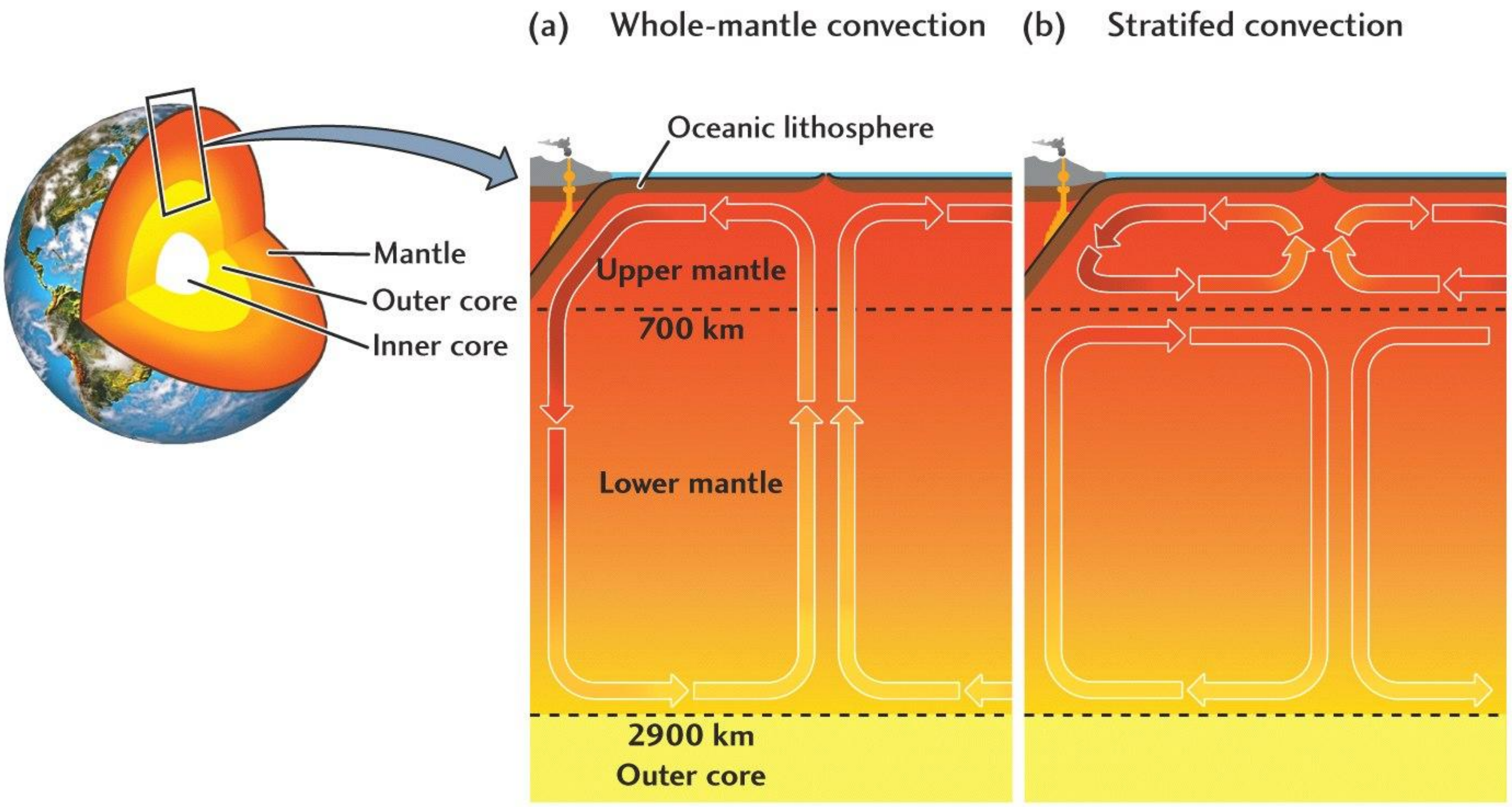
Two spatiotemporal scales of mantle dynamics: constraints from seismic tomography

Adam Dziewonski
Harvard University

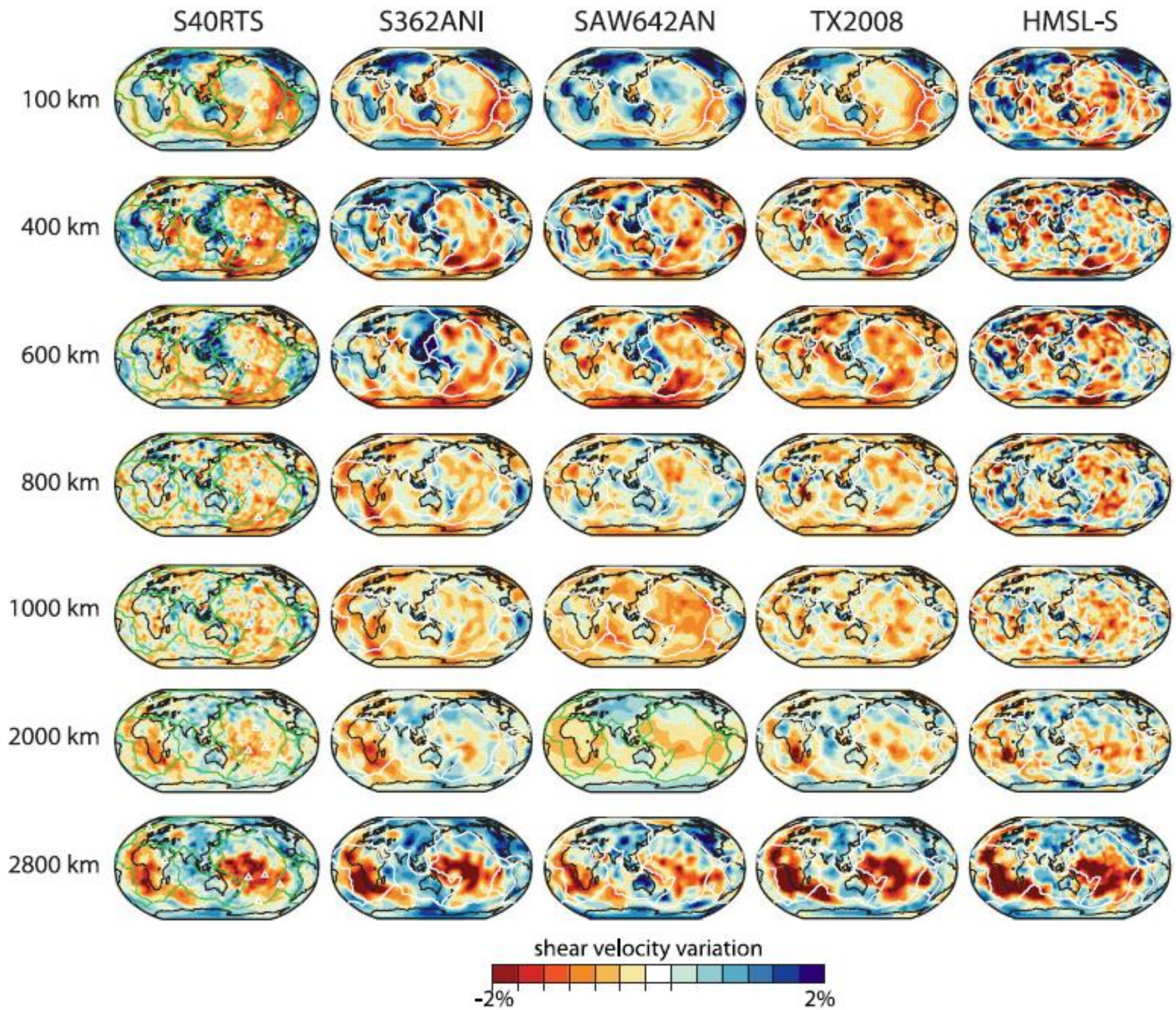
KITP, March 5, 2015

Which is it?



