Inner core anisotropy measured using new ultra-polar PKIKP data and corrected for mantle structure.

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Introduction & Data

Overview

The inner core is anisotropic: seismic body waves traveling in a polar (north-south) direction are faster than those which travel in a equatorial (east-west) direction. This anisotropy is due to alignment of iron crystals in the inner core. We measure anisotropy by studying travel times as a function of ζ which is the angle between an inner core raypath and Earth's axis of rotation and if ζ > 35º it is equatorial, if ζ <35º it is polar and if ζ<20º it is ultra-polar.

The three main challenges with measuring inner core anisotropy are:

1) A lack of Ultra-Polar data which results in extrapolation of inner core velocity at low values of ζ
2) Explaining the anomalously fast South Sandwich Islands to Alaska raypaths
3) Are the observed hemispherical variations an artefact of using South Sandwich Islands raypaths

We address these questions by collecting a large data set of polar raypaths which do not originate from the South Sandwich Islands and have very low values of ζ and by applying mantle corrections to our entire data set.

Data

We use PKPdf, PKPbc and PKPab phases to measure inner core velocity (Figure 1).

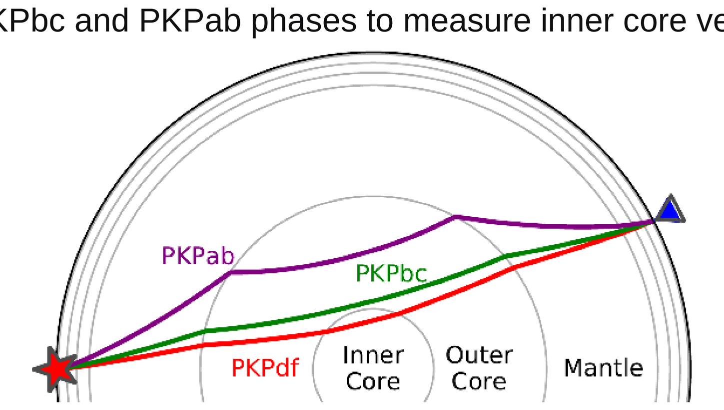


Figure 1) The paths taken by the PKPdf, PKPbc and PKPab phases through the Earth

Differences in the arrival times of these phases are used to measure inner core velocity. Seismograms with core phases (Figure 2) for different values of ζ show that the PKPdf phase arrives much earlier along the polar and ultra polar paths compared to the equatorial path.

