Elastic Interferometric modeling: The effects of an imperfect source distribution

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Introduction

In seismic interferometry the Green's function between two points is reconstructed by cross-correlating the received signal at these points. The accuracy of the result depends on how well the initial assumptions are satisfied. For example, energy should come from all directions isotropically. We investigate Green's function retrieval for imperfect cases, more akin to real (microseism) sources: Sources mostly distributed at/near the surface, or sources not completely surrounding the two receivers.

We use an elastic 3DFD code (Moczo et al., 2002) to calculate the displacement at location A (figure 1) due to a delta(-like) force acting at location B. We also compute the displacement at A and B, due to sources in an enclosing surface indicated by the red dots in figure 1. These are subsequently shot in the x,y, and z-direction. The integral of the cross-correlations of the received signal is then equal to the Green's function between A and B according to:

$$G_{im}(\mathbf{x_A},\mathbf{x_B},\omega) - G^*_{im}(\mathbf{x_A},\mathbf{x_B},\omega) \approx -2i\omega \oint_S G_{ip}(\mathbf{x_A},\mathbf{x},\omega) G^*_{mp}(\mathbf{x_B},\mathbf{x},\omega)\, dS(\mathbf{x})$$

in the frequency domain. Here is u the total displacement. Forces are summed over x, y and z. The term in the denominator represents the average work over the source surface.

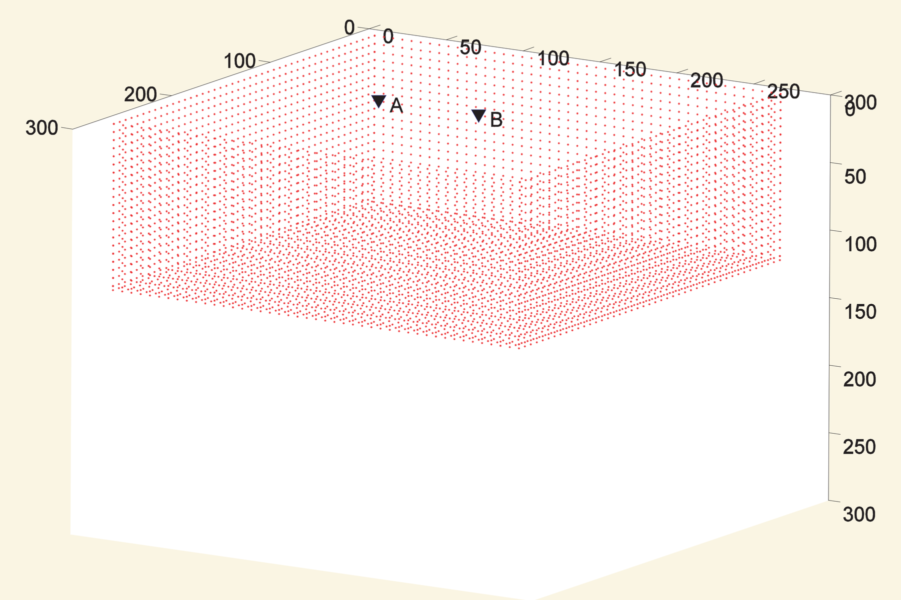

figure 1.

In the first configuration we consider a homogeneous isotropic halfspace, and place A and B inline with the x-direction (figure 1). The component Gxx of the Green's tensor contains a direct P- and a non-dispersive Rayleigh wave that are both reconstructed perfectly (figure 2). In blue is the retrieved Green's function (anti-symmetric around the time axis), and in red the direct Green's function (cross-correlated with the source wavelet).

Microseisms, that are the main source of ambient noise recordings, are pressure variations in deep oceans and/or ocean waves hitting the coast. In both cases one can consider this to be sources at the surface, usually far away from the explored region. In figure 3 we consider the case where sources are at the (free) surface only. Note that the stationary phase point for the direct P is the same as for the Rayleigh wave. Both the P and Rayleigh wave are retrieved, albeit not with the exact phase.