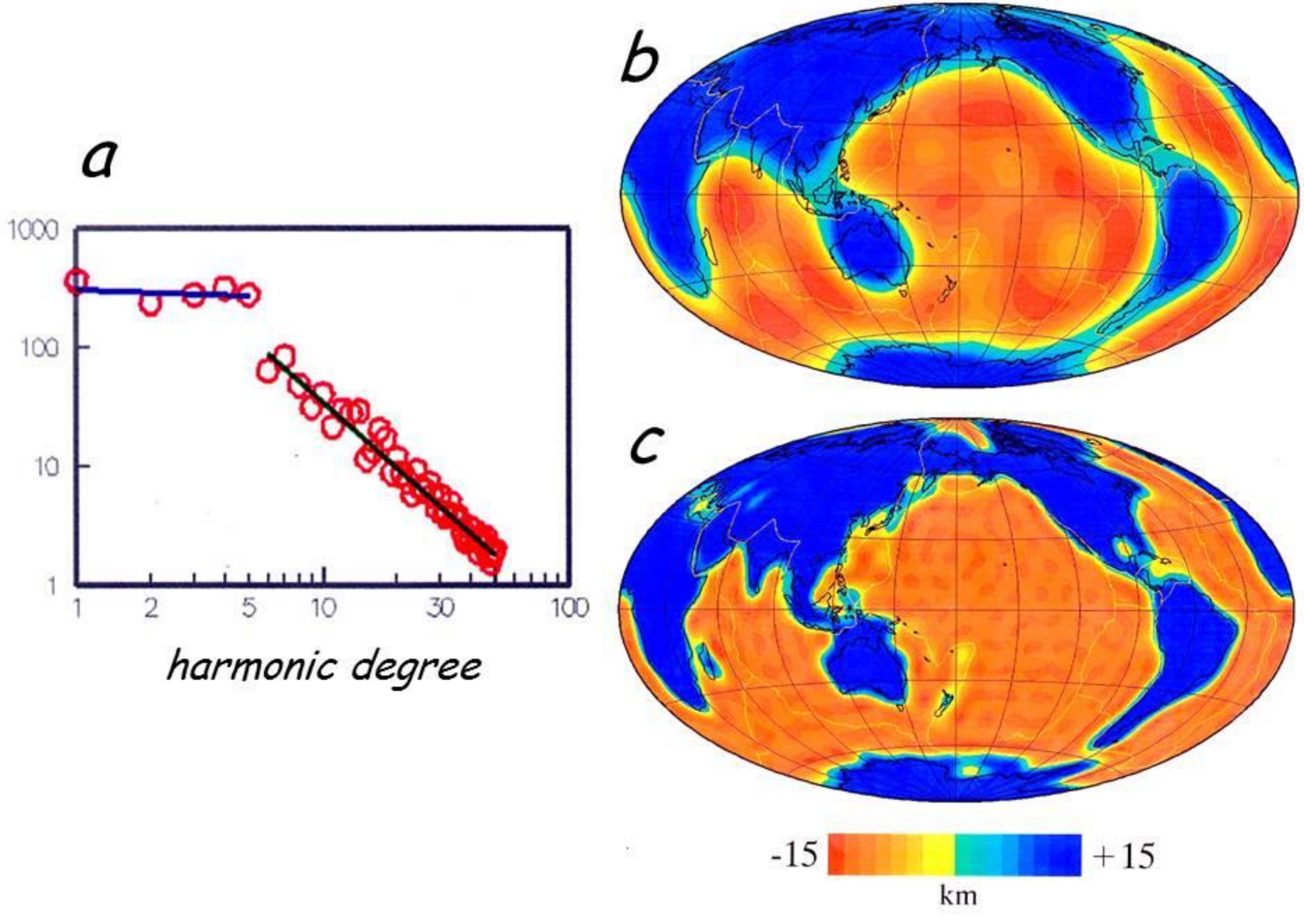
The answer : ***Neither !!!***

Congruence of 3-D S-velocity models



+/- 7%

Ritsema et al., 2011

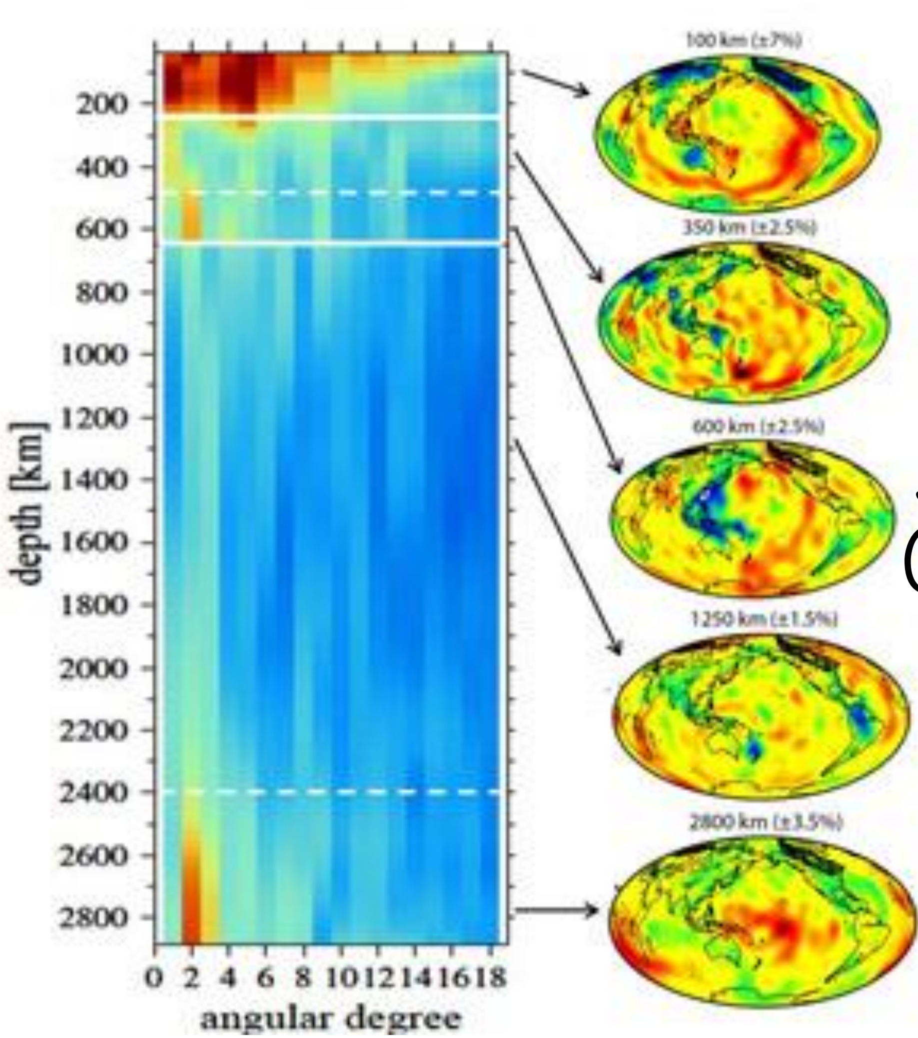


a
b
c
1000
100
10
1
1
2
5
10
30
100
harmonic degree
-15
+15
km

Beyond the snapshot

Seismic tomography can provide, at best, a present day snapshot of the anomalies of seismic wave speeds caused be variation of temperature and/or composition. To provide dynamic interpretation additional data are needed: records of plate motions, including subduction. This will be attempted here by comparing the seismological results with the history of plate motions, subduction history and tue polar wonder

