6 Detecting the 2011 M9.0 Tohoku Earthquake with Moment Tensors

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6.1 Introduction

The M9 Tohoku earthquake offshore Japan that occurred on May 11, 2011 triggered strong local and regional shaking as well as a large-scale tsunami that caused major damage in both the near- and far-field. The Japanese earthquake and tsunami warning systems were able to detect and locate the earthquake; however information regarding the focal mechanism of the event was unknown until the moment tensor from the W-phase was published about 20 minutes after the event. Because of the dense Japanese seismic network of strong-motion stations (K-NET), this event gives us the opportunity to test the approach proposed by Guilhem and Dreger (2011) to rapidly detect, locate, and obtain the moment magnitude and mechanism of megathrust earthquakes.

6.2 Method

We use the method proposed by Guilhem and Dreger (2011) to automatically compute moment tensors on a grid of virtual sources distributed every 0.25 in latitude and longitude and at the slab depth, following a streaming data procedure. Here, the grid is defined by 357 nodes and overlaps the rupture of the M9 Tohoku earthquake (Figure 2.12). Moment tensors are computed every second, and the detection of the earthquake and its source information (location, seismic moment, mechanism, origin time) is obtained once the variance reduction (VR), which measures the fit between the data and the synthetics, reaches a maximum value and is above a threshold value (65%, for example). Velocity Green’s functions (GFs) for each virtual source, and corresponding slab depths are pre-calculated using a 1D velocity model used by Tsuruoka et al. (2009) for the GridMT technique used in Japan. Because we target a large-scale earthquake, we include a source time duration in the GFs of 150 seconds.

6.3 Data

We download the strong-motion records of the M9 earthquake from the K-NET database, corresponding to a dataset of three-component acceleration seismograms for 273 stations. We select a set of 12 stations distributed along the earthquake rupture that recorded 300 seconds of data at 100 samples per second. We first correct the data for the instrumental gain and decimate them to 1 sample per second. Because the proposed method of Guilhem and Dreger (2011) for the rapid detection of M>7 earthquakes uses very long-period (100-200 second) data and inverts 8 minutes of records, we extend the strong-motion records by adding zeros to generate seismograms of 30 minutes in length; then we integrate them to velocity and use a causal bandpass filter with corner frequencies of 0.005 and 0.01 sec.

Figure 2.12: Map of the best moment tensor solutions using a set of strong motion stations distributed along the rupture. The star shows the JMA location, the black beach ball diagram shows the Global CMT USGS solution and the colored mechanism corresponds to the best solution using the grid. (See color version of this figure on the front cover.)

We use sets of four strong-motion stations per calculation, and we test the sensitivity of the moment tensor analysis for different limited station coverages (Figure 2.12).

6.4 Results

Figure 2.12 shows that the long period single point-source GFs used in the moment tensor approach allow the detection and characterization of the megathrust event with a high level of confidence (i.e. >70%) even if the station coverage is limited. The best solutions are cen-
tered within the rupture segment, and our best solutions (i.e. with the largest VRs) are in close proximity to the USGS CMT solution (black mechanism in Figure 2.12) and to the JMA epicenter (red star). The origin time, the moment magnitude, and the mechanism that we find are in agreement with other datasets (USGS CMT, USGS W-phase, Global CMT). This shows that this analysis that uses a 100-200 sec passband does not suffer from saturation, which is a common problem observed for such large earthquakes, and was observed again for the M9 Tohoku earthquake. Also, the higher variance reduction estimates do appear to define the limits of the main slip area.

Finally, we find similar results when using restricted data coverage; i.e. when we use stations that are only located in the northern part of the rupture and inversely with stations located to the south of it (Figure 2.13). However, as Figure 2.13 shows, having stations located along the entire rupture enables us to better define the area of slip with the best VRs for the earthquake.

6.5 Conclusion

These results are very promising for the rapid detection and characterization of the major M9 Tohoku earthquake and other large magnitude subduction zone earthquakes. The 100-200 sec period strong-motion data do not saturate, and, as a consequence, the seismic moment and mechanism can be obtained within 8 minutes of the origin time. Because the M9 Tohoku earthquake had a compact slip region over a relatively small rupture length for similar sized earthquakes, the single point-source GFs work well. However, for more elongated slip models with multiple large slip areas, the use of quasi-finite-source GFs might provide better constraints on the events, as demonstrated by Guilhem and Dreger (2011).

6.6 Acknowledgements

Strong motion data for the 2011 M9.1 Japan earthquake are from the K-NET, National Research Institute for Earth Science and Disaster Prevention (NIED).

6.7 References


Figure 2.13: Map of the best moment tensor solutions using a set of strong motion stations distributed along the rupture.