Improving tomographic maps using surface waves

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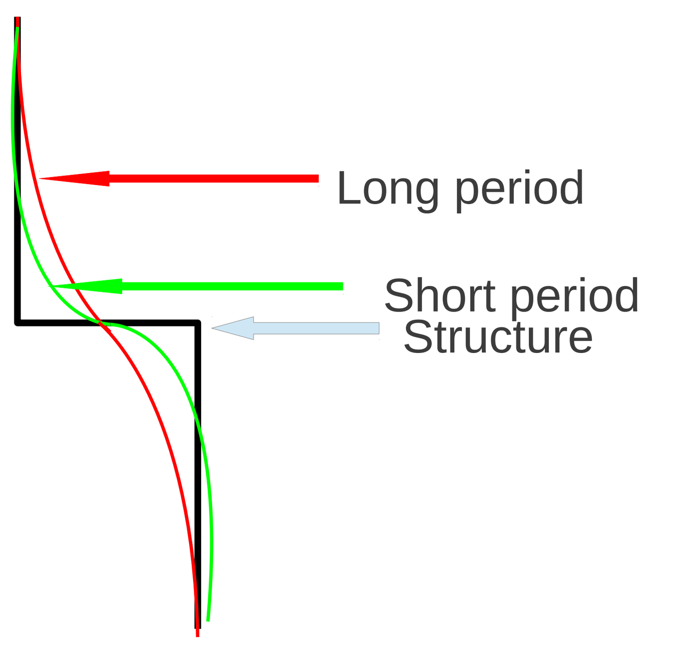
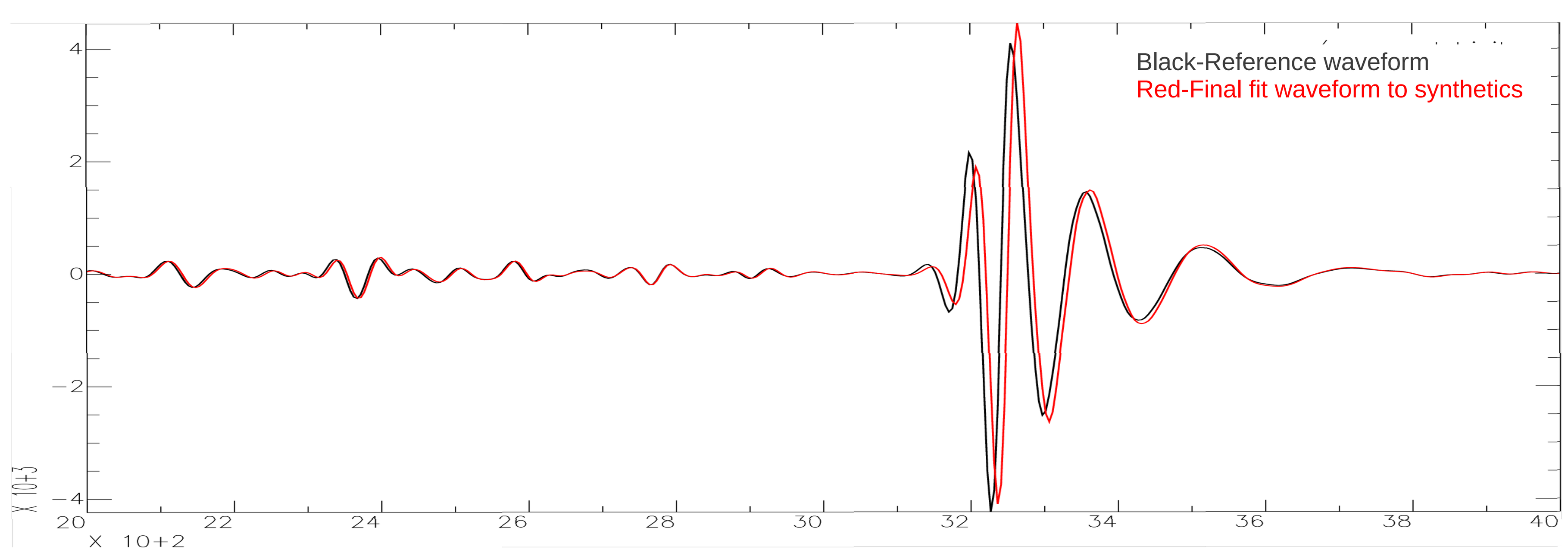
1. Introduction

