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Random Heterogeneity of the Earth Revealed from the Analysis of Short-Period Seismograms

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In short period seismograms of local earthquakes, long lasting coda waves follow the direct S arrival and the apparent duration of S waves is often much larger than the source duration time. For P-waves of teleseismic events, their envelopes are broadened longer than the source duration and waves are excited in the transverse component. Analyzing those seismogram envelopes on the basis of stochastic scattering models, we are able to quantify the random heterogeneities distributed in the earth's lithosphere: one is the scattering coefficient which phenomenologically characterizes the scattering power per unit volume for the radiative transfer theory; another is the power spectral density function (PSDF) of the fractional velocity fluctuation, which is more appropriate for the wave theoretical description of random media. Stochastic characterization and deterministic imaging such as tomography are complimentary to each other to enrich our understanding of the structure and the evolution of the solid Earth. Here we briefly review recent measurements by using statistical envelope syntheses and analytical methods.

Scattering coefficients in the lithosphere at various areas in the world are estimated to be from 0.001/km to 0.05/km and 0.01/km on average in the 1-30Hz range. Scattering coefficients beneath volcanoes are two order larger and those in the mantle at lower frequencies are two or three order smaller than those in the lithosphere.

Envelope broadening is well explained by multiple forward scattering due to random velocity inhomogeneities. When the wavelength is smaller than the correlation distance of random media, wave propagation is governed by the parabolic type equation. The Markov approximation, which is a stochastic extension of the split step algorithm, directly derives the mean square envelopes in random media. According to this approximation, the PSDF of fractional velocity fluctuation controls the frequency dependence and distance dependence of the envelope broadening. From the inversion analysis of S envelopes of microearthquakes, the PSDF is found to be larger and the spectral decay rate is smaller beneath Quaternary volcanoes compared with those between them and those in the fore-arc side of the volcanic front.

By using the Born approximation for random elastic media, we can derive nonisotropic scattering coefficients, which is a function of the PSDF of fractional velocity fluctuation. By using the raditiave transfer theory with the Born scattering coefficients, we are able to synthesize vector wave envelopes. The analysis of P wave envelopes of teleseismic events revealed that the PSDF in the lower mantle is smaller than that in the lithosphere and the upper mantle.

Keywords: coda waves, heterogeneity, lithosphere, random media, scattering, envelope