Effects of quasi-laminated random heterogeneity on surface wave propagation and apparent radial anisotropy

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Large-scale tomographic studies using long-period surface waves have revealed strong radial anisotropy with faster SH wave speed than SV in the upper mantle (e.g., Nettles &Dziewonski, 2008; Yoshizawa & Kennett, 2015). It has been well know that such radial anisotropy or transverse isotropy with SH>SV can also partly be generated by horizontal finely-layered structure (e,g., Aki, 1968). Some recent body-wave studies (e.g., Kennett & Furumura 2008) have suggested the existence of randomly-distributed quasi-laminated heterogeneity in the lithospheric mantle, which is required to explain the observations of strong high-frequency coda waves.

To investigate the effects of such fine-scale laminated heterogeneity on the propagation of long-period surface waves, we performed a series of two-dimensional finite-difference method simulations using velocity models with stochastic random heterogeneity with the background velocity from IASP91 model (Kennett &Engdahl, 1991). Following Kennett and Furumura (2008, GJI), we considered finely quasi-laminated heterogeneities with RMS 2% velocity deviations from the background model in three different depth ranges; (1) Moho~100km (equivalent to oceanic lithosphere), (2) Moho~200km (equivalent to continental lithosphere) and (3) 150km~250km (equivalent to asthenosphere).
The velocity deviation is controlled by a von Karman type distribution function with a Hurst number of 0.5 and different correlation scales vertically and horizontally. The vertical correlation length is fixed to 0.5 km, but the horizontal correlation lengths are varied from 10 km (as suggested by Furumura & Kennett, 2005) to 500 km (equivalent to a 1-D velocity profile as the lateral variation is smoothed out.). We also used three different event depths for our numerical simulations (5km, 50km and 100km) to check the effects of source depth.

Then, we measured average phase speeds of the fundamental-mode surface waves using inter-station non-linear waveform fitting method by Hamada & Yoshizawa (2015, GJI), using about 100 synthetic seismograms located at the epicentral distances between 800 and 2000 km for each model. Through the comparisons of the average inter-station phase speeds between different models, we quantitatively investigate the effects of finely-laminated heterogeneity with various horizontal correlation lengths on surface wave propagation, in particular, on the phase speeds of Love and Rayleigh waves.

These numerical experiments suggest the strong influence of the horizontal correlation length of quasi-laminated random heterogeneity on the phase speed drop of Rayleigh waves, resulting in the generation of apparent radial anisotropy; as we employ the longer horizontal correlation length, the apparent radial anisotropy becomes greater. While the Love wave phase speeds are less affected by such quasi-laminated heterogeneity at any scales, Rayleigh wave phase speeds decreased more than 1% compared to the isotropic case in the period range 50-80s for the heterogeneous continental model (quasi-laminated random heterogeneity in the depth of 35-200km) with a relatively large horizontal correlation length (500 km) and a shallow source at 5 km depth. Such effects become much weaker in the case of shorter horizontal correlation length (10 km), for which phase speed reduction of Rayleigh waves is reduced to about 0.2%. For models with all the correlation scales, we have observed strong high frequency (>1Hz) body wave signals with coda waves, which coincides well with earlier studies (e.g., Kennett & Furumura, 2013, GJI).

These results indicate that finely quasi-laminated structure with intermediate to long horizontal scales (several hundred kilometers) may cause non-negligible phase speed reduction of Rayleigh waves, resulting in apparent radial anisotropy with SH>SV in the upper mantle. Changing the source depths also affects the strength of velocity drop of Rayleigh waves; e.g., for an event at 50km depth located within the heterogeneous layer, Rayleigh wave phase seeds are reduced nearly 2 % at the maximum, which may indicate the strong influence of near-source heterogeneities. Further investigations with such numerical simulations incorporating realistic 3-D mantle structure models from latest tomographic studies in comparisons with observed waveform data will be of help in the better understanding of the nature of apparent radial anisotropy.

Keywords: random heterogeneity, surface waves, seismic anisotropy, numerical simulation