S229-010 Room: 303 Time: May 19 14:30-14:45

A new approach for locating deep low frequency tremors by envelope amplitude

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Non-volcanic deep low-frequency tremors in southwest Japan occurs at a depth of 30 km on the plate boundary on the forearc side along the Philippine Sea plate with a predominant frequency of 1-10Hz (Obara, 2002). On some occasions, impulsive onset appears on the wavetrains of the tremor. The Japan Meteorological Agency (JMA) measures this onset as S wave arrivals of Low Frequency Earthquake (LFE), and determines their epicenter by normal location procedure. By referring the LFE locations, more fine-scale distribution of LFEs relocated by using cross-correlation of tremor waveforms has been discussed (Shelly et al. 2006; Maeda et al. 2006). However, it is impossible to pick every tremor arrivals because tremor waveforms are too complicated. Envelope Correlation Method (ECM) enables us to locate tremor epicenters without arrival time picks (Obara, 2002). However, Obara and Hirose (2003) reports that ECM can not determine the tremor precisely on the most active stage of tremor activity associated with the short-term slow slip event. To understand the mechanisms of tremors and related slow-slip event, it is important to determine the location and radiated energy of continuous tremors more precisely. Here, we propose a new method for estimating the location and radiated energy of tremor by using envelope amplitude of deep tremor.

We found that the tremor amplitude decays in proportion to the reciprocal of the source-receiver distance even if the phases of the tremor are very complicated. Then we model the observed mean square (MS) envelope amplitude by time-dependent energy radiation with geometrical spreading factor in proportion to the distance to the power of -2. In the model, we do not have origin time of the tremor since we assume that the source continuously radiates the energy. To incorporate the migration of tremor, we locate the source of the tremor every 1 minute. Travel-time differences between stations estimated by the ECM technique also give important information for locating the tremor. Therefore, we locate the tremor epicenter and radiated energy by minimizing weighted summation of the squared residuals of the MS amplitude and travel-time difference. ECM method is applied to root mean square (RMS) envelope. Initial source location and energy is estimated by the amplitude grid search method (Obara and Hirose, 2003). We adopted 0.1 degree grid width lateral direction for initial source estimation. The depth of initial source is fixed to 35km.

We use three-component 1-hour Hi-net velocity continuous waveform for the inversion. After applying the pass-band filter of 2-10 Hz, we make MS and RMS envelopes. For reducing computational cost, envelope traces are decimated to 10 Hz and to 1 Hz samplings for RMS and MS envelopes, respectively. The source location and energy are estimated by applying least square inversion to the 1-min window iteratively.

Location by ECM generally has low resolution since we can only use relative travel time of S waves. We expect to have more fine-scale resolution of the tremor by mixing different MS amplitude information for estimating the source location in the present method. Additionally, we can estimate the source energy of tremor in the method. Recent reports show that the reduced amplitude of the tremor obeys the exponential-type distribution (Rokosky et al., 2006; Watanabe et al., 2006). Direct estimation of tremor energy may give more accurate information on size distribution of deep tremor.