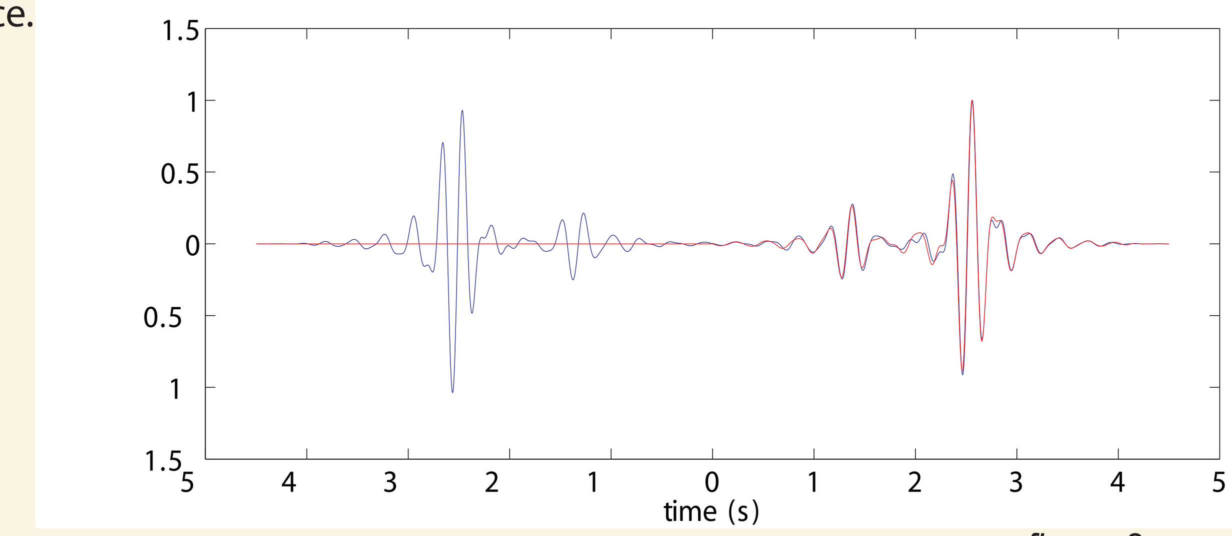

figure 2.

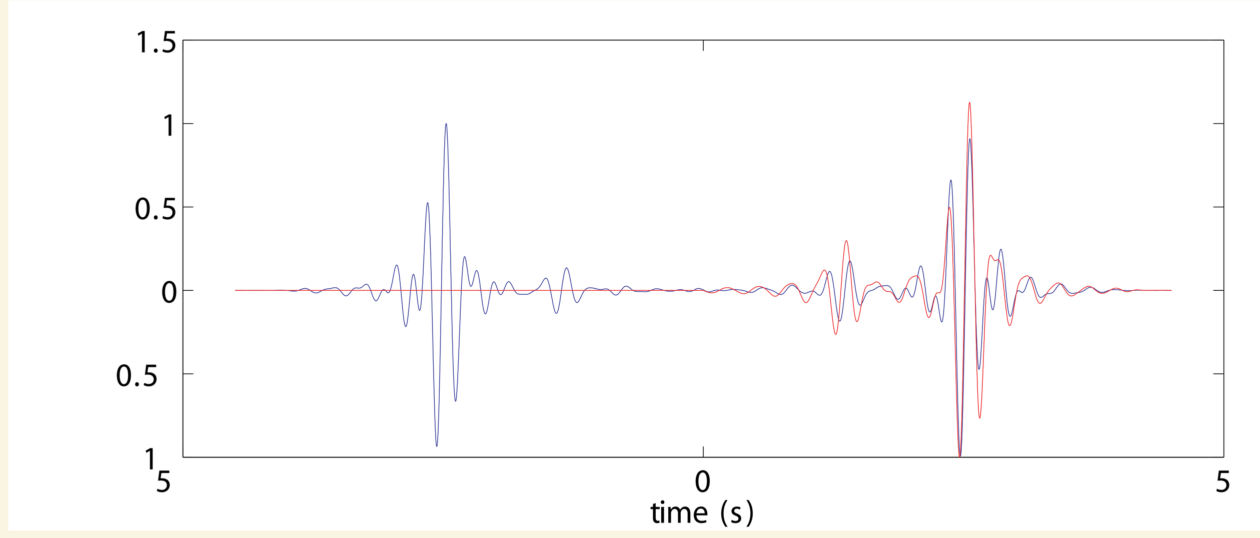

figure 3.