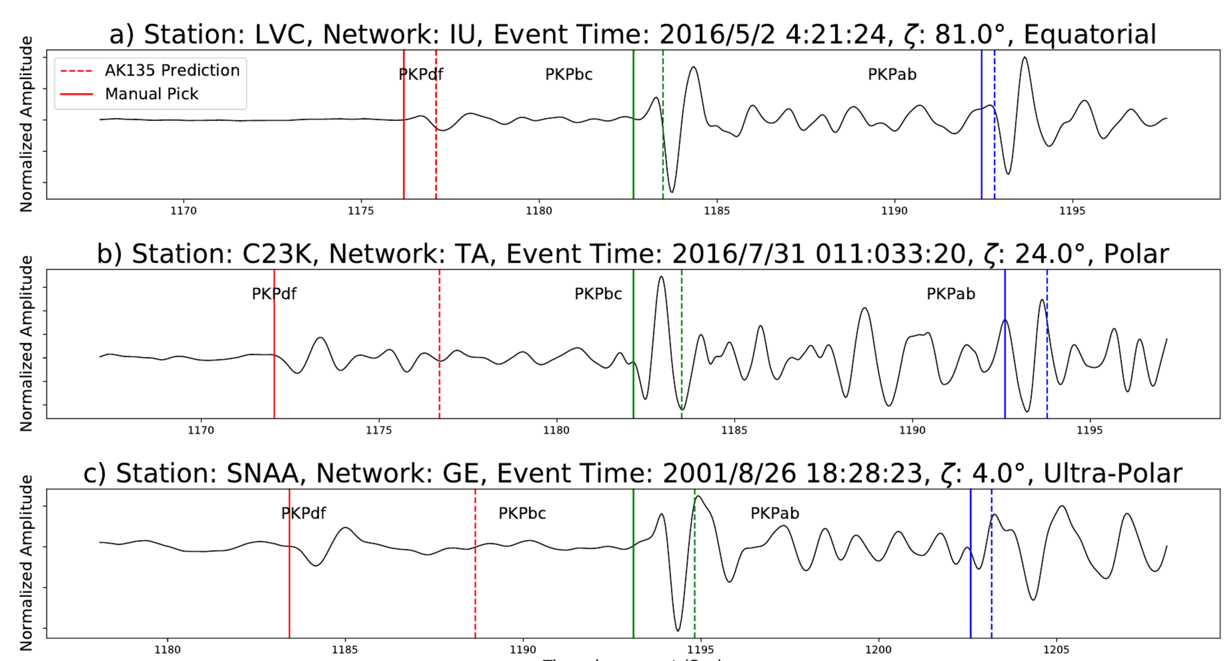


Figure 2) Three example seismograms showing an equatorial path, a polar path and an ultra polar path with the PKPdf, PKPbc and PKPab phases for different values of ζ.

We have collected a large data set of 755 PKPdf-PKPbc raypaths and 1580 PKPdf-PKPab raypaths, of which 998 are Polar (ζ<35º) and of those 148 are ultra polar (ζ<20º). This is after inspection of over 211,000 seismograms

We calculate differential travel times from these arrivals providing a measurement of inner core velocity using the following equation:

$$\frac{\delta t}{t} = \frac{\delta v}{v} = \frac{(\mathrm{PKP_{bc}} - \mathrm{PKP_{df}})_{\mathrm{data}} - (\mathrm{PKP_{bc}} - \mathrm{PKP_{df}})_{\mathrm{AK135}}}{t}$$

Where t is the time spent by the PKPdf phase in the inner core as modeled by the 1D reference model AK135.

With enough differential travel times over a large range of ζ we can then fit the following function to the data:

$$\frac{\delta t}{t} = \frac{\delta v}{v} = a + b\cos^2(\zeta) + c\cos^4(\zeta)$$

Where *a*, *b* and *c* are the Love parameters which describe cylindrical anisotropy, *a* is fractional difference in the velocity in the slow direction while *b+c* describes the difference in velocity between the slow and fast directions as a percentage.

Ultra-Polar Raypaths

Previous research has had poor sampling of polar data with very few ultra-polar paths (ζ < 20º), and most of the polar data originated from the anomalously fast South Sandwich Islands events traveling to stations in Alaska.

- Due to an increase in seismic stations in the polar regions (Figure 3) we have now collected arrivals from 963 Polar paths of which 150 have ζ < 20º and 623 do not originate from the South Sandwich Islands (Figure 4).
- This significantly improves estimates of inner core anisotropy as we can now sample the full range of ζ for the inner core and no longer have to rely on the South Sandwich Islands for polar data (Figure 4)

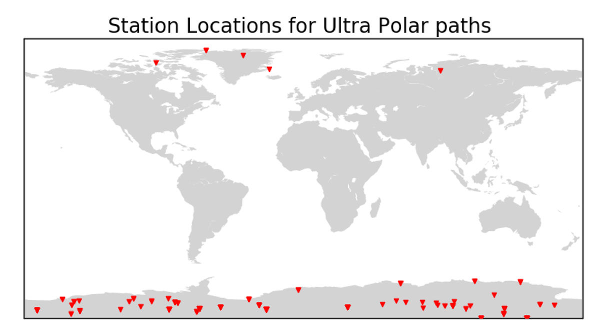


Figure 3) The seismic station locations used to measure ultra-polar (ζ <20º) data