- Global tomographic models have undergone vast improvements over the last 10-15 years. However, a large amount of data remains unused.
- Shorter period surface waves (<50 s) can be used to improve both horizontal and vertical resolution because they are more sensitive to sharper changes in velocity structure.
- Two problems occur arise when shorter period information is added – the great circle path approximation (GCP) and crustal uncertainty.
- We aim to assess the relative errors associated with these problems when going to shorter periods (<50 s) and we will be looking at Rayleigh waves in this study.



2. Upper mantle inversions and crustal errors

- When performing inversions of the upper mantle, we assume the crustal model (3SMAC) is accurate. We keep this fixed throughout the inversions process.
- Synthetic waveforms are generated with the average crustal structure along a source- receiver pair underlain with a reference mantle model. These are compared to the real data. Any differences in the waveform are attributed to the perturbation in mantle structure to the reference model.
- Problems occur when the crustal model used in the inversion is different from that which the surface wave has propagated through.

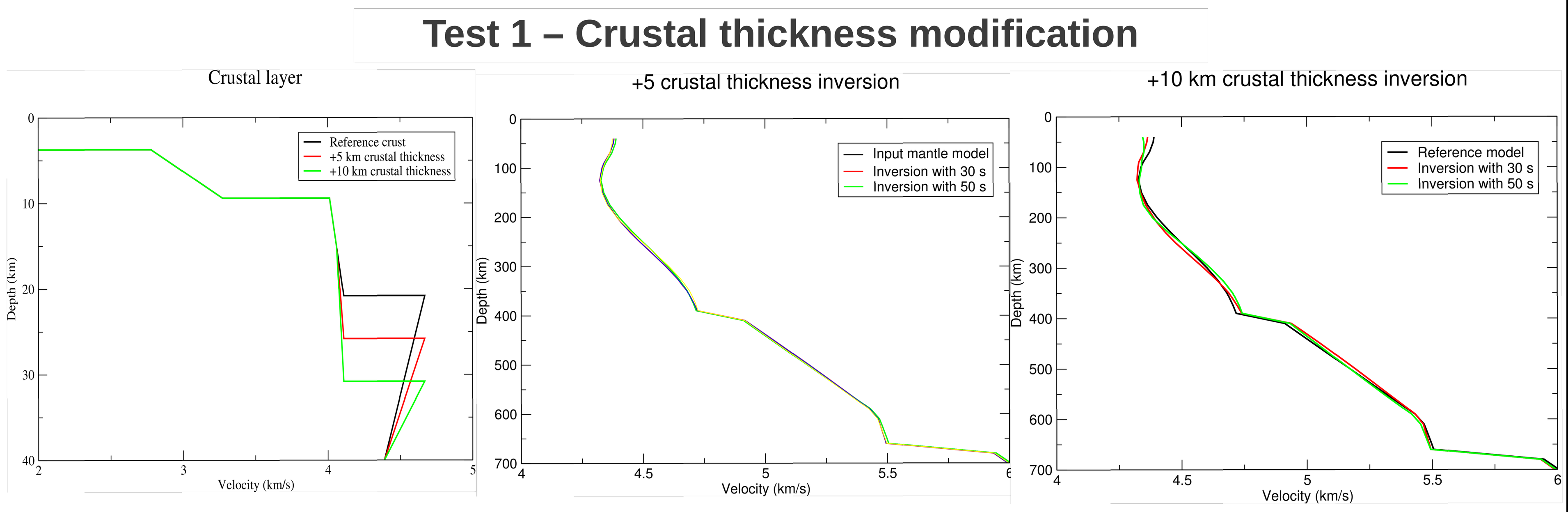


- A waveform fit including 30 s period information. Black line is the reference model waveform and the red line is the final fit waveform with a perturbation to the crustal thickness of +10 km (mantle layers and upper crust are the same as reference model). The difference in waveform is interpreted as a difference in mantle structure during inversion.