A second example shows the case with a layer on top of a halfspace (figures 4 and 5). Again receivers A and B are inline and the Gxx component is shown. The Green's function contains P and (mainly) Rayleigh waves, as well as reflections and multiples. Apart from minor amplitude errors the Green's function is correctly retrieved. In the case with sources at the surface only (figure 5) one does not expect reflections to be retrieved correctly. Still the match with the direct Green's function is surprisingly good.
In figures 6 and 7 we consider time-frequency analysis of respectively the direct Green's Function and the seismogram retrieved with source at the surface only. We see that the main difference is in the absence of low frequency fast travelling waves.

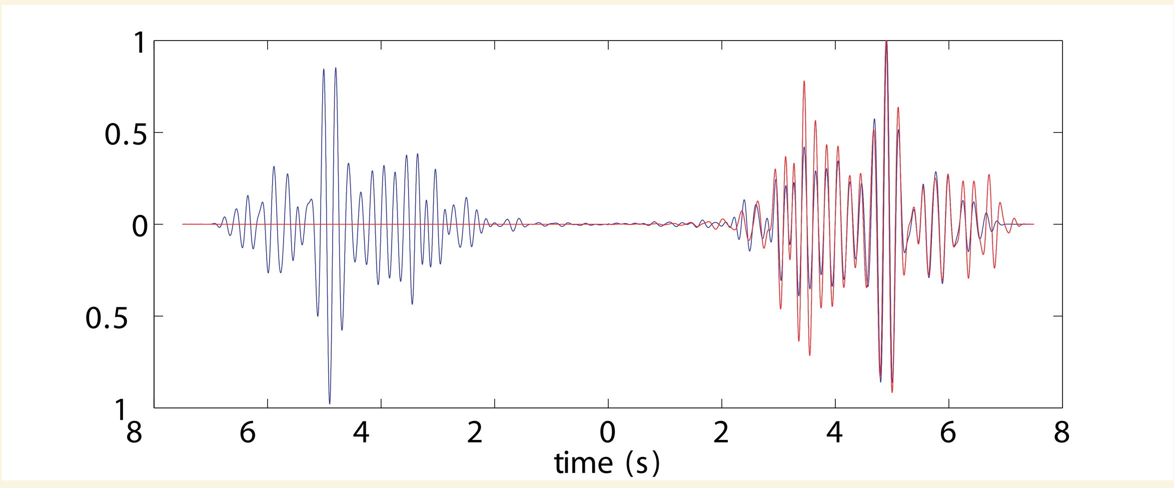

figure 4.

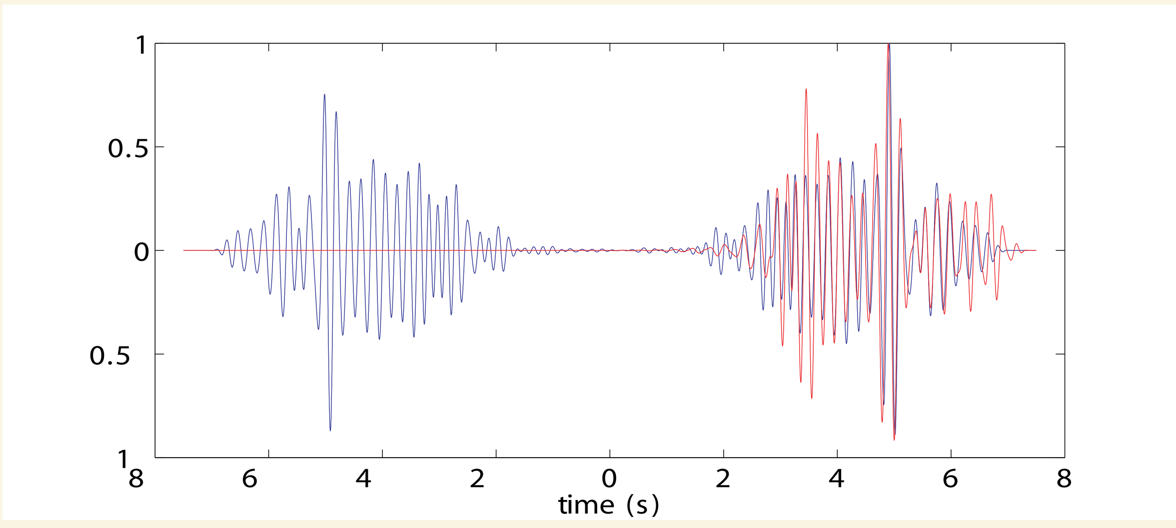

figure 5.

