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Improving Southern California Earthquake Locations and Focal Mechanisms

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Introduction

This project has been funded for several years by SCEC to improve southern California earthquake locations and focal mechanisms by applying waveform cross-correlation and other recently developed techniques to the vast waveform archives of the Southern California Seismic Network (SCSN). Our main accomplishment during the last year was the release of the SHLK_1.0 catalog of relocated earthquakes in southern California. The catalog and processing steps are described in two papers submitted to BSSA (*Shearer et al*., 2004; *Hauksson and Shearer*, 2004). The catalog is available at the SCEC Data Center and has already begun to be used by other SCEC researchers. We also completed some synthetic tests of different location methods (*Lin et al*., 2004) as part of our ongoing efforts to improve location accuracy. Finally we have measured *P*- and *S*-wave amplitude data in order to use the approach of *Hardebeck and Shearer* (2002, 2003) to better constrain focal mechanisms of small earthquakes.

Our SCEC funding was mainly been used for support of graduate student Guoqing Lin. Please note that results from a related project, a joint UCSD/Caltech project to systematically apply waveform cross-correlation and compute spectra for southern California seismograms, are described in a separate report.

Earthquake locations

We obtained precise relative relocations for over 340,000 southern California earthquakes between 1984 and 2002 by applying the source-specific station term (SSST) method to existing *P* and *S* phase picks and a differential location method to about 208,000 events within similar event clusters identified using waveform cross-correlation. The entire catalog was first relocated using existing phase picks, a reference one-dimensional velocity model, and the SSST method of *Richards-Dinger and Shearer* (2000). We also performed separate relocations of Imperial Valley events using a velocity model more suited to this region. Next, we applied cluster analysis to the waveform cross-correlation output to identify similar event clusters. The waveform cross-correlation itself was performed in a joint Caltech/UCSD project that received separate SCEC funding; the computational details are contained in *Hauksson and Shearer* (2004). Because we did not compute cross-correlation between all possible event pairs, some modifications to standard cluster analysis algorithms were necessary to achieve a suitable method. We relocated earthquakes within each similar event cluster using the differential times alone, keeping the cluster centroid fixed to its initial SSST location. We estimated standard errors for the relative locations from the internal consistency of differential locations between individual event pairs; these errors are often as small as tens of meters. In many cases the relocated events within each similar event cluster align in planar features suggestive of faults. We observed a surprising number of such faults at small scales that strike nearly perpendicular to the main seismicity trends. In general, the fine-scale details of the seismicity reveal a great deal of structural complexity in southern California fault systems.

