Application of data from ISC Bulletins to studies of Earth's 3-D structure

Adam M. Dziewonski
Harvard University

IUGG, Praha, 06/27/2015

The reason to try 3-D inversion

A decade after the hypothesis of the plate tectonics has been put forward and (gradually) accepted, the scale of the mantle flow associated with the plate motions has ben not agreed upon.

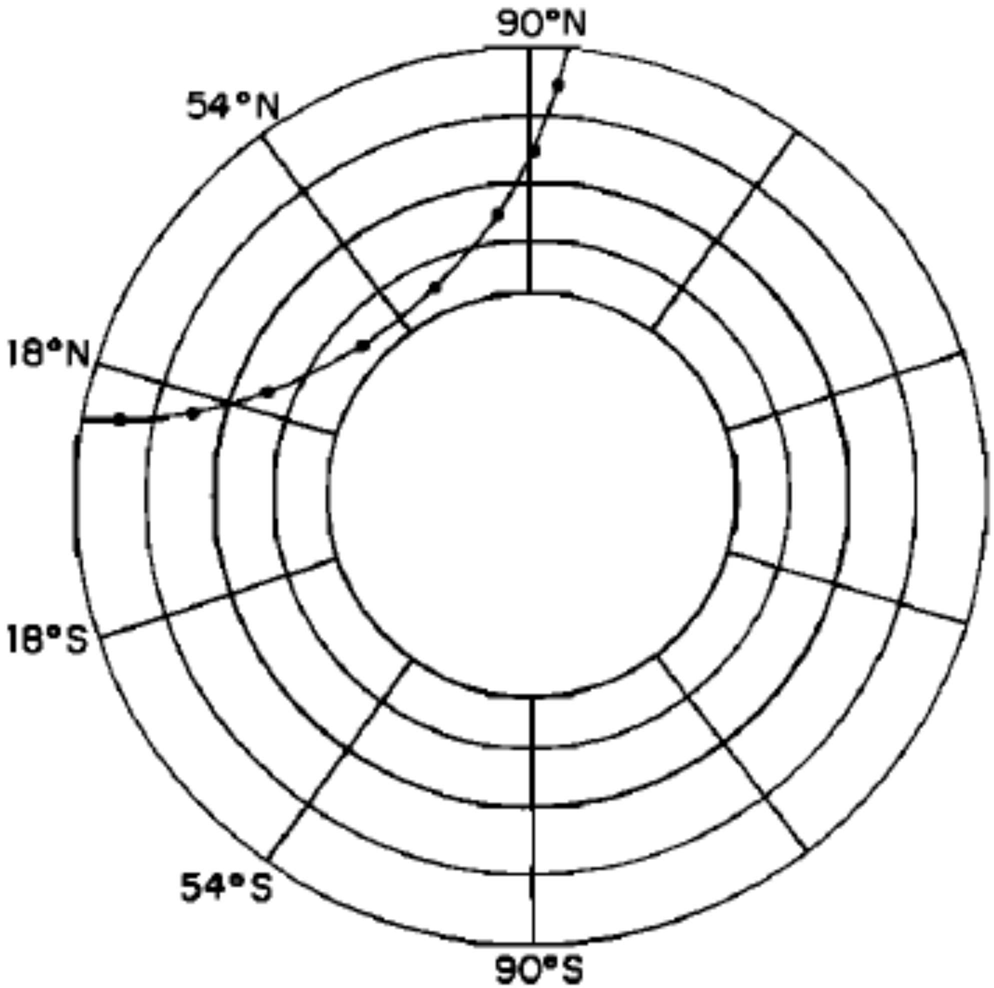
Since seismic velocities and density depend on temperature, it is possible that mapping velocity anomalies in three dimensions might reveal the pattern of the large scale mantle flow.

This would require enormous amounts of observations, but several years of ISC Bulletins could contain enough information to justify the initial experiment.

Data Extraction from 1964-1970 Bulletins

- Reading of the headings (hypocentral information) had been most difficult as the format and information content were highly variable.
- Only events with a certain minimum of teleseismic P-wave observations were used. Core phases were not used. Events were not relocated.
- A total of 700,000 teleseismic ($\Delta > 25^0$) travel time anomalies were extracted.

Parameterization



5 shells, 30 horizontal pixels;
Total of 150 unknowns

Does it work? The ellipticity test

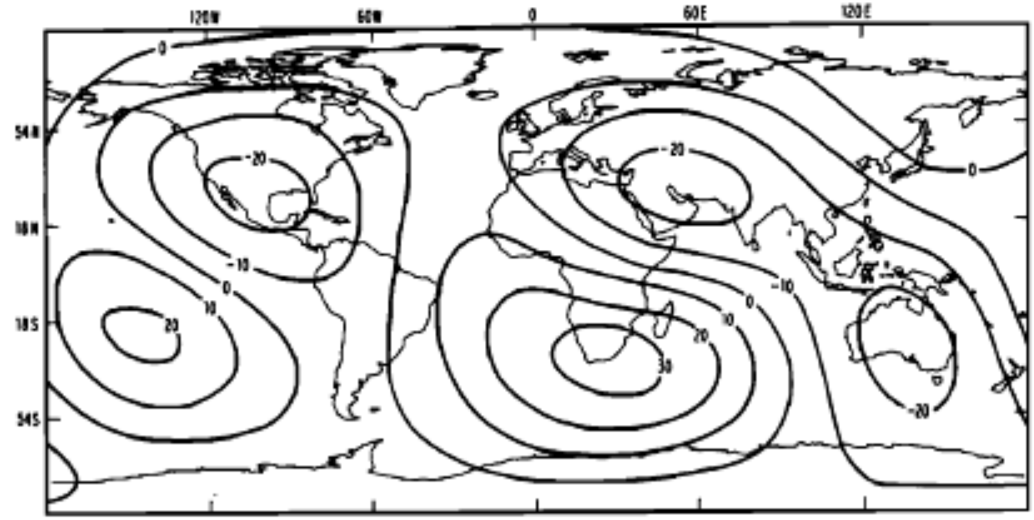
The one lateral heterogeneity that we know about is the Earth's ellipticity. It adds to the path length of a ray emerging at the equator and subtracts for rays emerging at high latitudes. There are ellipticity corrections added to travel time computed for a spherical Earth.

If we do not apply these corrections, the perturbations caused by ellipticity should express themselves in a result of inversion for 3-D structure as a $P_{20}\,cos(\theta)$ term with velocities lower near the equator and higher near the pole.

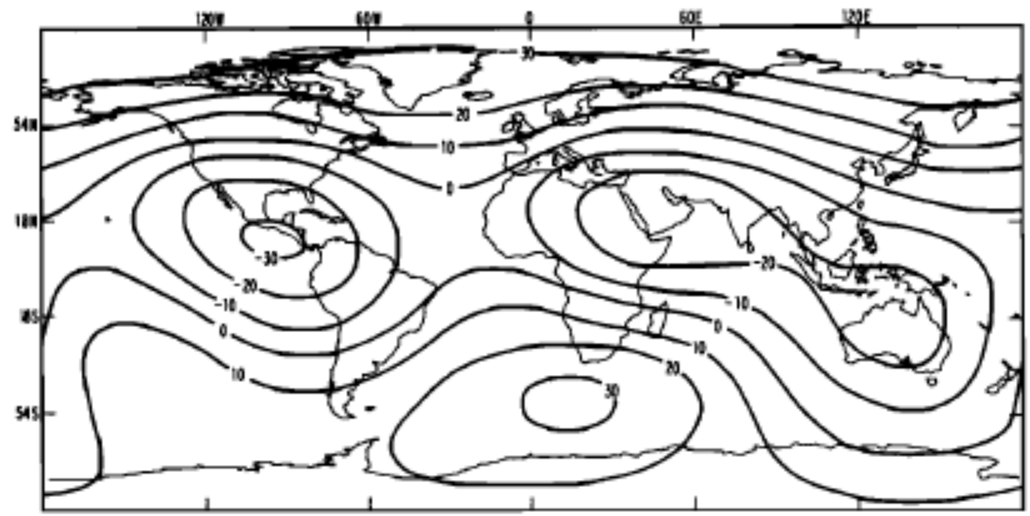
The most important factor in ellipticity corrections is the perturbation in the radius of the free surface. Thus, the pseudo-anomalies should be the largest in the top shell (Moho to 670 km)

