Improving tomographic maps-surface waves
Polarisation measurements and limitations

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Introduction

Surface wave phase velocity maps agree well on large scale structures, however, small scale structures are not well constrained. Constraining the phase velocity is important for understanding continental deformation and determining lithospheric thickness which can aid in the understanding of processes such as mountain building, volcanism and earthquakes. This requires an understanding of the lithosphere-asthenosphere boundary because he rigid lithosphere moves over the ductile asthenosphere. This needs to be mapped to determine its depth.

The current limitation is the spacial and depth resolution of the maps which limits the ability to locate the boundary depths. At present, only areas where lithospheric thickness is thick (greater than 120km) can the lithosphere-asthenosphere boundary be located. This can be resolved by adding more information into the velocity inversion from seismograms such as higher order waves, polarisation and information at different frequency bands. Shorter period information can also add to the 3D velocity inversions. Whether these have a significant effect and can be measured effectively requires closer analysis and is the main focus. Here, our ability to make polarisation measurements is refined to better improve the data that goes into the velocity inversions. It is not only more sensitive to velocity structure but it increases the amount of information available to us for velocity inversions, even at short periods. Hence it is a good candidate for improving spacial and depth resolution.

Effects of polarisation

Polarisation is more sensitive to small changes in structure than phase. This is because it varies with the partial derivative of the velocity anomaly. Phase however varies with velocity anomaly. The deviation from the great circle path between source and receiver v is given by:

$$v(\Delta) = -\frac{1}{\sin(\Delta)}\int_0^{\Delta} \sin(\phi)\frac{\partial\frac{\partial c(\pi/2,\phi)}{c_0}}{\partial c_0}d\phi \qquad (1)$$

Δ is the epicentral distance and c_0 is the reference velocity of the model. v is defined by $\tan(\theta_{2H})$. θ_{2H} is the value measured using the multi-taper analysis for polarisation outlined in Park et al 1987. To illustrate the effects of structure on the polarisation measurements, two models were analysed (Figure 1).

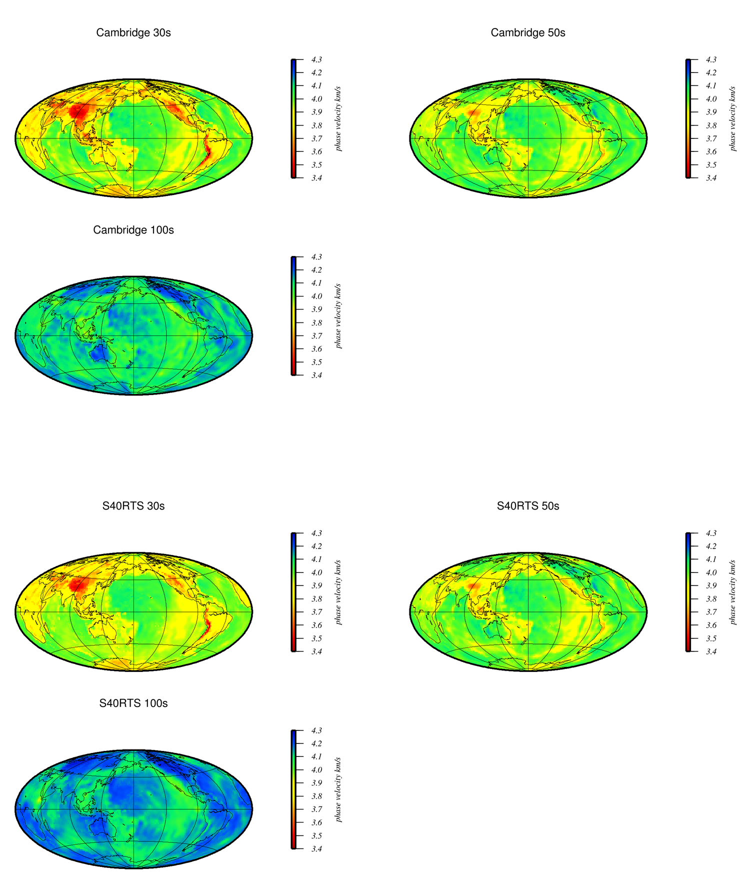

Figure 1: *Two phase velocity models at various periods. S40RTS and Cambridge model. Both exhibit the identifiable large scale structure at short periods.*

Ray tracing was used to simulate a path from source to receiver through these two models at 30 s. Although both models have the same large scale structures, their small scale differences cause the path of propagation to differ (Figure 2).

