Stochastic direct synthesis of wave-envelopes in 3-D random media characterized by a non-isotropic Gaussian ACF

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Seismogram envelopes are broadened with travel distance increasing and become much longer than the earthquake source duration time. Envelope broadening can be interpreted as caused by scattering due to velocity inhomogeneities randomly spreading over the lithosphere. When the wavelength is shorter than the correlation distance of random media, the Markov approximation is known as a powerful tool for the direct synthesis of wave envelopes. It is a stochastic extension of the phase screen method. In the case of impulsive radiation from a source, this approximation statistically derives the mean square envelope of waves at a given travel distance from the source. The peak delay from the onset and the envelope width are characterized by a few number of statistical parameters which describe the ensemble of random media.

In the real Earth, randomness is generally non-isotropic as revealed from log data of deep wells and precise velocity tomography surveys; however, most of the previous works are founded on the isotropic assumption for randomness and there have been few studies on wave envelopes especially in non-isotropic random media in 3-D. On the basis of the Markov approximation, here, we propose a stochastic direct synthesis of wave envelopes in 3-D random media which are characterized by a non-isotropic Gaussian ACF. In the case that the global ray direction is along one of the three principal axes of the non-isotropic ACF, we are able to solve analytically the stochastic master equation for the two-frequency mutual coherence function of wave fields, of which the Fourier transform gives the mean square wave envelope at a given travel distance. The peak delay and the envelope width increase in proportion to the square of travel distance. They depend not only on the non-isotropic statistical parameters but also on the global ray direction, where the mean square fractional velocity fluctuation, the correlation distance in the propagation direction and the ratios of non-isotropic correlation distances are key parameters. Especially in the case that the non-isotropic ACF has rotational symmetry around the global ray direction, mean square envelopes in time domain are analytically written by using the elliptic Theta function. The synthesis of scalar waves is extendable to the synthesis of vector waves. When the correlation distances in the horizontal direction are larger than that in the vertical direction as typically seen in the crustal inhomogeneity, the envelope broadening of horizontally propagating waves is more prominent than that of vertically propagating waves. It suggests that we have to pay attention to seismic ray angles from a vertical line for the analysis of envelope broadening. In parallel it is necessary to study coda excitation in non-isotropic random media.