Velocity anomalies; top shell: Moho – 670 km

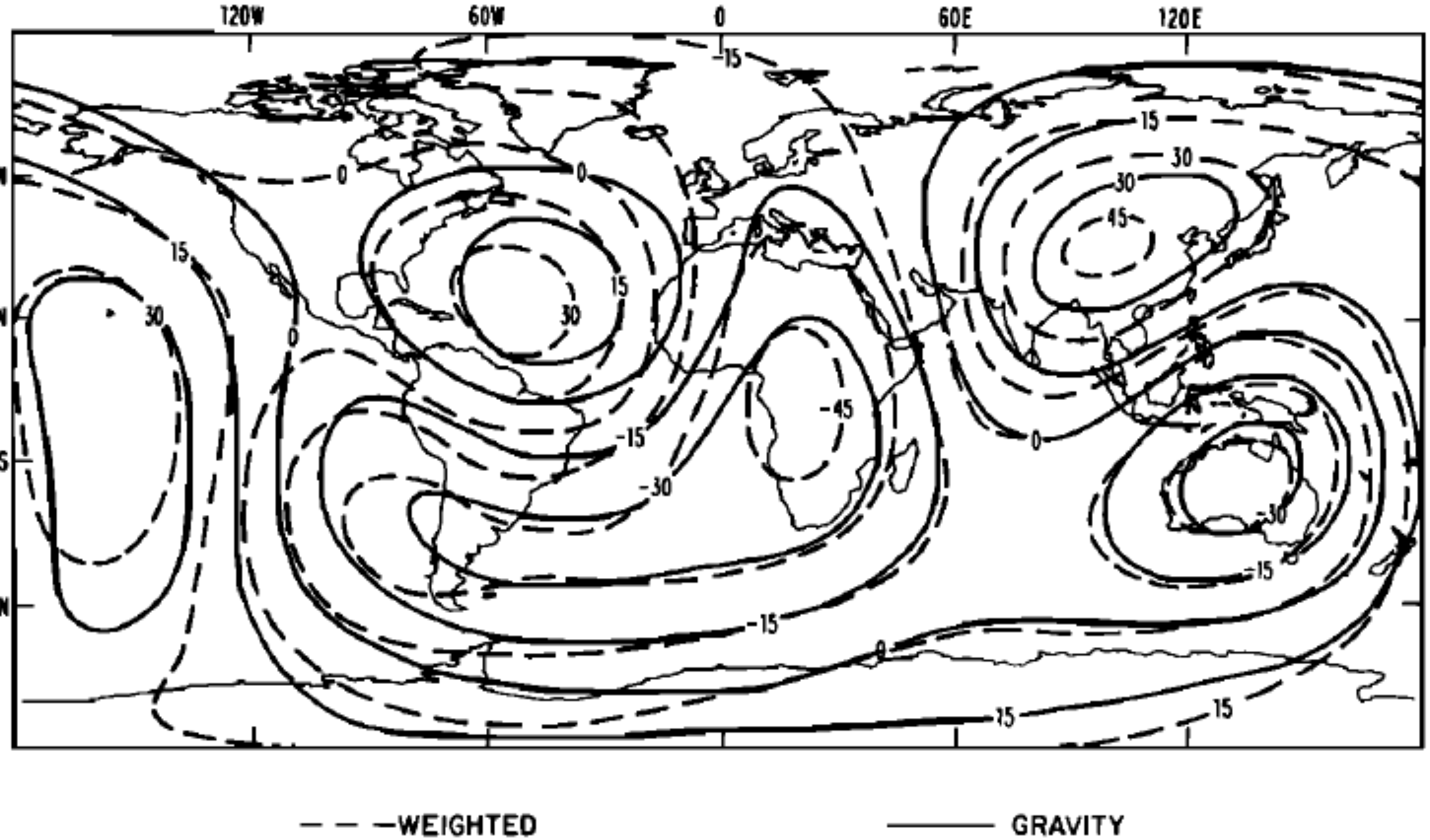
Data corrected for ellipticity



Data not corrected for ellipticity; Notice large zonal P_{20} term negative at the equator



Model DH077; 2200 km - CMB

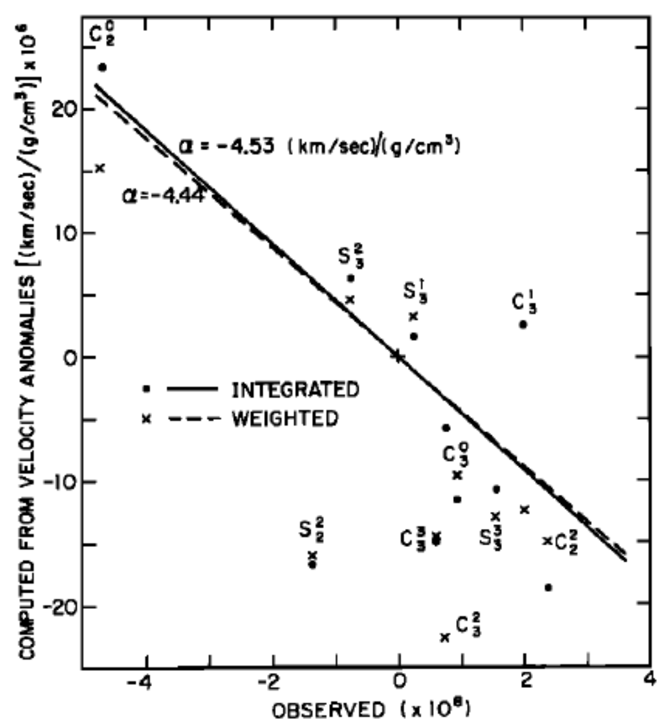


The largest velocity anomalies were found in the lower-most mantle. Significant correlation with gravity data

The key result

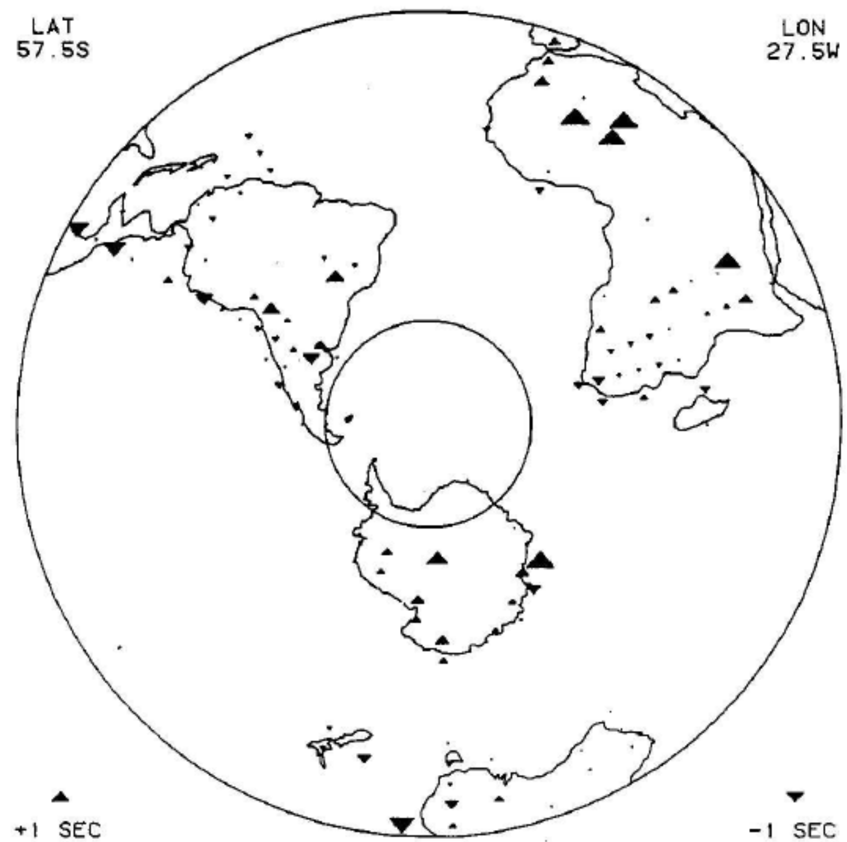
Assuming a proportionality constant between velocity and density anomalies, DHO found that for degrees 2 and 3 there is statistically significant negative correlation between the observed and computed geoid. The structure in the lowermost mantle contributes most to this result.

