Seismotectonics and the state of stress in the North American lithosphere: Analysis of small, unusual earthquakes

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The determination of earthquake source parameters provides critical information for regional and global tectonic studies, geodetic studies, and hazard analysis, as well as for numerous types of seismological investigations. In addition to earthquake hypocenters and times, many such studies require information about the geometry of faulting in a given earthquake. Centroid-moment tensor (CMT) analysis (Dziewonski et al., 1981; Dziewonski and Woodhouse, 1983) has proven to be an effective approach for the determination of seismic moment tensors, and the Harvard CMT catalog now includes source parameters for ∼18,000 earthquakes spanning nearly 26 years (1976–2001). The catalog is believed to be complete for earthquakes of $M_W \geq 5.5$. The CMT catalog thus provides a good description of the seismicity of most tectonically active regions, and it is used frequently for studies of all of the types mentioned above.

In tectonically stable regions, or in regions of low seismicity, earthquakes of sufficient magnitude for CMT analysis are rare. Smaller earthquakes like those shown in Figure 1, with magnitudes $4.0 \leq M_W \leq 5.5$, are thus of special interest in these regions, as they provide some of the only information available about local seismotectonics and the state of stress in the crust and lithosphere. It is also important to understand these earthquakes for the estimation of seismic hazards. While some earthquakes as small as $M_W = 4.9$ can, under favorable conditions, be analyzed in the standard CMT manner, most smaller earthquakes cannot be studied in this way. The parts of the seismogram used for CMT analysis and other similar studies — primarily the long-period body waves — are simply too noisy. Unlike in well-instrumented regions such as the western United States, however, too few recordings are typically available for other, non-CMT methods to be used.

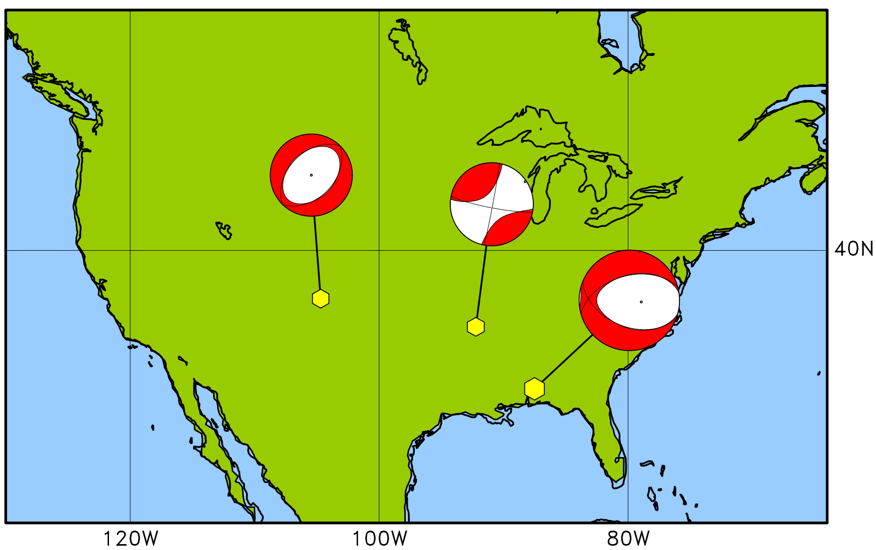

Figure 1: Hybrid CMT solutions for three small earthquakes analyzed in near-real time. Left to right: the $M_W = 4.4$ Colorado earthquake of Sept. 5, 2001; the $M_W = 4.4$ Arkansas earthquake of May 4, 2001; and the $M_W = 4.9$ Alabama earthquake of Oct. 24, 1997.

For these smaller earthquakes, the largest signal in the seismogram is often the first-arriving surface wave. These arrivals are strongly affected by lateral variations in the Earth's seismic velocity structure, and they have thus been difficult to use for routine moment-tensor analysis. Progress in the mapping of surface-wave phase velocities at intermediate periods (T ∼40–150 s) has, however, recently made it possible to begin using these surface waves for source parameter determination. Arvidsson and Ekström (1998) and Ekström (2000) have developed a hybrid method for the modeling of the surface-wave portion of the seismogram. The method combines the normal-mode approach of the standard CMT with a ray-theoretical description of surface-wave propagation. The phase-velocity maps of Ekström et al. (1997) are used to account for phase advances and delays suffered during surface-wave propagation from the source to the receiver.

