Analysis of similar event clusters in southern California

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Annual Progress Summary Report

Investigations Undertaken

Comprehensive analysis of similar earthquake clusters in southern California, as identified using waveform cross correlation, including:

• Systematic mapping of the fraction of similar events found as a function of location and depth, and comparisons to local geology and tectonics. In this way, we hope to understand why similar events seem to be much more common in northern California than in southern California, at least in results obtained so far.

• Relocation experiments to compute the most accurate possible locations for the events within each cluster. We will use these locations to delineate fault surfaces, improve focal mechanism analyses and to study earthquake source properties.

• A comprehensive study of the temporal stability of seismic properties within the southern California crust, including *P* and *S* velocities, shear-wave splitting and coda *Q*. By examining a variety of cluster and station locations, we should be able to characterize the source regions of large earthquakes as well as the large-scale bulk properties of the crust.

• Quality control analyses to identify possible timing and amplitude calibration problems in the southern California waveform databases.

Results

Many small earthquakes occur in tight clusters of repeating events that produce nearly identical seismograms. The similarity of their waveforms permits the use of waveform cross-correlation and other methods that provide much more accurate timing and calibration information than is normally possible. These analyses yield very precise earthquake locations that can be used to map fault structures in great detail as well as providing constraints on temporal variations of seismic properties that are useful for earthquake monitoring purposes. Our research has involved a comprehensive analysis of similar event clusters in southern California, as identified and relocated using waveform cross-correlation.

We are collaborating with Egill Hauksson at Caltech to perform waveform cross-correlation on southern California seismograms for over 380,000 events between 1984 and 2002. Waveforms recorded by the SCSN were first extracted from the SCEDC data center in 50 s

windows that include both P and S waves. The resulting online waveform archive uses about 0.5 TB on a RAID system. To simplify the computation, we divided southern California into five polygons, such that there are ~100,000 events or less in each region (see Figure 1). Polygon boundaries are chosen to lie in regions of sparse seismicity.

