Comparison of the 3D FD simulation and statistical methods for the scalar wavelet propagation through random media

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Considering seismic wave scattering due to small-scale heterogeneities is important for the analysis of short-period (<1s) seismograms. The scattering causes the broadening of seismogram envelopes and the attenuation of peak amplitudes with travel distance increasing. There are statistical methods to model these phenomena by considering an ensemble of random media and investigating statistical characteristics of the propagation of a wavelet through random media. In order to synthesize the theoretical envelope of a short-period wavelet, the radiative transfer equation with the Born approximation (RTE+Born) and the Markov approximation based on the parabolic approximation have been developed and applied to the observed data to estimate the statistical properties of the earth medium. Comparison of these methods with the finite difference (FD) simulation of the wave propagation is important to check the validity of each method; however, there have been few studies since the computation cost of the FD simulation in 3D is expensive.

In this study, we conduct 3D FD simulations of the scalar wavelet propagation by using the Earth Simulator, which is a vector supercomputer managed by JAMSTEC. The target frequency is 1.5Hz and the grid spacing is 0.08 km. The average propagation velocity is 4 km/s, so there are 33 grids per a wavelength, which ensure to prevent grid dispersion. Precisions of the differentiation are 4^{th} and 2^{nd} order in space and time, respectively. A model medium is a cube of 307 km each side and the number of grids for each axis is 3840. In order to realize such a large random medium, we smoothly merge small-size random media generated by using different random seeds. We use 6 merged random media in total. We set an isotropic source of a Ricker wavelet at the center of the medium and receivers at propagation distances of 25, 50, 75 and 100km. The velocity fluctuation is characterized by an exponential autocorrelation function where the fractional fluctuation is 0.05 and the correlation distances (a) are 1 or 5 km. First, we compare the stacked mean square (MS) envelopes of FD simulations with those obtained by RTE+Born and those by the improved Markov approximation (Sato, 2016). For the correlation distance of 1km (ak_c=2.3, where kc is the centered wavenumber), RTE+Born envelopes adequately fit with FD envelopes in entire lapse time. On the other hand, Markov envelopes well model FD envelopes around the peak for the case of the correlation distance of 5 km (ak_c=12). In this case, late coda of FD envelopes are well reproduced by RTE+Born. Next we investigate the distribution of squared amplitudes of each trace. We find that the distribution changes from the log normal distribution at the onset to the exponential distribution at coda. For the case of the correlation distance of 1 km, squared amplitudes show the exponential distribution soon after the onset. This means that the random scattered waves are dominant. According to the FK analysis of the FD traces, we found that the squared amplitudes obey the exponential distribution even when the energy flux of scattered waves is not isotropic.

Keywords: Scattering, Finite Difference Simulation, Markov Approximation, Born Approximation