Geophysical Research Abstracts
Vol. 15, EGU2013-10799, 2013
EGU General Assembly 2013

Depth sensitivity of seismic coda waves to velocity perturbations in an elastic heterogeneous medium

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Numerous monitoring applications make use of seismic coda waves to evaluate velocity changes in the Earth. This raises the question of the spatial sensitivity of coda-wave-based measurements. Here, we investigate the depth sensitivity of coda waves to local velocity perturbations using two-dimensional numerical wave-field simulations. We calculate the impulse response at the surface before and after a slight perturbation of the velocity within a thin layer at depth is introduced. We perform a parametric analysis of the observed apparent relative velocity changes, $\varepsilon^{\mathrm{obs}}$, versus the depth of the thin perturbed layer. Through the analysis of the decay of $\varepsilon^{\mathrm{obs}}$, we can discriminate two different regimes: one for a shallow perturbation and the other for a deep perturbation. We interpret the first regime as the footprint of the one-dimensional depth sensitivity of the fundamental surface-wave mode. To interpret the second regime, we need to model the sensitivity of the multiply scattered body waves in the bulk. We show that the depth sensitivity of coda waves can be modeled as a combination of bulk-wave sensitivity and surface-wave sensitivity. The transition between these two regimes is governed by mode conversions due to scattering. We indicate the importance of surface waves for the sensitivity of coda waves at shallow depths and at early times in the coda. At later times, bulk waves clearly dominate the depth sensitivity and offer the possibility of monitoring changes at depths below the sensitivity of the surface waves. Based on the transition between the two regimes, we can discriminate a change that occurs at the surface from a change that occurs at depth. This is illustrated for shallow depth perturbations through an example from lunar data.