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Workshop: Converting Advances in Seismology into Earthquake Science

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Converting Advances in Seismology into Earthquake Science

We convened a workshop for seismic network operators and the Southern California Earthquake Center (SCEC) user community of seismologists to discuss several seismic shifts that are occurring in regional seismology. The availability of high quality digital seismic data and modern low cost storage technology is making it possible for seismologists to work with large datasets and to perform complex measurements on millions of waveforms. As researchers assemble their datasets as soon as the shaking stops and focus on getting their results published quickly, there is a need to improve the algorithms, automation, timeliness, and quality of data products such as hypocenters, magnitudes and moment tensors. Some of these products are being improved with new algorithms provided by the research seismologists.

New seismic instrumentation is in place across southern California and significant progress has been made in improving instrumentation in northern California. Since 2001, these new field instrumentation efforts, data sharing, and software development for real-time reporting and archiving have been coordinated through the California Integrated Seismic Network (CISN). The CISN is also the California region of the Advanced National Seismic Network (ANSS). In addition, EarthScope deployments of USArray will begin deployment in early 2004 in California. The southern and northern California earthquake data centers (SCEDC and NCEDC) have new capabilities that enable seismologists to obtain large volumes of data with only modest effort.

Seismologists from Caltech, UCSD, and UCLA convened the workshop that was held at California Institute of Technology (Caltech) in Pasadena in late September 2003. A total of 60 seismologists and students participated in the workshop for two days. The focus of the workshop was aimed toward observational seismology, where seismologists analyze earthquake data and undertake a variety of seismological research to improve earthquake locations, moment tensor solutions, resolution of physical processes within earthquake clusters, and tomographic models. Many of the most successful users of the seismic network data do not reside in California because the web enabled data centers provide equal access to the seismic data, both to remote users as well as to users at the host institutions.

Federal and state agencies, and university groups all operate seismic networks in California. The USGS operates seismic networks in California in cooperation with California Institute of Technology (Caltech) in southern California and UC Berkeley in northern California. The California Geological Survey (CGS) and the USGS National Strong Motion Program (NSMP) operate dial-out strong motion instruments in the state, primarily to capture data from large earthquakes for earthquake engineering and more recently, emergency response. The California Governor's Office of Emergency Services (OES) provides leadership for the most recent project, the California Integrated Seismic Network (CISN), to integrate all the California efforts and to take advantage of the emergency response capabilities of the seismic networks. The core members of the CISN are Caltech, UC Berkeley, CGS, USGS Menlo Park, and USGS Pasadena.

The goals and implementation of strong motion networks and seismic networks have been different in the past. The strong motion networks focused on deploying many sensors in strategic locations to collect rare records with large signals. The seismic networks focused on real-time data communications and using high gain sensors. Now the two types of networks are merging because both see some benefits in real-time or near-real-time data transmission and the same sensor systems can be used to detect both large and small ground motions. Similarly, instrumentation to monitor building response is evolving to have real-time data communications to record both linear and potentially non-linear ground motions in buildings. Many of the same data processing techniques apply to both kinds of data and thus new frontiers in research for seismologists and earthquake engineers are converging on several fronts.

The core and affiliated members of CISN operate more than 500 short-period stations, 200 broadband and strong motion stations, and 1000 strong-motion stations in California. The users expressed interest in greater density of broadband and strong-motion stations in northern California. The CISN is already addressing several statewide integration issues.

Products such as hypocenters, magnitudes, ShakeMaps, and moment tensors are being standardized to ensure that they are uniform statewide. In the case of a major earthquake, all the data from all the CISN members will be made available through several web sites to service many different user communities such as seismologists, earthquake engineers, and the public. The users expressed interest in saving more of the high sample rate data during unusual times. Such times could be the hours or days before and following a major local earthquake or a major teleseism. These data sets could for instance be used to test rate and state friction laws and improve our understanding of earthquake triggering.

The meeting participants clearly expressed interest in having high quality earthquake locations available within minutes following an earthquake. The common seismological practice of updating the hypocenter information in the following hours, days, or weeks, can create a "moving target" that complicates later analyses. Greater uniformity in hypocenter information would facilitate tectonic interpretation as well as the production of the derivative products that use the hypocenter as a point of reference and are generated following an earthquake. There is also a clear need for near-real-time moment tensors and first motion focal mechanisms that are an essential part of the parametric description of the earthquake. The new frontier of rapid finite source inversion was also discussed and its potential application by seismic networks. The major and potentially most damaging earthquakes have sources that may extend from tens to a few hundred miles and thus finite source descriptions are a must.

The complexity of metadata used by seismologists to describe their instruments is extreme. It requires detailed understanding of signal processing theory as well as the instruments themselves. The users expressed strong need for easy and timely access to metadata and associated documentation. In addition to the modern high fidelity seismic instrumentation there is a need to determine the ground conditions, often called the site response, where the instrument is deployed. The site response can be measured through a variety of means. The simplest measurements are the field observations done by a seismologist. The more complex measurements involve cone penetration measurements, and the most complex involve a borehole and detailed logging of the borehole. The users expressed great interest in having a database of site response to facilitate interpretation of waveforms for basic source studies, ShakeMap, and long term seismic hazards studies.

One of the many products routinely produced and maintained by seismic networks are earthquake catalogs. The catalogs contain the date and time, location, magnitude, and solution quality parameters for each earthquake that occurred within the reporting boundary of the network. The California earthquake catalogs contain more than 800,000 earthquakes recorded for the last 75 years. Seismologists use the catalogs to determine earthquake statistics to further their understanding of earthquake occurrence. They also use the catalog along with other types of geological and earthquake information to estimate seismic hazards. The discussion at the workshop about earthquake catalogs focused on several aspects that might improve the existing catalogs. There was strong consensus about the need for improved documentation of the procedures used to produce and maintain the catalog so users could track any changes.

New discoveries are often made from new data that are not easily explained with current seismological theory or practice. The users at the workshop expressed interest in having more data saved for later data mining. As part of using more of the bandwidth of the seismic signal, the workshop participants discussed the mutual benefits of improved coordination between global positioning system (GPS) networks such as the Southern California Integrated Geodetic Network (SCIGN) and the seismic networks. The GPS networks are now able to capture high amplitude seismic waves using a dense network of GPS stations that record data at high sampling rates.

The data centers have several tasks, such as, to curate legacy data, maintain various types of metadata, archive the latest data and derived products, and to provide user access to all of the data and products. The SCEDC and NCEDC store the legacy earthquake data back for 75 years in the south and almost 100 years in the north. They also provide web-enabled access to the latest data within minutes in the south, and within days in the north. The SCEDC has pioneered a network based application called Seismic Transfer Protocol or (STP). The STP provides web and command line interface to the data and allows rapid retrieval of both waveforms and parametric data. These new facilities are making possible new seismological research based on ready access to seismograms. Users strongly supported ongoing efforts to make data access more uniform at both data centers and possibly providing one virtual California data center.

The existing infrastructure of the CISN will be beneficial to the EarthScope project. For instance, the CISN will provide the USArray Big Foot deployment with sites that are spaced 70 km apart, and communication infrastructure to assist in launching USArray. The ANSS program has deployed instruments to provide improved density of free field sites and reference sites (near major buildings or structures) in the San Francisco Bay area, and assisted with operations of the new instrumentation in southern California. Plans for new building instrumentation with real-time data communications are underway as ANSS initiates the necessary user review and implementation process.