2004 SCEC Annual Report: A comparative Study of Results from Different Earthquake Location Procedures in California - Waldhauser, Columbia U.

Background

Under the current SCEC contract for fiscal year 2004 we have started the process of comparing results from different efforts on improving earthquake locations in California. These efforts are carried out in Southern California by Peter Shearer (Scripps) and Egill Hauksson (Caltech), and in Northern California by Waldhauser and Schaff (Lamont). In our own effort to relocate 225,000 local earthquakes in northern California using data recorded at the Northern California Seismic Network (NCSN), we completed the first step in a ongoing USGS funded relocation project. We computed a total of about 3 billion accurate P- and S-wave differential times by means of waveform cross correlation (Schaff et al., 2004), that are on the order of a factor of ten to a hundred times more accurate than those obtained from routinely picked phase onsets (Schaff and Waldhauser, 2004a,b). The cross correlation measurements indicate that approximately 90% of the seismicity in Northern California includes events that have cross-correlation coefficients of CC > 0.7, with at least one other event recorded at four or more stations (Figure 1). At some stations more than 40% of the recorded events are similar at the CC > 0.9 level. Large numbers of correlated events occur in different tectonic regions, including the San Andreas Fault, Long Valley Caldera, Geysers geothermal field and Mendocino triple junction Figure 1). We are in the process to carry out step two, which is to use the differential time data to improve event locations in Northern California by the double-difference method of Waldhauser and Ellsworth (2000), using an improved version of hypoDD (Waldhauser, 2001).

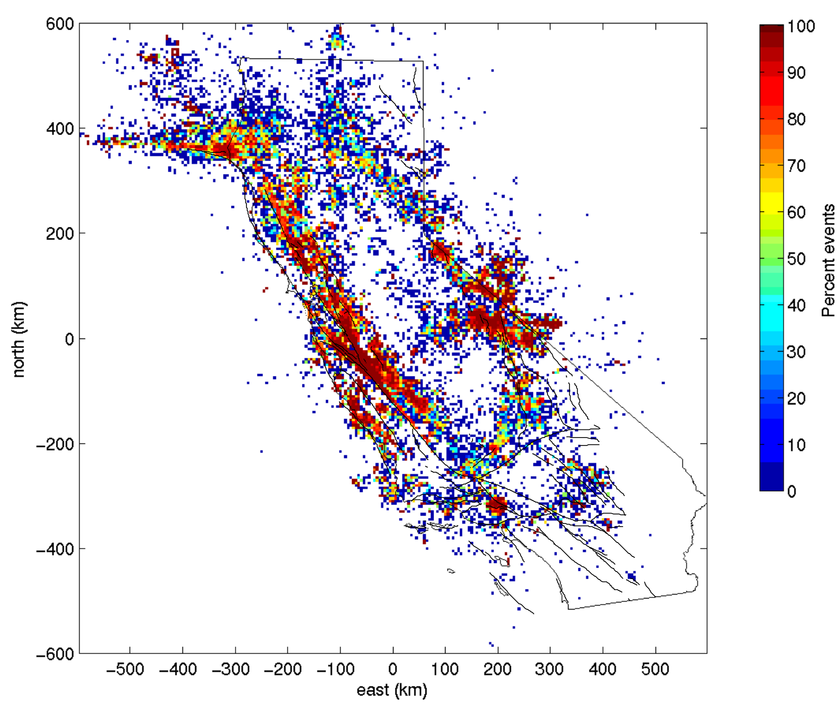

Figure 1 Percentage of correlated events recorded at the NCSN that have cross-correlation coefficients of CC > 0.7 with at least one other event recorded at four or more stations. Percentages are computed from the total number of events within bins of 5x5 km. From Schaff and Waldhauser (2004a,b).

Similar efforts of large scale waveform based event relocation were recently completed in Southern California by Hauksson and Shearer (Hauksson and Shearer, 2003; Shearer et al., 2003; Hauksson and Shearer, 2004; Shearer et al, 2004), using data recorded at the Southern California Seismic Network (SCSN). The methods they employed differ from the ones applied by us in northern California. In particular, Shearer/Hauksson use a different algorithm to compute differential times. They also use both the SSST (Richards-Dinger and Shearer, 2000) and the double-difference method (Waldhauser and Ellsworth, 2000) for relocating the events.

To capitalize on the various efforts of improving event locations on a large scale in California we have started to compare performance and results of the different techniques, in collaboration with Shearer and Hauksson. The ultimate goal is to obtain a more precise and consistent image of the seismicity in California within and across seismic networks, consistent with the SCEC priorities. In what follows is a description of work performed and results obtained under the 2004 SCEC contract.