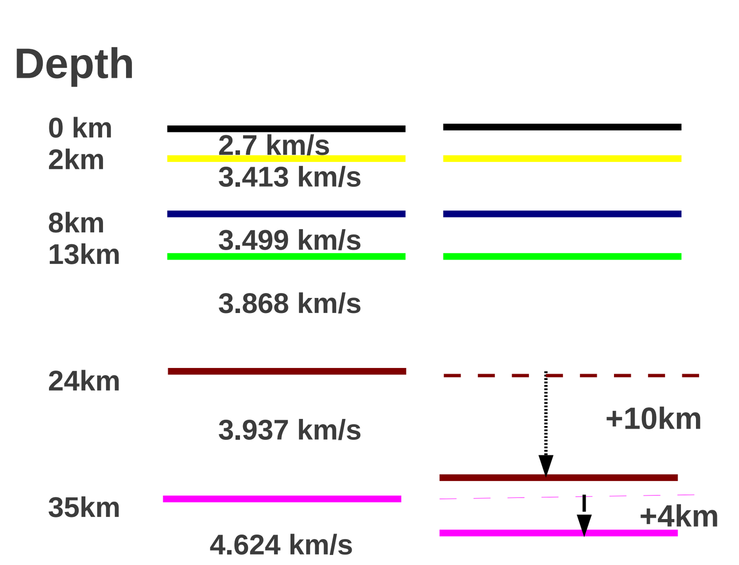
3. Synthetic tests of crustal errors

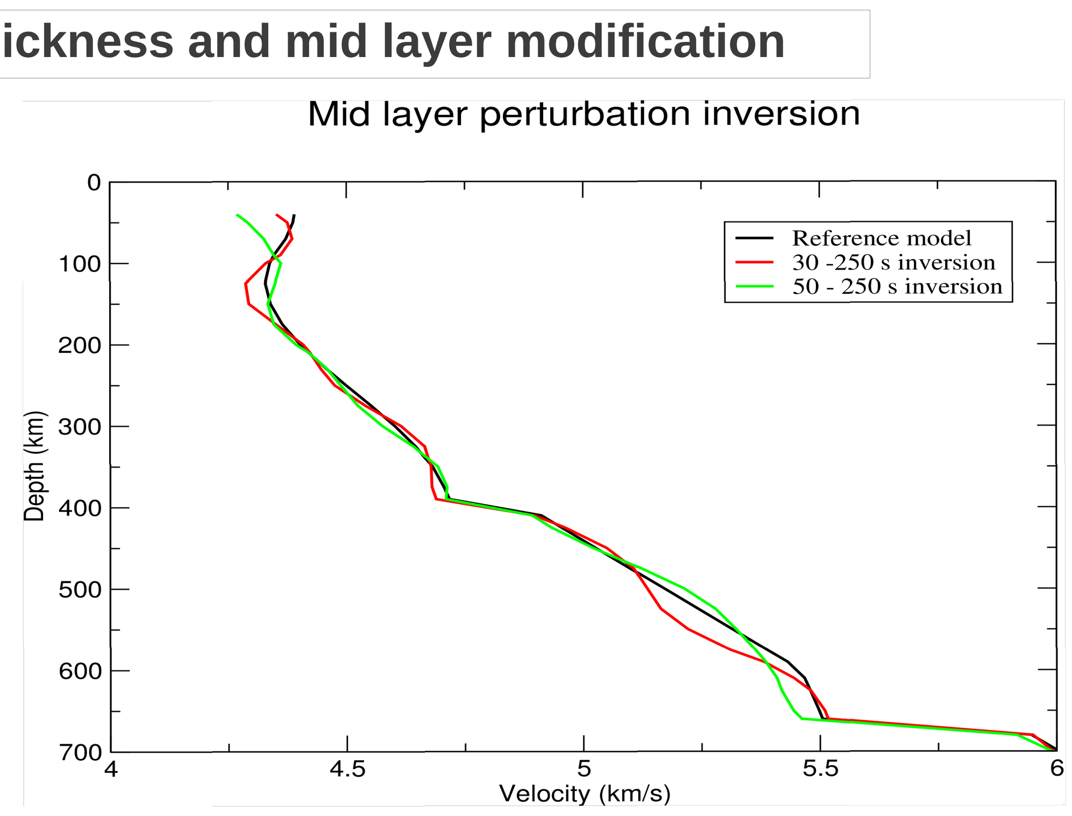
- Synthetics generated using modal summation [Saito 1988] . A reference mantle model is superimposed on three different crustal structures, two where the crust is made thicker than the assumed crustal model (test 1) and one where both crustal thickening and a perturbation to the thickness of a mid layer at 24 km has been made (+10 thickening).
- The reference mantle model is the same starting model used in the inversion. This allows us to see the effects of the crust only.
- Inversion performed using an automated waveform inversion [Debayle and Ricard 2012].

