Abstract of Doctoral Dissertation

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Title of Doctoral Dissertation

Influence of laminated random heterogeneity on surface wave dispersion and radial anisotropy
（ラミナ状ランダム不均質性による表面波分散性及び鉛直異方性への影響）

A series of numerical experiments are performed to evaluate the influence of laminated stochastic heterogeneity on seismic surface waves and its potential contribution to radial anisotropy. The information derived from such numerical experiments can be the basis for interpreting real observations on large-scale seismic anisotropy in the upper mantle that are generally derived from surface wave tomography. Since the effects of such fine layering or laminated heterogeneities on surface wave dispersion have rarely been considered in tomographic studies when interpreting observed radial anisotropy, our results can provide insight into the possible cause of apparent radial anisotropy.

Recent studies on the high-frequency scattering of body waves have suggested the existence of fine-scale elongated random heterogeneity in the upper mantle. Such finely-layered heterogeneity can cause "apparent" radial anisotropy (differences in the shear wave speeds between the horizontally-polarized SH and vertically-polarized SV waves) when observed by seismic surface waves with much longer wavelength than the characteristic scale of such heterogeneity. In this study, we performed numerical experiments using 1-D and 2-D Earth models to investigate the influence of such layered or laminated velocity fluctuations on generating "apparent" radial anisotropy.

We first consider the 1-D cases, including the perturbed shear velocities relative to an isotropic reference 1-D model. Using the normal mode method, we compute the synthetic dispersion curves for the fluctuated isotropic velocity profiles. The results suggest that such layered structures would make the effective shear modulus for SV waves smaller and that for SH waves almost unchanged from the average (or reference) model, resulting in slower Rayleigh-wave phase speeds and almost unchanged Love-wave phase speeds from the reference model, which leads to weak apparent radial anisotropy. These results are mostly consistent with the theoretical estimations based on the Backus average, which represents the long-wavelength equivalent of a layered model. However, the discrepancy between the dispersion curves from the normal-mode estimation and the Backus average becomes large for strongly heterogeneous media with large velocity fluctuations.

We also perform 2-D simulations for various laminated stochastic heterogeneities using the finite difference method (FDM). The model space extends 2000 km horizontally and 360 km vertically with 0.05 km grid spacing to incorporate the fine-scale stochastic heterogeneity. We suppose 101 virtual seismic stations located in the epicentral distances from 900 to 1900 km at a 10 km interval. 2-D simulations are performed independently for P-SV and SH waves using the same heterogeneous models. The computed seismograms in 2-D models are then used to measure single-station phase speeds of surface waves.

To extract the surface-wave phase speeds, we employ the single-station waveform fitting method for source-receiver paths based on a fully nonlinear waveform fitting with global optimization. Despite the limitations in 2-D FDM simulations, we could extract reliable average phase speed perturbations in heterogeneous models relative to the homogeneous one for both the fundamental-mode Rayleigh and Love waves in a period range from 30 to 100 s.

We investigate the influence of three main factors that control or affect the character of stochastic heterogeneity in the upper mantle based on the von Karman type distribution function; the strength of heterogeneity (the standard deviation of velocity fluctuation, σ), the lateral scale of heterogeneity (the horizontal correlation length, a_x), and the thickness of the heterogeneous layer. To consider finely laminated heterogeneity in this study, the vertical correlation length, a_z, is fixed at 0.5 km. We also consider the effective strength of velocity fluctuations, σ_{eff}, to quantify the realistic strength of heterogeneity in each 2-D heterogeneous model.

The results indicate that the strength of heterogeneity σ (or σ_{eff}) exhibits noticeable influence on the perturbations of the fundamental-mode Rayleigh wave phase speed; for models with random heterogeneity (a_x = 5 km and a_z = 0.5 km) in the depth range from 35 to 120 km, the Rayleigh wave phase speed drop reaches around around 2.0% for σ = 0.1 (σ_{eff} = 0.13), and around 0.5% for σ = 0.05 (σ_{eff} = 0.066), depending on periods. For weaker heterogeneity, the influence on phase speed can be almost negligible. The changes in the horizontal correlation length a_x also show some influence; for larger a_x, phase speed reduction becomes greater, although we could confirm it only for limited cases. The results of the varying thicknesses of the heterogeneous layer suggest that their influence on phase speed perturbations mostly reflects the vertical sensitivity of Rayleigh waves as a function of periods. In all cases, the influence on the fundamental-mode Love waves is insignificant. Through the numerical experiments, we could confirm how laminated stochastic heterogeneity affects surface-wave phase dispersion.

We then invert for 1-D radially anisotropic S wave models using the phase speed perturbations of the fundamental-mode Rayleigh and Love waves for specific stochastic models. The results indicates that, for σ_{eff} = 0.1, the expected apparent radial anisotropy can be about $\xi \approx 1.04$, which can be nearly half of the observed radial anisotropy commonly seen in tomographic models. For a case with σ_{eff} = 0.05, apparent radial anisotropy can be about $\xi \approx 1.01$. The results obtained in this study suggest that the laminated heterogeneity with specific properties may generate a certain level of apparent radial anisotropy, and the observed radial anisotropy could be partially attributed to the existence of laminated random heterogeneity.