The Impact of Lateral Velocity Heterogeneities on Multi-Mode Surface Waveform Inversions

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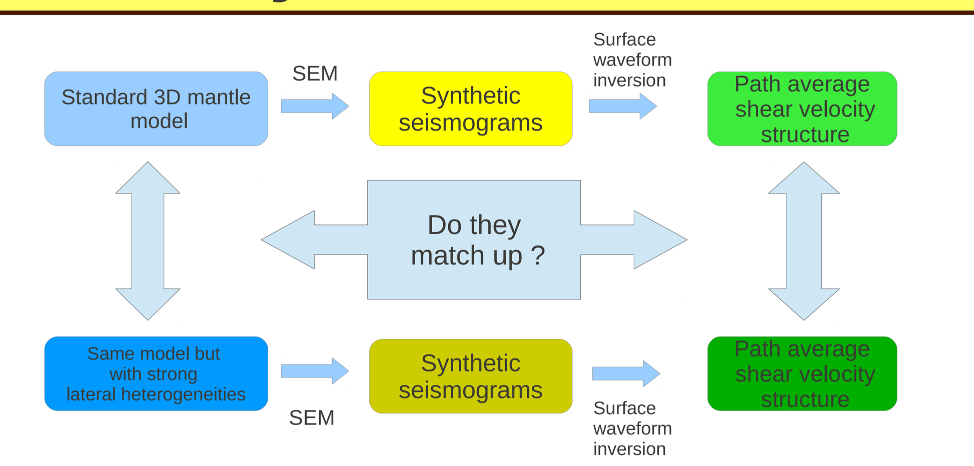
1. Overview

- The ultimate goal is high resolution imaging of the global upper mantle through surface wave tomography
- This requires incorporation of shorter period and higher mode surface waves than we are currently able to use
- At short periods, strong lateral variations in velocity structure may lead to effects like mode coupling which are not accounted for in the tomographic procedure
- The tomography is done in 2 steps – waveform inversion of each seismogram for path average shear velocity structure and then a tomographic inversion that combines all path average models
- This study focusses on the first step, which is performed using Debayle and Ricard's (2012) automated implementation of the Cara and Leveque (1987) method of inversion using secondary variables

2. Study Method



3. Forward Modelling using the Spectral Element Method

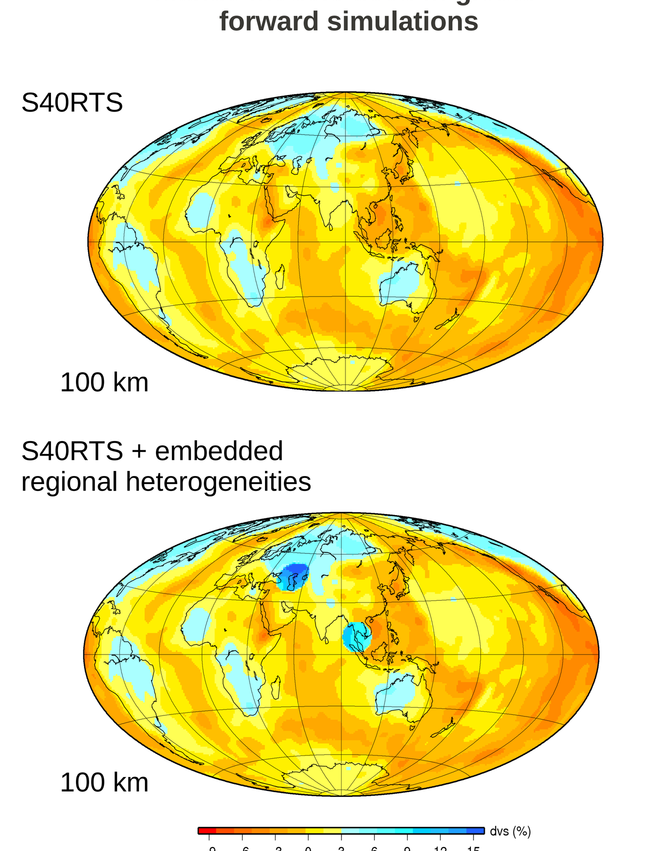


Figure 1: Depth slice showing the 'regular' and 'perturbed' mantle models used in this study. The 2 velocity heterogeneities in the perturbed model have a thickness of 140km and strength of +10% each. They extend 2000 km across