This indicates the potential of 3-D modeling of velocity anomalies for determining location of the source of geophysically important signals, such as the gravity field, plate motions, etc. Busse (1983) proposed a model of quadrupole convection consistent with DHO77 model.



The next attempt

In an attempt to improve the resolution and quality of the model we have used more ISC data (1964 – 1979) and introduced an iterative relocation procedure; this influenced the final result. Two complete iterations were enough for the model to converge.



Global Parameterization: Spherical Harmonics and Legendre Polynomials

Thus it is natural that one should seek perturbations to the spherically symmetric model in the form

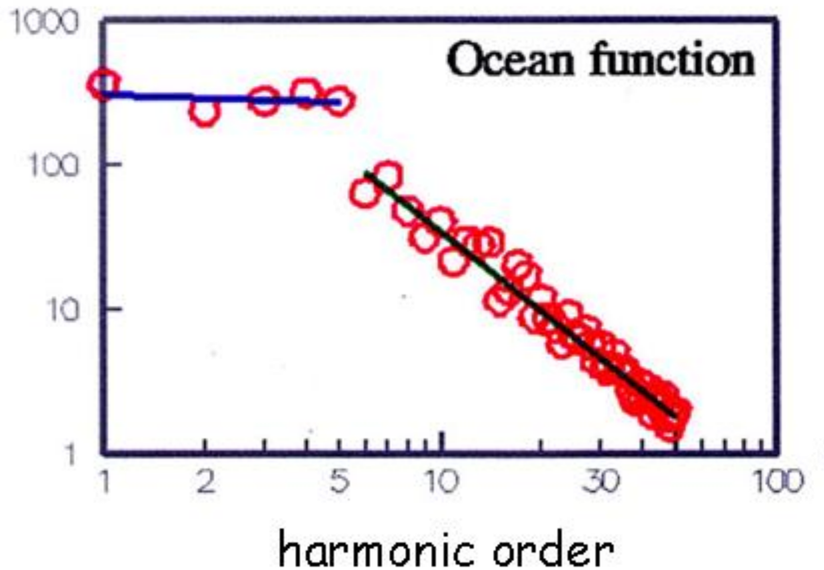
$$\delta v(r, \theta, \phi) = \sum_{k=0}^{K} \sum_{l=0}^{L} \sum_{m=-l}^{l} {}_kc_l{}^m f_k(r) Y_l{}^m(\theta, \phi) \qquad (7)$$

The $l = 0$ terms are included because it is possible that perturbations to the average earth model will be needed when lateral heterogeneity is taken into account.

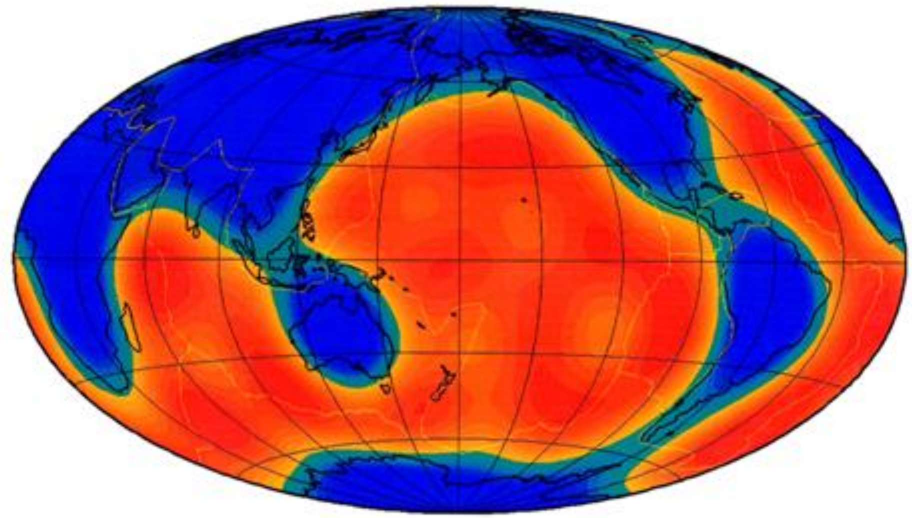
(Dziewonski, 1984)

In consideration of the available computer power We have limited the harmonic order to 6, Legendre Polynomial to 5 and performed two complete Iterations. The final model is names L02.56.

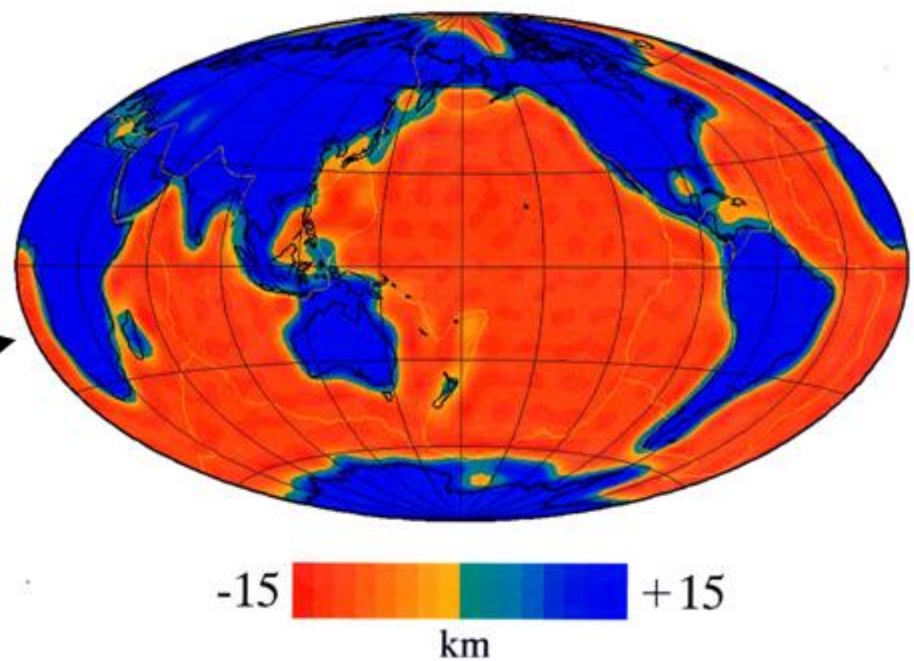
The properties of a "super-red" spectrum



Ocean function (l=1-8)