Test 1 – Crustal thickness modification



Test 2 – Crustal thickness and mid layer modification

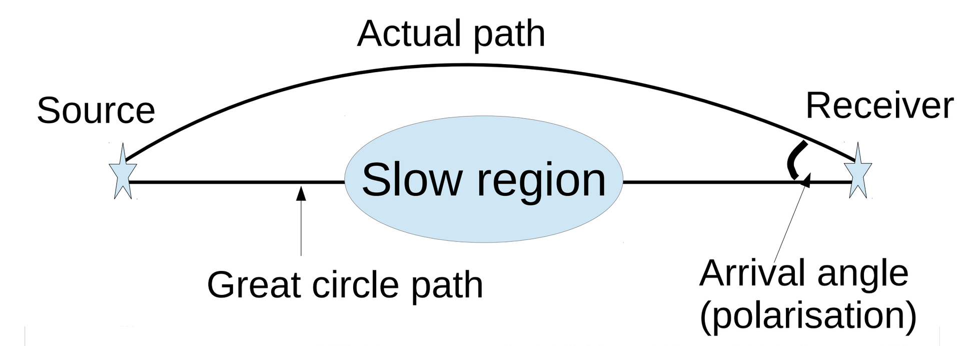


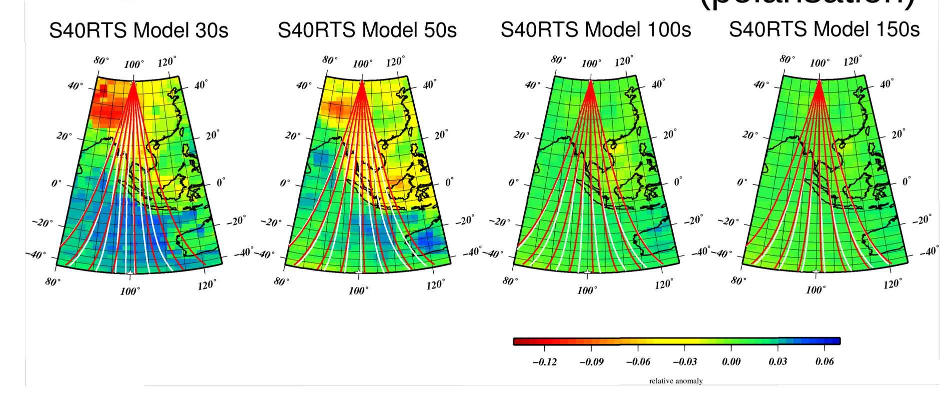


- In general, errors are larger as the difference in crustal structure increases. Deviation is very slightly larger when 30 s period information is included.