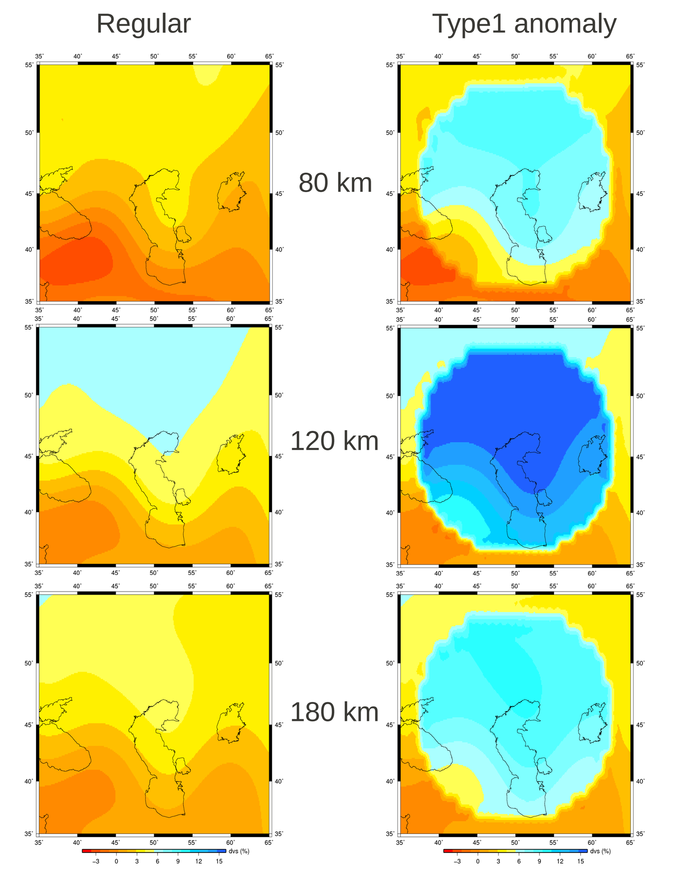


Figure 2: The heterogeneities extend from 60 to 200km depth but are vertically smooth over a length scale of 40km. The strength of the perturbation Is 10% between 100 and 160km, but falls off linearly above and below these depths.

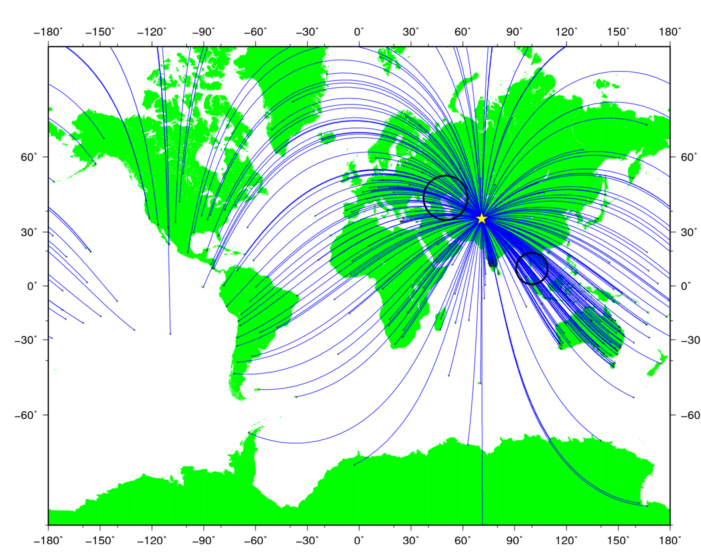


Figure 3: The yellow star marks the event location and blue lines are great circle paths to stations (red dots). The event chosen in this study is a magnitude 6.1 earthquake that occurred in 2009 in the Hindu Kush region. Depth of the event was 186 km. Relatively large and deep events are suitable for such a study as they are likely to excite higher surface wave modes.