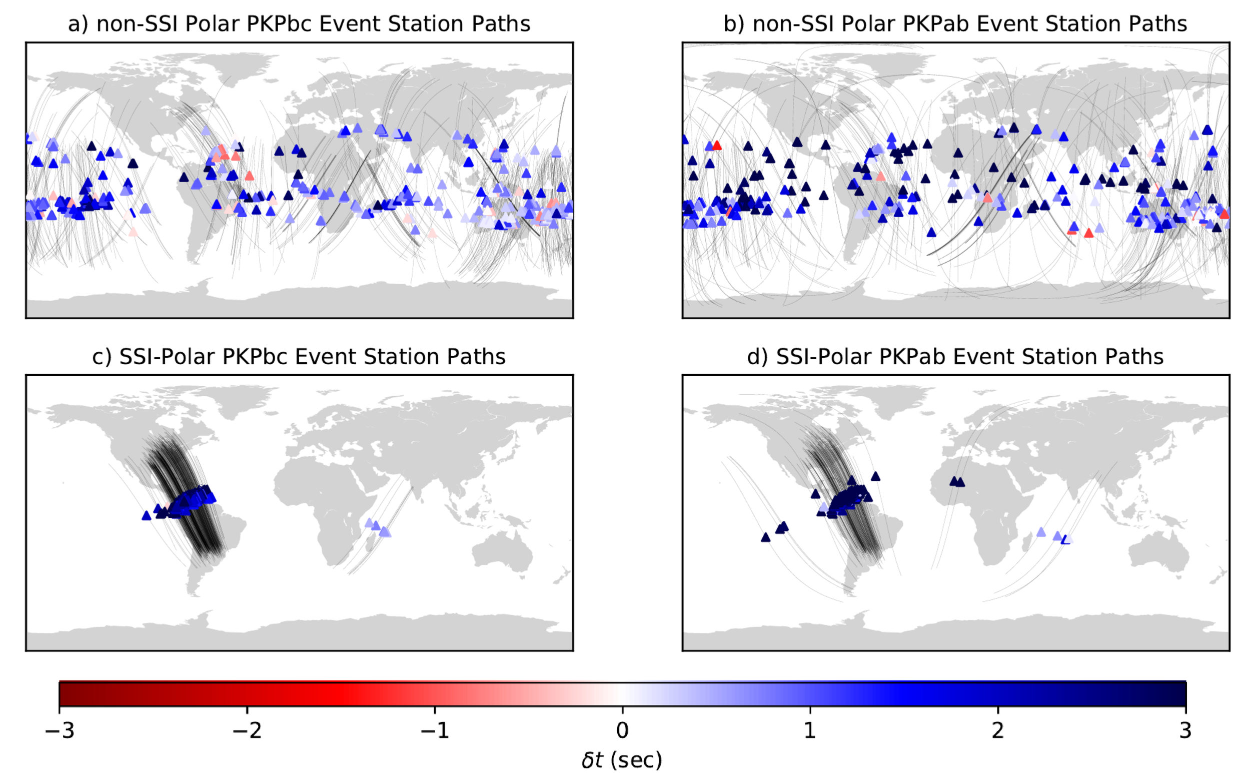


Figure 4) a) and b) maps of the PKPbc-PKPdf and PKPab-PKPdf inner core paths for non-SSI polar data and c) and d) for the SSI data. The δt of the raypath is plotted at the turning point.

Mantle Corrections & The South Sandwich Islands

Strong mantle heterogeneity may affect differential travel times, so to correct for this we do 1D ray tracing through the UUP07 (Amaru 2007) P-wave tomographic model. We find that the South Sandwich Islands data is most affected with velocities significantly reduced

- CMB pierce points for the PKPdf phase sample much faster mantle structure than the PKPbc phase underneath the South Georgia slab.
- The mantle corrections for UUP07 and the South Sandwich Islands measured differential travel times are strongly correlated (Figure 6)
- Doubling the amplitude of the velocity anomalies in UUP07 moves the SSI measurements to be similar to the other measurements (Figure 7) reducing anisotropy from 2.2%-2.5% to 1.8%-2.3%

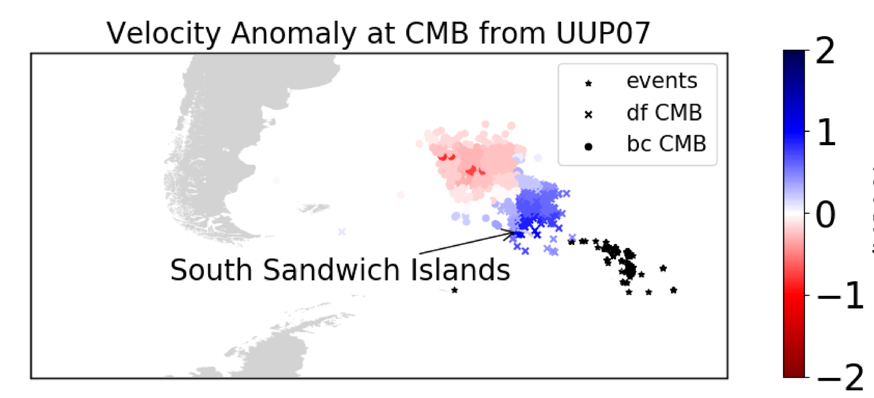


Figure 5) Locations of the South Sandwich Islands events, the PKPdf and PKPbc CMB pierce points. The color is the velocity anomaly from UUP07 at those locations at the CMB. This shows that the PKPdf and PKPbc phases sample very different velocity structure in the lower most mantle

Mantle structure under the South Sandwich Islands is the cause of the anomalously fast velocities from the South Sandwich Islands to Alaska raypaths