Tomographic Stratigraphy I



Heterosphere

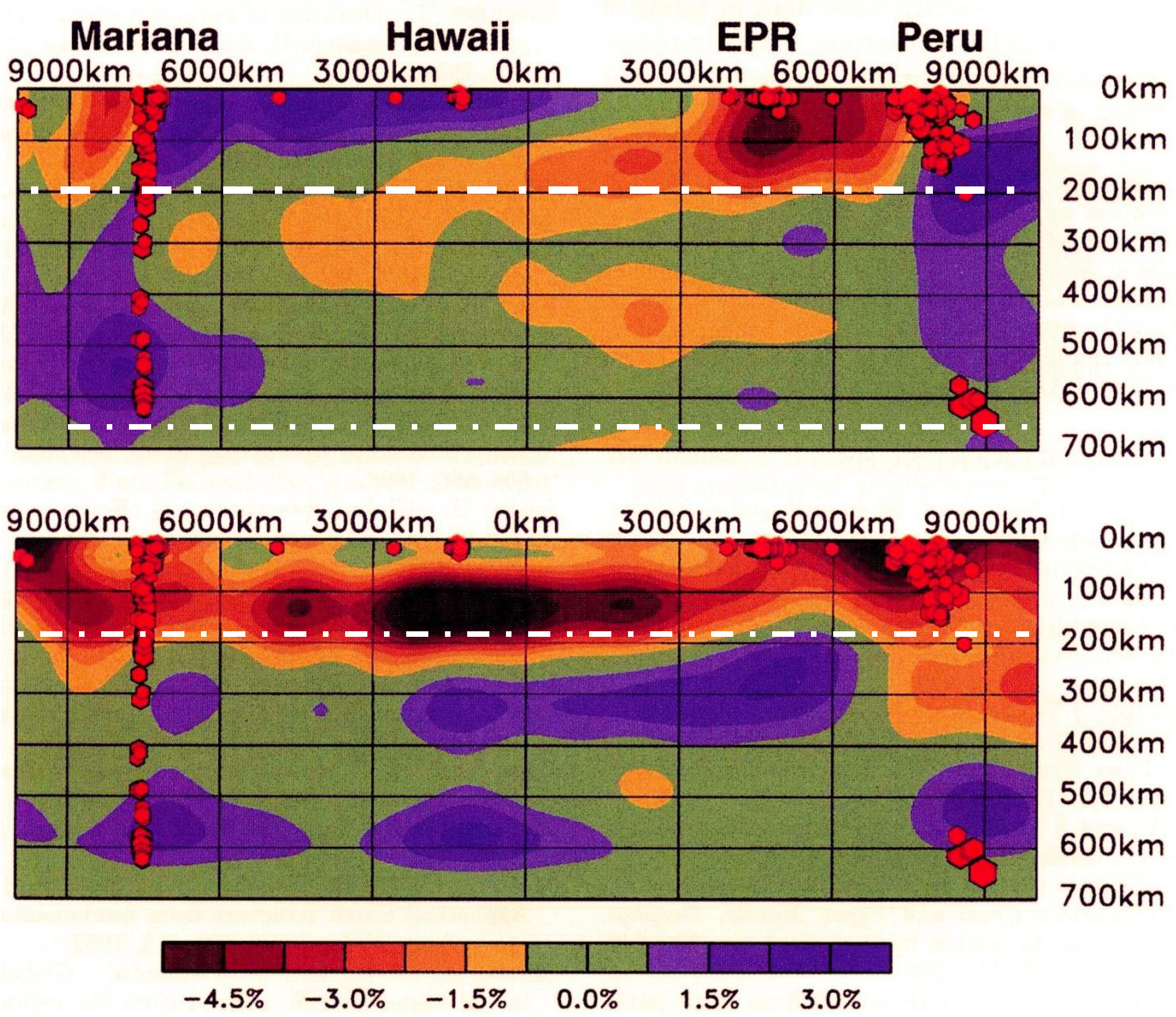
ETZ

Super=plume
(LLSVP) Zone

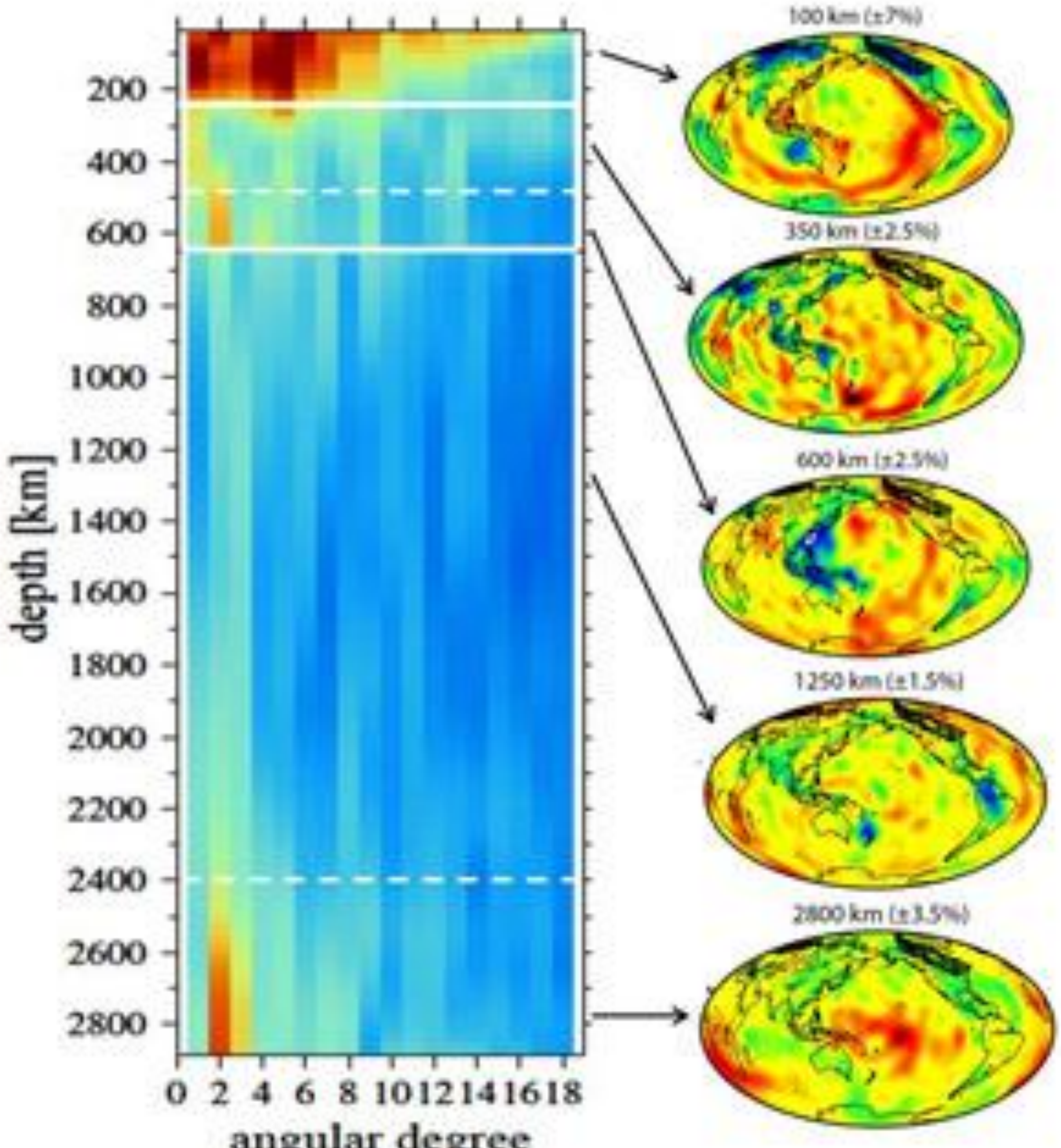
Heterosphere

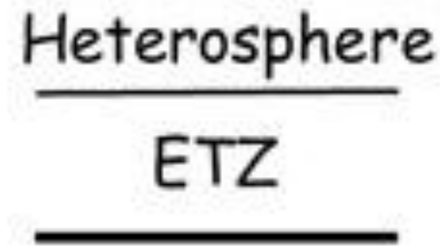
isotropic

anisotropic

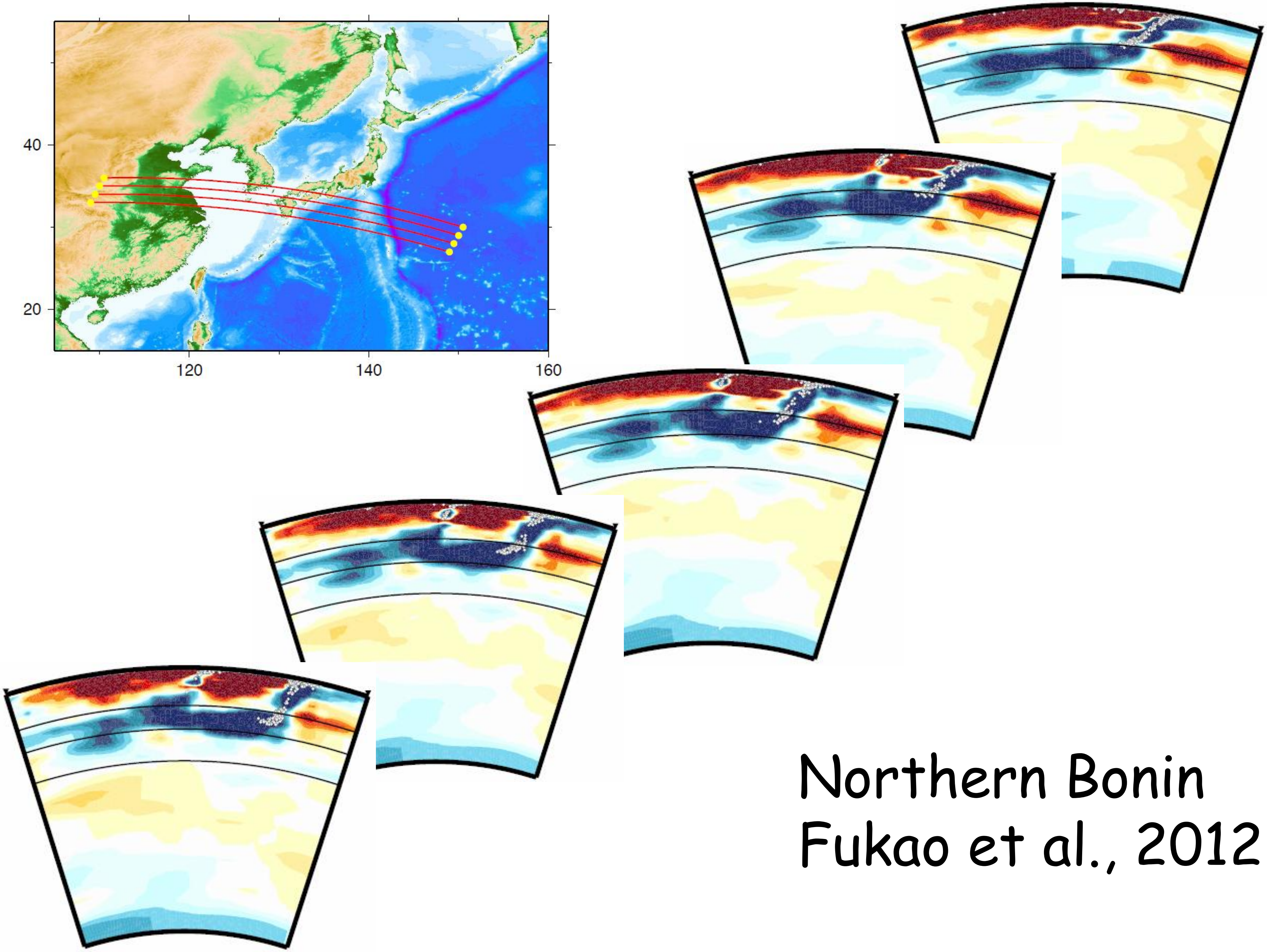


Tomographic Stratigraphy I





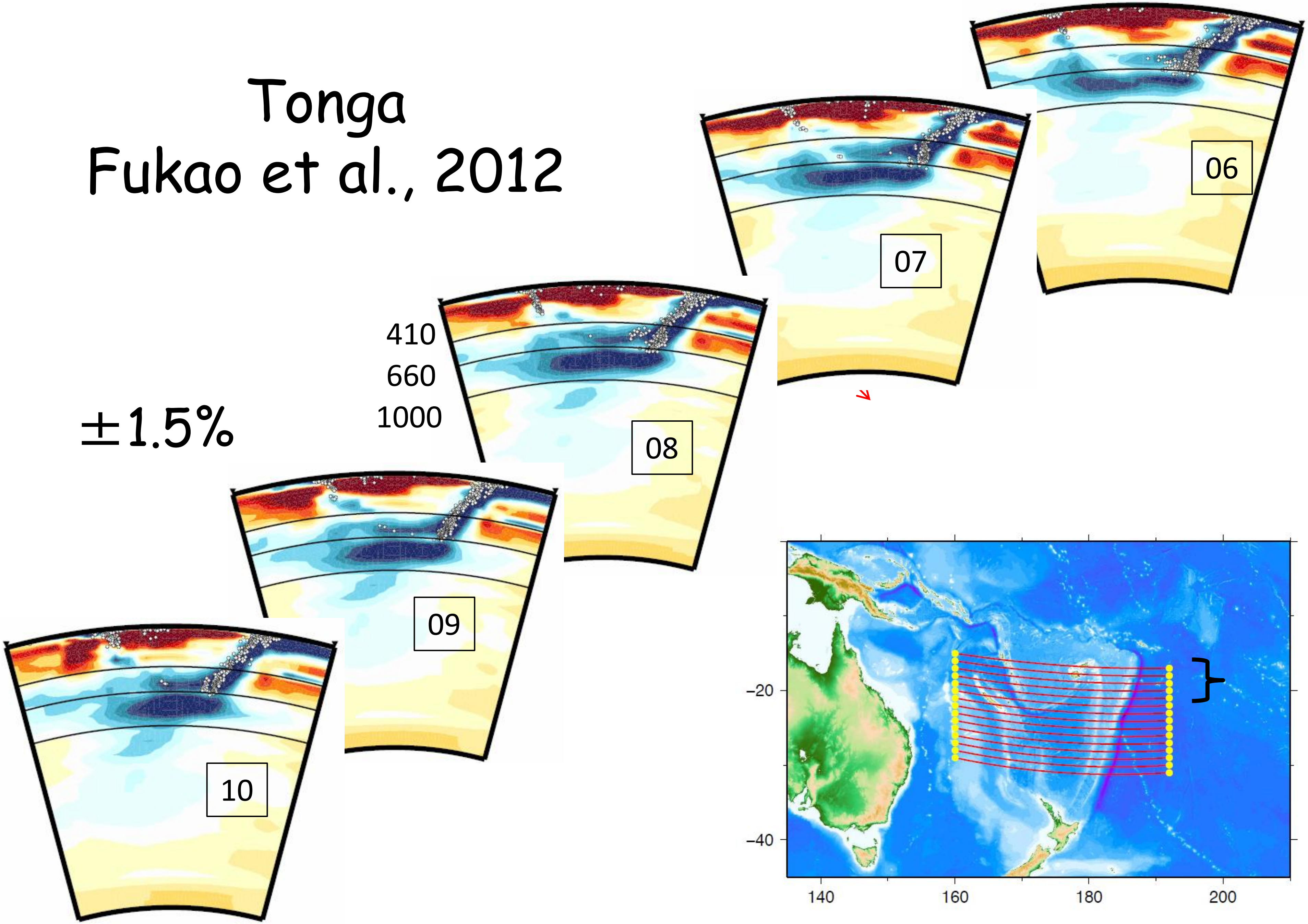