All simulations performed using SPECFEM3D GLOBE v5.1.5 PREM crust is used

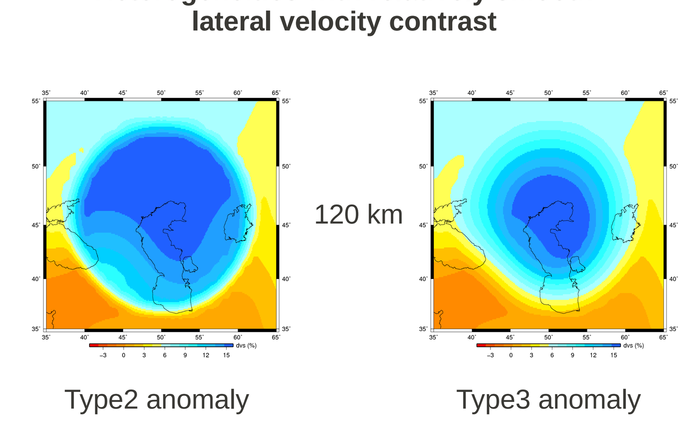


Figure 4: In the latter part of this study, we alter the nature of artificial heterogeneities so as to reduce the sharpness of their boundaries. This is done because the extent of surface wave mode coupling depends on lateral velocity gradients. The figure shows a slice of the same anomaly as in Figure 2, but with lateral tapers of 200km (left) & 600km (right)