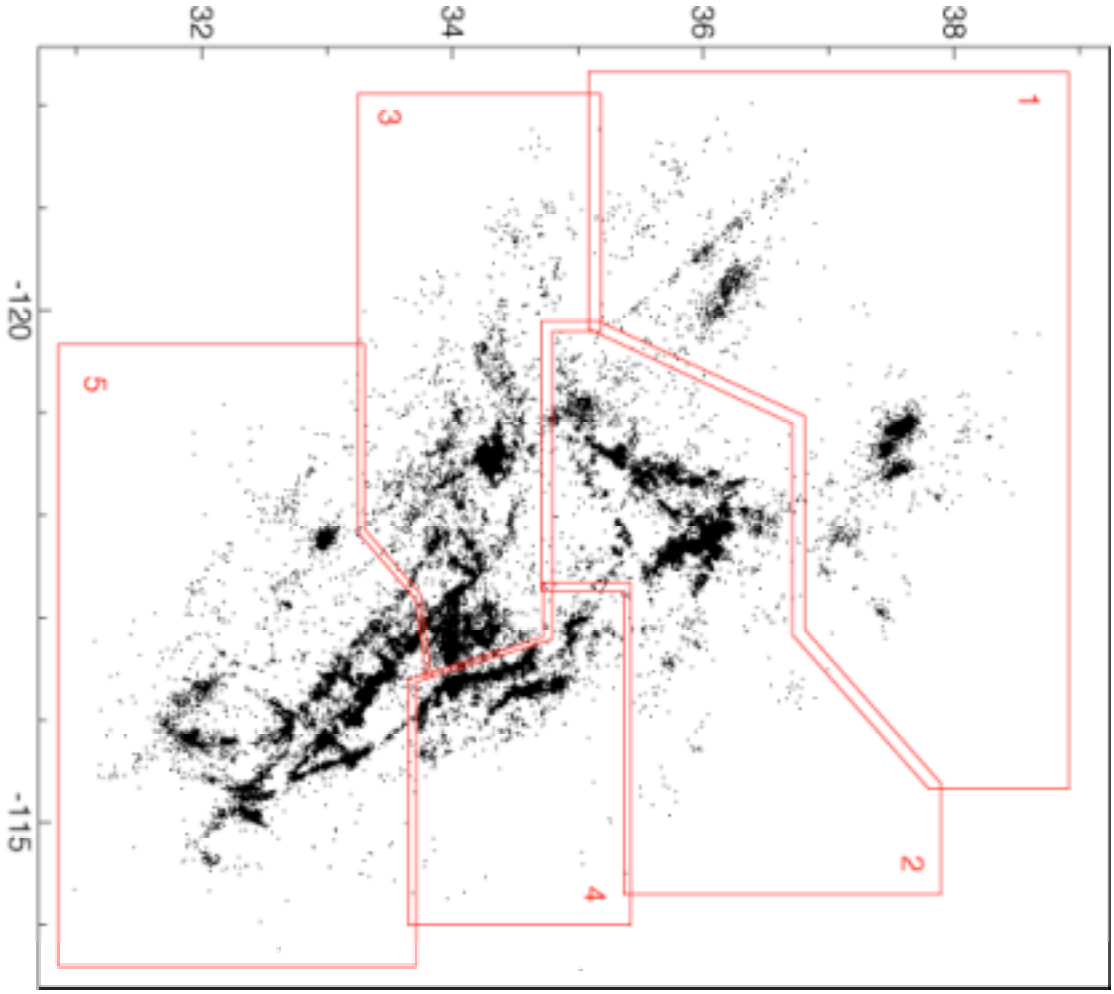

Figure 1. Southern California seismicity, showing the boundaries of the 5 polygons used to divide the events into subsets of 100,000 or fewer events.

The traces were then re-sampled to a uniform 100 Hz sample rate and band-pass filtered to between 1 and 10 Hz. Next, we computed time domain waveform cross-correlation times for P and S waves between each event and 100 neighboring events (identified from the catalog based on Hauksson's 3-D velocity model). The algorithm identified and saved differential times from the peaks in the cross-correlation functions and used a spline interpolation method to achieve a nominal timing precision of 0.001 s.

Next, we relocated the events using the cluster analysis approach of Shearer (2003). This method obtains precise relative locations for the earthquakes by applying the source-specific station term (SSST) method to existing P and S phase picks and a differential location method to about ~150,000 events within similar event clusters identified using waveform cross-correlation. The entire catalog was first relocated using existing phase picks and the SSST method of Richards-Dinger and Shearer (2000). Next, we applied cluster analysis to the waveform cross-correlation output in order to identify similar event clusters. Because

cross-correlation results are obtained for only some of all possible event pairs, some modifications to standard cluster analysis algorithms were necessary to achieve a suitable method. Earthquakes were then relocated within each similar event cluster using the differential times alone, keeping the cluster centroid fixed to its initial SSST location.