Super=plume
(LLSVP) Zone

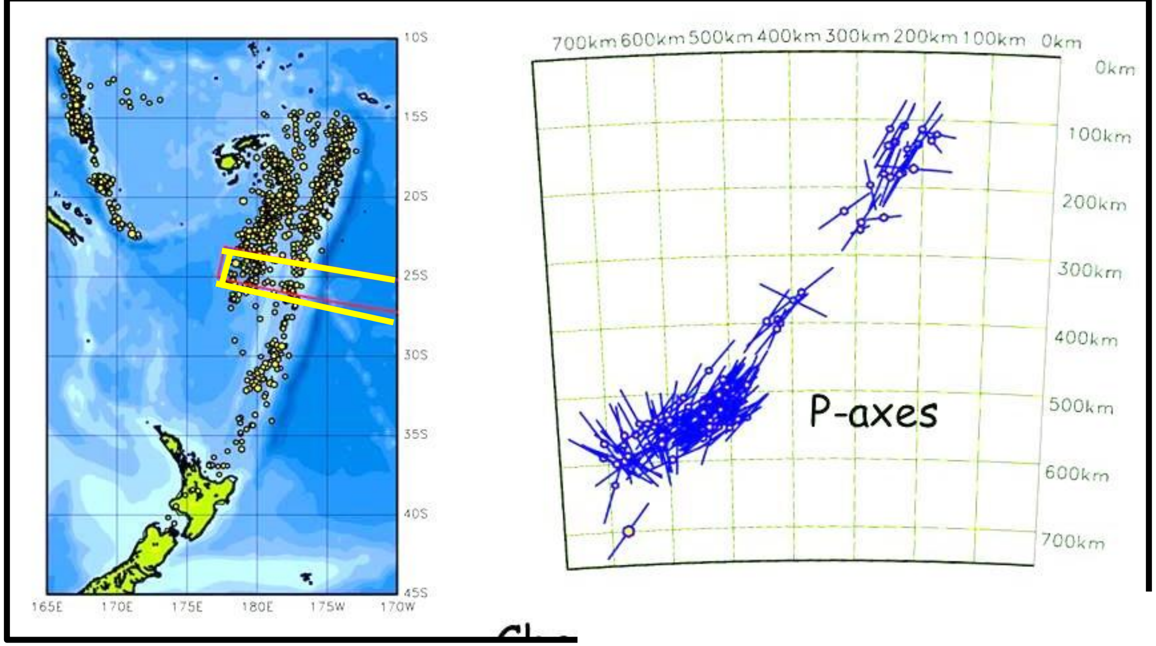


Northern Bonin
Fukao et al., 2012

Tonga
Fukao et al., 2012

±1.5%

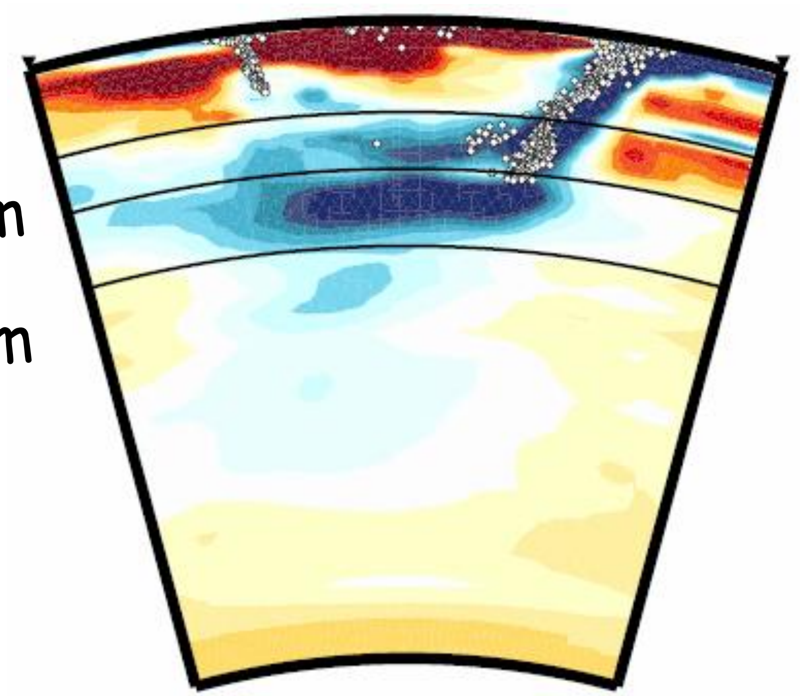




Tonga
Seismicity
split

650 km

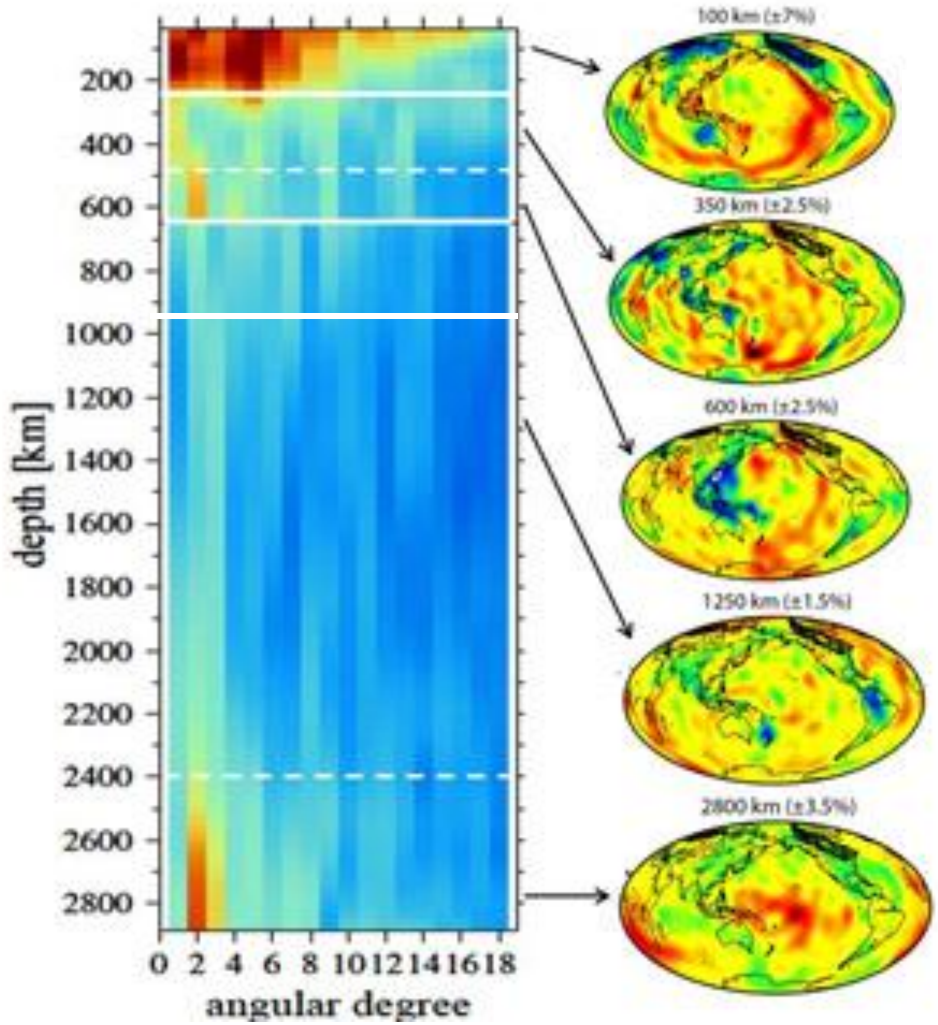
1000 km



Tonga
Velocity anomalies
Split slab

From Fukao et al. (2013)