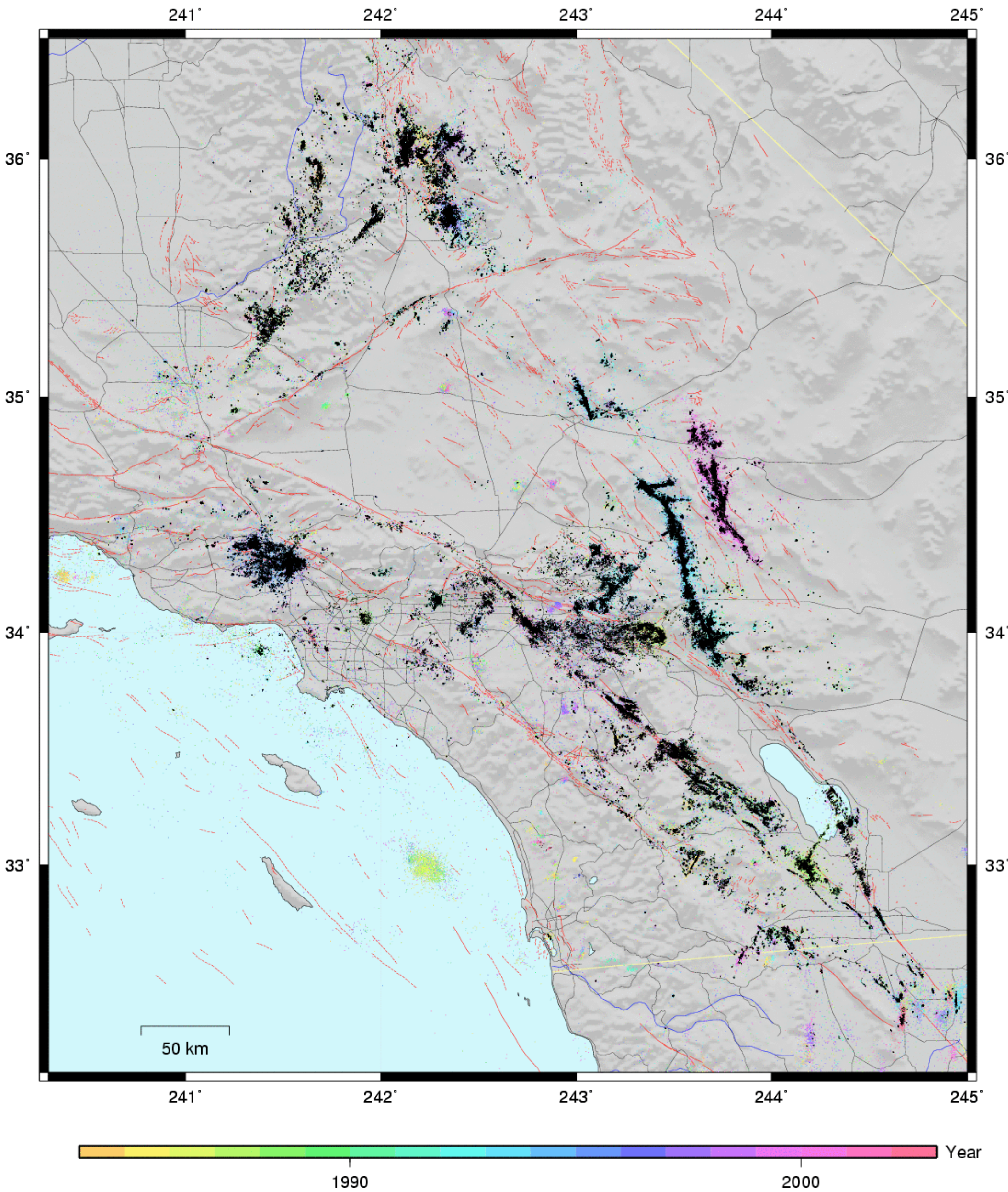

Figure 1. A map showing the final set of locations obtained for 1984–2002 southern California seismicity. Event within similar event clusters that have been relocated using waveform cross-correlation are shown in black. Uncorrelated events that are located using the SSST method applied to phase data alone are colored by their year of occurrence.

In general these results agree with previous cross-correlation studies in specific regions (e.g., *Shearer,* 1997, 1998, 2002; *Astiz et al.,* 2000; *Shearer et al.*, 2003) but there are often differences in absolute depth related to the velocity model used in the SSST locations. For example, the Whittier Narrows aftershocks are located at ~13 km depth, about 3 km shallower than in *Shearer* (1997) but close to the revised depths obtained by *Shaw and Shearer* (1999). The Oak Ridge cluster is located at 13 km depth rather than the 18 km obtained by *Shearer* (1998). The revised absolute location for the Oak Ridge cluster affects the dip of the seismicity plane resolved by the waveform cross-correlation; our new results show the dip direction to be just west of north rather than northeast as resolved by *Shearer* (1998).

