slides for these tutorials are in the SIS wiki: http://maui.gps.caltech.edu/SISTrac.
- Continued documenting SIS-TIC meetings, functional specifications, software bugs and enhancement requests in SIS wiki in http://maui.gps.caltech.edu/SISTrac.

Anticipated Future Needs

- Development of features that have been requested since this effort began:
  - Higher priority:
    - Expand field work documentation
    - Integrate additional telemetry tracking resources
    - Integrate access to local RSN archives (email, photos, documents, etc)
    - Implement full user permissions if needed
  - Lower priority:
    - Implement strong motion community requests (building arrays, Cosmos designations, etc)
    - Implement GPS community requests.

SIS Development Group

- Ellen Yu (Caltech) – technical lead and database administrator.
- Faria Chowdhury (Caltech) – SIS developer, focusing on the user interface.
- Prabha Acharya (Caltech) – SIS developer, focusing on stored procedures.
- Sue Kientz (Caltech) – technical documentation and general support.
- Valerie Thomas (USGS) – TIC chairman.

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