Tomographic Stratigraphy II

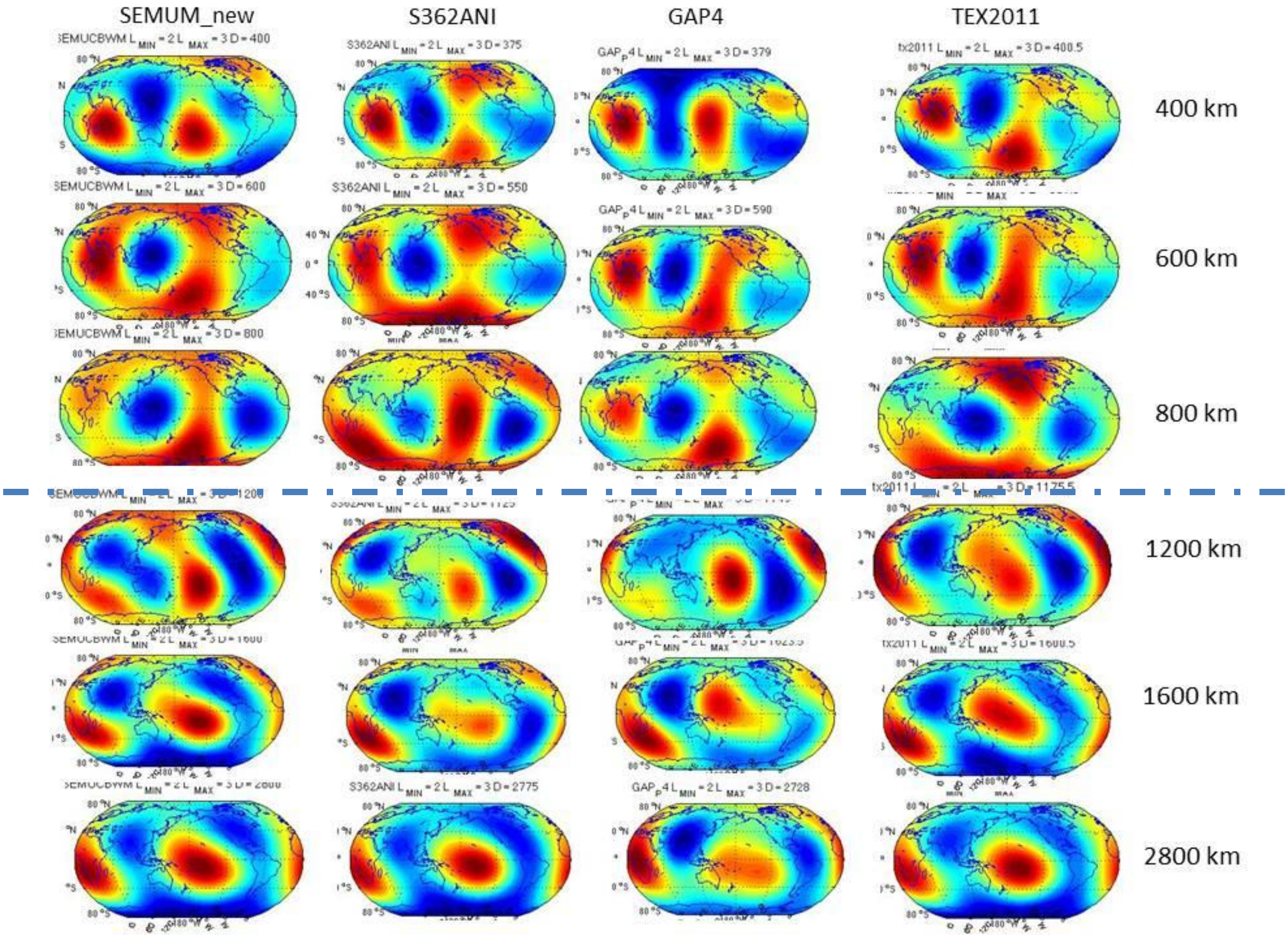


Heterosphere

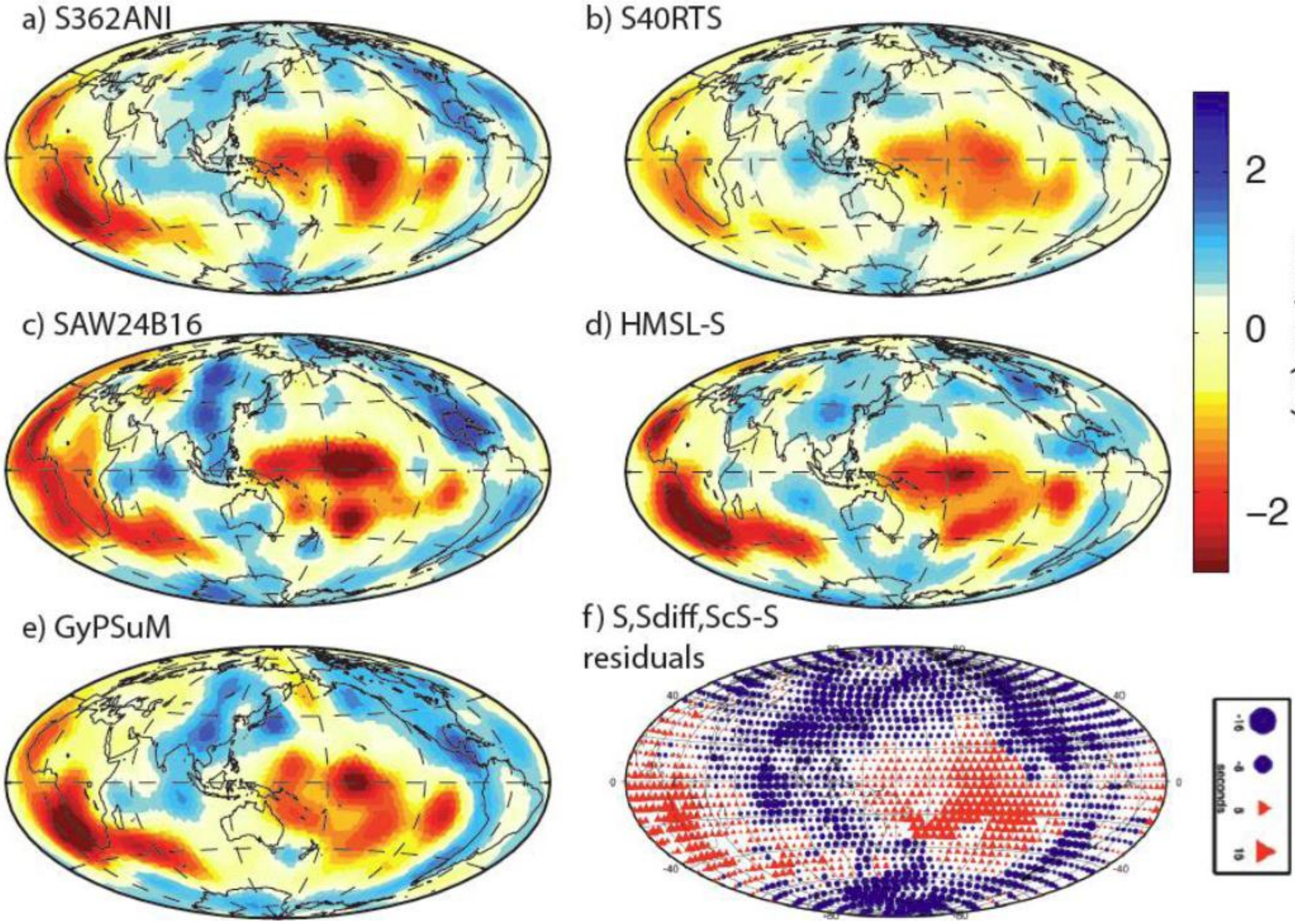
ETZ

Super-plume (LLVSP) Zone

Degrees 2&3: 1000 km pattern change

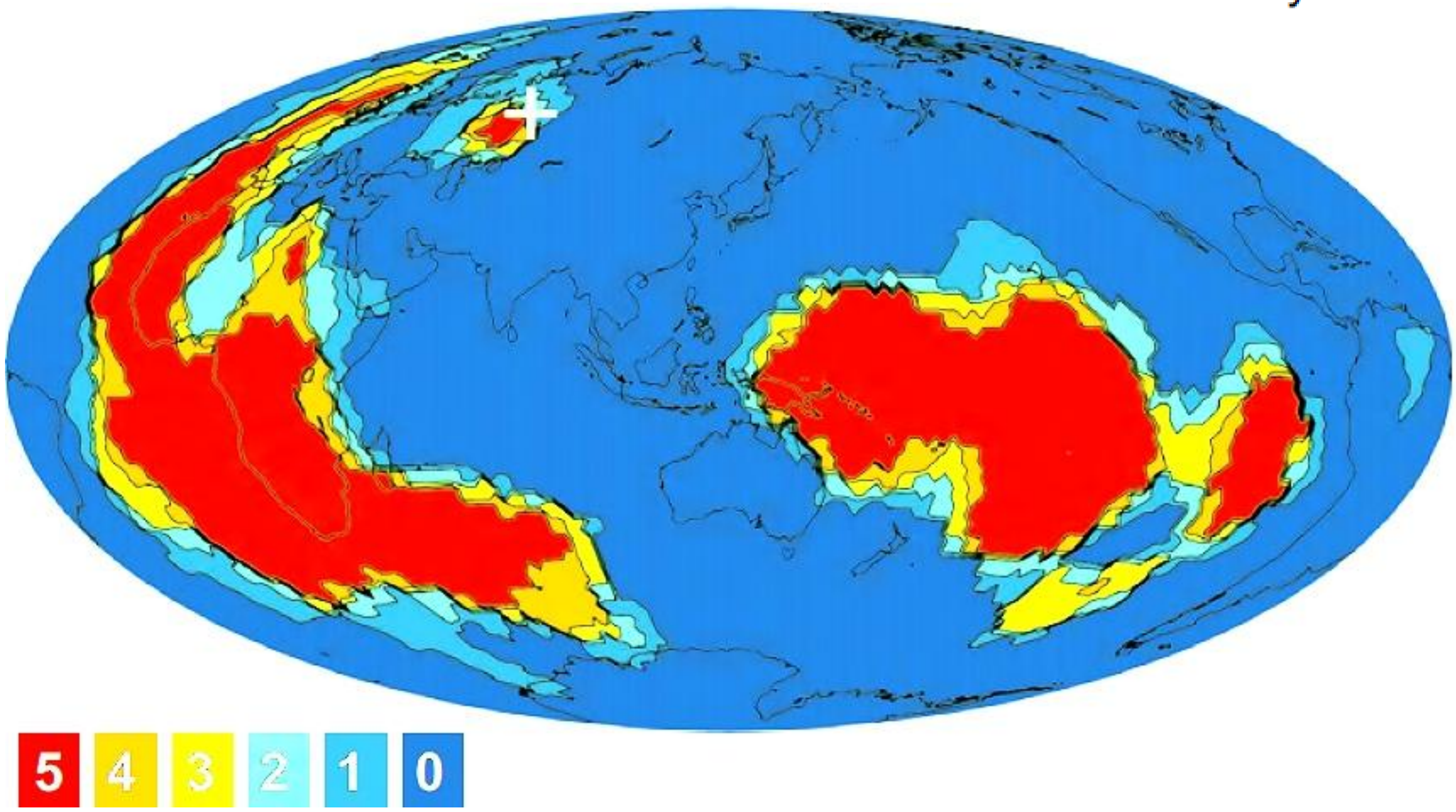


Models and Data

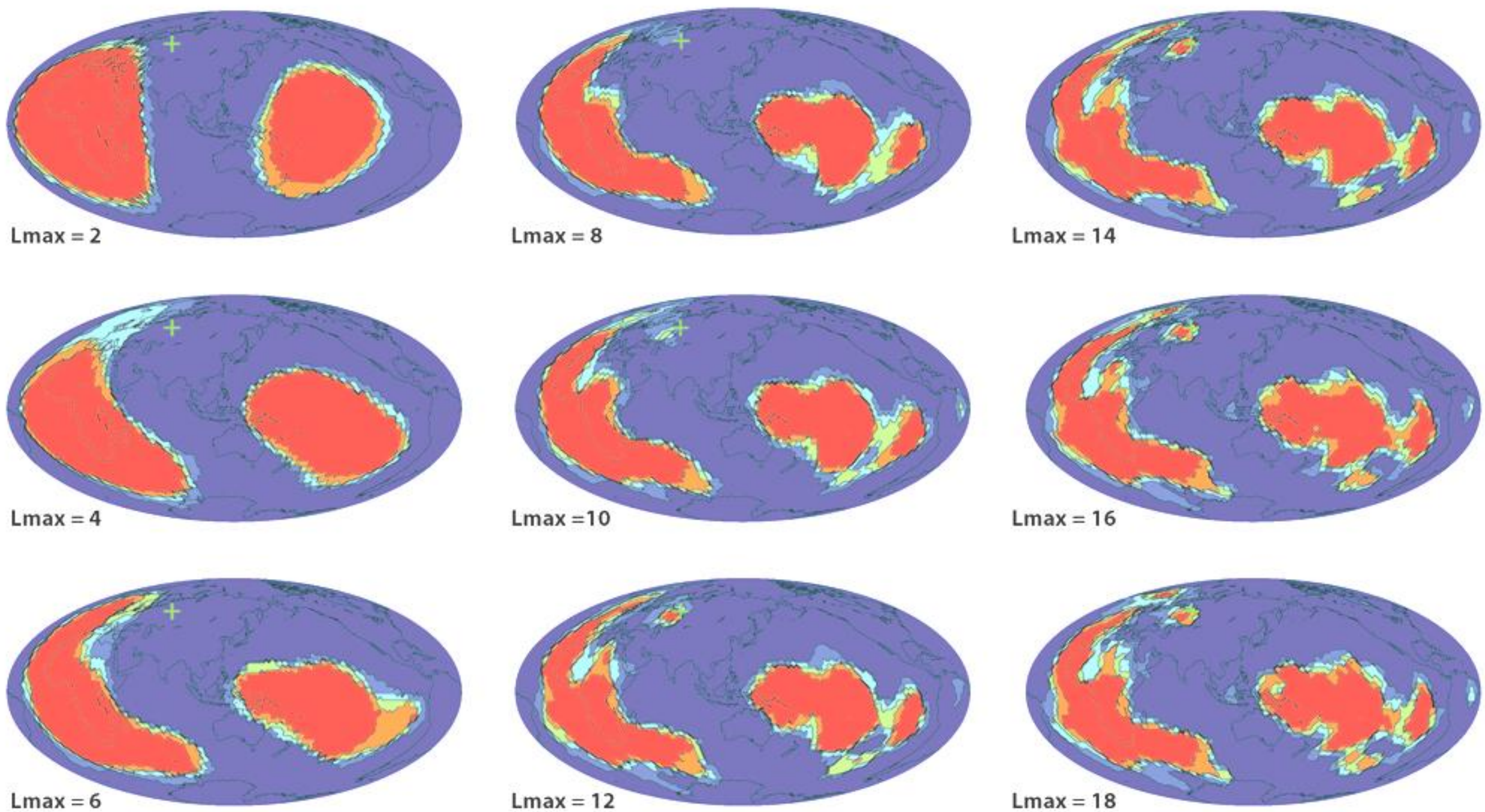


Slow – fast cluster analysis; Five models voting

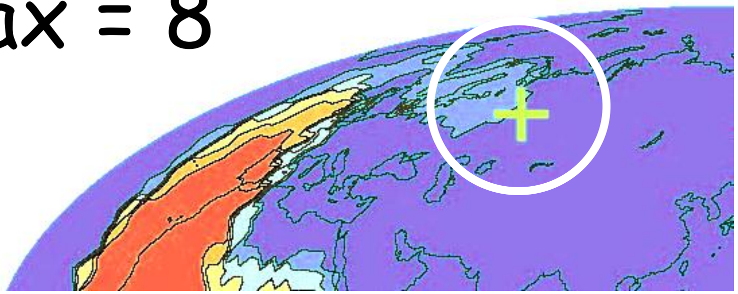
- S362ANI
- S40RTS
- SAW24B16
- HSML-S
- GyPSuM