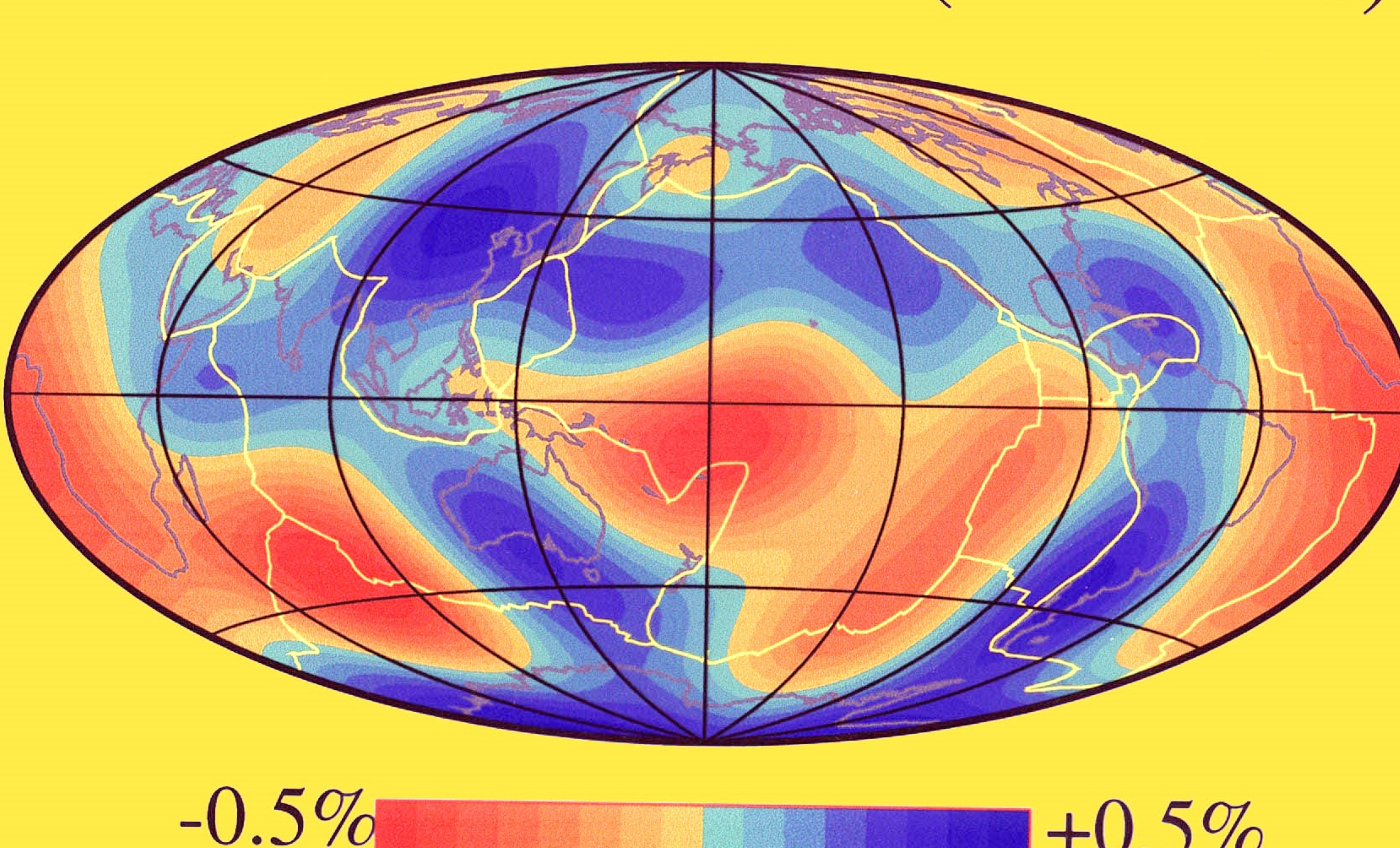


Ocean function (l=1-32)

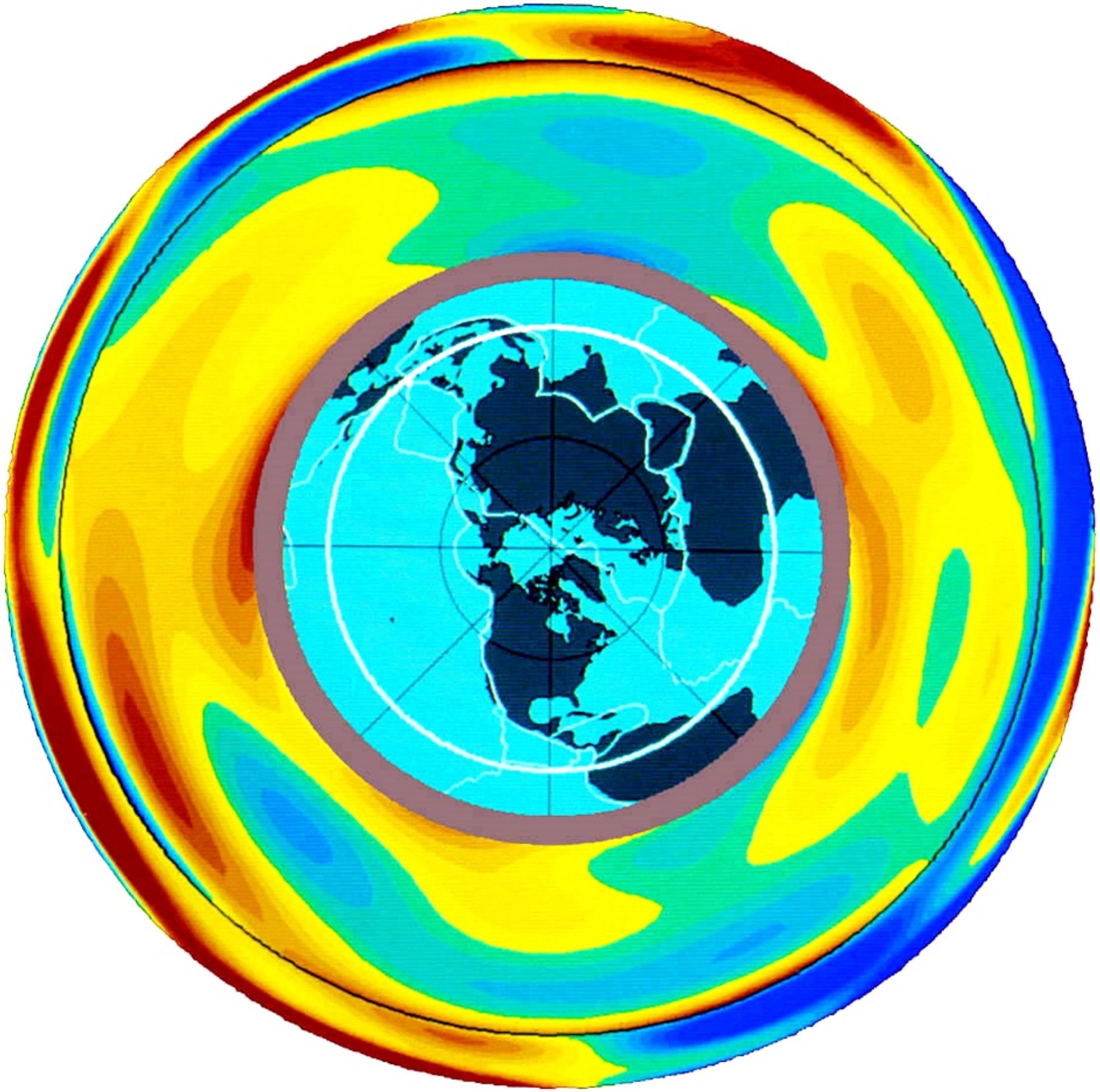


15 times more coefficients

Model L02.56 (2500 km)



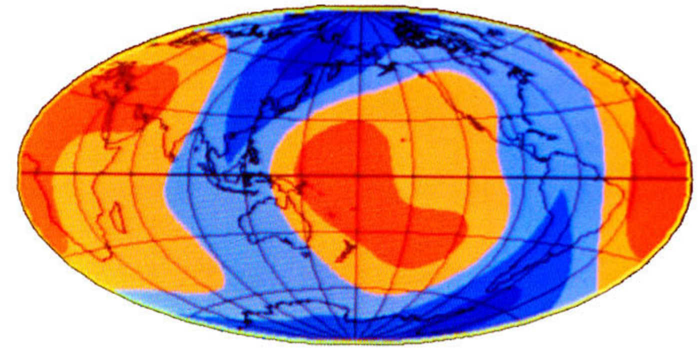
The equatorial cross-section and super-plumes



“We have one Earth” (at 2500 km depth)

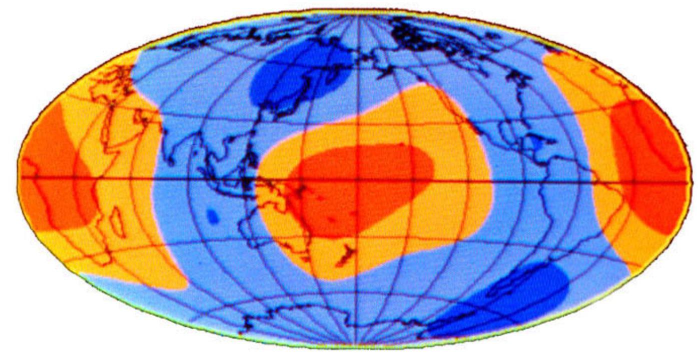
P- model from ISC data

V_P (ℓ = 1 – 6)



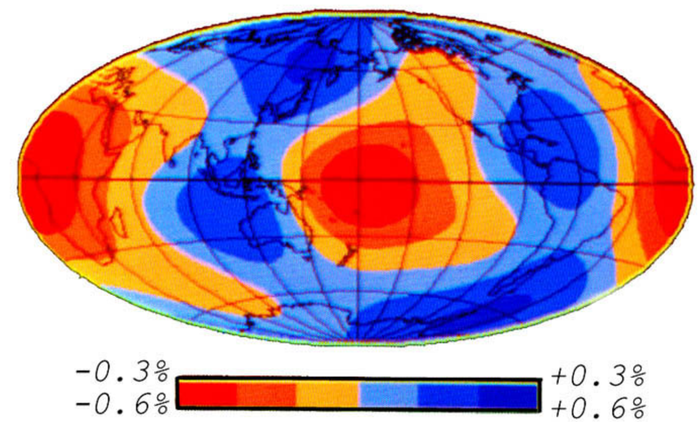
P-model filtered

V_P (ℓ = 2 & 4)