4. Synthetic Seismograms from Forward Modelling

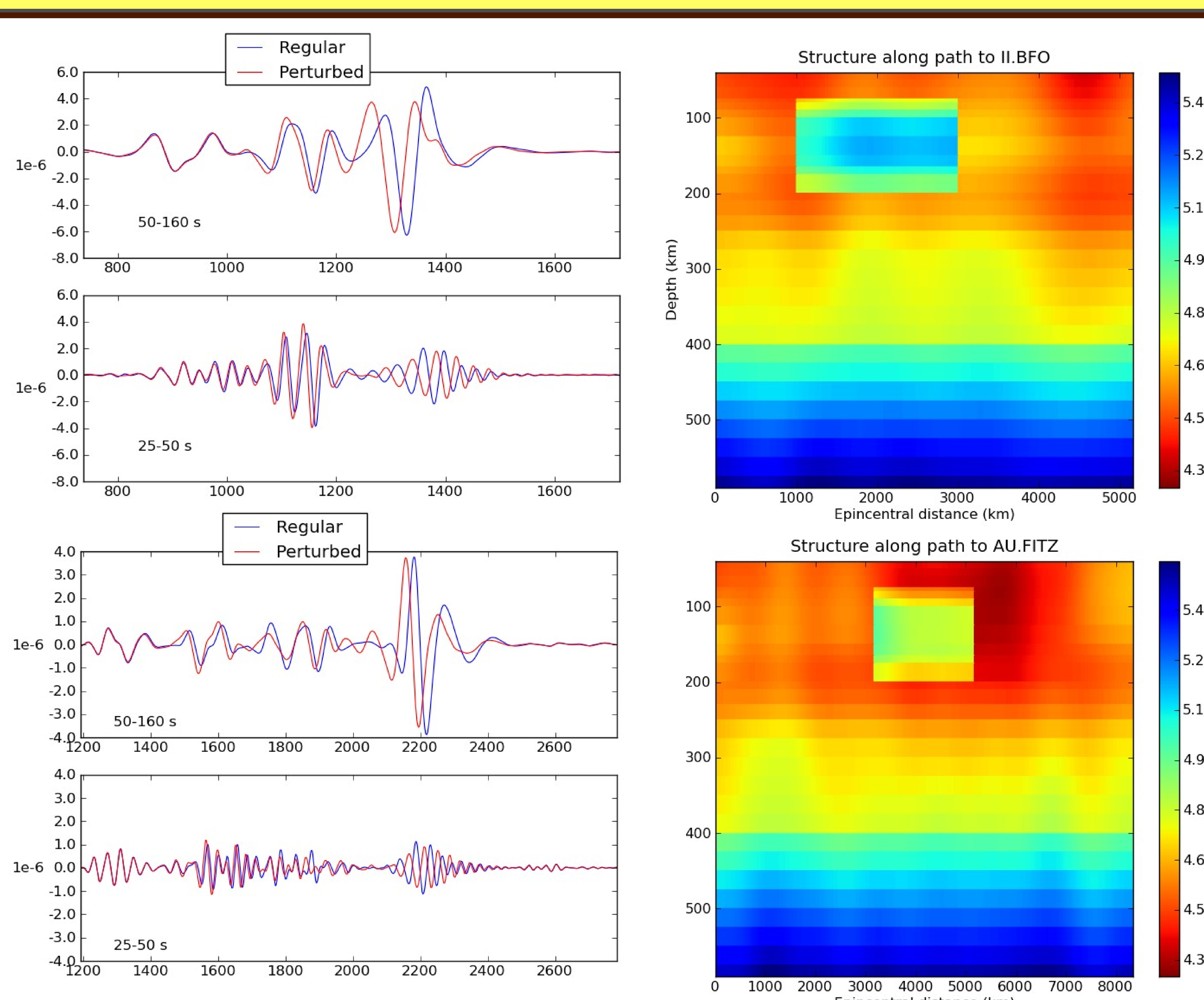


Figure 5: Synthetic seismograms (left panel) and absolute shear velocity models along the great circle path (right panel) for two particular stations. The seismograms have been filtered in 2 different frequency bands indicated on the figures, and windowed to show the surface wave part. The x-axis is time in seconds. In the right panel, a Type1 anomaly is clearly visible for both paths.