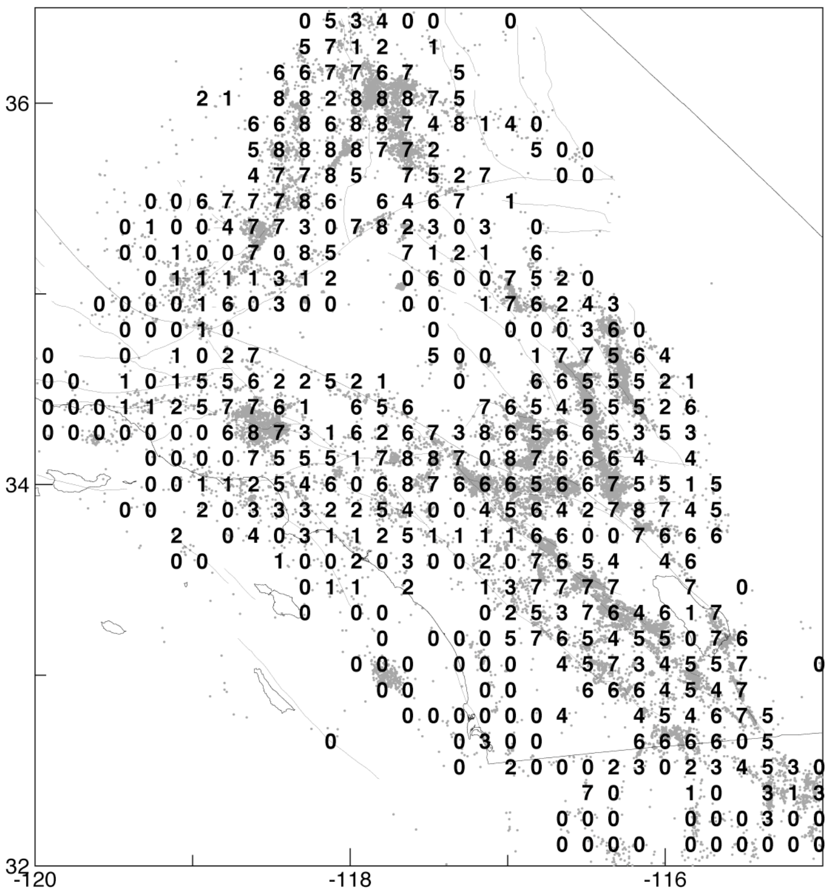

Figure 2. The fraction of events that are contained in the similar event clusters that were computed in this study from waveform cross-correlation. The numbers are plotted at the center of 15 by 15 km cells, with 0 indicating from 0% to 10% similar events, 1 indicating from 10% to 20% similar events, etc. Cells with fewer than 20 total events are not plotted.

The tendency for earthquakes to be part of similar event clusters varies across southern California, as illustrated in Figure 2, which plots the fraction of events that are contained in the similar event clusters as a function of epicenter position. The highest percentages of similar events are found in the northernmost part of the network in the Ridgecrest and Coso areas, where the number of similar events typically exceeds 80%. Artificial seismicity, such as the quarry blasts seen in the Mojave block, very rarely forms similar event clusters. This may be a result of ripple firing and other source complexity, as well as strong heterogeneity in the near surface, which results in non-repeatable waveforms. The Landers and Hector Mine aftershock sequences yield about 50% to 70% similar events. The Northridge aftershocks contain about 70% to 80% similar events.

Synthetic location tests

As part of our program to develop improved earthquake location methods, we compared three relative earthquake location techniques using tests on synthetic data that simulate many of the statistical properties of real travel time data (*Lin and Shearer*, 2004). The methods are: (1) the hypocentroidal decomposition method of *Jordan and Sverdrup* (1981), (2) the source-specific station term method (SSST) of *Richards-Dinger and Shearer* (2000), and (3) the modified double-difference method (DD) of *Waldhauser and Ellsworth* (2000). We generated a set of synthetic earthquakes, stations and arrival time picks in half-space velocity models. We simulated the effect of travel time variations caused by random picking errors, station terms, and general three-dimensional velocity structure. We implemented the algorithms with a common linearized approach and solved the systems using a conjugate gradient method. We constrained the mean location shift to be zero for the hypocentroidal decomposition and double-difference locations. For a single compact cluster of events, these three methods yielded very similar improvements in relative location accuracy. For distributed seismicity, the DD and SSST algorithms both provided improved relative locations of comparable accuracy. We also present a new location technique, termed the SSST shrinking box method, which provides some improvement in absolute location accuracy compared to the SSST method. In our implementation of these algorithms, the SSST method runs significantly faster than the DD method.

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