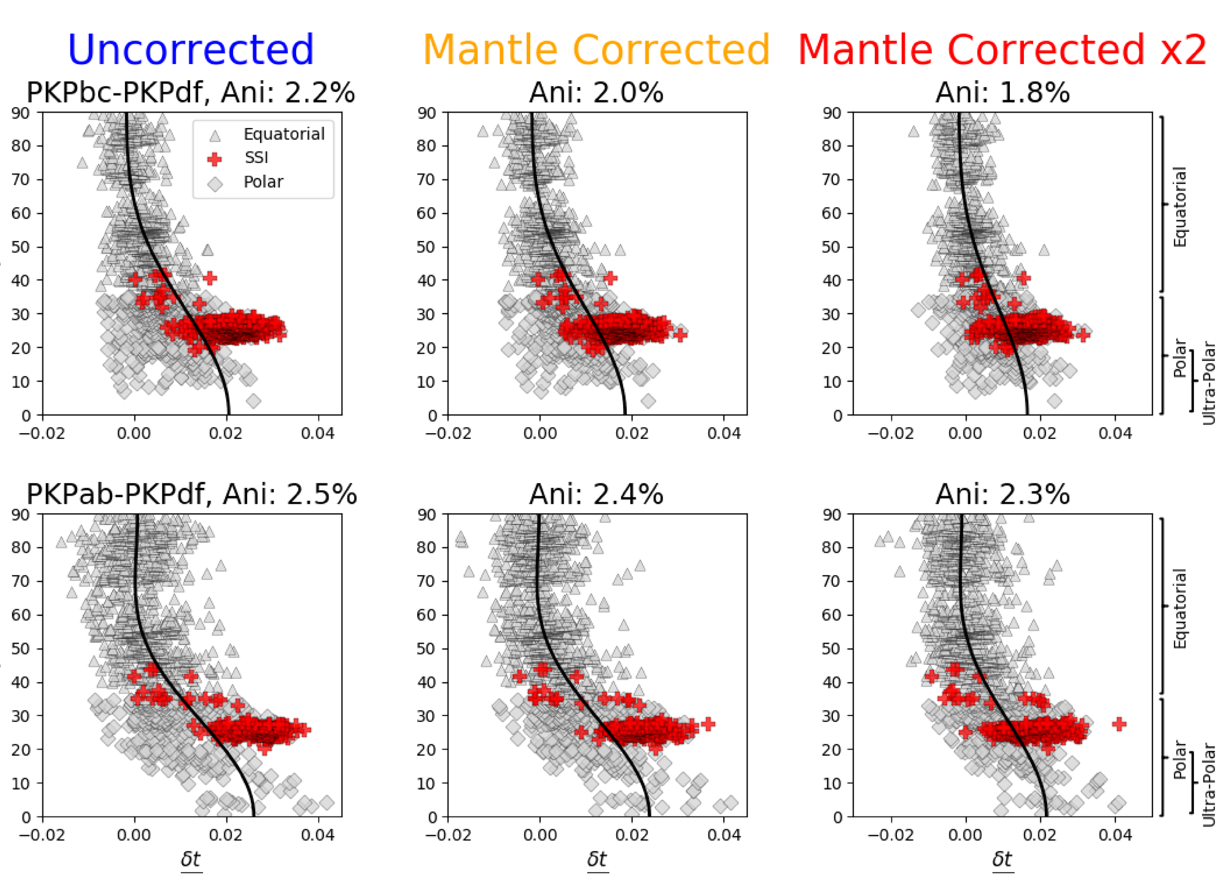


Figure 7) $\frac{\delta t}{t}$ plotted against ζ for PKPdf-PKPbc and PKPdf-PKPab differential travel times without mantle corrections (Column 1), With mantle corrections (Column 2) and with mantle corrections where the original UUP07 velocities had been doubled (Column 3). The black line represents the anisotropy which best fits each data set.

