21 Rapid Detection of Large Earthquakes Using Quasi-Finite-Source Green’s Functions in Moment Tensor Analysis

Aurelie Guilhem and Douglas S. Dreger

21.1 Introduction

Rapid procedures (i.e. within 5 to 15 minutes) for earthquake and tsunami early warnings focus on earthquake location, depth, magnitude, and slowness, but initial tsunami early warnings are more often issued without knowing the mechanism of the earthquake. Kawakatsu (1998) proposed using a limited number of stations to automatically detect, locate and determine the source parameters of earthquakes occurring within a predefined region by computing moment tensors at each point of a grid from continuously streaming long-period waveform data. This method gives correct results in terms of detection and source characterization of up to M7 earthquakes offshore Japan (Tsuruoka et al., 2009). For major earthquakes (M8+), we propose to improve the point-source moment tensor inversion by using QFS Green’s functions (QFS GFs) that takes into account the finiteness of the rupture zone. Using a direct and single-step procedure, it becomes possible to monitor all Mw>3.5 earthquakes.

21.2 Method

Kawakatsu (1998) proposed to continuously invert the long period seismic wavefield (> 10 sec) for moment tensors at grid points representing virtual sources distributed over a region. At each station, the data \( d \) are represented as the convolution of the GF tensor, \( G \), describing the wave propagation between the source and the receiver, and the moment tensor components \( m \) of the source:

\[
d = G \cdot m
\]

The least-square solution for the moment tensor can be obtained:

\[
M = (G^T G)^{-1} G^T d
\]

where the \((G^T G)^{-1} G^T\) matrix for each point-source can be computed in advance. The multiplication of this matrix with streaming data can be performed continuously. Earthquake detection is given when the variance reduction (VR), or fit between the data and the synthetics, exceeds a detection threshold.

We set up a moment tensor grid search for the Mendocino Triple Junction (MTJ) using four BDSN stations and virtual sources located every 0.2° in latitude and longitude and every 3 km in depth (Figure 2.43). We propose to run in parallel a system for small to moderate earthquakes (inversion of 380 seconds of 20-50 second period data) and a second one for large (M8+) earthquakes along the CSZ (inversion of 480 seconds of 100-200 second period data). For large earthquakes, we also include an 84-second source time function in the GFs corresponding to the tested synthetic M 8.2 earthquake (Figure 2.44).

Because for large subduction zone earthquakes the problem grows into a near-field problem, we propose to employ quasi-finite-source adjusted GFs where GFs of \( n \) grid points are averaged in advance to generate composite GFs, \( G_{tot} \), which take into account the source-receiver back-azimuth and by consequence the radiation patterns of each component (Figure 2.44):  

\[
G_{tot}(t) = \frac{\sum_{i=1}^{n} G_i(t)}{n}
\]

Directivity can also be pre-included in the composite GFs, giving constraints on the nature of finite rupture (i.e. unilateral or bilateral) (Figure 2):

\[
G_{tot} = \left[ G_1(t) + \sum_{i=2}^{n} G_i(t) \cdot \left( \frac{\Delta_{i-1} - \Delta_{i-n}}{v_r} \right) \right] \frac{1}{n}
\]

where \( \Delta_{i-n} \) is the distance between Source 1 (reference source) and Source \( n \), and \( v_r \) is the rupture velocity. The
moment tensor inversion itself is performed assuming a point-source analysis method, which maintains the computational speed.

21.3 Detection of large and potentially tsunamigenic earthquakes along the Cascadia Subduction Zone

We tested the concept on M4 to M7.1 earthquakes (Figure 2.43). The solutions obtained using a 1D velocity model (i.e. Gil7) agree well with the Berkeley moment tensor catalog solutions, confirming that this system is suitable for implementation in the MTJ region. However, because of the narrow band processing (0.02-0.05 Hz), the point-source inversion for a large M8.2 earthquake only fits a small part of the record. As a consequence, it does not recover the earthquake parameters. But we find that the 100-200 second passband gives a point-source location near the fault centroid, and the correct $M_w$ and focal mechanism (VR= 54.6% in Figure 2.44). It is possible to improve the fit between the synthetics and the data (Figure 2.44c) after simultaneously summing the GFs of several grid points centered on the event centroid. Figure 2.44d shows that, by considering a northward rupture in the composite GFs and a rupture velocity of 3 km/sec, the corresponding earthquake solution has a larger VR and better estimates the focal parameters. Similar results are obtained for a M 8.4 synthetic seismic event, which presents an extended rupture (i.e. 480 km) and two major slip areas (Guilhem and Dreger, 2011). This method permits raising the detection level of large earthquakes and allows us to obtain more precise source parameters, by considering a range of QFS GFs for different directivity scenarios and source time durations.

21.4 Conclusion

We show that it is possible to rapidly detect and characterize the seismic activity of the MTJ region using an algorithm that performs moment tensor inversions. The QFS GFs allow more rapid detection of major events and more precise determination of their source parameters than is likely to be available using standard processing systems. Complete earthquake information is retrieved about 6 minutes after a M 4-7 earthquake and 8 minutes after a M 8+ earthquake and may allow for tens of minutes of warning in the near field.

21.5 Acknowledgements

Supported by the U.S. Geological Survey through external award G10AP00069.

21.6 References