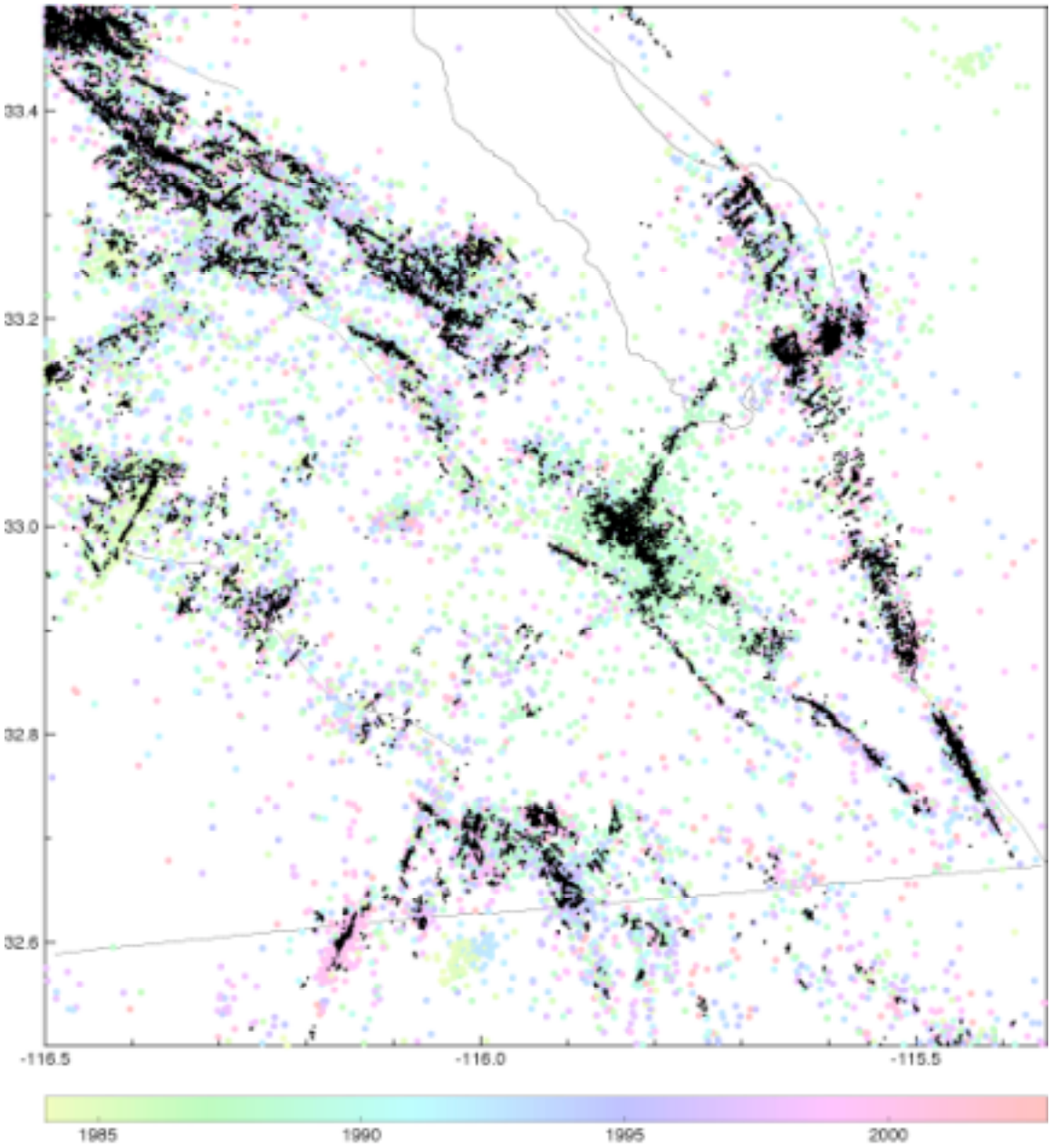

Figure 2. Relocated seismicity in southeastern California. The SSST locations are colored by year of occurrence. Similar event clusters relocated using waveform cross-correlation are shown in black. Note the cross-cutting faults in the Brawley Seismic Zone in the upper right of the plot. The Salton Sea and US/Mexico border are also shown.

Results for the Imperial Valley and surrounding areas to the west are shown in Figure 2. Note the many faults resolved at fine scales. Standard errors are obtained 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. There are a surprising number of conjugate faults at small scales that strike nearly perpendicular to the main seismicity trends. For example, note the many parallel faults in the Brawley Seismic Zone (along eastern edge of the Salton Sea). In general, the fine-scale details of the seismicity reveal a great deal of structural complexity in southern California fault systems.

These relocated event catalogs are still preliminary but are planned to be released to the seismology community by the end of the year. Future work will concentrate on comparisons between the methods and detailed assessments of location accuracy and strategies for further improvements. A long term goal is to integrate an improved location method into routine network processing.

References

Richards-Dinger, K.B. and P.M. Shearer, Earthquake locations in southern California obtained using source-specific station terms, *J. Geophys Res.*, **105**, 10,939-10,960, 2000.

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Non-technical Summary

Clusters of similar earthquakes provide a valuable tool for improving earthquake location accuracy and for probing the fine-scale structure of faults and seismic sources. We perform analyses of similar event clusters throughout southern California and use them to map the locations and structural details of subsurface faults and constrain the direction of stresses in the crust.

Reports Published

Shearer, P.M., Analysis of similar event clusters in aftershocks of the 1994 Northridge, California, earthquake, *J. Geophys. Res.*, 108, B8, 2035, doi:10.1029/2001JB000685, 2003.