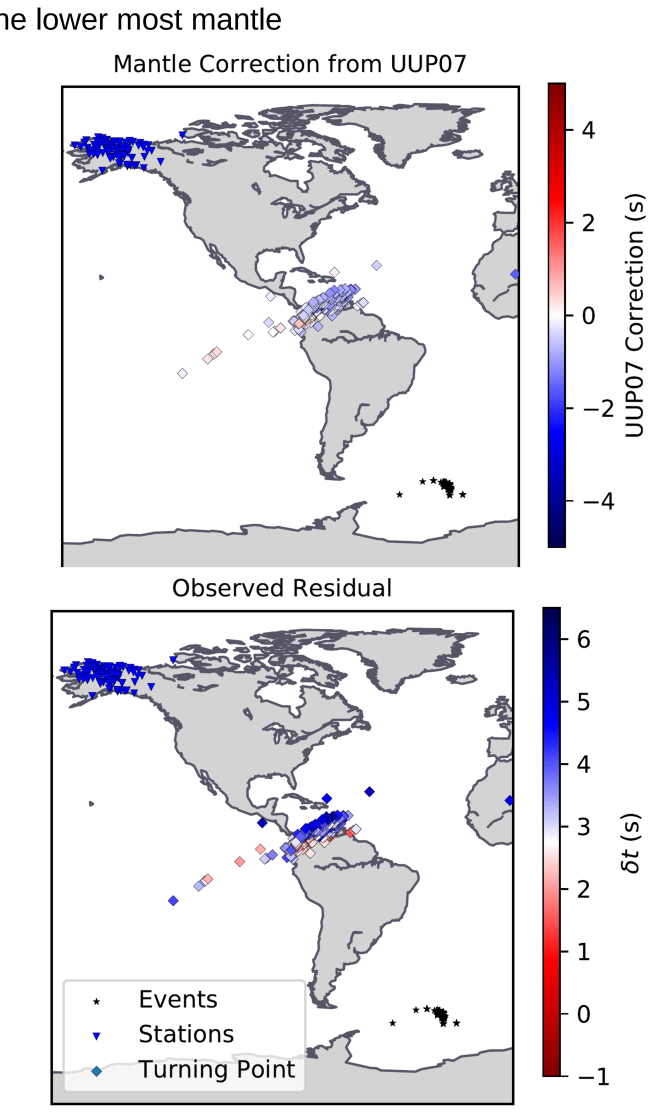


Figure 6) a) The size of the mantle corrections for the SSI raypaths plotted on the turning point. b) the observed travel time residual of the SSI to Alaska raypaths plotted on the turning point.

Hemispherical Structure

Next we check if our new data set still requires hemispherical variations. We apply a damped least squares inversion to solve for anisotropy within sub volumes of the inner core defined using spherical co-ordinates (Figure 8). We combine our data with the data set of Waszek and Deuss (2011) for the upper most inner core

- We find variations in inner core anisotropy as a function of longitude: a western hemisphere in the inner core with strong anisotropy (2%-4%) and an eastern hemisphere with low or no anisotropy
- Hemispheres are still required with or without the South Sandwich Islands data (Figure 9 a,b).

We also find that an inner-most-inner core with 3% anisotropy and a radius of 750-690km significantly reduces the misfit of our models, This result is also consistent with and without including the South Sandwich Islands (Figure 9 a,b).

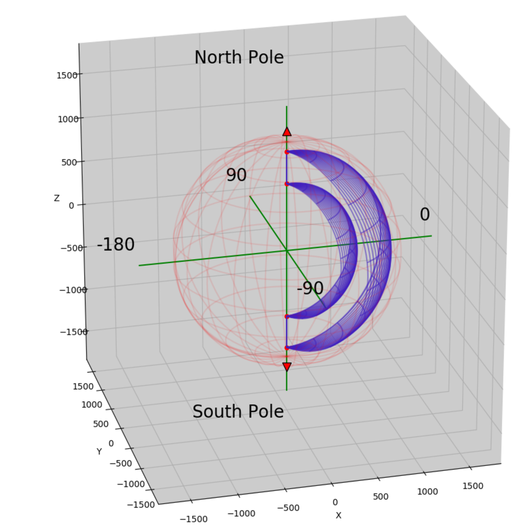
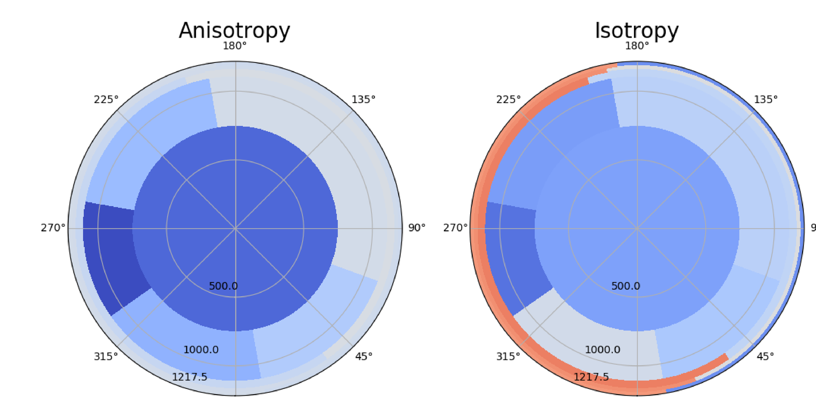