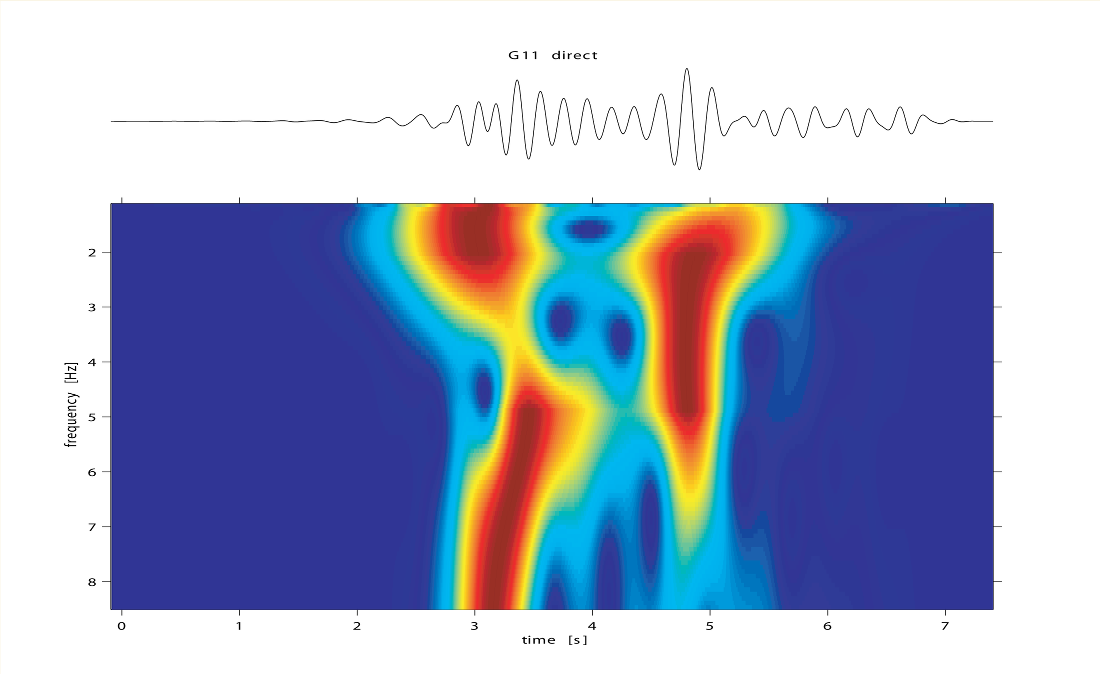

figure 6.

