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Multiscale Slip Inversion Analysis of the 2004 Mid-Niigata Prefecture, Central Japan, Earthquake

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It is one of the most fundamental, important, and interesting problems in earthquake seismology to understand the initiation of seismic rupture, which is essential to answer several principal physical questions. How different are large earthquakes from small ones? Does a small rupture grow up accidentally to a large earthquake? Is there a self-similarity in a rupture growth?

A slip inversion method is useful for analyzing the spatio-temporal feature of source process, and many authors have analyzed whole rupture process. Shibazaki et al. [2002] investigated the first 0.7 s of the source process of the 1995 Hyogo-Ken Nanbu earthquake. A main and an initial rupture processes are analyzed independently, and the consistency between them is not guaranteed.

We have developed multiscale slip inversion method [Uchide and Ide, Japan Earth and Planetary Science Joint Meeting, 2005] to analyze a main and an initial rupture processes simultaneously using a multiscale fault model [Aochi and Ide, 2004], which is composed by several monoscale source models, on which slip rate distributions are connected by renormalization.

We applied this method for the 2004 Mid-Niigata Prefecture earthquake (Mw6.6) using data of dense high-sensitivity and strong-motion seismic networks, such as the seismic network of JMA, and Hi-net and KiK-net provided by NIED. Combining these two kinds of networks enables us to analyze seismograms in wide dynamic range.

An analysis on a large scale employs theoretical Green's functions for layered structures based on the double-difference tomography analysis [Kato et al., 2005] calculated by the discrete wavenumber integral method [Bouchon, 1981] using the reflection and transmission matrices [Kennett and Kerry, 1979]. Anelastic attenuation is introduced by the use of complex velocities [Takeo, 1985]. Since a detailed analysis requires fine Green's functions, an analysis on a small scale employs empirical Green's functions (EGF) [Hartzell, 1978]. We selected two EGF events, EGF1 (Mw2.3) and EGF2 (Mw3.3) [Uchide and Ide, SSJ Fall Meeting, 2005].

A multiscale source model for this study is composed by three monoscale source model on different scales. The theoretical Green's functions are used for the largest scale (Scale 3), and EGF1 and EGF2 are utilized for the smallest (Scale 1) and the middle scales (Scale 2), respectively. We constructed Bayes model by connecting a temporal smoothing constraint by Bayes' rule, and selected the value of a superparameter, which is the weight of the constraint, to minimize Akaike's Bayesian information criterion (ABIC).

The multiscale slip model provides us the detailed image of an initial rupture process successfully, while the slip models determined using an ordinary slip inversion method (monoscale slip models) on each scale independently, have large estimation errors. The renormalization produces a good consistency among estimated source processes on all scales and prevents abrupt increase observed in the monoscale analysis on a smaller scale, as expected.

The multiscale analysis suggests statistical self-similarity of the rupture growth process. The initial rupture process has heterogeneity of rupture area as observed on the eventual scale. The maximum slip rate (approximately 1.0 m/s) and the rupture velocity (2.5 - 3.0 km/s) in the initial rupture process are comparable to those of the main rupture of usual earthquakes. Four stages of the rupture growth with different rupture directivities are found:

(a) the first 0.4 s with northeastward directivity;
(b) from 0.6 s to 1.0 s with southward;
(c) until 2.0 s with northeastward again;
(d) after 2.0 s with southwestward.

Stage (b) is also estimated by deconvolution analysis [Uchide and Ide, SSJ Fall Meeting, 2005]. The earlier dynamic stages are the preparation for the major rupture and my multiscale slip inversion method is useful for a careful analysis of such a rupture growth process.