4. The great circle path approximation

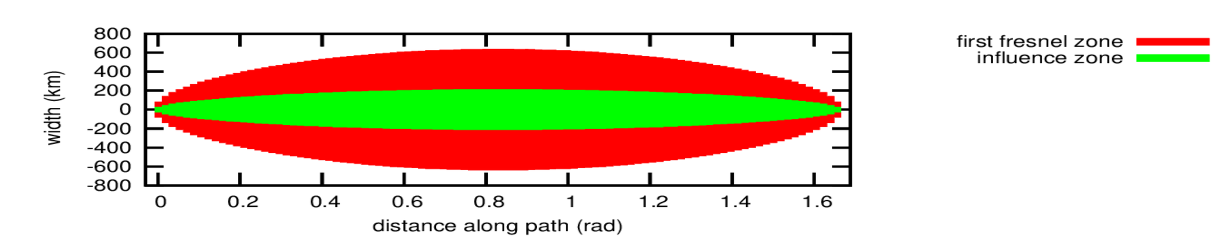
- GCP approximation-seismic energy travels from source to receiver along the shortest path.
- Short period surface waves are more likely to deviate from this due to scattering
- A plot of surface wave propagation paths thorugh Asia. These were calculated using ray theory (Boschi and Woodhouse 2006). Red lines are GCP and white lines are the propagation paths. Each were simulated with different take-off angles.





