Summary & Conclusions

Observed surface wave group-velocity delays depend both on relative phase speed and relative group speed. This dual-dependence can be described in two different ways. We ask two questions:

(a) Is one of the two formulations preferable over the other?
(b) Does either or both of the formulations provide a firm foundation for group-delay tomography?

From forward simulations and tomography with real data, we conclude the following:

(1) Although the group speed kernels in the two formulations differ strongly in their side-lobes, both formulations provide valid basis functions for group-delay tomography.
(2) At and below 100 sec period, the phase speed terms contribute only about 10% of the group delay times which is well below data noise. The phase speed integrals can be safely ignored at these periods.
(3) At periods above 100 sec, observed group-delays should be corrected for the phase speed integral using a 3-D model or an empirical scaling relation between the relative group and phase speeds.

(4) Correcting for the phase speed terms using a 3-D model or an empirical scaling relation between group and phase speeds should improve the results maps at all periods, but the effect will be small at and below 100 sec period.

Theory

Adopting the notation of Dahlin and Zhou (2005), which itself follows the notations of Zhou et al. (2004), the dual-dependence of group delay $\Delta t(x,w)$ on group and phase speed perturbations is written:

$$\Delta t = \int \left[ \kappa_i \left( \frac{\partial k}{\partial w} \right) + k_j \left( \frac{\partial k}{\partial x} \right) \right] dx$$

where $\kappa_i$ is the relative phase speed perturbation, $\kappa_j$ is the relative group speed perturbation, and both depend on frequency.

Kernels from equation (1) and (3)

Kernels from equation (3)

Sensitivity Kernels

Tomography with Different Theories

Using eqn. (6), the phase correction

Using eqn. (9), the phase correction

Figure 1 and 2 give examples of the relative phases and amplitudes of the group and phase speed kernels (not shown in this figure). The magnitude and phase of the side lobes differ significantly between the two formulations. The main lobes of the phase speed kernels are directed towards the source, while the main lobes of the group speed kernels are directed towards the observer. The main lobes are separated in phase and are in quadrature at high frequencies.

North America

Central Pacific

Figure 3. Examples of finite frequency group-velocity sensitivity kernels computed from the phase speed (left) and group speed (right) versions of the spherical wave equation. The kernels are computed for a frequency ranging from 0.01 Hz to 1.0 Hz and a period ranging from 10 sec to 200 sec.

Results at 20 s, 50 s, 100 s Period:

The effect of neglecting the phase term

Group-Delay Simulation

Table 1. Example of group- and phase-velocity kernels for the Cornell model and phase-velocity kernels for the Siple and Ritzwoller (2002) model. The kernels are computed for a frequency ranging from 0.01 Hz to 1.0 Hz and a period ranging from 10 sec to 200 sec.

<table>
<thead>
<tr>
<th>Model</th>
<th>Phase Delay (s)</th>
<th>Group Delay (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornell</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Siple</td>
<td>0.02</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Although we recommend correcting the observed group-delays for the phase speed terms in equations (1) and (3), tomography can be performed without this correction. This is expressed by equations (6) and (9).

Figure 4 shows a comparison of phase-velocity kernels for the Cornell model and phase-velocity kernels for the Siple and Ritzwoller (2002) model. The phase delay is computed for a frequency ranging from 0.01 Hz to 1.0 Hz and a period ranging from 10 sec to 200 sec.

References


