The effect of topography of upper mantle discontinuities on *SS* precursors

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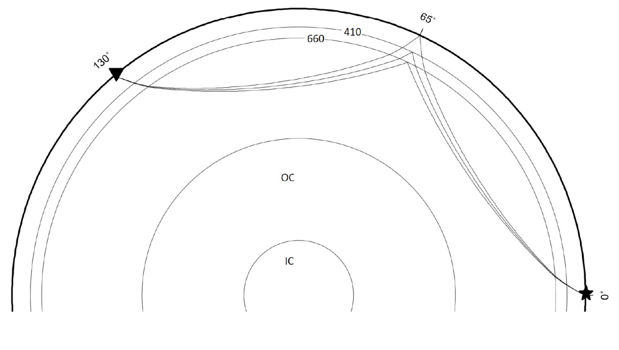
Introduction

The topography of mantle discontinuities found at about 410 and 660 km depth indicates phase, temperature and/or compositional changes. Studying the seismic structure of these discontinuities can deepen our understanding of the 3-D extend of these changes.

To date researchers relied on linearised ray theory to resolve the topography; however, many discrepancies amongst topographic models exist as well as biases towards existing mantle velocity models. Here, we test the reliability of these common approaches in a fully synthetic test. The linearised ray theory framework consists in gathering real data and assuming a similar ray geometry between the *SS* seismic phase and its precursors (Fig. 1). This enables the estimation of the topographic variation, δh, beneath the midpoint by measuring time differences (δt^{cc}) between the main phase and its precursors.

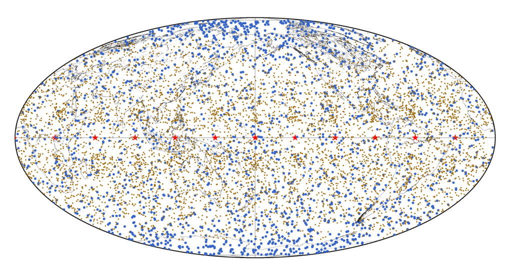


1) Ray geometry of *SdS*

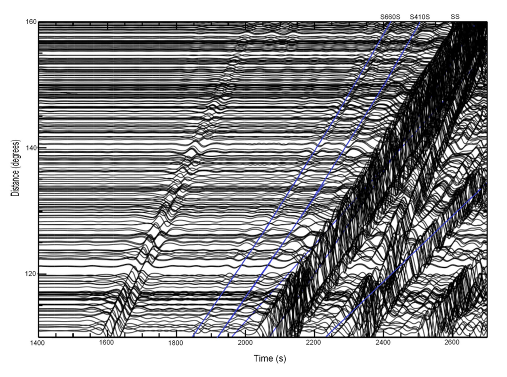
Method

Using SPECFEM3D [1, 2] we compute synthetic seismograms for PREM [3] and S20RTS [4]. All Earth properties are switched off, while topography models of the '410' & '660' [5] are added.

We simulate 6211 1-hr long transverse components for 4 different models (1-D & 3-D with and without topography). We used a random, uniform distribution of midpoints (Fig. 2a) to ensure even, global coverage. The synthetic waveforms are noise-free which allows us to identify the precursors in single seismograms (Fig. 2b).



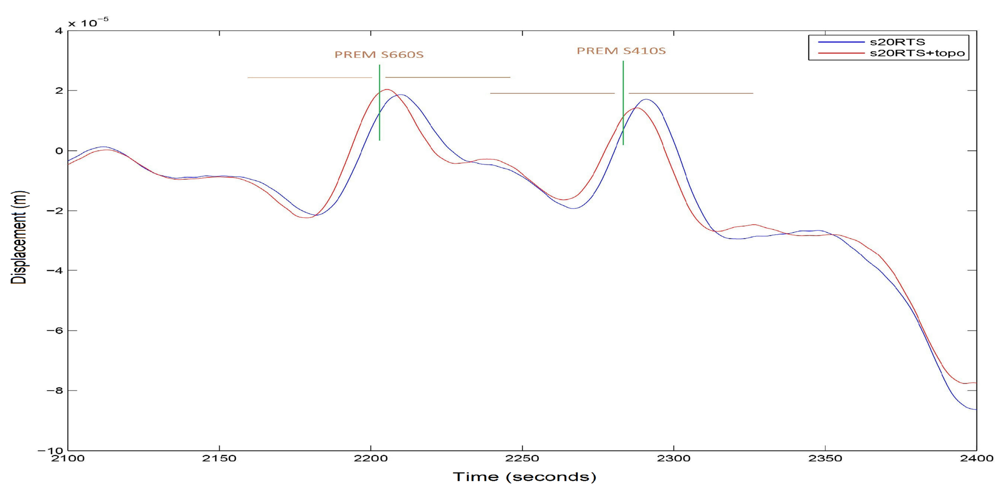
2a) *SdS* dataset



2b) Record section of *SdS*, between 110-160°

We measure δt^{cc} of the *SdS* phases caused by the added topography by cross correlation between transverse component seismograms of single stations.

$$\delta t^{cc} = t^{X+topo} - t^{X} \qquad (1)$$



3) Zooming on *SdS*, marked are the PREM arrivals and ±40 s windows.