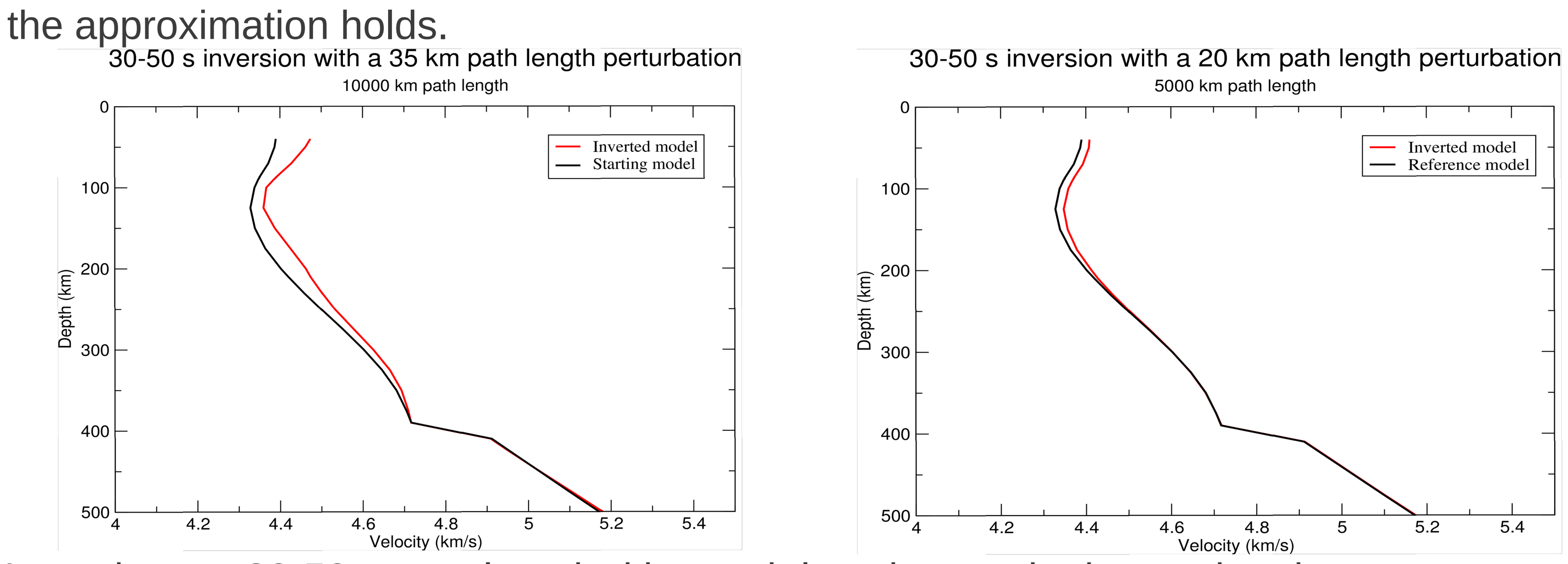
5. The effects of the GCP approximation

- The GCP will always be shorter than the actual propagation path. Arrival time measured during an inversion however is correct. Since we assume a shorter path in the inversion, the velocity calculated is then slower than actual velocity of the wave.
- Additional problems arise due to the sensitivity of the wave.



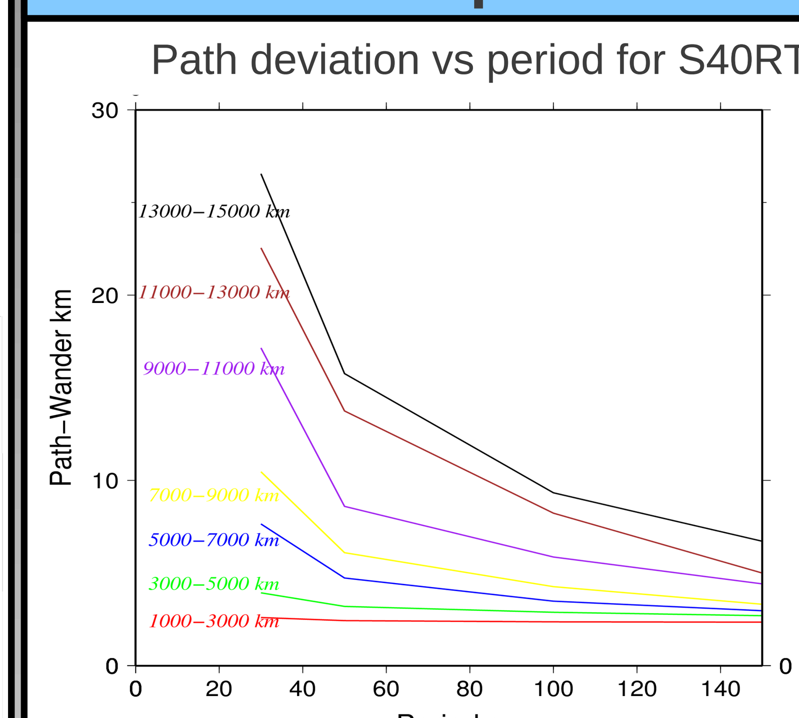
Calculated for 30 s on a 10000 km path length.

- Any wave propagating within the influence zone (green) is sensitive to the GCP [Yoshizawa and Kennett 2002] . If it propagates outside this area, the approximation breaks down.
- If the propagation path length is shorter than the path that grazes the edge of the influence zone, the approximation holds.