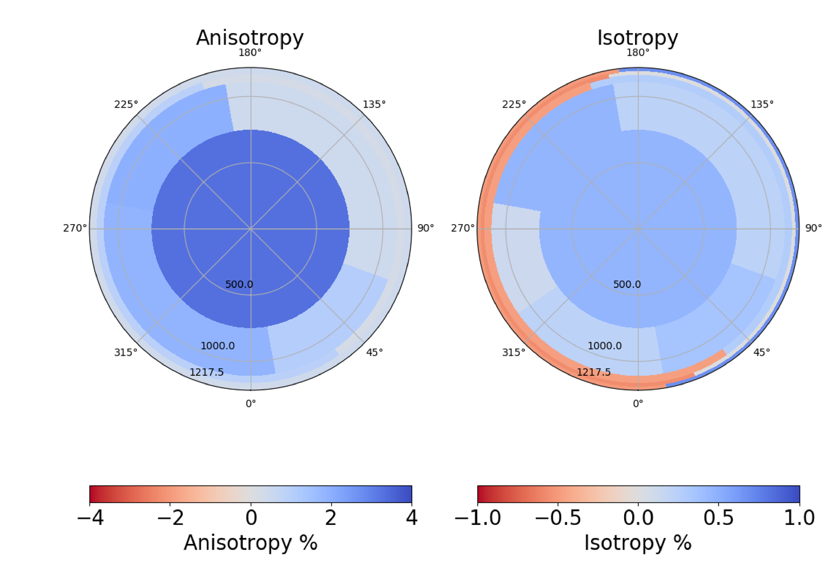
Figure 8) An example of the geometry used

There are still hemispheres in the inner core with or without using the South Sandwich Islands data and there is an inner most inner core with strong anisotropy

a) Inversion results with South Sandwich Islands:



b) Inversion results without South Sandwich Islands:



c) Polar data used in inversions:

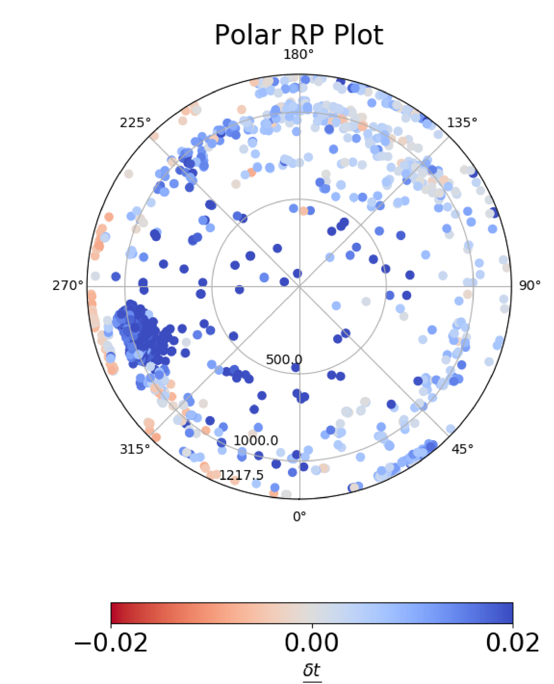


Figure 9 a), b) and c) are all slices through the equatorial plane of the models. a) and b) show the Anisotropy and Isotropy results with and without the South Sandwich Islands data being included respectively. c) shows the polar data used in my inversions plotted at the turning point with color representing the observed travel time residual

Conclusions

- New ultra polar data reduce the measured value of inner core anisotropy to 2% which is significantly lower than previous research and in better agreement with normal mode studies
- The anomalous South Sandwich Islands raypaths can be explained by mantle structure and can be corrected for using mantle tomographic models
- There are still hemispheres in the inner core with a western hemisphere with 2% Anisotropy and an eastern hemisphere with little or no anisotropy, this result does not change with or without the South Sandwich Islands data
- There is a clear inner most inner core with 3% Anisotropy and a radius between 690-750km

References

Amaru, M. L. (2007). Global travel time tomography with 3-D reference models,PhD thesis,

Waszek, L. and Deuss, A. (2011). Distinct layering in the hemispherical seismic velocity structure of Earth's upper inner core. Journal of Geophysical Research: Solid Earth, 116(B12)

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