Regional difference in small-scale heterogeneities in the crust and upper mantle derived by the analysis of high-density regional seismic network and high-resolution computer simulations

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In order to understand distribution of small-scale heterogeneities in the crust and upper mantle structure, which modify high-frequency seismic wavefield of over 1 Hz very dramatically, we studied change in P-wave energy distribution in 3-component seismograms and its frequency- and distance- dependent properties by analyzing a large number regional waveform derived by the Hi-net dense array in Japan. We then conduct FDM simulation for high-frequency seismic wave propagation using the Earth Simulator supercomputer employing a standard Earth model with stochastic random heterogeneities in the crust and upper mantle in order to simulate observed features of scattering seismic wavefield and to confirm effectiveness of our FDM model for modeling high-frequency seismic wavefield which is needed to simulate strong ground motion and expecting for large earthquake. We analyzed the Hi-net velocity waveform for shallow ($h < 30$ km) crustal earthquakes with $M_{JMA} = 2.0 - 5.3$ which occurred in the area around Japan. We first apply band-pass filter to each waveform with pass band frequency if 1-2, 2-4, 4-8, 8-16, 16-32 Hz and synthesize envelope of each component by using the Hilbert transform. Then, mean P-wave energies of each component are calculated for 3-sec window of P wave. Finally, an energy partition (EP) of P-wave energy in the transverse (T) component relative to total energy in three component seismogram is evaluated. In this study, we analyze 53,220 waveforms in total using 310 earthquakes and 773 Hi-net stations. The results show that at hypocentral distance 50-150 km, EP values increase with increasing frequency very clearly. The change in EP value is not found in this distance range. In the low frequencies band (f=2-4 Hz), EP value is small (0.08) but in the high frequency band (f=8-16 Hz) EP shows larger value (0.2). This suggests that high-frequency seismic wave with shorter wavelength significantly affected by heterogeneities in the crust and mantle structure. This results in P-wave energy almost equally partitioned into three-components as wave propagates in some distance (> 50 km) from the source. In order to examine the difference in the scattering properties in different regions in Japan we compare EP values at three regions, fore-arc side of Tohoku, back-arc side of Tohoku and Chugoku-Shikoku. We found clear regional difference of EP value; the estimated EP value at back-arc side of Tohoku area is 0.2, fore-arc side of Tohoku area is 0.1 and Chugoku-Shikoku region is 0.1. The result indicates regional difference in the distribution properties of small-scale heterogeneity in Japan. We then conducted 3-D FDM simulations of seismic wavefield using stochastic random media in order to confirm observed features of scattering seismic wavefield and distortion of P waveform in regional distances. Though the FDM simulation we clarify the causes of regional difference in the observed scattering seismic wavefield, The 3-D model covers a zone

204.8 km by 204.8 km by 64.0 km, which has been descretized with grid size 0.1 km in horizontal direction and 0.05 km in vertical direction. The heterogeneous models of small-scale heterogeneity in the crust and upper mantle are constructed by velocity fluctuation g(x) from average velocity V_0. The fluctuation g(x) is statistically characterized by the correlation length a ,the rms value e and the decay order k. Here, we employ von Karman-type auto-correlation function to characterize the property of g(x) and average background velocities of P-wave and S-wave are $V_P = 5.8$ km/s and $V_S = 3.36$ km/s, respectively. We employ an explosive point source which radiates P-wave isotropically into the model. We conducted a number of FDM simulation using different model parameters of stochastic random media for different e(= 0.03, 0.05, 0.07, 0.09) and fixed a and k (a = 5km, k = 0.5) and confirmed that EP does not change with increasing distances in the cases of larger e (0.07 and 0.09), while EP value increases with increasing distance in case of small e (< 0.05). This would be a proof of larger e in the crust and upper-mantle structure. Based on a number of FDM simulation using different stochastic random heterogeneity parameters we found that the heterogeneity model of a = 5km, e = 0.07 and k = 0.5, is efficient to reproduces observed features of P-wave energy partition in the area around for-arc side of Tohoku, such as distance and frequency dependence in higher frequencies ($f > 4$ Hz).