S-model from mode splitting

V_S (ℓ = 2 & 4)



After Giardini et al., 1987

Simultaneous inversion for 3-D variations in shear and bulk velocity in the mantle

Wei-jia Su *, Adam M. Dziewonski

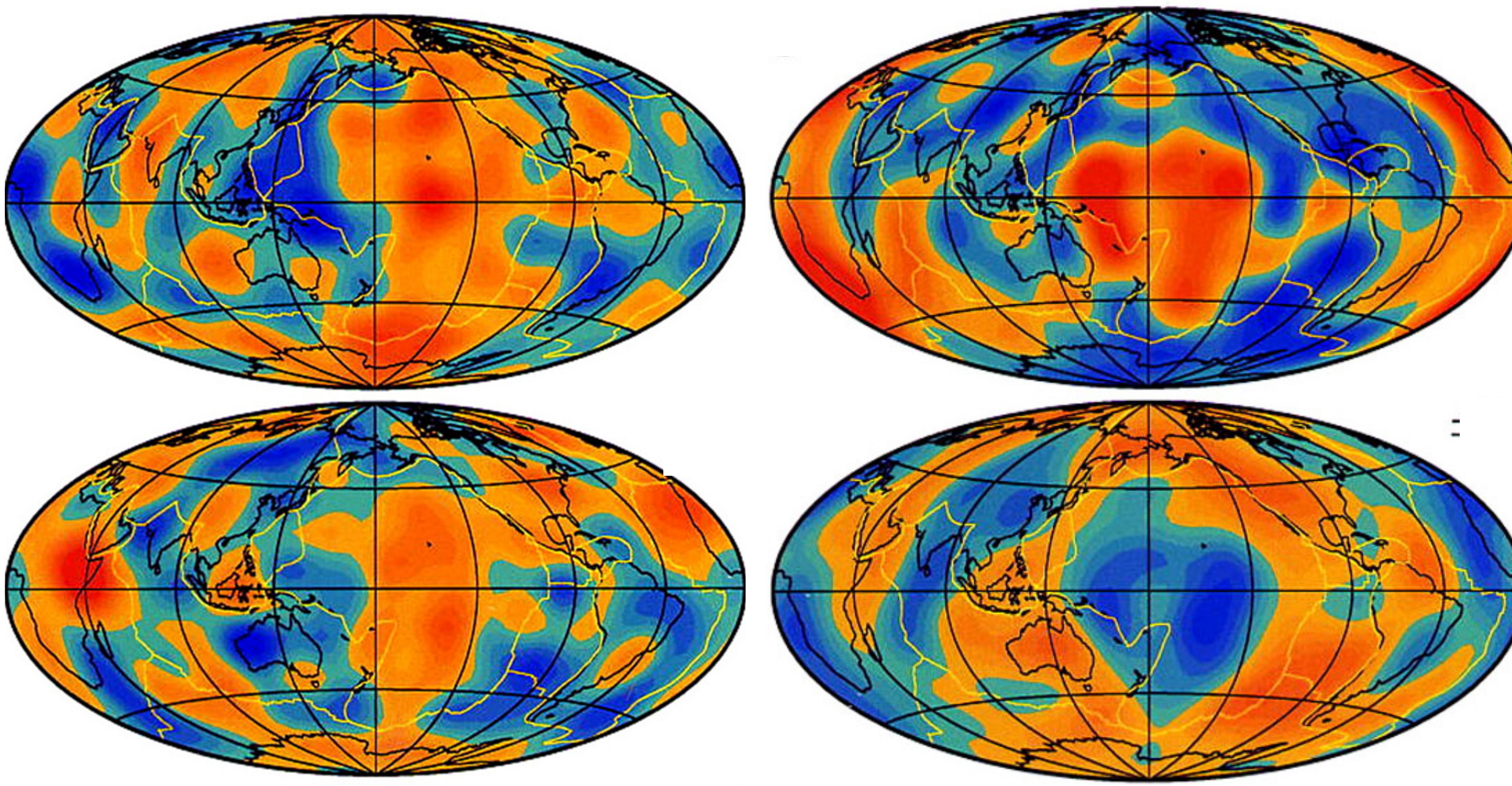
PEPI, 1997

Compressional velocity depends on the compressional modulus (*K*) and shear modulus (μ). It may be advantageous to invert travel time anomalies of P- and S-waves in terms of the two independent moduli: K (bulk sound Velocity) and μ (shear velocity).