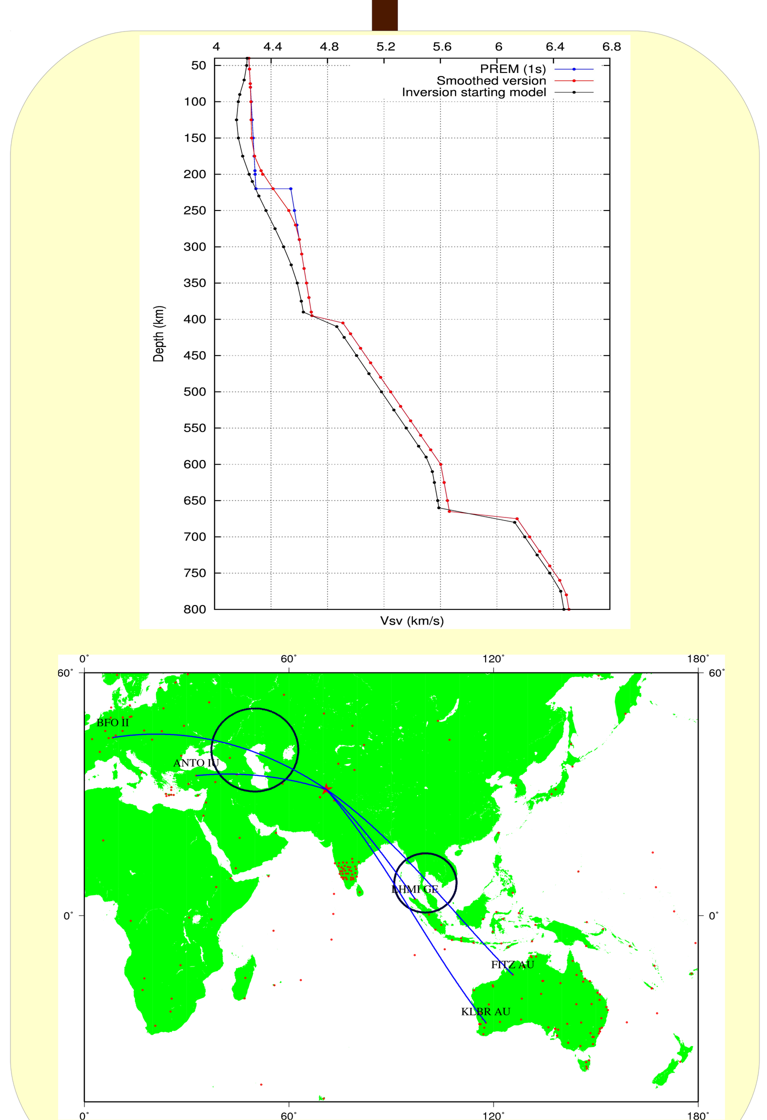
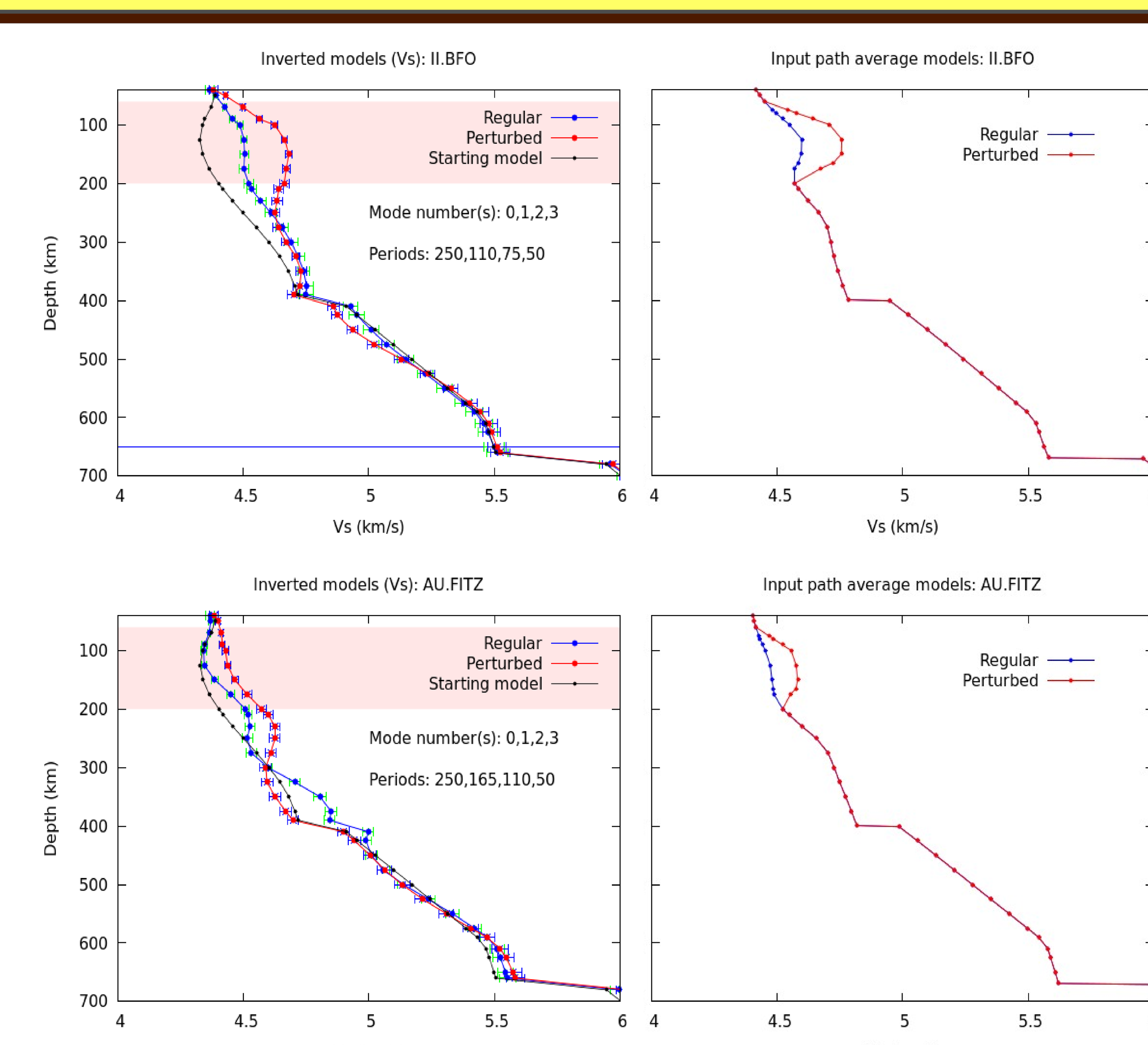