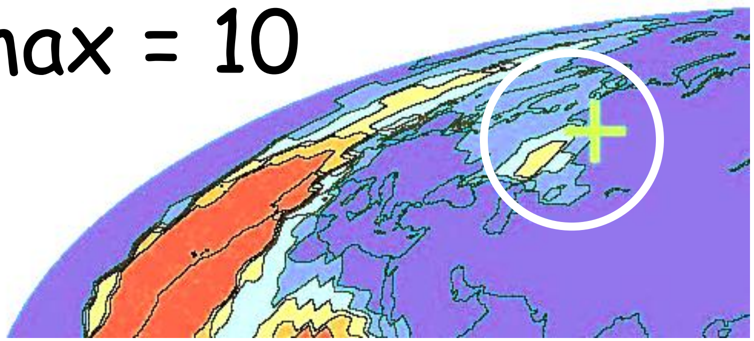
Voting vs. harmonic order



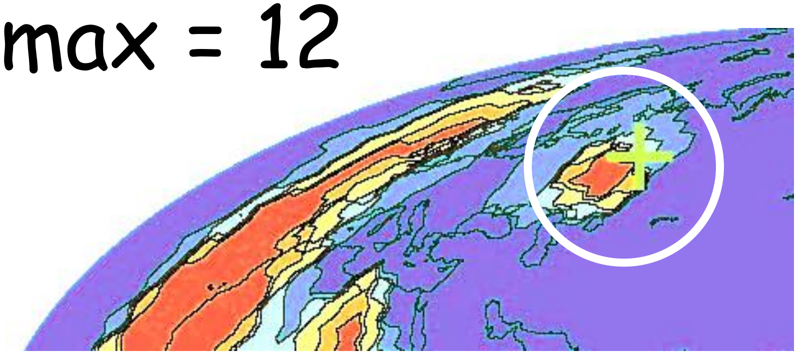
Lmax = 8



Lmax = 10

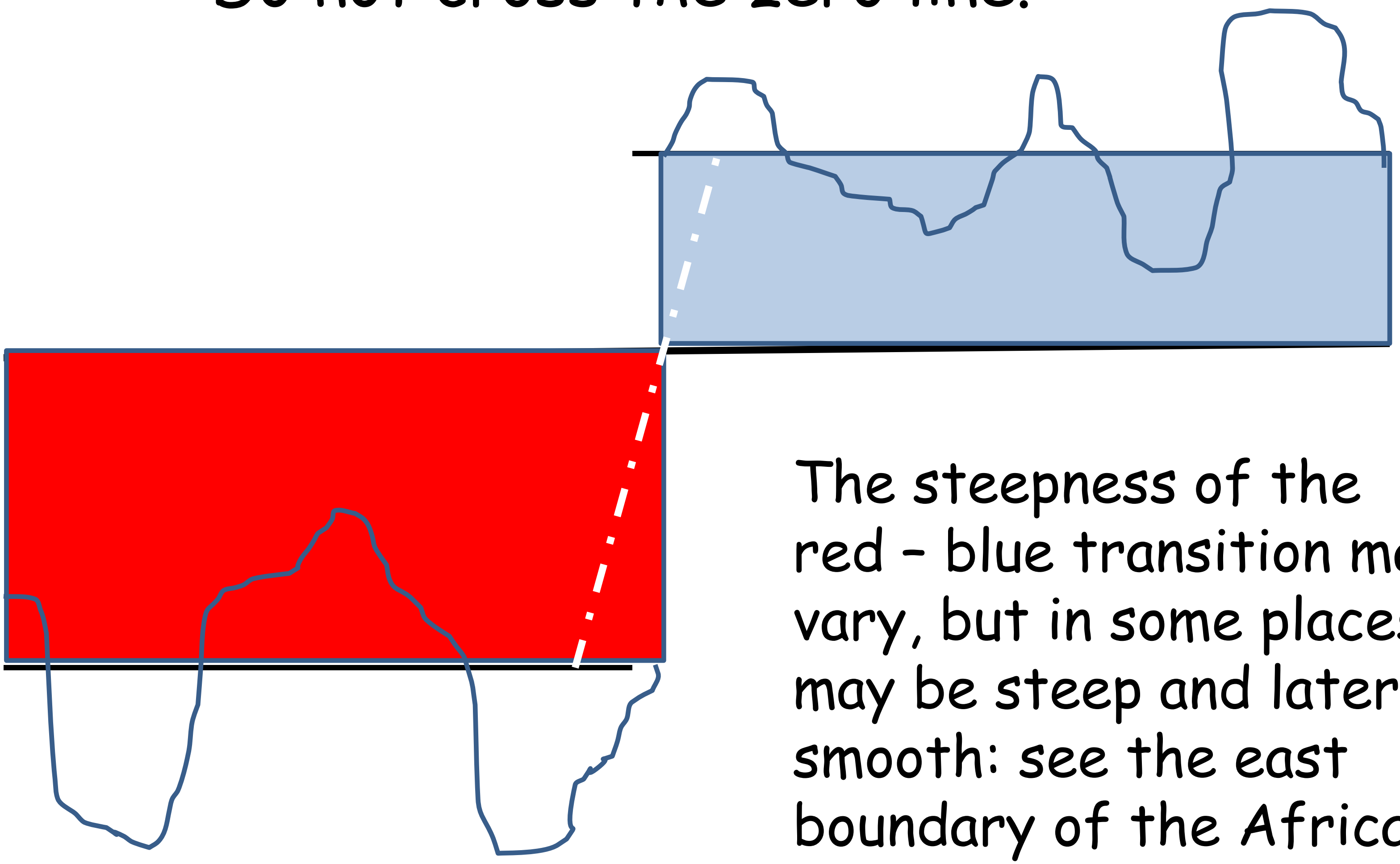


Lmax = 12



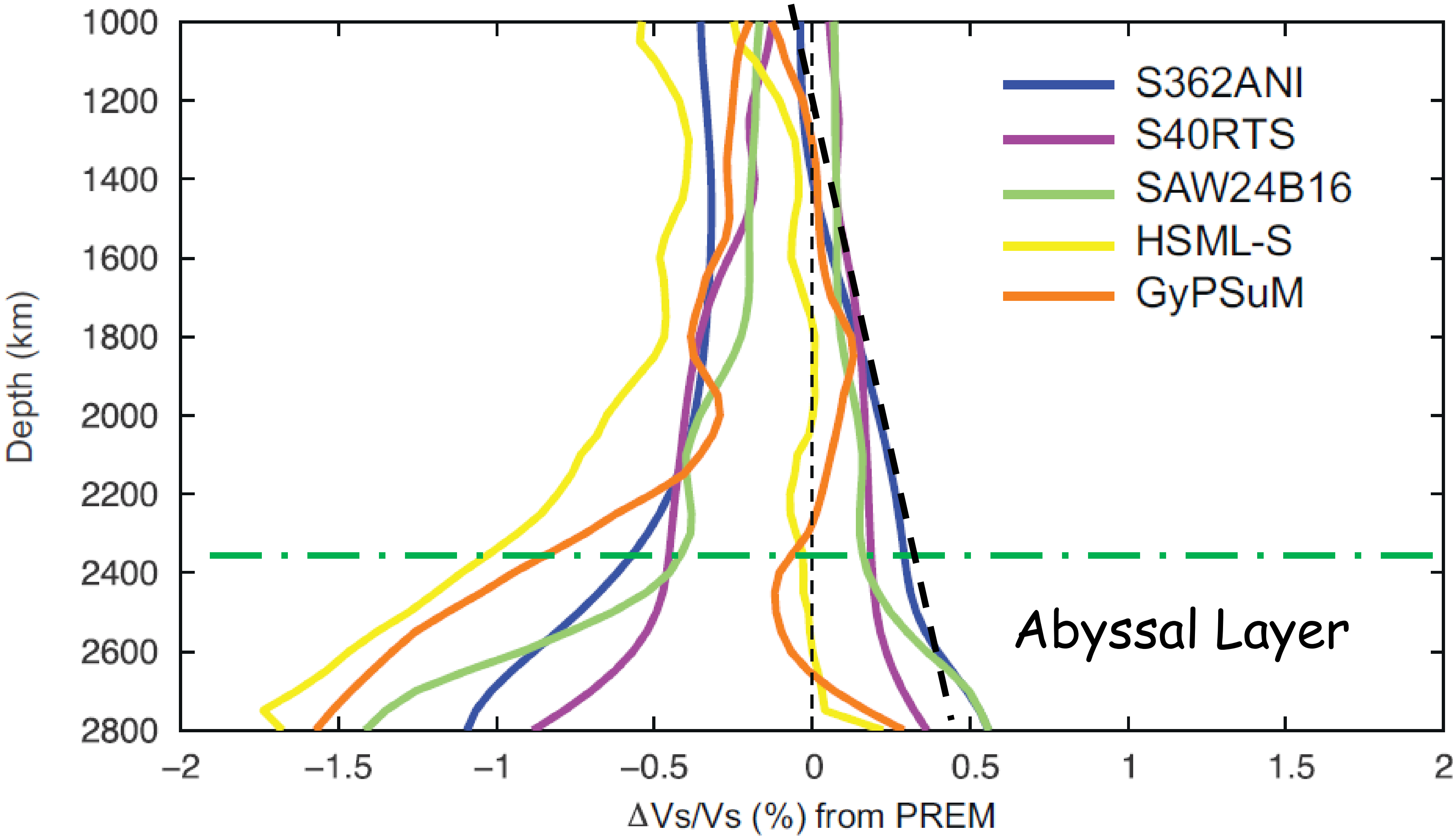
“Building” the “Perm” Anomaly

Variations in heterogeneities exist but
Do not cross the zero line.



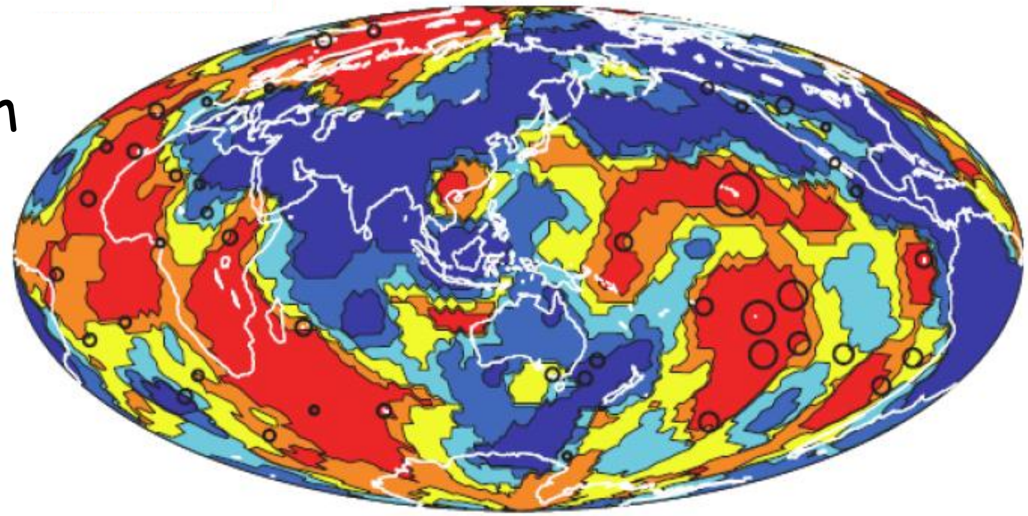
The steepness of the red – blue transition may vary, but in some places may be steep and laterally smooth: see the east boundary of the African superplume,.

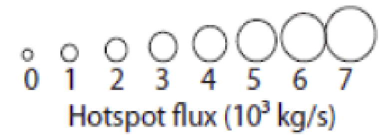
“Slow” and “Fast” average velocity anomalies for each of the five models



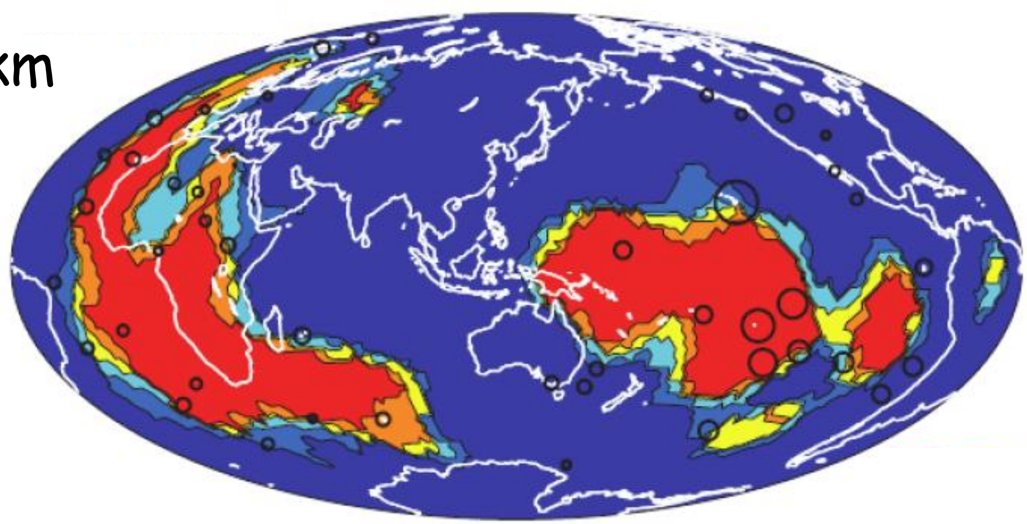
What happens to the superplumes in the middle mantle?

800 = 1800 km

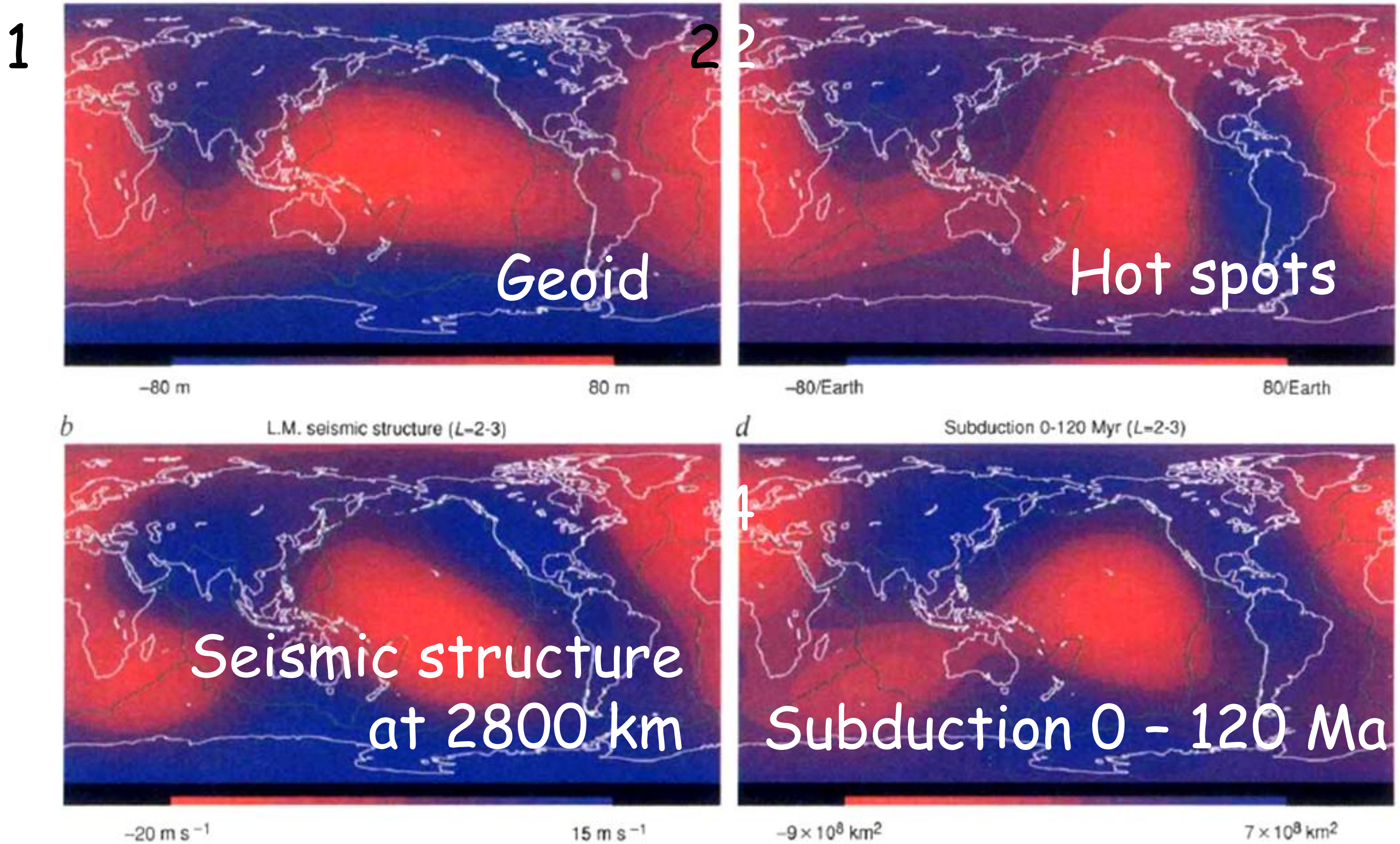




1800 – 2800 km



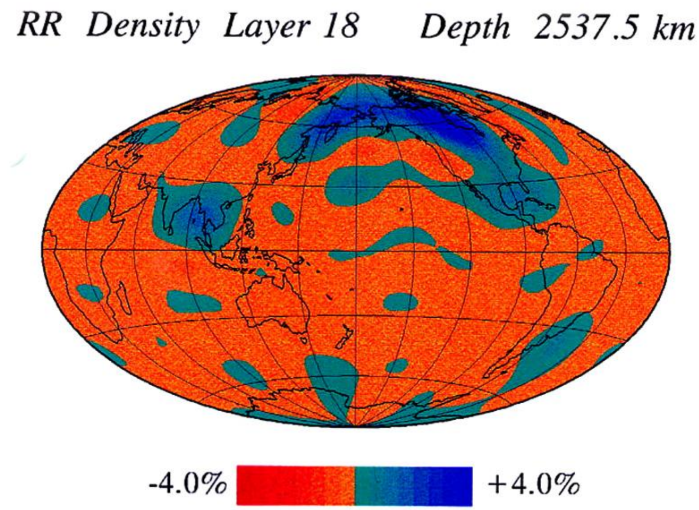
A slab sinking paradox:
Geodynamic functions; degrees 2 & 3 only

