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Frequency-dependence of the apparent S-wave radiation pattern: FDM simulations of scattering high-frequency seismic wavefield

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The purpose of this study is to understand the influence of small-scale heterogeneity on the propagation of high-frequency seismic waves based on the analysis of dense seismic array data and finite-difference method (FDM) simulations of seismic wave. Many seismologists pointed out that high-frequency (higher than 1Hz) components of S wave don't show clear four-robe radiation pattern predicted from a double-couple source. One of the candidates to cause such frequency dependent properties of the S-wave radiation pattern is caused by the strong scattering of seismic waves due to small-scale heterogeneities in the subsurface structure [e.g. Liu and Helmberger, 1985; Satoh, 2002]. The energy fraction (E_T) can be a measure to quantify such seismic wave scattering [Takenaka et al., 2003]. The value is defined as the fraction of the transverse component energy relative to the total horizontal-components energy. Assume that an earthquake occurs in a flat-layered structure, the maximum value of E_T equals to 1, but when the earthquake occurs in heterogeneous structure, E_T decreases to approximately 0.5 due to the scattering of seismic waves to many directions. Analyzing the three-component S-wave form of the aftershock events of the 2000 Tottori-ken Seibu earthquake (Mw6.6) which occurred in western Japan, we found clear frequency dependencies in the of E_T. The value of E_T gradually drops from about 2 Hz and decreases approximately to 0.65 at high-frequency (higher than 5Hz) band [Takemura et al., 2007]. It indicates that seismic scattering is more dominant with increasing frequency above 2 Hz.

In order to demonstrate the characteristics of the scattering high-frequency seismic wavefield mentioned above we have conducted a 2-D FDM simulation of seismic waves using heterogeneous structure of the upper crust. The heterogeneous model of small-scale heterogeneity in the crust, was constructed by velocity fluctuation written as $V(x)=V_0[1+g(x)]$, where V_0 is the average velocity and g is a random velocity fluctuation. The fluctuation g is statistically characterized by the correlation length a and the rms value e. We employ a strike-slip source with a dominant frequency of 2Hz which has been implemented into a 2-D space. The 2-D model covers a region of 256km and 256km, descretized with uniform grid interval of 0.05 km. We use a parallel FDM code of a staggered 4th order model.

The results of FDM simulation of high-frequency scattering wavefield demonstrate clearly that small-scale heterogeneities in the structure modify energy fraction of the high-frequency S-waves. We found that the rms value of the fluctuation e, E_T drops more rapidly with increasing frequency, because large results in strong wave scattering and thus the conversion of seismic energy from transverse to radial motion. As increasing the correlation distance a, of the heterogeneous structure the strength of the high-frequency wave scattering decreases, and E_T increases. With increasing hypocentral distance D, the scattering of seismic wave is more significant and decrease E_T. The results of our simulation explain qualitatively the observations [Takemura et al. 2007]. However, the calculated E_T is still larger than the observation even if using very large fluctuation (e = 0.1) of heterogeneities in the model. For more quantitative modeling of E_T, we will extend the present model to 3-D and examine the proper distribution of small-scale random heterogeneities in horizontal and in vertical directions.

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