Figure 6: general information

The 220km discontinuity in PREM (background model to S40RTS) is smoothed out to mimic the inversion apriori model

5. Waveform Inversion of Synthetic Seismograms



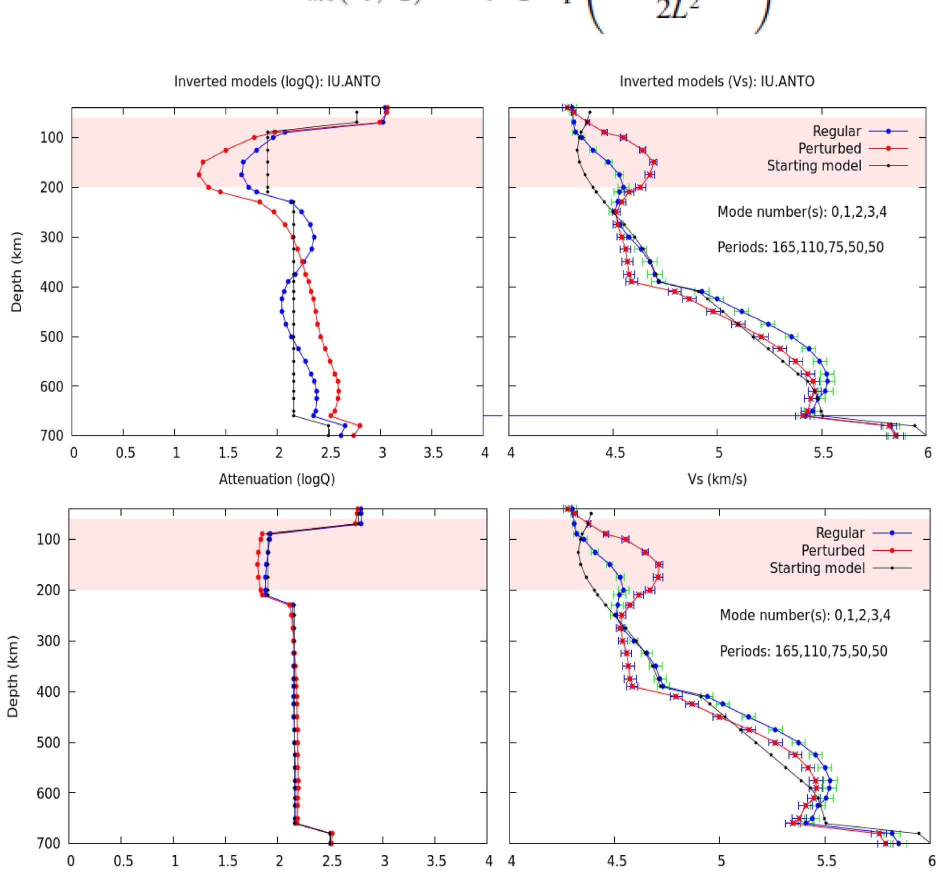
The crust, which is held fixed in the inversion, is taken from PREM. This represents an exactly correct apriori choice

Figure 7: Inversion results for the 2 stations considered in section 4. The left panel shows the inverted models, with the shaded region showing the depth extent of heterogeneities. The right panel shows the true path average models. Clearly, the inversion for the first path is much more desirable than that for the 2nd, which shows artefacts at depth.