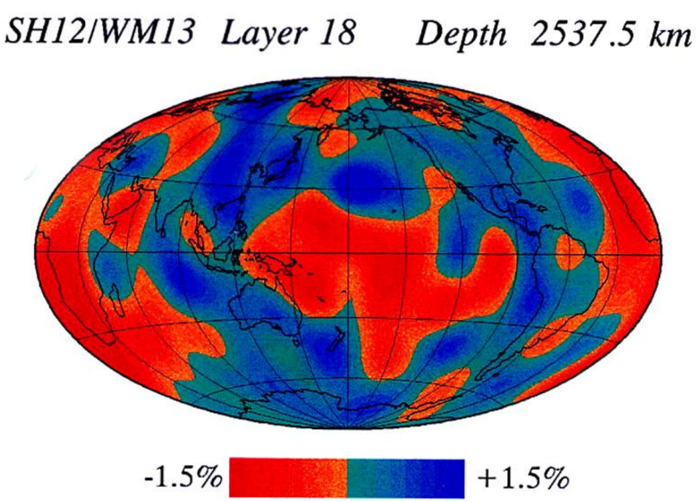


1 – 3: Dziewonski et al. (1977); **1 - 2** : Crough & Jurdy (1980).
3 – 4: Richards & Engerbretsen (1992)

Richards & Engerbretsen, 1992

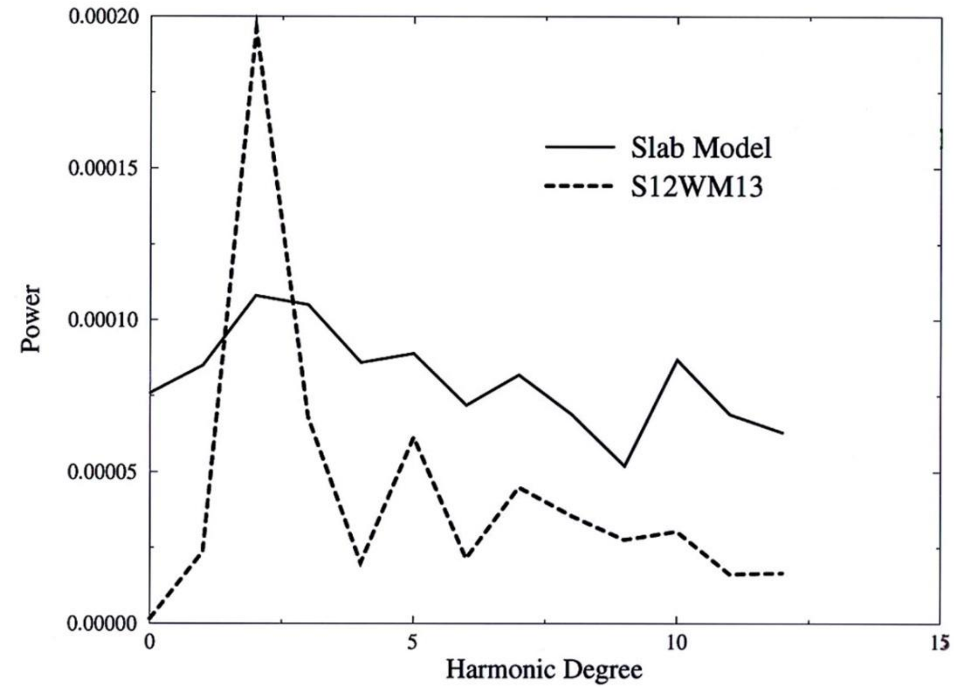
Slabs at depth do not correlate with the velocity anomalies



