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A scalar radiative transfer model including the coupling between surface and body waves

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In seismology, Radiative transfer (RT) has been used for more than three decades to characterize the scattering and absorption properties of Earth's crust. More recently, RT has also been applied to the computation of sensitivity kernels for time-lapse imaging methods such as coda wave interferometry (CWI). One key issue in ambient noise applications -and a current limit to the depth-resolution of techniques such as CWI- is the lack of a self-consistent theory to model a coda wavefield composed of a mixture of scattered surface and body waves. To address this problem, we develop a simplified model based on the Helmholtz equation in a half-space geometry with mixed boundary conditions. In this model, Green's function can be represented as a sum of body waves and surface waves, which mimics the situation on Earth. We then study the single-scattering problem for point-like objects. Upon assuming that the phase of the body waves is randomized by the surface reflection, we show that it is possible to define in the usual manner scattering cross-sections for surface-to-body and body-to-surface scattering. Using the independent scattering approximation, we then derive a set of coupled transport equations satisfied by the specific energy density of surface and body waves in a medium containing a homogeneous distribution of point scatterers. In our model, the scattering mean free path of body waves is depth dependent as a consequence of the body-to-surface coupling. We show that an equipartition between surface and body waves is established at long lapse time, with a ratio which is predicted by usual mode counting arguments. A diffusion approximation is derived which shows that the diffusivity is both anisotropic and depth dependent. Finally, we present Monte-Carlo solutions of the transport equations which illustrate the importance of the coupling between surface and body waves in the generation of coda waves.