Work Performed and Results Obtained

We developed the necessary tools to efficiently access the approximately 3 billion measurements in the differential travel time data base of Northern California. This new data base is described in Schaff and Waldhauser (2004b), and summarized in Figure 1. The new tools allow extraction of data based on various selection criteria, in order to compare them with the differential travel times measured at the SCSN by Peter Shearer (Shearer et al., 2004; Shearer, pers. comm.).

General differences between the two differential time data bases, and differences in the methods by which they were derived, are described to some extent in the 2005 SCEC proposal. Here we report on two special studies that involved the analysis of a subset of each data base.

We have analyzed and compared Shearer's differential travel times with our measurements for events in an area where both the NCSN and SCSN network overlap. We have mined the two earthquake catalogs (NCSN and SCSN) in the selected area for common events using an event association criteria based on time and of occurrence and location. A set of 966 events (red dots, Figure 2a) that are common in both catalogs have been chosen for comparison. While the differential times at the SCSN are computed for the 100 nearest neighbors based on Delaunay tessellation, our measurements at the NCSN include all event pairs separated by less than 5 km, at all stations that recorded the pair. For the 966 events, 129,024 dtimes were measured at 500 NCSN stations (blue triangles) (Schaff and Waldhauser). 51,659 dtimes were measured at 65 SCSN stations (green triangles) (Shearer and Hauksson) (Figure 2a). 17 stations (black triangles; Figure 2b) are common in both networks, and recorded the 966 events.

Since the NCSN and the SCSN catalog list different event origin times relative to which the differential travel times were determined, the SCSN times were corrected so that they are relative to the NCSN origin times. Differences in P-wave differential times and cross correlation coefficients for 5655 matching event pairs observed at the 17 common stations are shown in Figure 3. While the general shape of the distribution looks reasonable (Figure 3a,b), the standard deviation of ~100 msec is much higher than expected. We are in the process of investigating the cause for this discrepancy. One reason may be a glitch in removing the differences in the origin time. Cross correlation coefficients (Figure 3c) tend to be higher for measurements at NCSN stations, compared to those at SCSN stations. This is likely due to the different window lengths used by the two groups. Even though both 1 and 2 sec windows were computed for the NCSN data, only cross correlations over 1 sec window lengths are analyzed here. We typically use the 1 sec window length data for relocation purposes. Shearer computes the cross correlation function for window lengths of 2 sec around the P-wave train.

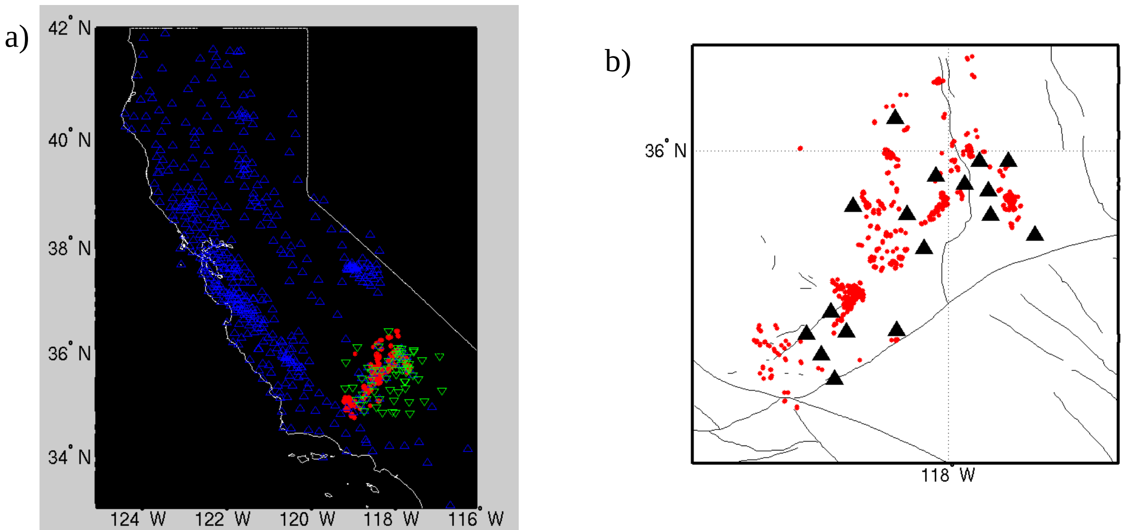

Figure 2 A total of 966 common events (red dots) recorded at the NCSN and the SCSN network. a) Blue triangles indicate NCSN stations, green triangles SCSN stations at which diff. times were measured. b) Black triangles indicate common stations at which diff. times were measured by both Shearer and Schaff, allowing direct comparison.