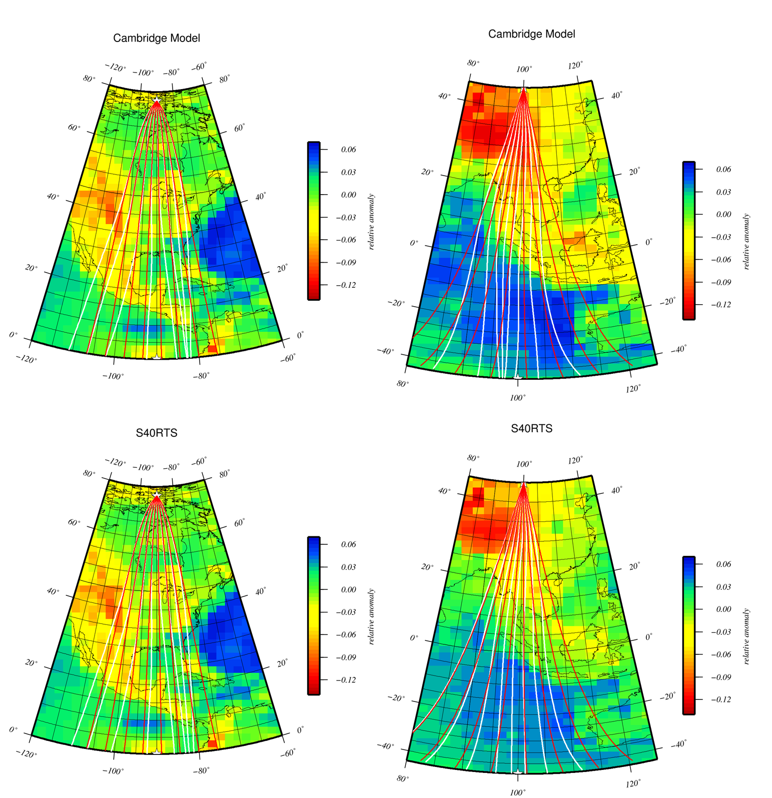

Figure 2: *Ray tracing through America and Tibet for different take-off angles. Differences are observed between the models indicating an effect on polarisation due to structure. Red lines are great circle paths and white lines are ray traced. Deviations from great circle paths are large.*

This is an encouraging result, suggesting that incorporation of polarisation into 3D velocity inversions can produce greater resolution to the velocity maps to to greater sensitivity to small scale structures.

Measurement-Errors and uncertainties

Polarisation can be measured using a multi-taper technique outlined in Park et al 1987. A problem faced with this kind of measurements is the necessity for high quality 3-component seismograms. Noise on the radial components are generally quite large and are a limiting factor on polarisation measurements (Figure 3 and 4).

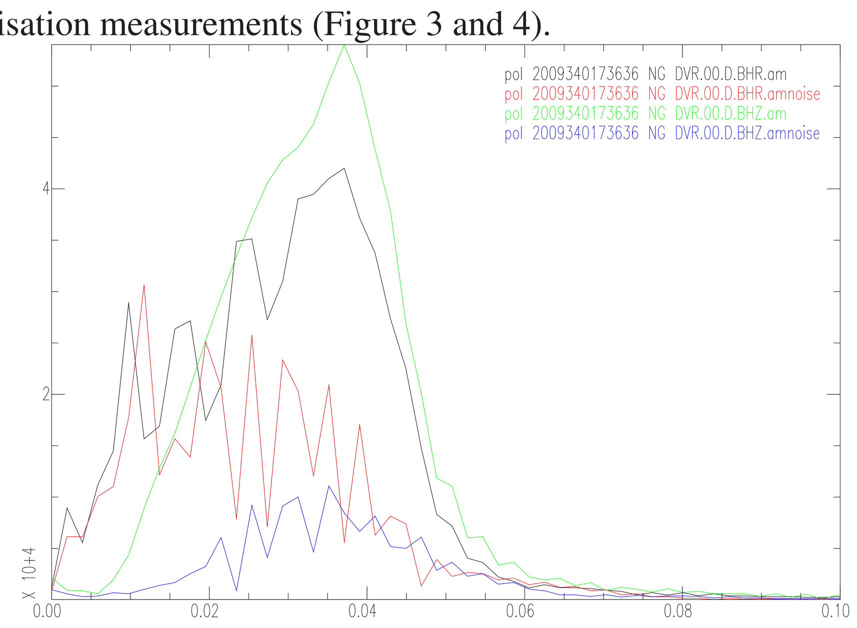

Figure 3: *An example amplitude spectrum for a station (DVR) located in the southern tip of India. The vertical component has very little noise. However the radial component noise drowns out part of the signal on the radial component.*

