Scalar wave propagation in 2-D anisotropic random media: Envelope, phase/amplitude variance, and velocity shift

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Regional seismograms are composed of number of scattered waves which are not readily explained by a simple deterministic subsurface-structure. Recognizing their complexities, seismologists have attempted to simulate statistical properties of seismograms supposing random media where velocity value fluctuates randomly in space (e.g. Sato & Fehler 1998). Although many conventional studies assumed isotropic random media due to the mathematical simplicity, some papers reported that anisotropic random media were able to simulate observed seismograms better than isotropic random media (e.g. Kamei et al. 2005; Furumura & Kennette 2005). This study investigates scalar-wave propagation in the 2-D random media where velocity fluctuates more rapidly in the vertical direction than in the horizontal. In particular, we study statistical properties of the waves such as wave envelope, the variances of travel time and amplitude, and velocity shift.

Wave envelopes in random media are theoretically calculated with parabolic wave-equation where small-angle scattering is included and large-angle scattering is neglected (Ishimaru, 1978; Sato 1989; Saito et al. 2002). Recently, Saito (2006) formulated the method supposing 2-D anisotropic random media. The theoretical envelope increases in the duration and decreases in the maximum amplitude more rapidly in the horizontal direction than in the vertical direction.

Variances of travel time and amplitude are theoretically calculated with the Rtyov method (e.g. Aki 1973; Rytov et al. 1998). The method assumes small-angle scattering and weak scattering, where the first-order fractional-fluctuation of the wavefield is considered. Recently, the methods are formulated with the assumption of anisotropic random media (e.g. Iooss 1998). The variances are larger in the case of the horizontal wave propagation than in the vertical.

Velocity shift is defined as the difference between effective-average velocity and spatial-average velocity. Since wave prefers high velocity portion, the effective-average velocity is usually larger than the spatial-average velocity. Also, the effective-average velocity depends on wave frequency due to the scattering of waves (e.g. Shapiro et al. 1996). Saito (submitted to GJI) formulated the Rytov method for the velocity shift in the 2-D anisotropic random media, where the second-order fractional-fluctuation of the wavefield was considered. The results show that waves apparently propagate faster in the horizontal direction than in the vertical. Furthermore, the velocity anisotropy becomes more dominant with increasing the wave frequency.

Velocity anisotropy, which might be considered as effective-average velocity, has been often analyzed for estimating anisotropic structures. The anisotropy was often discussed in relation to preferred orientation of cracks or minerals which were usually much smaller than the wavelength. On the other hand, the results shown above indicate that the anisotropic inhomogeneity whose size is comparable to the wavelength also results in the velocity anisotropy. Furthermore, envelopes and amplitude/phase variances can also be significant measures for detecting the anisotropic structures in lithosphere.