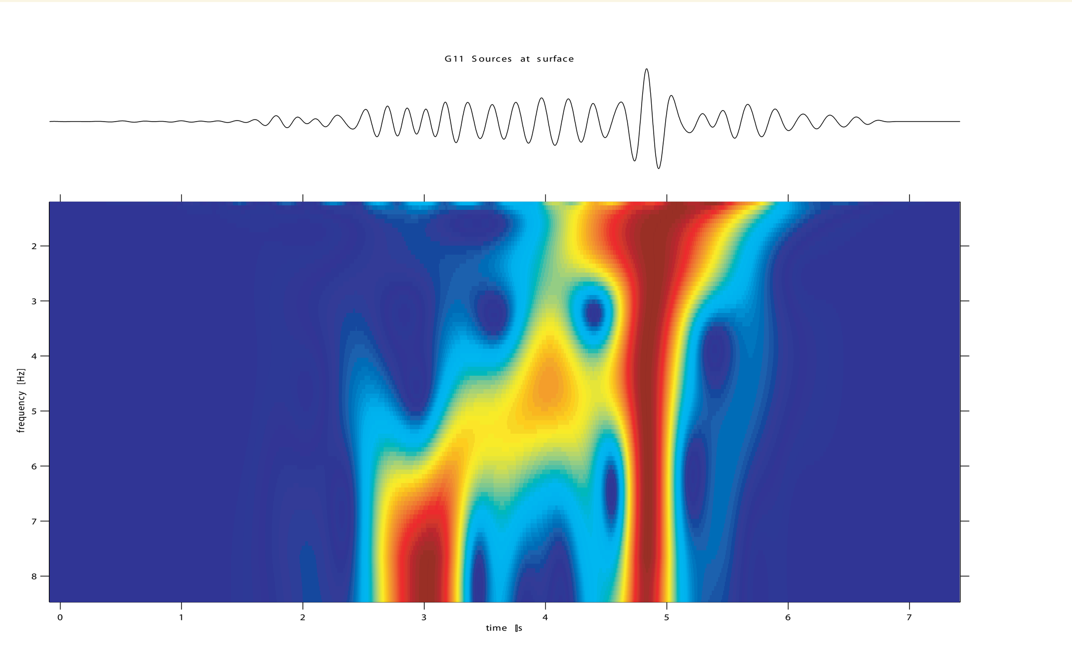

figure 7.

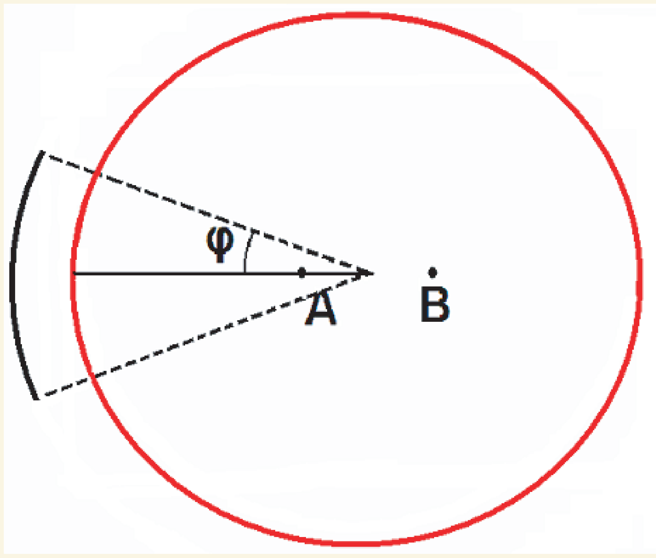

figure 8.

The $\pi/4$-ambiguity: The Rayleigh wave Green's function has a phase advanced (z-component) or delayed (radial component) by $\pi/4$ (Aki & Richards 2002). At the stationary phase point however, one measures the exact time delay. Therefore, for an imperfect coverage of azimuth, a phase shift in between 0 and $\pi/4$ is possible (Snieder 2004, Bensen 2006). We map out this phase shift by gradually including sources in the black area in figure 8. The result is shown in figure 10. Zero degrees is at the stationary phase point (including only 1 source). At + and - 90 degrees the complete Green's function is recovered. From + and - 20 degrees on the phase shift is relatively small. The phase-shift concerned depends on the region where sources are interfering constructively, shown in figure 9. This region on its turn is dependent on the interstation distance and wavelength. Three examples are shown.

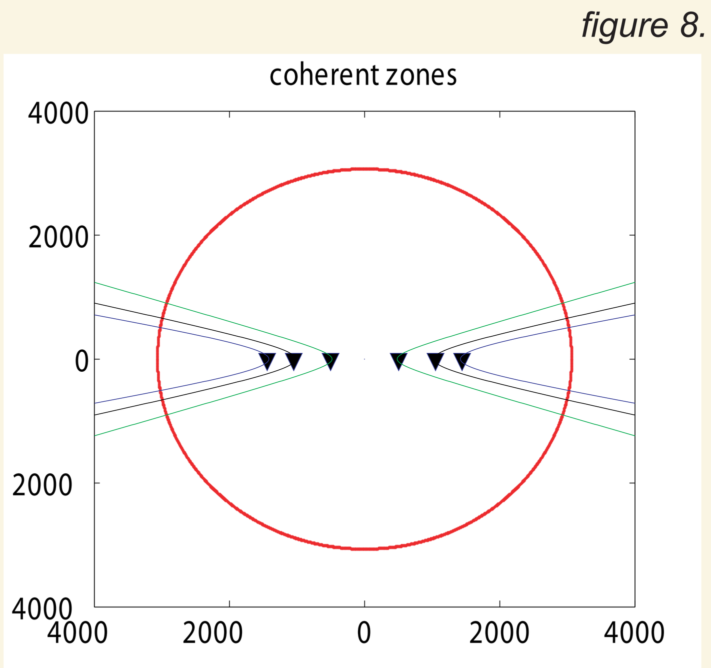

figure 9.