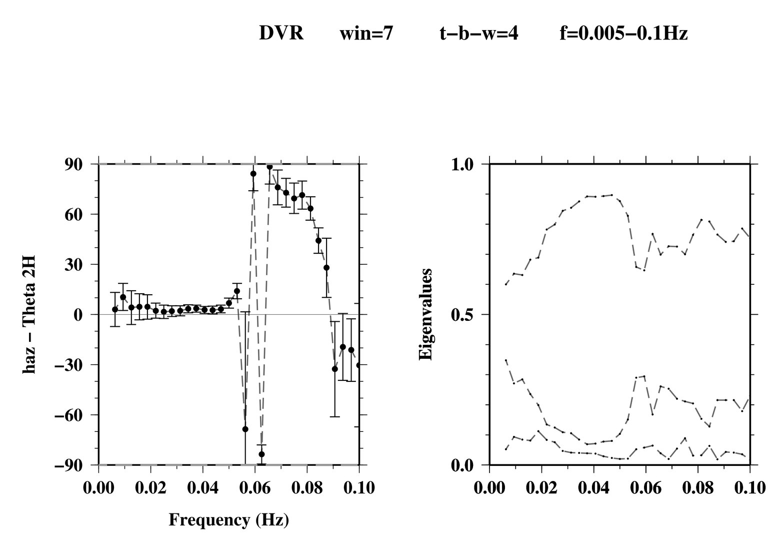

Figure 4: *The corresponding eigenvalue plot and azimuth plot for DVR. The frequencies where a single eigenvalue is largest corresponds well to where the signal to noise is high. Large singular eigenvalues are points where polarisation is well defined.*

The lower and upper limit in frequency for which polarisation measurements can be made was investigated using ray paths on oceanic crust where scattering and noise is minimal (Figure 5 and 6).

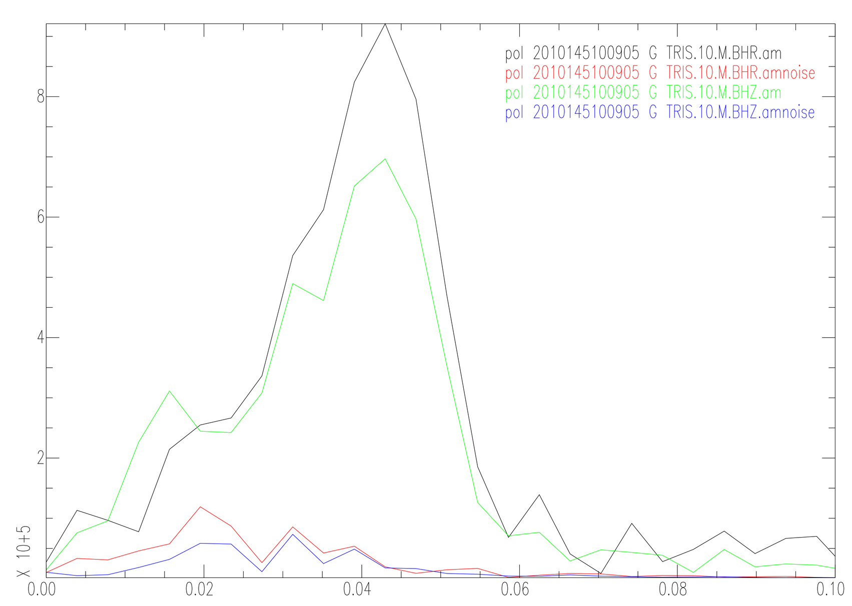

Figure 5: *An example amplitude spectrum for a station located in the North Atlantic with a travel path along oceanic crust only. Little noise is seen.*