Shear and bulk sound velocity: correlation and anti-correlation

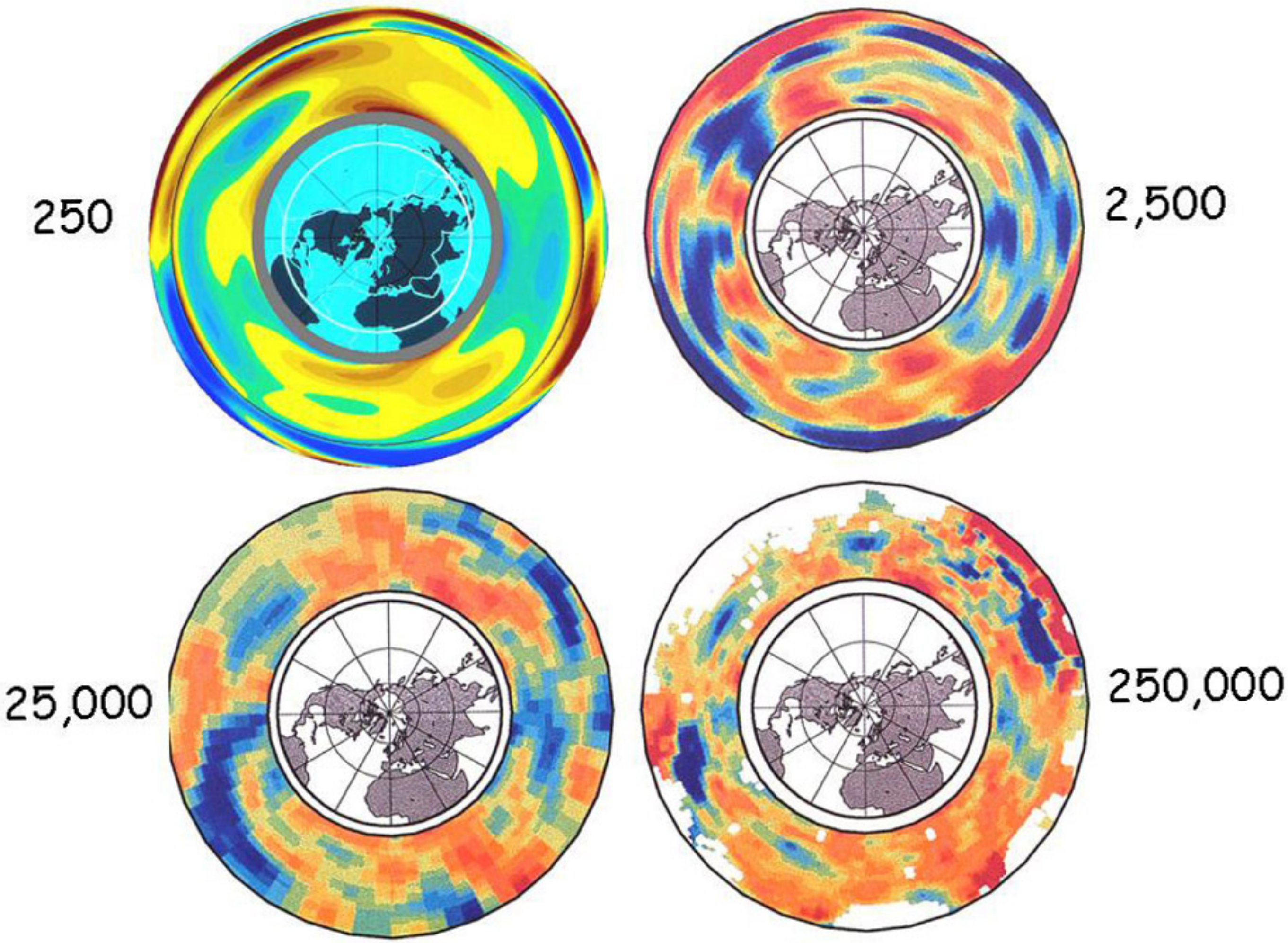
shear
±2%

bulk
±1%



Depth 550 km   Depth 2800 km

4 P-wave models from ISC data



Same data source, different parameterization, very different outcome

Anisotropy of the inner core

Beware of dangers of biased data sets

Based on analysis of data from ISC Bulletins

Possible heterogeneity of the Earth's core deduced from PKIKP travel times

G. Poupinet*, R. Pillet† & A. Souriau‡

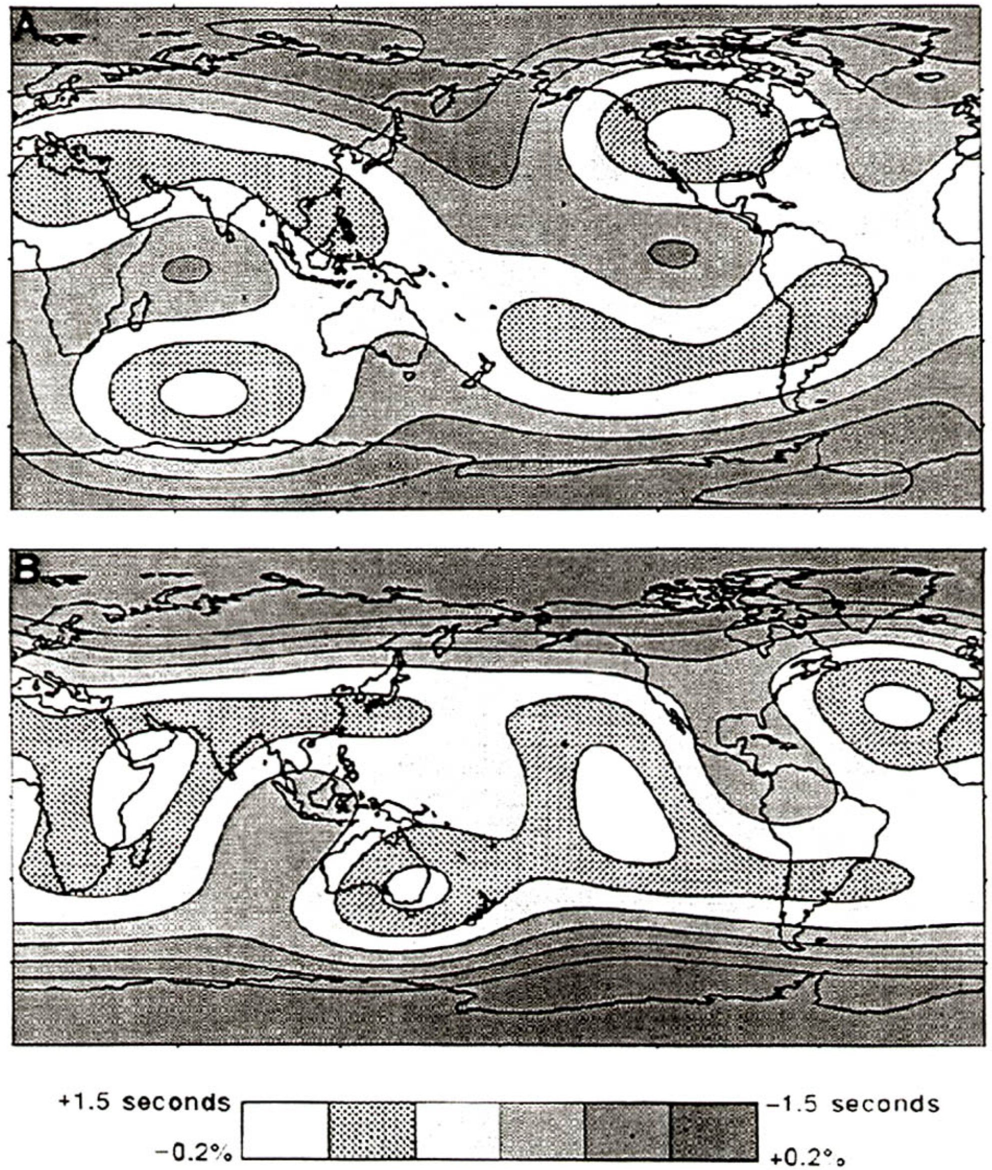
PKIKP − P exhibit a latitudinal dependence: polar stations tend to be faster than equatorial stations. We show here that this pattern may reflect a departure from spherical symmetry in the P-velocity distribution in the vicinity of the inner core boundary of the Earth.

Nature, 1983

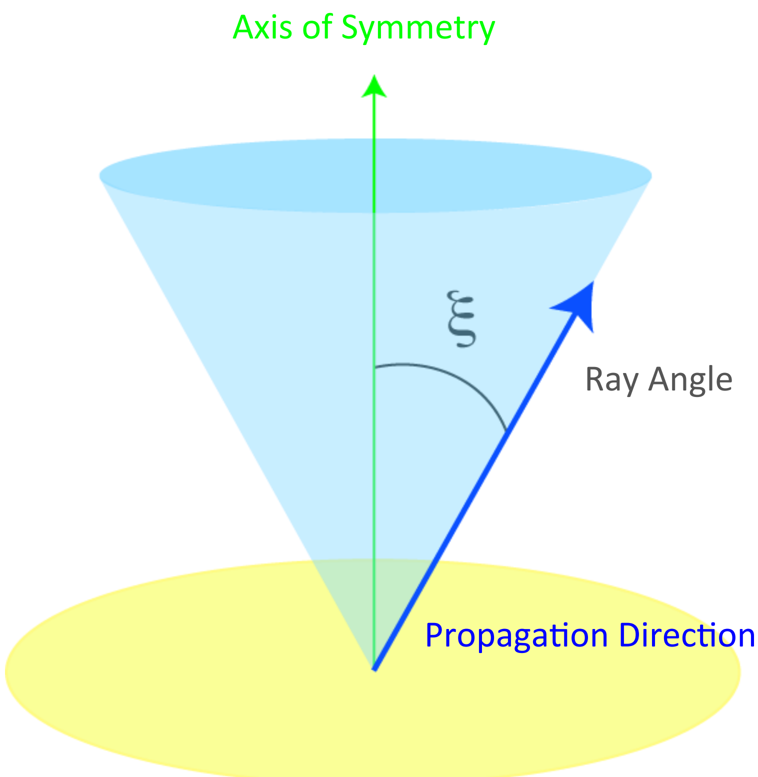
Axial symmetry: travel times and modes

Antipodal T.T.

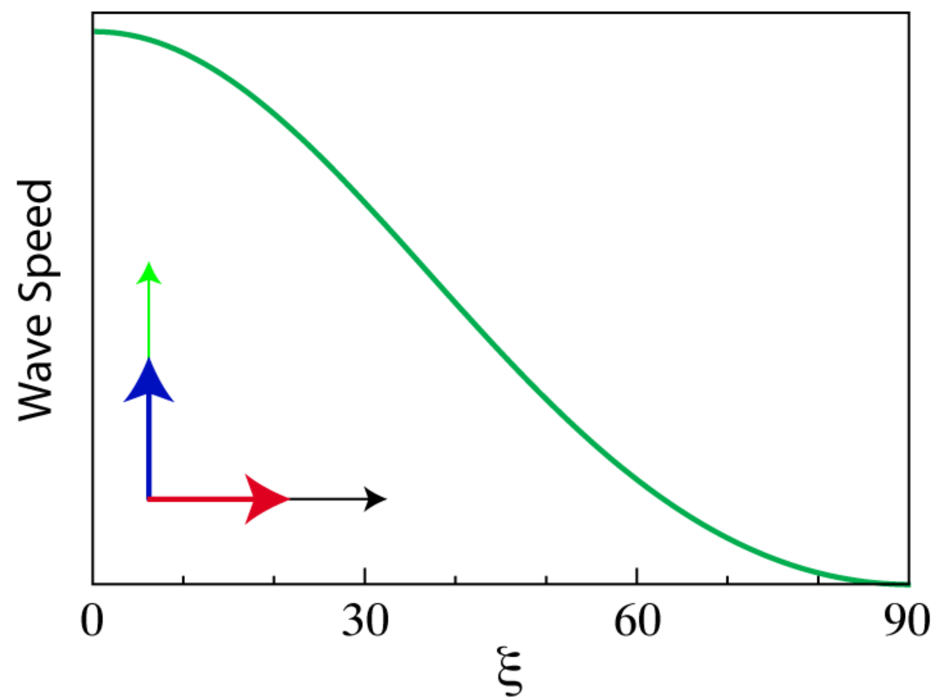
Splitting function of inner core sensitive mode $_{13}S_2$