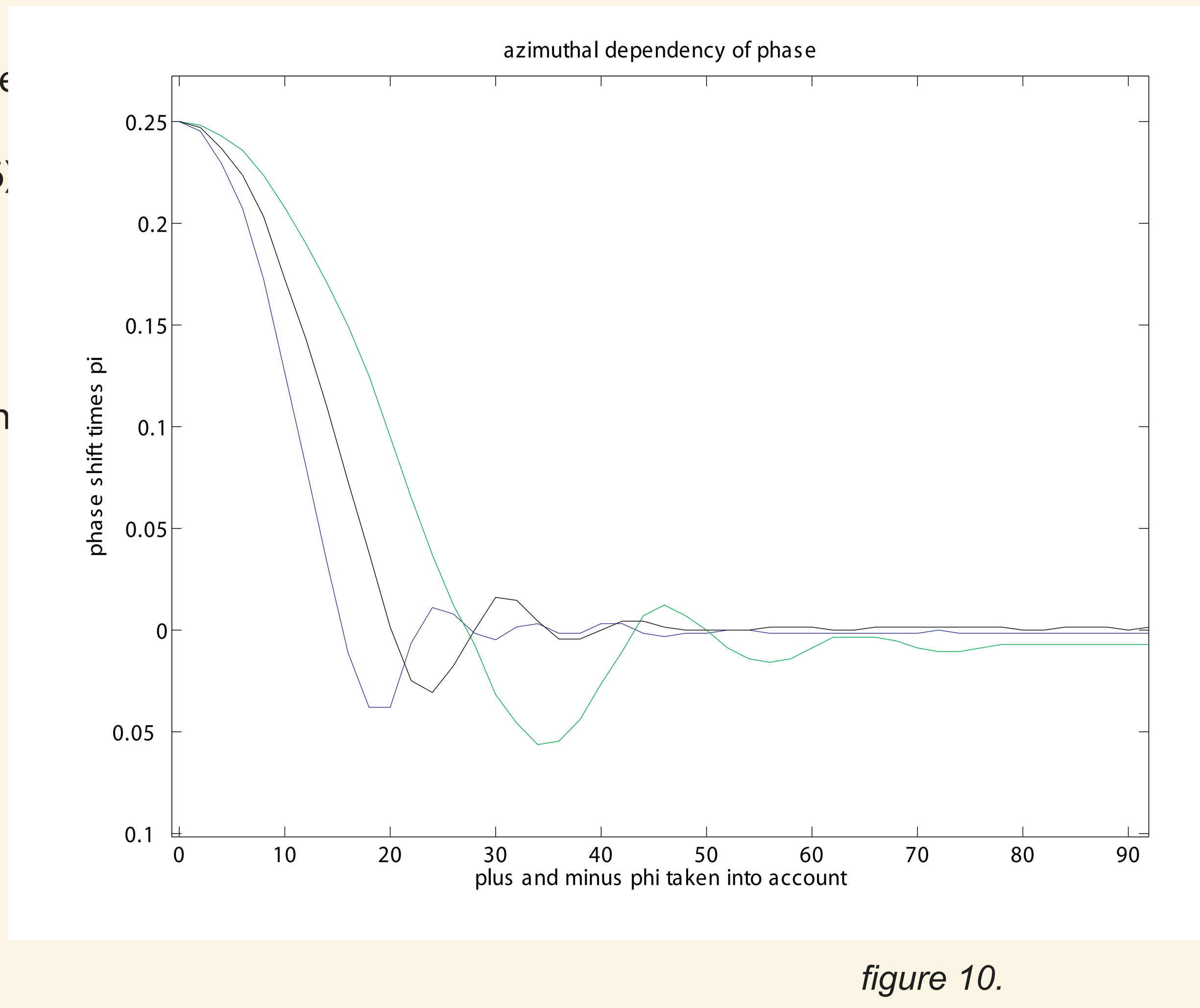

figure 10.

Conclusions

We can accurately retrieve the Green's function in an elastic heterogeneous model. Surface waves and overtones (body waves) can be retrieved by using sources at the surface only. When measuring phase in the Green's function, care should be taken to correct for phase shifts due to imperfect source distributions with azimuth.

References

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