The improvement in signal-to-noise ratios achieved by using the intermediate-period surface waves for CMT analysis allows us to analyze, in a routine fashion, earthquakes of $M_W \geq 4.0$. The hybrid approach to the determination of source parameters for smaller earthquakes has been tested in several regions, including Greece (Arvidsson and Ekström, 1998), Iceland (Nettles and Ekström, 1998; Allen et al., 2001), and the Mediterranean (e.g., Ekström et al., 1998; see also `http://mednet.ingrm.it/events/QRCMT/Welcome.html`). During the past few years, several moment tensors have also been determined for small earthquakes occurring in the central and eastern United States (Figure 1). Though these earthquakes are relatively infrequent, they occur often enough that a 10-year deployment of closely spaced seismometers, like that proposed for Earthscope, would record a significant number of such events, as shown in Figure 2.

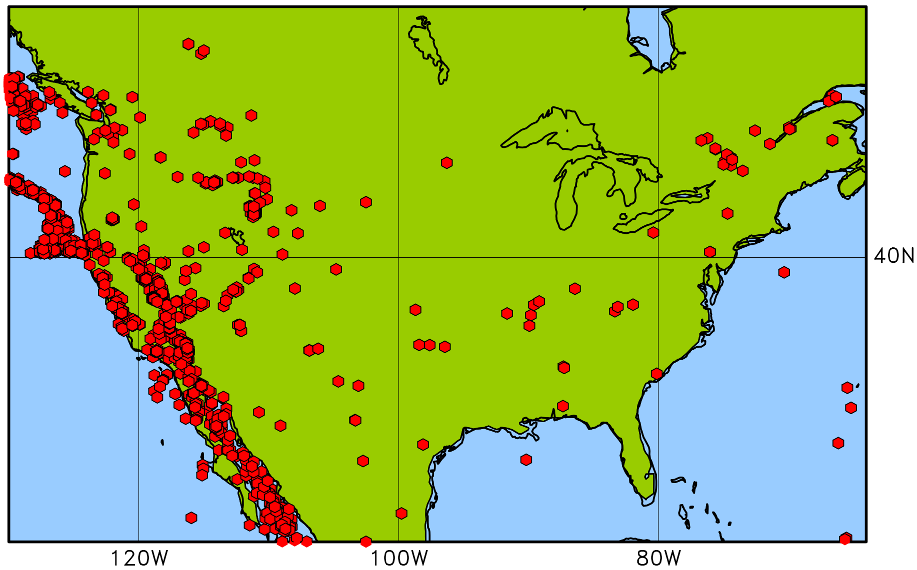

Figure 2: Map showing all earthquakes of $M_W \geq 4.0$ occurring within the United States during the 10-year period from 1990-1999, as reported by the NEIC. Similar levels of seismicity can be expected during the 10-year deployment of the USArray.

Currently, the ability to analyze earthquakes like the three shown in Figure 1 depends primarily on data availability. With current station coverage, it is rare that more than 10 stations are close enough to the earthquake epicenter to provide useful recordings of the event (typically $\Delta \leq 20 - 30°$). The deployment of USArray would make it possible to analyze earthquakes of $M_W \geq 4.0$ anywhere within the United States, as good data coverage would be assured. Based on experiments in which PASSCAL-type broadband data were used to determine earthquake source parameters by the hybrid-CMT approach (Allen et al., 2001), it appears that even the temporary stations of USArray could be used for hybrid-CMT moment-tensor determination. We note also that the moment-tensor analysis discussed here could be conducted in near-real time, given reliable telemetry of data from USArray stations. The CMT solutions shown in Figure 1 were all determined within a few hours of the earthquakes' occurrence, as are standard Quick CMTs. While the intensity of current-day earthquake monitoring in the western United States would not be matched nationwide by the Earthscope/USArray deployment, the imbalance in our understanding of deformation processes in different parts of North America would be reduced substantially by the recording and analysis of small, unusual earthquakes.

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