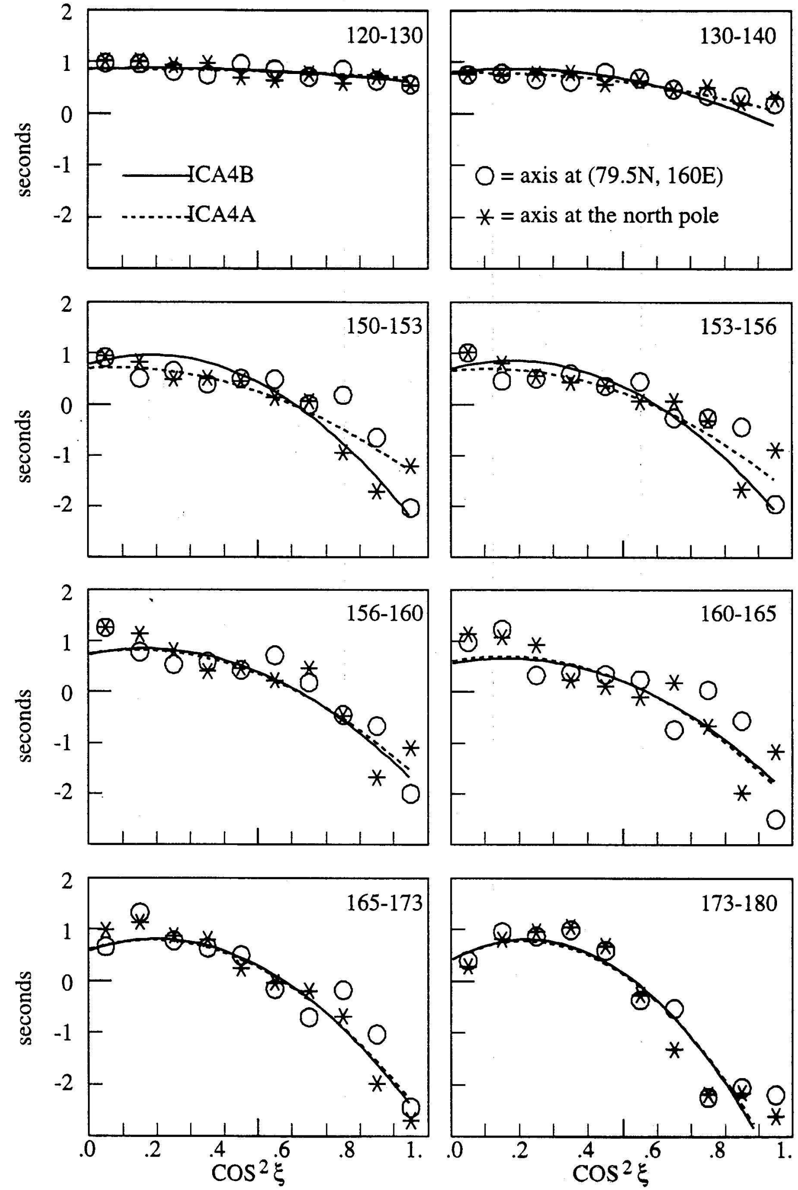
Radial anisotropy
(aligned with the axis of rotation)



$$\frac{\delta v}{v} = k \left[(\epsilon + \sigma) \cos^2 \xi - \sigma \cos^4 \xi \right]$$

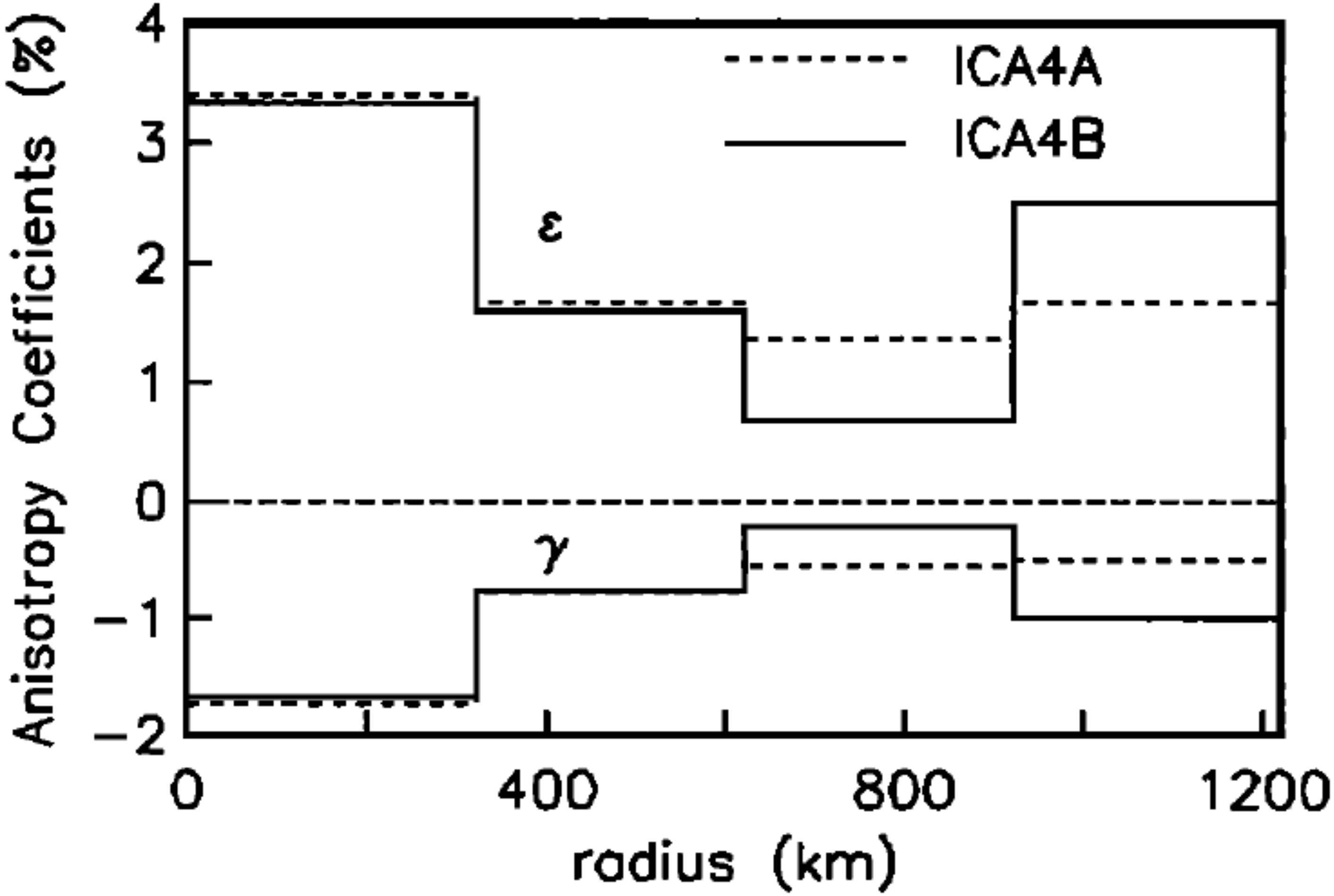


ISC PKIKP data averaged and binned in 8 distant ranges (bottoming depths)



Su and Dziewonski(1995)