5. Effect of Attenuation

- Besides shear wave velocity, 2 other parameters are inverted for in this method – attenuation and seismic moment (parameterized as logQ and logM₀ respectively)
- In this study, the apriori attenuation model was taken to be equal to that used in the computation of spectral element synthetics (PREM at 1s period)
- Despite this highly accurate apriori choice, here we investigate the effects of inverting for logQ or keeping it fixed in the inversions
- This is done by changing the apriori error for logQ. The covariance function for 2 depths z_1 and z_2 is given, for a vertical correlation length L (50 km), by

$$C_{m0}(z_1, z_2) = \sigma_1 \sigma_2 \exp\left(\frac{-(z_1 - z_2)^2}{2L^2}\right)$$



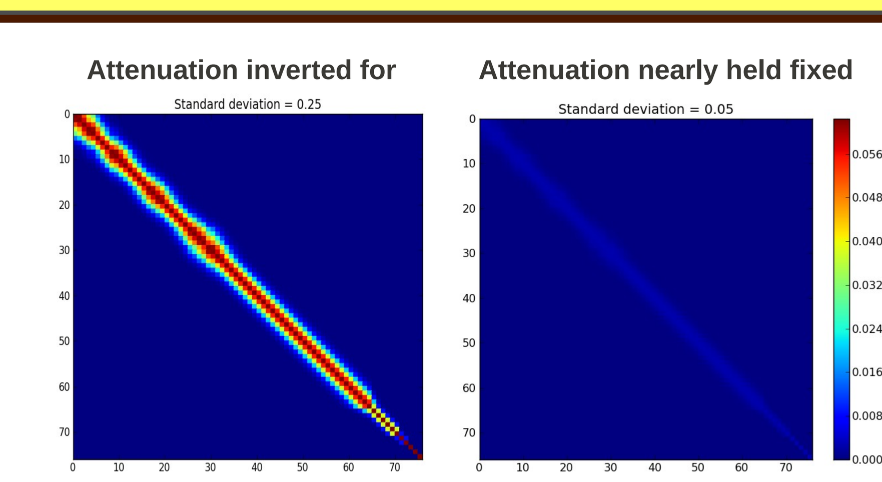
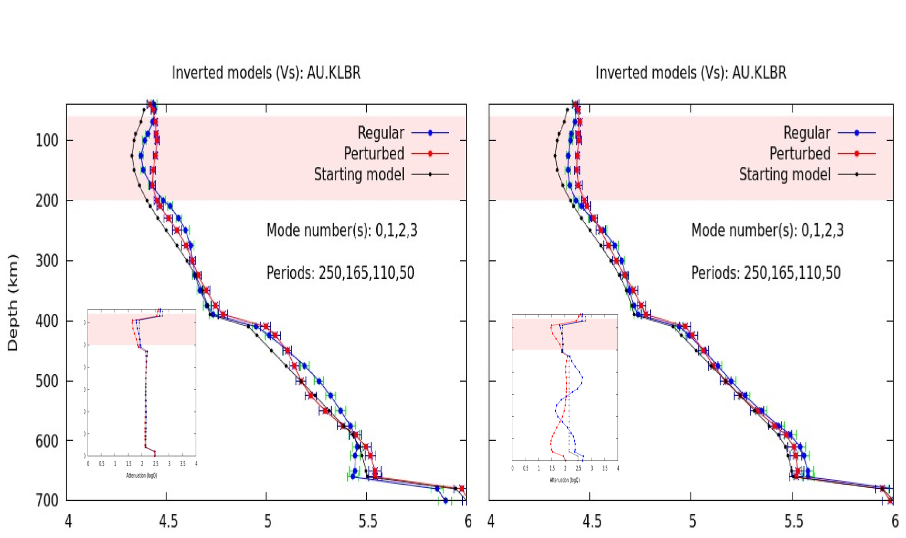


Figure 8: Apriori covariance matrices for logQ when it is allowed to vary and when it is held fixed in the inversion. These are obtained using a large and a small value respectively, for the depth-independent standard deviation on logQ

Figure 9: Examples to illustrate that allowing logQ to vary in the inversion despite having an accurate apriori attenuation model, may not affect the shear velocity model obtained from the inversion (left) or may actually improve it (below). This may be indicative of 'apparent' attenuation due to focussing/de-focussing in a 3D earth.

