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Statistical approach to the propagation of seismic waves through the random structure of the Earth (Beno Gutenberg Medal Lecture)

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Seismograms of earthquakes are complex because of scattering by medium inhomogeneities. The straight forward method for the synthesis of a wavelet in an inhomogeneous structure is the finite difference simulation; however, it requires the precise information of the wave velocity inhomogeneity. Instead, a radiative transfer equation (RTE) was proposed for the synthesis of a wavelet intensity, the mean square amplitude, where the key parameter is the scattering coefficient representing the scattering power per unit volume. Focusing on the smooth and systematic variation of the coda wave intensity and disregarding the phase complexity, Aki first proposed a simple model of the RTE for the synthesis of the coda intensity. Since then, RTE approaches have been widely used for the synthesis of not only coda but also the whole wave intensity. I first review measurements of scattering coefficients supposing isotropic scattering in different seismo-tectonic settings.

The RTE can be derived from the second moment equation for an ensemble of random fractional fluctuation of wave velocity, of which the power spectral density function (PSDF) is statistically characterized by a few number of parameters. Measurements of acoustic well-logging and velocity tomography data show that the PSDF obeys a power-law decay, which is well represented by a von Karman-type. The conventional synthesis of a wavelet intensity is to use the anisotropic scattering coefficient calculated by the Born approximation in the RTE. As the center wavenumber of the wavelet increases higher than the corner wavenumber, however, we have to use the Markov approximation based on the parabolic approximation. It leads to the envelope-broadening and the peak-delay from the onset caused by successive narrow-angle scattering around the forward direction. There have been many measurements of PSDF in the lithosphere of various seismo-tectonic settings and in the upper mantle. I present some of those analyses and a log-log plot of reported PSDFs which shows a power-law decay in a wide wavenumber range. Those observational facts require us to synthesize the wavelet intensity from its onset through the peak until coda in a unified manner for a wide wavenumber range. I discuss mathematical approaches to this task within the framework of RTE.