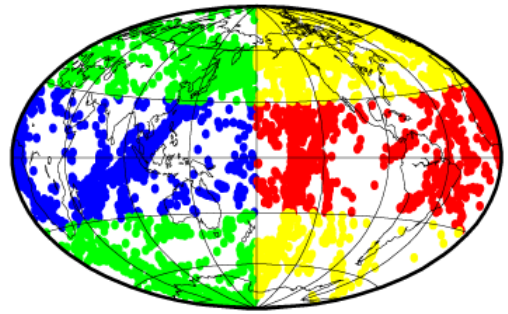
4 shell models of anisotropy in the inner core

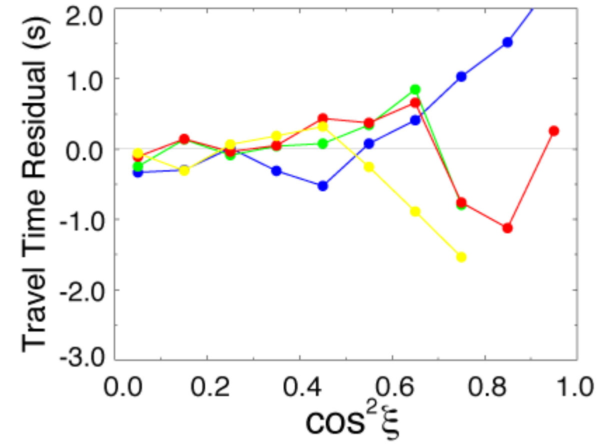


Su and Dziewonski, 1995

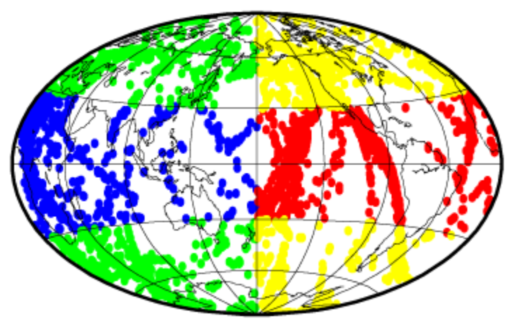
Robustness of inner-most inner core inference

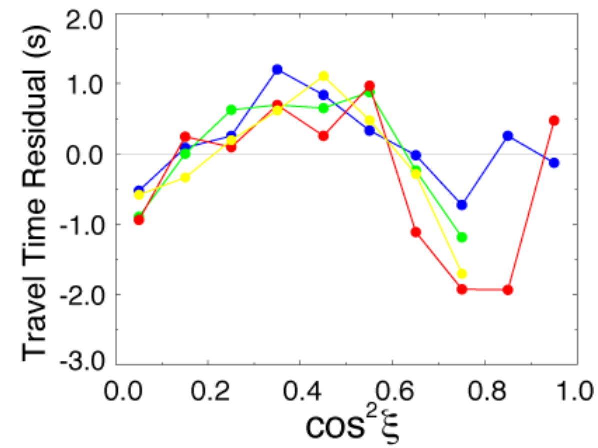
149^0 - 153^0





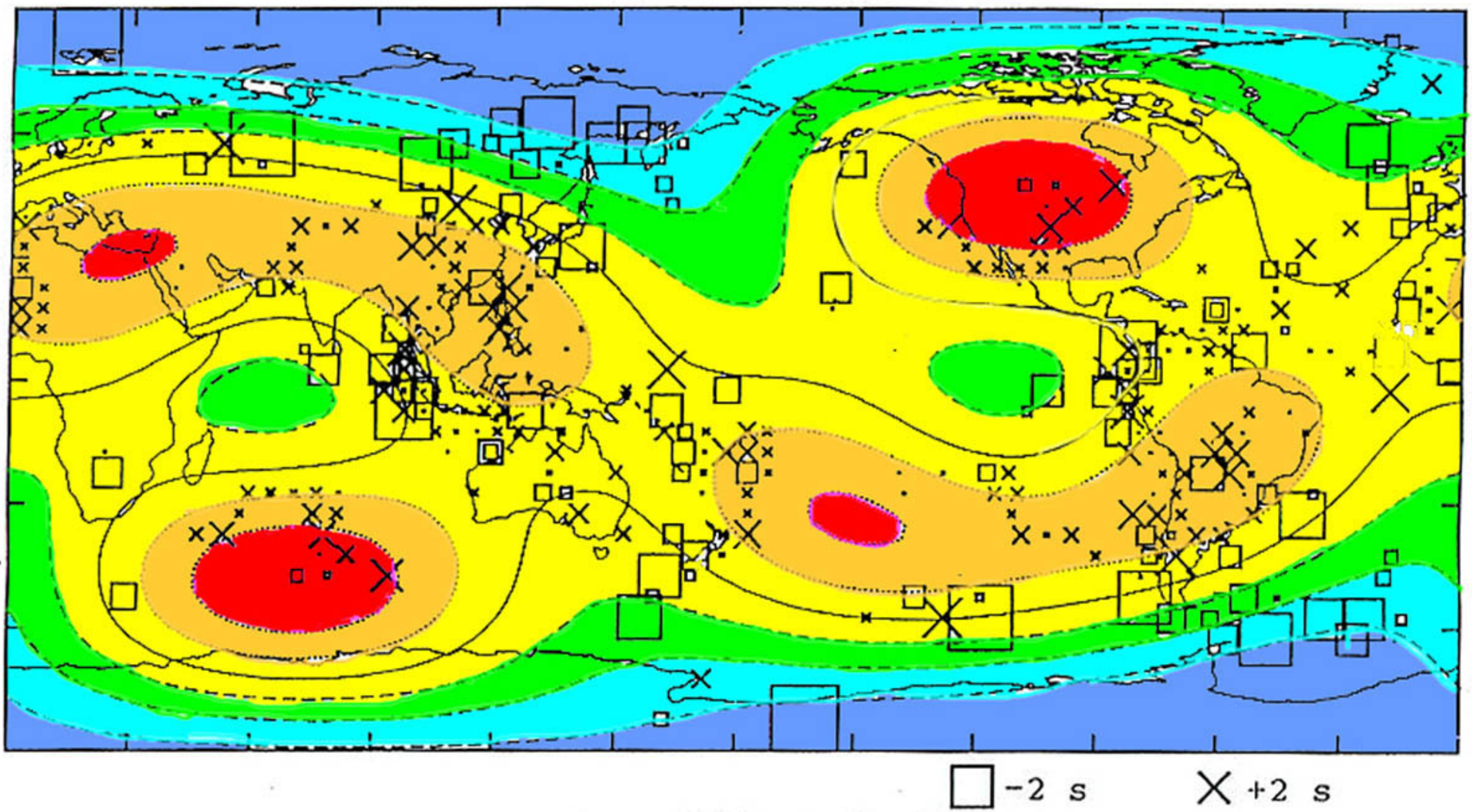
173^0 - 180^0





All four subsets of data show slowest times
At ξ of about 45 degrees

Nearly antipodal P-wave residuals

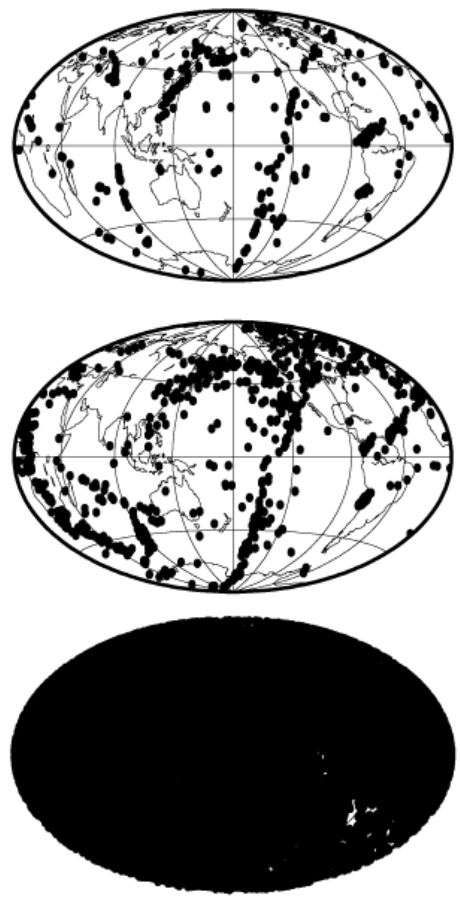


Comparison of Data Coverage

BC-DF

AB-DF

DF



Differential travel times from waveforms

Absolute PKIKP travel times from ISC Bulletins