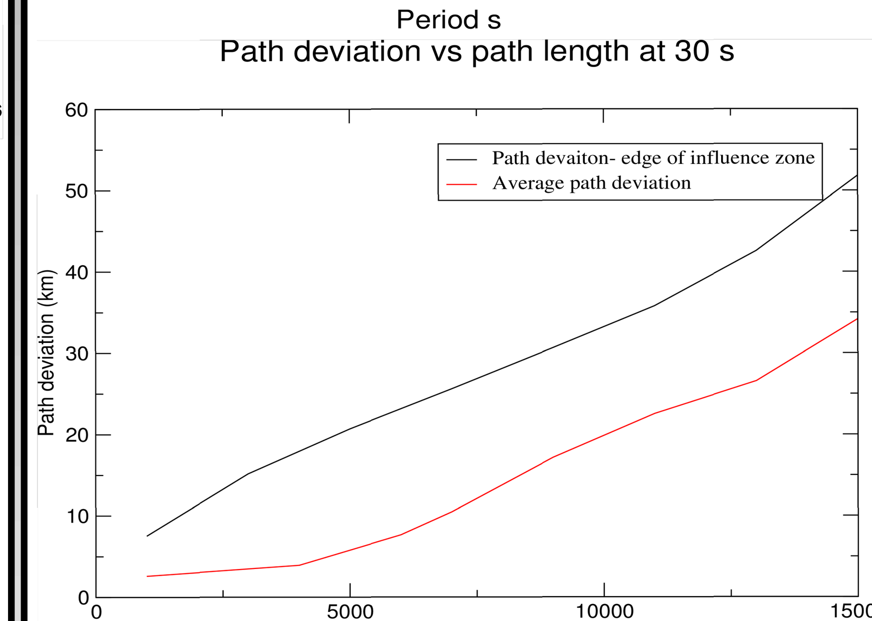


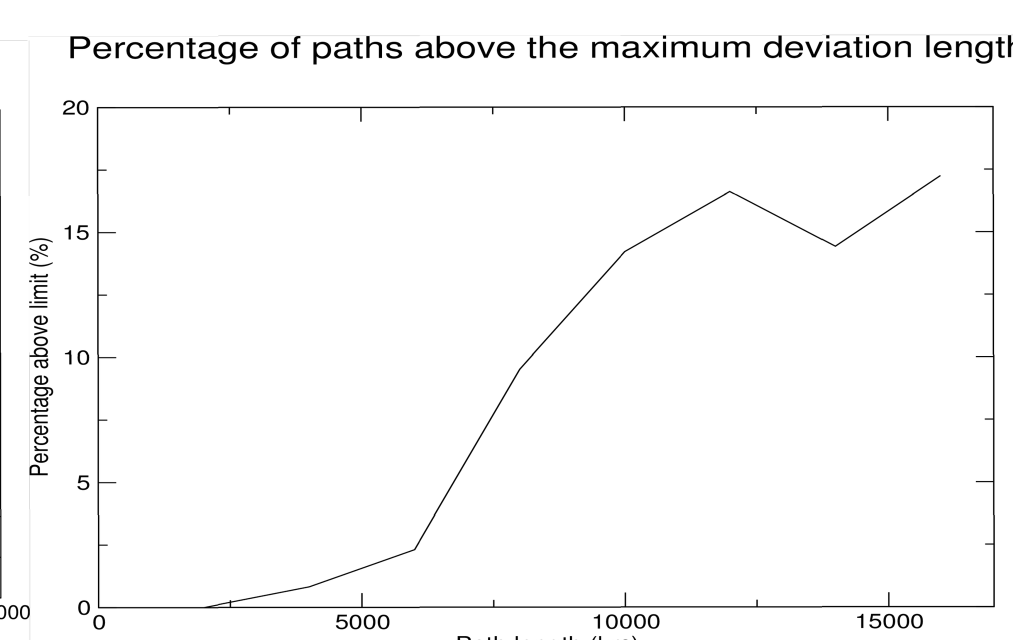
- Inversions at 30-50 s are plotted with a path length perturbation so that the wave propagates near the influence zone edge for 5000 km and 10000 km. These represent the upper bound in the errors of the inversions for the particular path lengths.

6. Theoretical path deviations from ray tracing



- Average path wander (path length difference between the GCP and propagation path) was calculated using the fast marching method for 20 sources and 141 receivers across the world for model S40RTS.
- Path wander increases with decreasing period and increasing path lengths.
- Plotted below are the maximum path deviations (edge of the influence zone) relative to the average deviation and the percentage of paths greater than maximum length for each path length.





7. Summary

- An accurate crustal model must be used in the inversion process to reduce the errors caused by the difference in assumed and actual crustal structure.
- The GCP approximation will hold in most cases but gets worse with longer path lengths. Using paths shorter than 6000 km is an option to minimise the problem. This means that there will be sensitivity on the great circle path and the error in structure due to a wrongly assumed path length is reduced.