Angular distribution of energy fluxes of seismic waves in two-dimensional random heterogeneous media

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Seismic waves propagating in small-scale heterogeneous media have long-lasting coda waves. Coda waves consist of scattered waves coming from various directions. Multiple forward-scattered waves arrive just after the onset of the direct wave and multiple backward-scattered waves arrive at the coda. The coda energy distribution is often approximated by the diffusion process. After the diffusion state, the coda field can be considered as the equipartition state in which the energy flux is isotropic. Emoto (2018, JpGU) investigated the angular distribution of energy fluxes of scalar waves and found that the dependence on the medium parameters is weak in terms of the shape of the angular distribution. Different from the scattering of scalar waves, both P and S waves exist in the seismic waves and conversion scattering occurs between them. Moreover, the ratio of P and S wave energy radiated from the source is different in different directions due to the radiation pattern of the double-couple source. In this study, we investigate the angular distribution of scattered seismic waves by using the finite difference simulation of the seismic wave propagation in two-dimensional small-scale heterogeneous media.

The energy flux of seismic waves can be calculated by taking the product of the velocity and the stress at a certain point. The angular distribution of the energy fluxes, that is the angular spectrum is the ensemble of energy fluxes. The medium size of the finite difference simulation is 384 x 384 km and the grid separation is 100 m. The background velocities are 6.00 and 3.46 km/s for P and S waves, respectively. The random heterogeneous medium is characterized by an exponential type auto-correlation function with the characteristic scale of 0.5 or 5 km and the RMS fractional fluctuation of 5 %. The strike-slip type source located at the center of the medium. The source time function if the Kupper wavelet whose dominant frequency is 3 Hz. Receivers are located at propagation distances 25, 50, 75 and 100 km. At a distance, 8 receivers are located with the interval of the azimuth of 45 degrees. According to the radiation pattern, we stack the energy fluxes of along and perpendicular directions (E90), and oblique directions (E45), respectively. The maximum lapse time of the simulation is 45 s.

The angular spectrum never becomes isotropic within the maximum lapse time of the simulation for both cases (characteristic scales of 0.5 and 5 km). The anisotropy of the angular spectrum at the P coda is stronger than that at the S coda. The difference between the two cases is not strong in terms of the shape of the angular distribution at the S coda. This is the same result as obtained by the scalar wave simulation. Conversely, the angular distribution at the P coda of the case of the characteristic scale of 5 km is anisotropic compared to that of 0.5 km. After the onset of S wave, the angular spectrum approaches the isotropic distribution. This approaching speed of E90 direction is faster than that of E45 direction.

The numerical simulation revealed that the dependence of the angular distribution of scattered waves at the S coda on the medium parameter is weak. However, at the P coda, P to S scattering plays an important role to determine the angular distribution of the energy flux. We will extend our simulation to three-dimensional heterogeneous media in the future.

Keywords: Scattering, Angular spectrum, coda