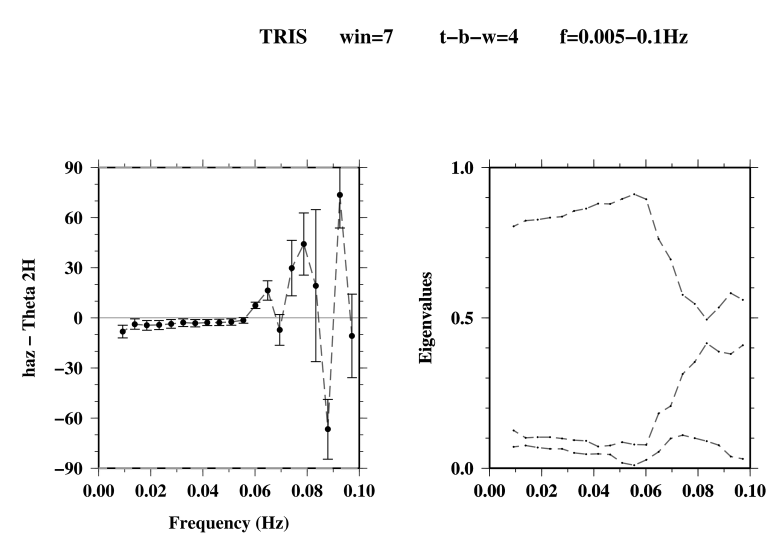

Figure 6: *The corresponding eigenvalue plot and azimuth plot for TRIS. It is clear that polarisations for frequencies above 0.06 Hz are poor, corresponding well to the drop in signal in the amplitude spectrum.*

The upper limit found for polarisation measurements is 0.06 Hz. The lower limit is indeterminate and will likely be due to other factors as indicated in figure 3 and 4.

Other additional factors that limit measurements which need to be addressed include:

- Interference of scattered phases-the fundamental may not be well defined. Phases may not be well separated for short epicentral distances.
- Radiation patterns-the fundamental may not be visible as the station is located on a node.
- Magnitude and depth-whether the fundamental is sufficiently excited and is clear to pick.

These factors limit the amount of data available for inversion

Additional effects that limit resolution

Epicentral distance effects were tested using ray tracing for different source-receiver pairs. Previous studies indicate that taking short epicentral distance paths can reduce the effect of great circle path approximation limitations. Taking longer paths tend to increase the deviation from great circle path. Information from these longer paths are ignored and limits the amount of data available for velocity inversions. It was found that while it holds for most areas, for more interesting places, this approximation breaks down and must be taken into account. Properly incorporating off great circle path information can therefore assist in improving resolution by increasing the amount of data available for 3D inversions and to minimise path averaging. Polarisation can be measured for long paths as well adding to the data set.

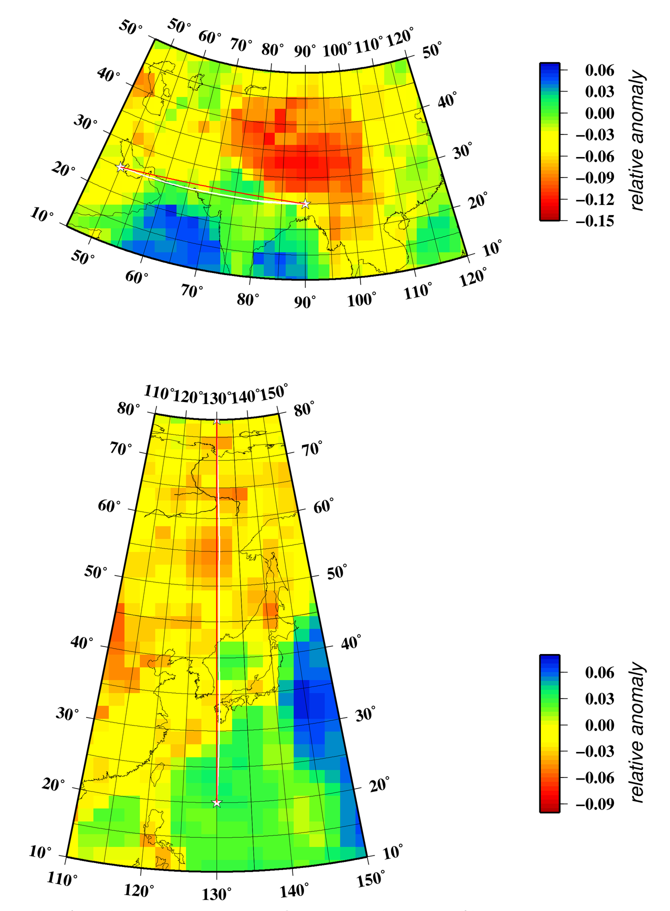

Figure 7: *Polarisation test for various distances. Areas such as Tibet (top figure) bend rays even for short epicentral distances. A polarisation of up to 10^o is seen for 30s Rayleigh waves. More homogeneous areas do not bend rays by very much.*

Concluding remarks

- Polarisation has good sensitivity to small scale structures, providing additional information for 3D velocity inversions.
- Factors that affect measurements are noise, epicentral distances, source depth and magnitude, and scatter from the crust. Taking these factors into account for event and station selection for inversions will greatly enhance the quality of phase velocity maps.
- Further work needs to be done to determine the effects of these and to produce an algorithm to sort events that will likely yield good measurements. Including polarisation can then be carried out to produce improved global velocity maps to locate the lithosphere-asthenosphere boundary.

Key References and acknowledgements

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