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Development of an epicenter estimation method using 3D polarity and its application to dynamic triggering events

Takahiko Uchide[1*]

[1]Disaster Prevention Research Institute, Kyoto University

Recently based on the development of seismic observations and computational resources, many methods to locate earthquakes with unclear P and S onset, such as low-frequency earthquakes and dynamic triggering earthquakes, have been proposed [e.g., Obara, 2002; Kao et al., 2005; Shelly et al., 2007].

Here I show a new method to estimate epicenters using the polarities of seismograms. The basic idea is as follows: First, we detect rectilinear signal from seismograms; then assuming such rectilinear waveforms are P waves and the polarization direction is same as the back azimuth, we estimate epicenters directed by multiple stations. This kind of strategy is often used to confirm hypocenter determinations with few stations. This study carries out this procedure automatically. The test field of this study is Hida region, Central Japan. The goal of this paper is so far to detect more events dynamically triggered by the 2011 Tohoku earthquake than those detected by manual process [Miyazawa, 2011].

I apply a polarization analysis method using analytic signal (its real and imaginary parts are an original signal and its Hilbert transform, respectively) of both horizontal and vertical components [Vidale, 1986]. We construct a variance-covariance matrix $\boldsymbol{C}(t)$ of the analytic signal at each time. Its eigenvector corresponding to the largest eigenvalue represents the polarization direction. The use of the moving average of data will stabilize the analysis. The strength of the polarization is represented by $P_s = 1 - (a_2 + a_3)/a_1$, where $a_1 > a_2 > a_3$ are the eigenvalues of $\boldsymbol{C}(t)$. If the polarization direct is downward, we change it to an upward one by changing the sign of dip angle and taking 180 degrees opposite of the azimuth.

In a realistic case, the polarization direction and back azimuth are not exactly same, because (1) the horizontal heterogeneity of seismic velocity structure and (2) the misorientation of seismometers. Those directions also differs, when (3) other phases such as S waves are analyzed. In case of (3), it is less probable that multiple stations indicate the same point. To check the effect of (1) and (2) quantitatively, I calculate the differences between the back azimuth and the polarization direction of seismograms for 0.5 s from P arrivals, from the phase information in the JMA unified earthquake catalog, from earthquakes in Hida region. At most of stations, the average and the standard deviation of them are within 5 degrees and 5 to 10 degrees, respectively, though at some stations the average is much larger, probably due to the misorientation of seismometers.

Based on the time history of the polarities, epicenters are searched by a grid-search manner, taking account of (a) travel time of P waves from a grid to stations, (b) difference between the polarization direction and azimuths from stations to a grid, and (c) the strength of the polarity P_s. I construct an evaluation function to search for an epicenter location and origin time.

This method is applied to single M2-class earthquakes in the Hida region using velocity seismograms from Hi-net and DPRI seismic network. The data is high-pass filtered at 4 Hz. The epicenters determined by my method are close to those of JMA unified catalog. When I analyze an earthquake outside of the network, ghost errors are seen.

Finally I apply this method to seismic data in the Hida region during seismic waves from the 2011 Tohoku earthquake are passing. The velocity seismograms are high-pass filtered at 4 Hz. Many events are detected. Some of them correspond to events detected by Miyazawa [2011], but some of them are not in his catalog.

This study will improve the catalog of dynamic triggering earthquakes and promotes the dynamic triggering studies. Moreover this method will contribute to other type of seismological studies, such as automatic data processing and structure studies.

Keywords: Epicenter determination method, 3D polarity of motion, Hida, Dynamic triggering of earthquakes, the 2011 Tohoku earthquake