Analysing δt^{cc} data

The measured travel time data δt^{cc} are analysed in 2 different ways:

1. By computing the predicted travel times using the already known δh, i.e:

$$\delta t^{rt} = \frac{-2\delta h cos i}{V_s} \qquad (2)$$

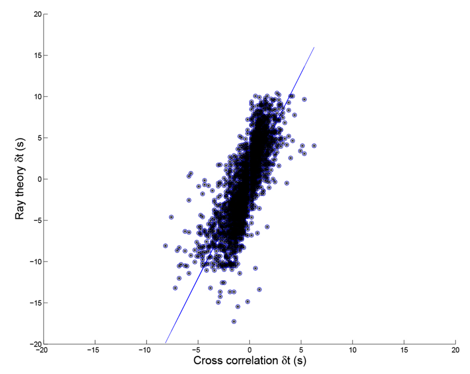
   we create scatter plots and perform a linear least-squares regression to see how well δt^{cc} & δt^{rt} agree (Figs 4a & 4b).

   The difference between the 2, i.e $\Delta t = \delta t^{cc} - \delta t^{rt}$, is presented in histograms to further inspect their statistical representation (Figs 4c & 4d).

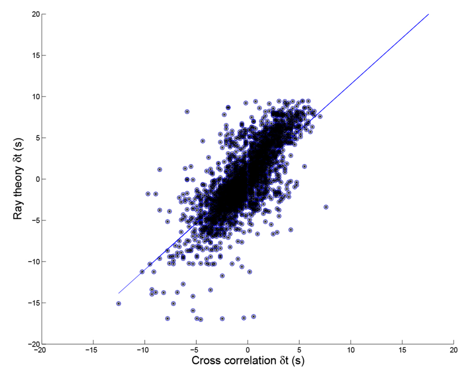
2. We infer the topography using $\delta h^{pred} = \frac{-\delta t^{cc} V_s}{2 cos i}$ (Fig. 5a), which we then expand into spherical harmonics (SH) in order to be able to compare it to the initial model (see Fig. 5b).

   We quantitatively compare the predicted and initial topography model (Fig. 5b) and show their correlation and rms amplitude ratio per harmonic degree (refer to Figs 5c & 5d).

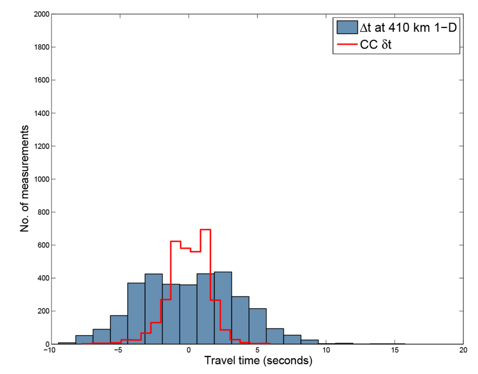
Results



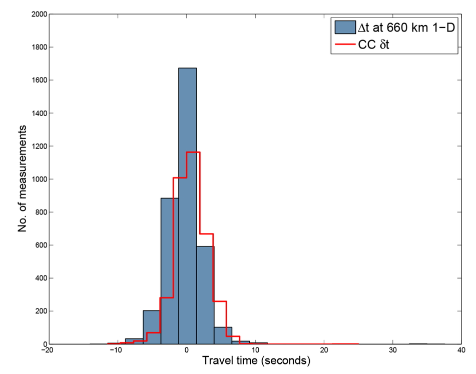
4a)



4b)

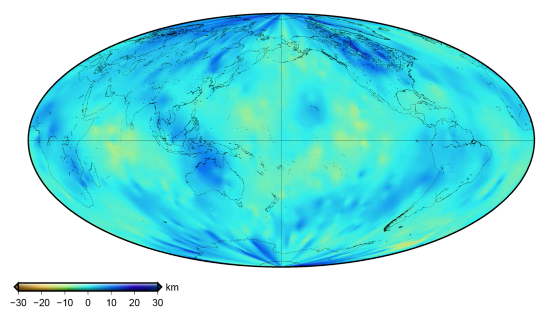


4c)

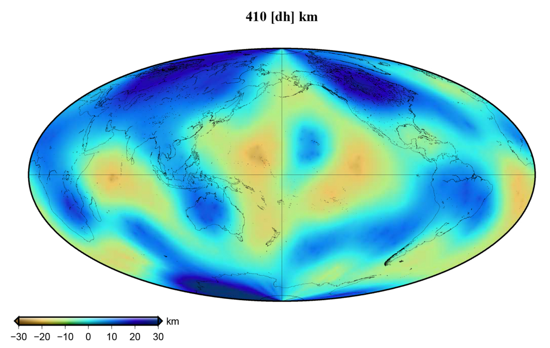


4d)

