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Envelope inversion for the short-period energy radiation of the 2003 Tokachi-Oki Earthquake

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Since high-frequency seismic waves (>2Hz) are strongly scattered by small scale random inhomogeneities, it is efficient for us to use the envelope of the seismic waves for the analysis of the source process in high-frequencies. We newly developed a method to synthesize theoretical envelopes based on the forward scattering approximation including the effect of the double-coupled source radiation. Using the synthesized envelopes as Green's function, we estimate the spatial distribution of the high-frequency energy radiation of the 2003 Tokachi-Oki Earthquake and site amplification factors.
We assume a von-Karman type random inhomogeneous medium, where the power spectral density function (PSDF) of the velocity fluctuation obeys a power-law for large wavenumbers. The parameters which characterize the shape of the PSDF are the RMS value of the velocity fluctuation, ep, the correlation distance of the velocity fluctuation, and the parameter kappa which controls the power of the PSDF at large wavenumbers. When the wavelength is much shorter than the correlation distance, we can apply the parabolic approximation and the stochastic Markov approximation to the wave equation neglecting backscattering. In the wavenumber domain, we can describe spatial evolution of the angular spectral function, which represents the distribution of ray directions. The variation of the ray direction is simulated by the Monte-Carlo method, in which the effect of the non-spherical source radiation is taken into account. The amplitude of the synthesized envelope clearly shows the radiation pattern of double-coupled source mechanism just after the direct wave arrival. However, the azimuth dependence becomes obscure as the lapse time increases. The time width and the peak delay time of the S-wave envelope increases as the hypocentral distance increases especially for the case of large ep and small correlation distance. Analyzing the power of the attenuation slope of the maximum MS amplitude and the width of the observed envelopes of small earthquakes, we estimate Q_i^{-1}, ep, kappa in Hokkaido, where the correlation distance is fixed at 5 km. As a result, Q_i^{-1} is estimated to be $1.1*10^{-3}$, $1.0*10^{-3}$, and $0.8*10^{-3}$ for 2-4 Hz, 4-8 Hz, and 8-16 Hz, respectively. The parameter ep and kappa are estimated to be 0.07 and 0.9, respectively.
Using the envelopes calculated for the estimated parameters as Green's functions, we determine spatial distributions of the energy radiation of the 2003 Tokachi-Oki Earthquake and site amplification factors from 2 Hz to 16 Hz by applying an envelope inversion method. We use MS energy density envelopes recorded by 27 KiK-net borehole stations for the inversion. Assuming a constant rupture propagation from the initial rupture point, we estimate the rupture velocity to be 3.4km/s by the grid search method. The strongest energy radiation area (SERA) is located at 20-60km northwestward of the initial rupture point, which is closer to the initial rupture point compared to the epicenter determined by the peak arrival times at the used stations. This difference of the two locations reflects whether the peak delay effect is included in Green's function or not. The SERA well coincides with the large slip area estimated from the waveform inversion for frequencies less than 1 Hz, but it does not coincide with the active aftershock area. The radiated energies are estimated to be $3.0*10^{14}$J, $7.4*10^{13}$J, and $7.2*10^{12}$J for 2-4 Hz, 4-8 Hz, and 8-16 Hz, respectively. These values agree to the radiated energies calculated from the omega-

square model for a general MW 8 earthquake. The peak of the energy radiation function of 2-16 Hz appears 23s after the initial rupture, which is the same as the peak arrival time of the moment rate function estimated from waveform analysis for frequencies less than 1 Hz. The estimated site amplification factors agree to those estimated by the coda normalization method.

Keywords: short period strong motion, forward scattering approximation,
the 2003 Tokachi-Oki Earthquake, high frequency energy radiation