Development of a waveform inversion method in the frequency domain to estimate earthquake source mechanism

Masaru Nakano[1]; Hiroyuki Kumagai[1]; Tadashi Yamashina[1]; Koji Miyakawa[1]; Hiroshi Inoue[1]

[1] NIED

We develop a method to estimate source location, focal mechanism, and source-time function based on a waveform inversion carried out in the frequency domain.

In the waveform inversion, the source mechanism is estimated by solving the normal equation d=Gm, where d is the vector representing the observed data and m is the vector representing the parameters for a source mechanism and source-time function. G is the matrix representing the Green functions, of which the size is (number of data)x(number of parameters). If we solve the equation in the time domain, the size of G is (Nt Ns)x(Nm Np), where Nt, Ns, Nm, and Np are the number of data traces, the number of samples in each trace, the number of source-mechanism components, and the number of parameters to represent temporal variations of the source-time function. If we solve the equation in the frequency domain, on the other hand, the normal equation can be solved for each frequency separately. In this case, the size of G becomes as small as (Nt)x(Nm). Solving the small matrices Nf times is much faster than solving the single large matrix in the time domain, in which Nf is the number of frequency components used for the inversion. In this approach, there is no need to care about elementary source-time functions. Accordingly, this method can be applied even for tsunami earthquakes without a priori information about source-time function.

In the inversion method described above, the frequency components of the estimated source-time function mf(t) are limited to those used for the solution of the inversion. Therefore, the frequency components not included in the inversion or the observations, as a DC component of a ramp-function like source-time function, can't be recovered. We develop a method to recover the original source-time function as follows. First, we assume the original source-time function m(t) is represented by a convolution of an elementary function s(t) (e.g. a ramp function) with a function a(t) ($m(t)=a(t)*s(t)$). Second, we apply the filter used for the inversion to s(t), and we represent the filtered function as sf(t). Then, we estimate a(t) by fitting $a(t)*sf(t)$ to mf(t), in which we apply the non-negative constraint on a(t) because m(t) represents a fault slip, and obtain m(t).

We apply the method to observed waveform data from JISNET. The analysis relies on seismograms obtained from a few stations since JISNET station distribution is not dense. In this analysis, we assume slip on a fault represented by a pure double couple as the source mechanism. Grid searches with respect to strike, dip, and rake angles are performed to estimate fault orientation. We also carried out a spatial grid search to find the best fit source location. This approach is an extension of the method proposed by Nakano and Kumagai (2005; GRL) for source mechanism analysis of volcano-seismic signals. Examples of the applications are given below.

The event on July 17, 2006 (South of Java; Mw 7.8): This earthquake is characterized by a long rupture duration over 100 s, which implies a tsunami earthquake (e.g. Ammon et al., 2006: GRL). We investigate this earthquake by using observed waveforms bandpassed between 50 and 200 s. The centroid is located at 9.8S, 107.4E and a depth of 10 km. A reverse-type fault mechanism with moment magnitude (Mw) of 7.5 is estimated. We obtain the rupture duration of about 120 s. These results are consistent with the results by Ammon et al. (2006), USGS, and Harvard CMT.

The event on January 21, 2007 (Northeast of Sulawesi; Mw 7.5): We investigate this earthquake by using the period band between 50-100 s. The source is located at 1.0N, 126.2E and a depth of 25 km. We obtain the magnitude of Mw 7.5, reverse-type fault mechanism, and rupture duration of about 15 s. The source location and focal mechanism are consistent with the results by USGS and Harvard CMT. The obtained rupture duration is consistent with the typical value of this size of earthquakes.