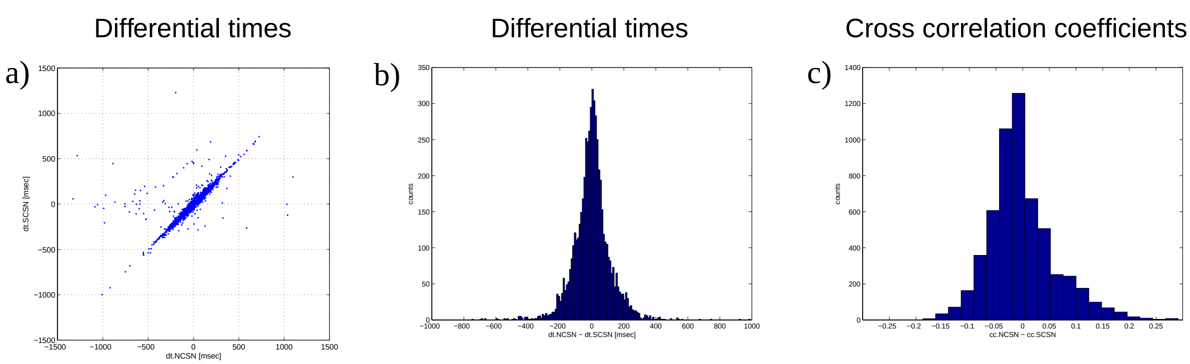

Figure 3 Distribution of differences between differential times (a, b) and cross correlation coefficients (c) measured at the SCSN and the NCSN, for events shown in Figure 2.

To investigate differences in differential travel times in a more straightforward way we made use of a data set that Shearer computed from NCSN data for events in Mendocino, northern California, using the same methods he used for the SCSN data. As can be seen from Figure 4, the distribution of the differences between the two data sets have very long tails that go out to almost 1500 msec. Note that Shearer searches over +/- 1.5 sec lags, while we use +/- 1 sec lags. The tails are most likely caused by glitches during the cross correlation process such as cycle skipping or correlation of noise. However, most differences are smaller than 10 msec, which is still 10 times larger than the estimated measurement precision for the optimal case, but by an order of magnitude better than the results shown in Figure 3. Further research is needed to understand the origin of these discrepancies. The distribution of differences in cross correlation coefficients shows again a bias towards higher correlation coefficients for measurements performed by us, the reason of which is as noted above likely due to the shorter correlation window used in our approach.

Finally, we have participated at the SCEC 2004 annual meeting in Palm Springs (Schaff and Waldhauser, 2004a). A paper has been submitted to BSSA that describes methods and results of our work on cross-correlation based differential time measurements across Northern California (Schaff and Waldhauser, 2004b). This paper will be a necessary reference for all future work regarding comparison of techniques in Southern and Northern California.

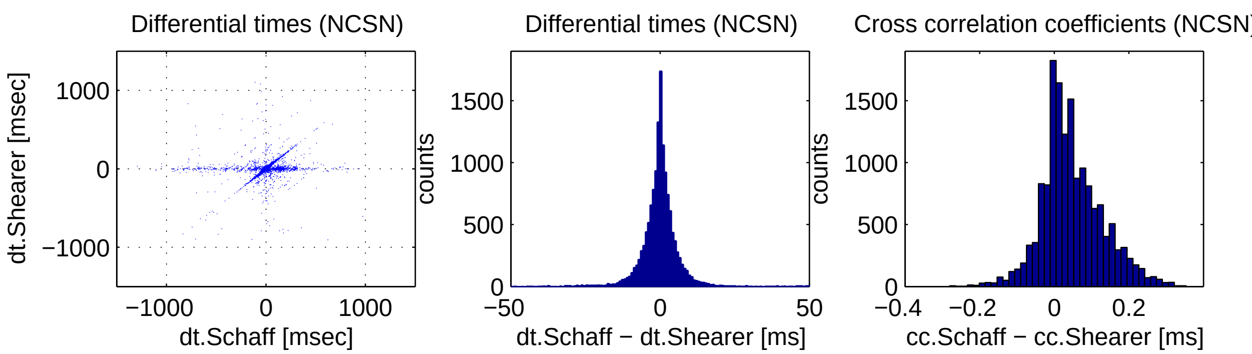

Figure 4 Distribution of differences between differential times (a, b) and cross correlation coefficients (c) measured at the NCSN by the methods of Schaff et al (Lamont) and Shearer et al. (Scripps).

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