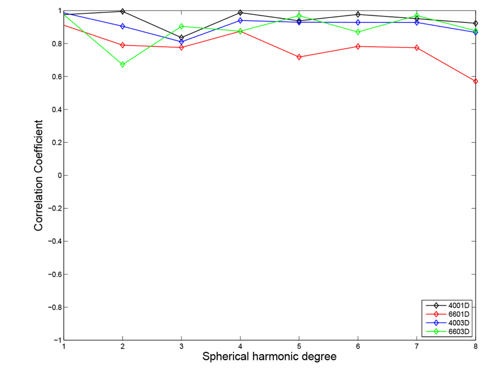
Scatter plot for '410' in 1-D (4a), the slope is far from 1. For the '660' (4b) the slope is less steep. Histogram showing the bi-modality of Δt at the '410' (4c), while the '660' (4d) exhibits normal distribution.



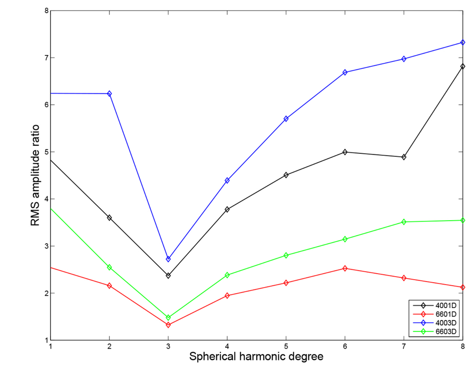
5a)



5b)



5c)



5d)

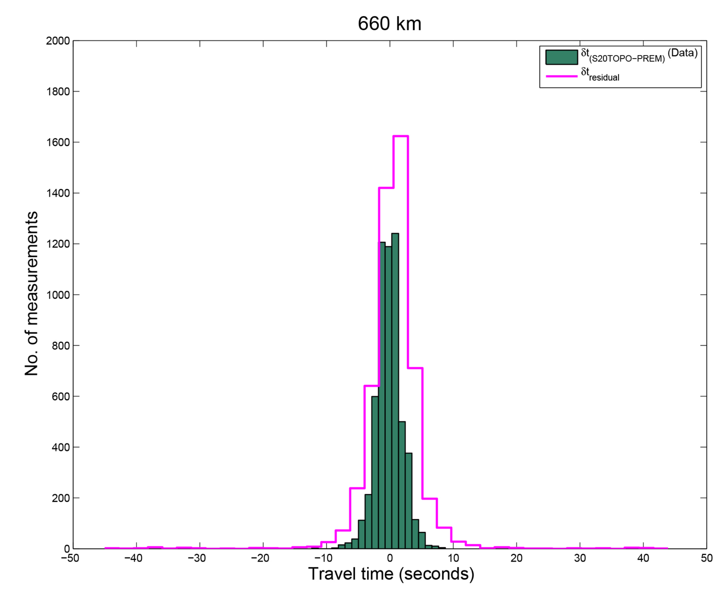
Comparing the inferred topography model of the '410' (Fig. 5a) to the initial (Fig. 5b), the subdued amplitudes are easily noticed. The correlation per SH degree (Fig. 5c) shows that the locations of models are well resolved, while the amplitude of the inferred topographic variations is much weaker (Fig. 5d), note that the rms ratio ranges from 2-7.

Linear Decomposition

Researchers usually get a 'clean' time difference due to the topography by considering that the δt^{cc} data can be linearly decomposed into a topography part, i.e $\delta t_{topo} = \delta t^{S20RTS+TOPO} - \delta t^{S20RTS}$, and a 3-D structure part, i.e $\delta t^{3-Dstructure} = \delta t^{S20RTS-PREM}$. We test this linear decomposition by defining the residual:

$$\delta t_{residual} = \delta t^{[S20RTS+TOPO]-PREM} - \delta t^{[S20RTS+TOPO]-S20RTS} - \delta t^{S20RTS-PREM} \qquad (3)$$

If the delay times can indeed be linearly decomposed, this residual should be identically zero.



The histogram shows that the $\delta t_{residual}$ is wider than the data themselves, indicating that the linear decomposition usually deployed to obtain a time delay only due to topography cannot give accurate results because of the non-linearity characterising the δt data.

Conclusions

Our analysis of *SdS* delay times due to added topography showed that these cannot be linearly decomposed into a 3-D velocity and a topography part, which means that linearised theories will never be able to invert for the topography in a single iteration. It is essential to infer the topography and the velocity structure together using a fully non-linear technique (ray theory or full waveform). More details can be found in our paper [6].

References

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