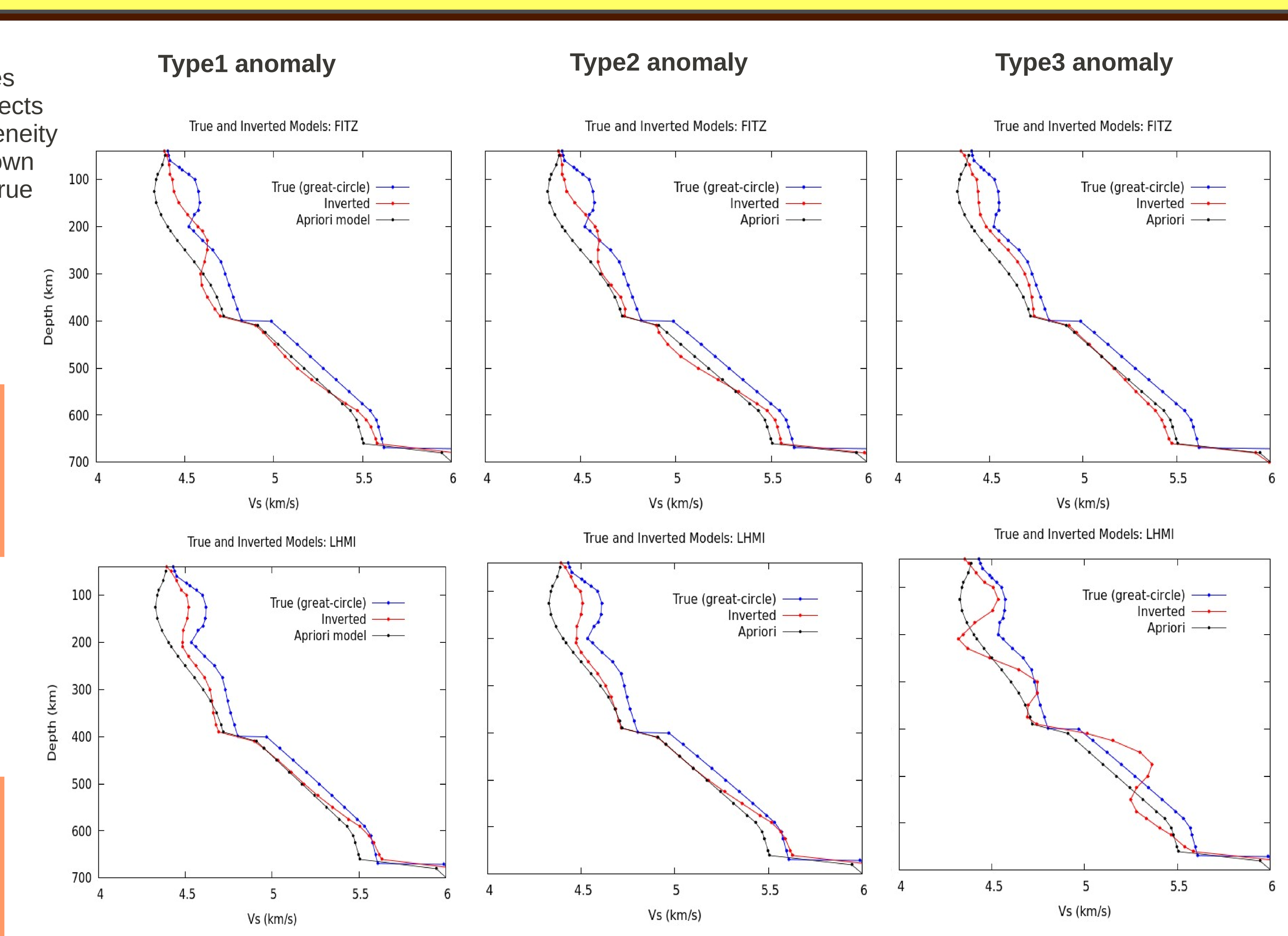


6. Effect of Lateral Gradient in Velocity Structure

Figure 10: Two examples exhibiting contrasting effects of sharpness of heterogeneity on inversion results. Shown are comparisons of the true and inverted models for the 'perturbed' case

Inversion improves with reduced sharpness of boundary

Inversion worsens with reduced sharpness of boundary



References and acknowledgements

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