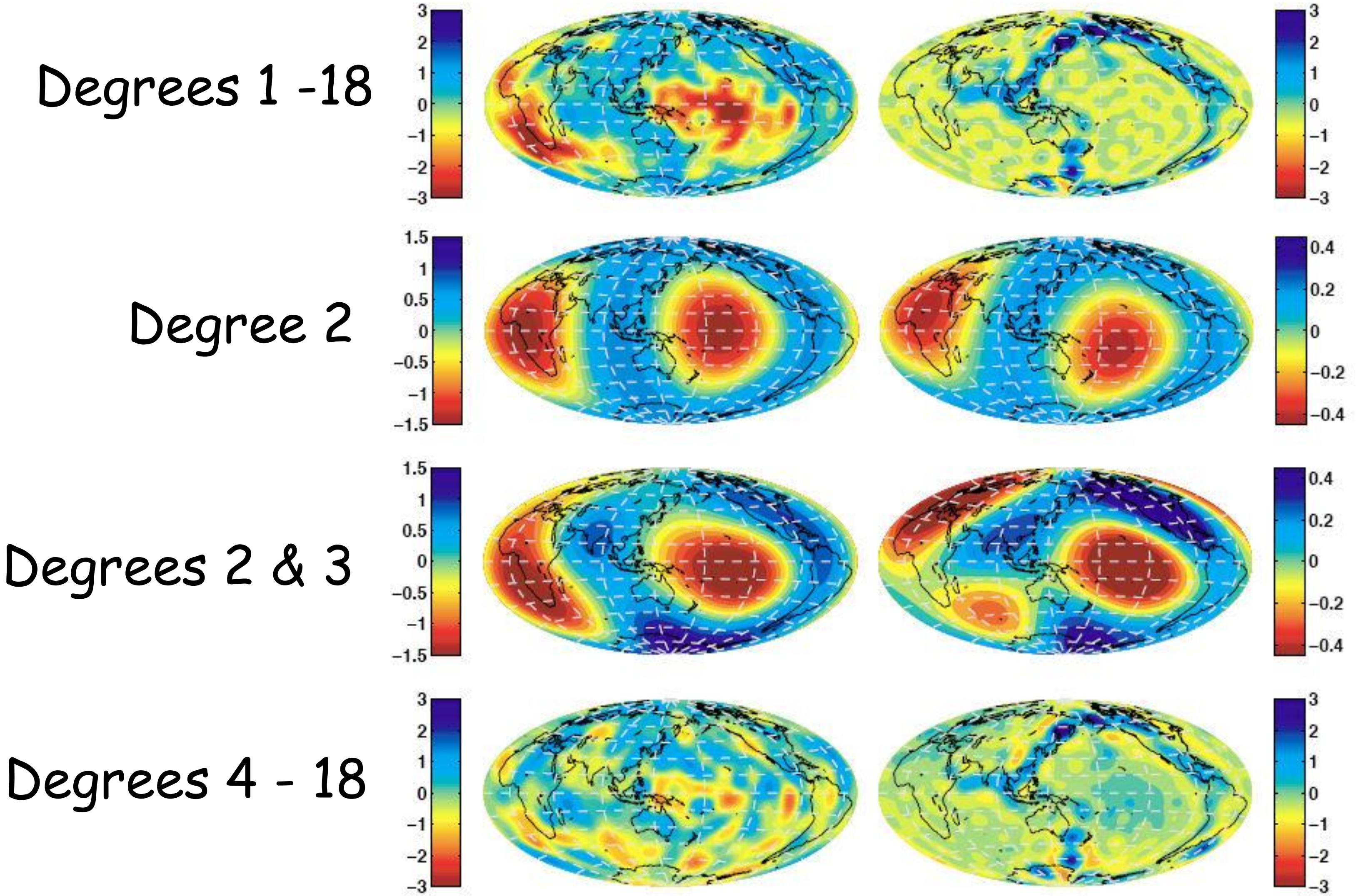


Slabs and seismic velocities; Degrees 1-12

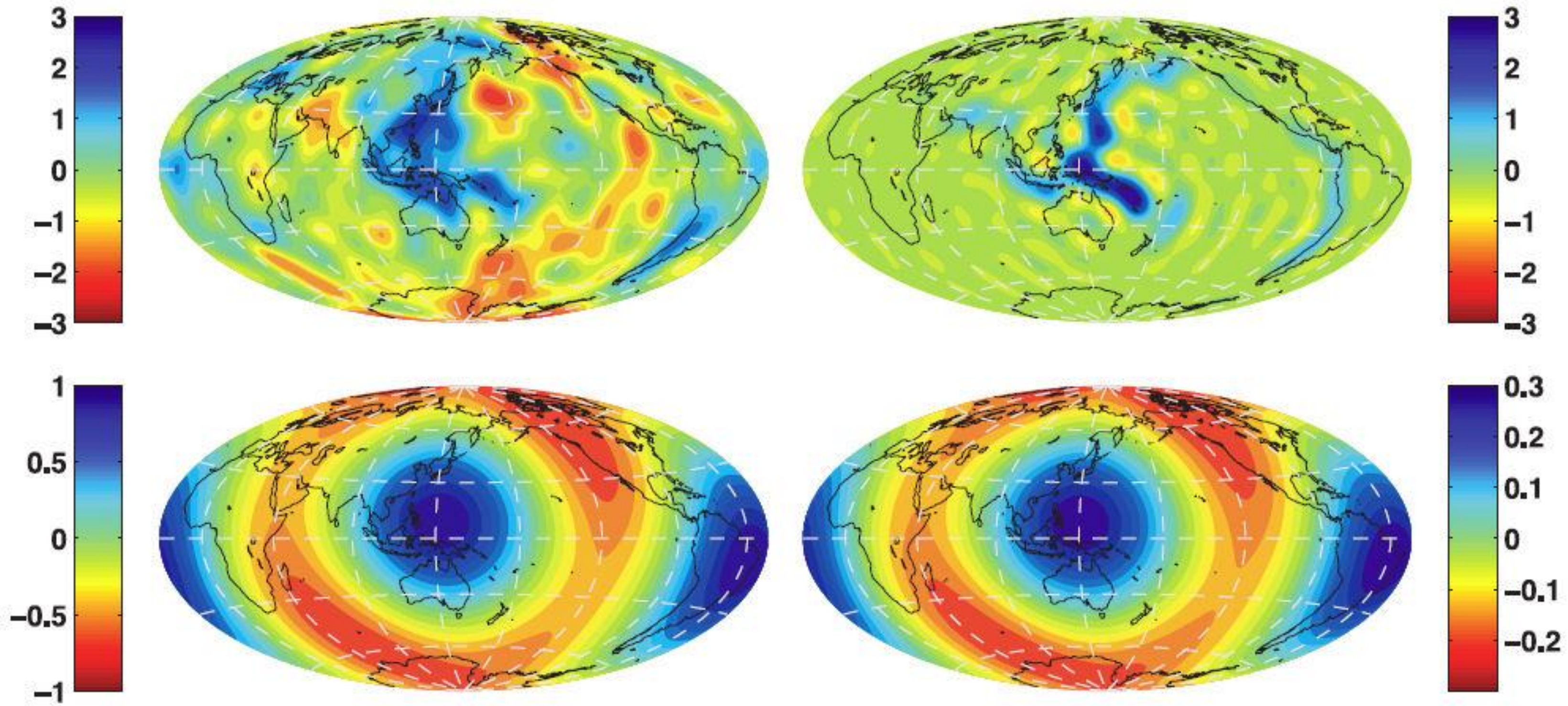
Power spectra



Velocity anomalies at 2800 km depth and integrated subduction

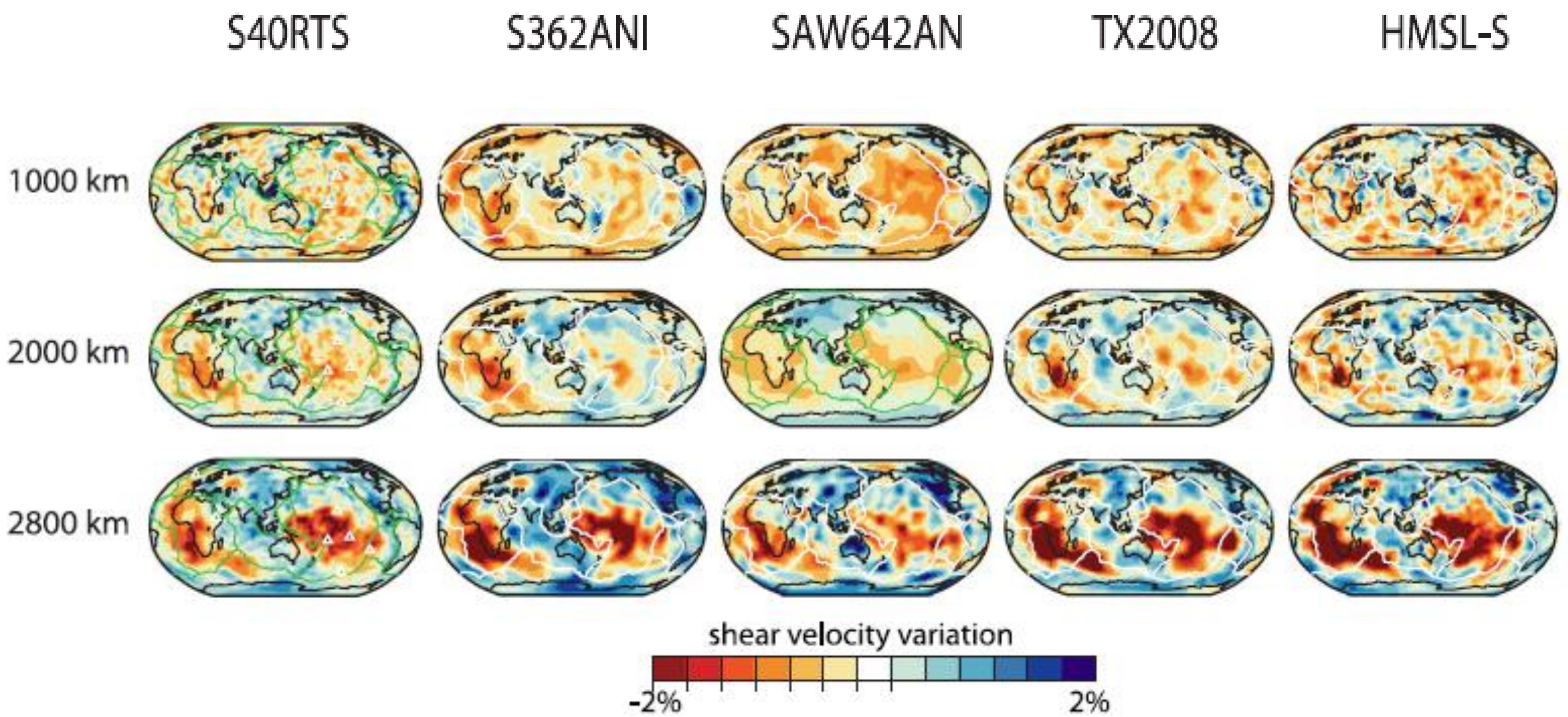


Velocities and Slabs in the Transition Zone



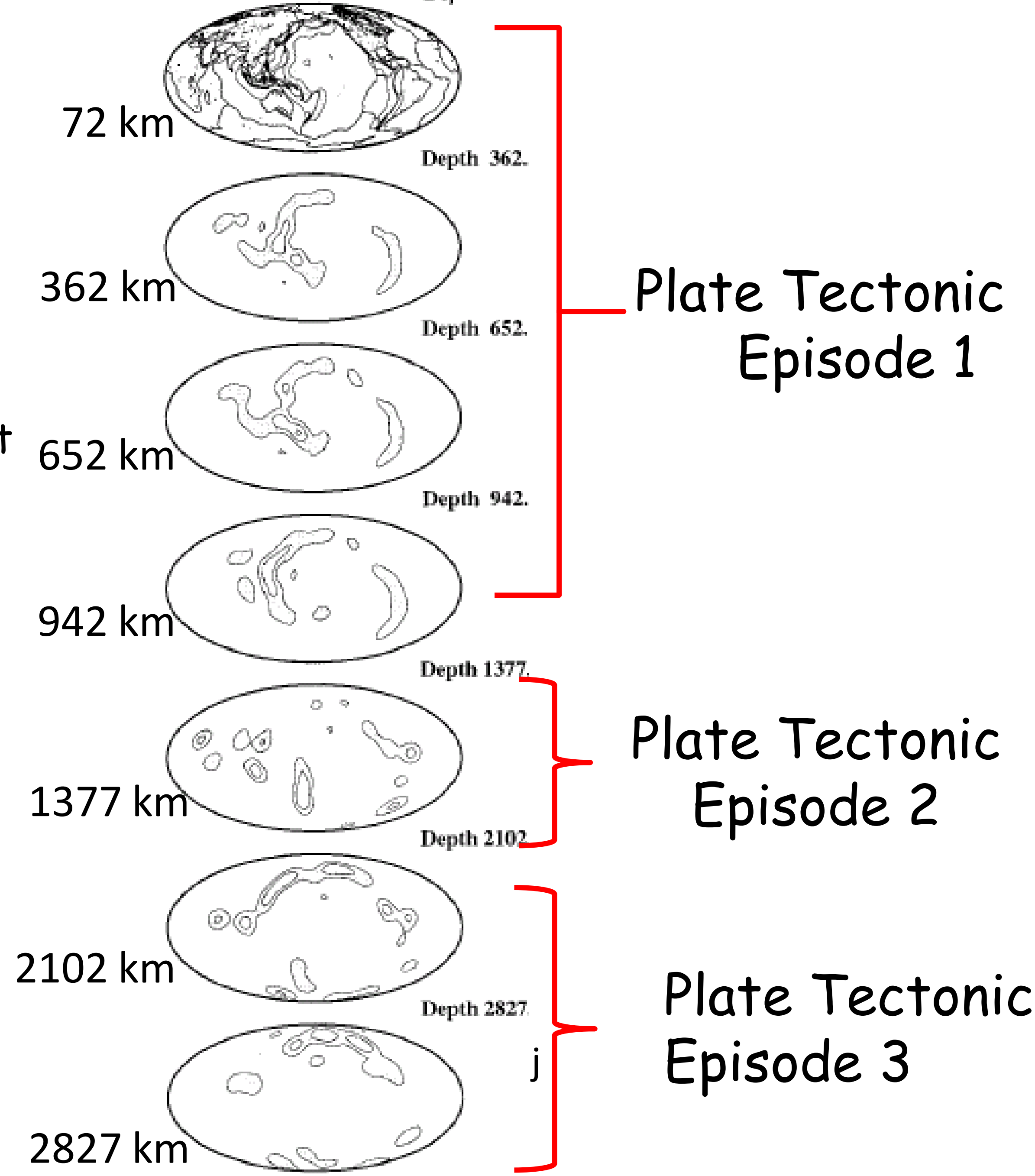
Comparison of seismic model S362ANI (left column) at 600 km and integrated mass anomaly for slab model L-B&R (right column). The top maps show the velocity model at 600 km and the whole-mantle integrated slab model for degrees 1-18. The bottom row shows degree-2 pattern only (note the changed color scale).

Lower Mantle



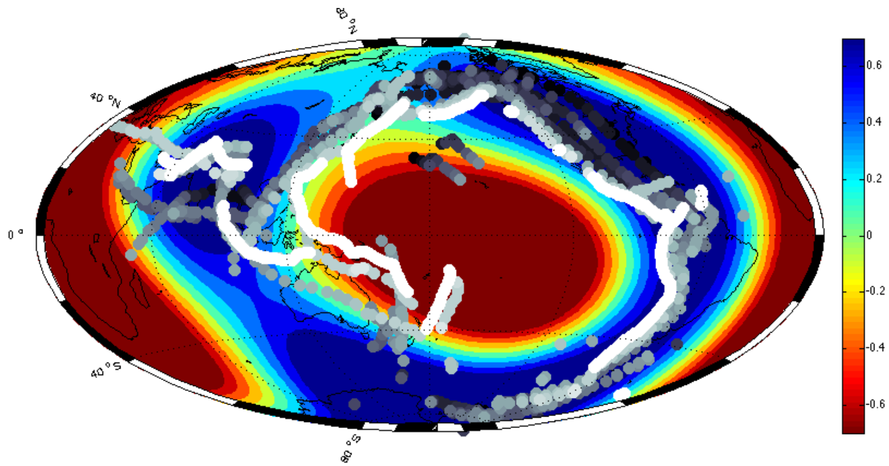
Ritsema et al., 2011

Each "Episode" lasting 20 – 40 Ma shows a distinct change in the subduction (and plate motion) pattern but they all share the same envelope, which is the long term component of the Earth's dynamics. CMB

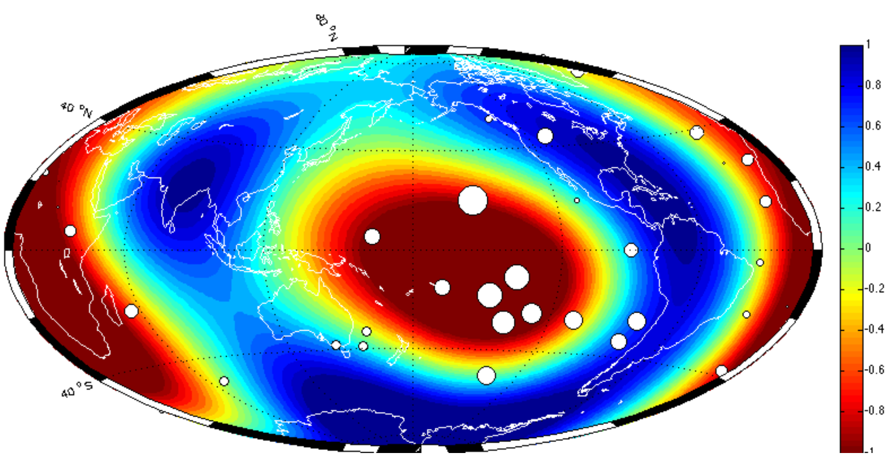


After Lithgow-Bertelloni and Richards, 1998

Degree 2 & 3 vs. subduction history and hotspot distribution



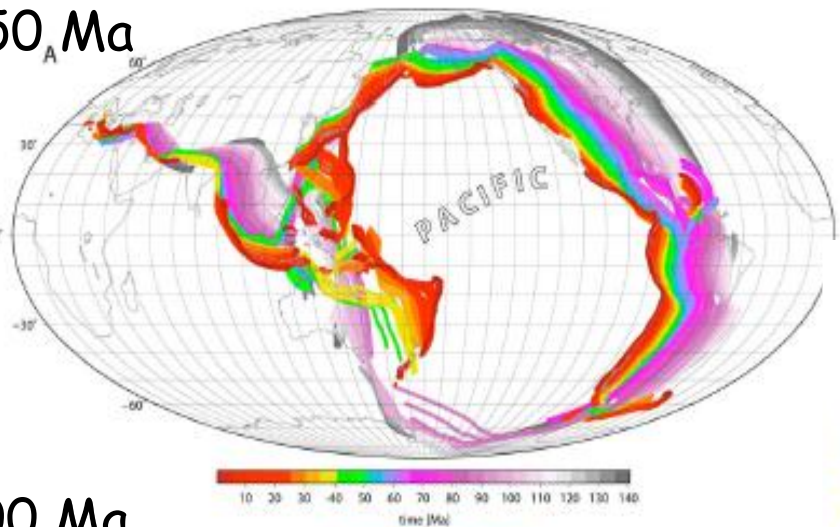
Top: “Slablets” as a function of time; recent - white, oldest - black. Most of subduction is inside the fast ring This envelope coincides, roughly, with the zero contour of the degree 2 and 3 of velocity anomalies near the CMB.



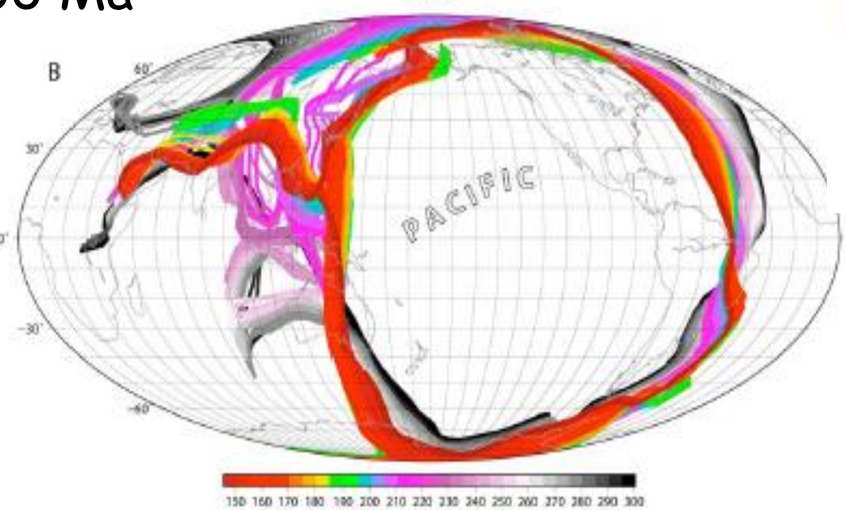
Bottom: hotspot distribution with size as a function of flux. Most of hotspots are within the slow velocity field. So, the zero contour corresponds to the long-term component of the Earth’s dynamics

Past positions of subduction zones: 0 – 300 Ma (right) and 0 - 120 Ma (right)

0 – 150 Ma

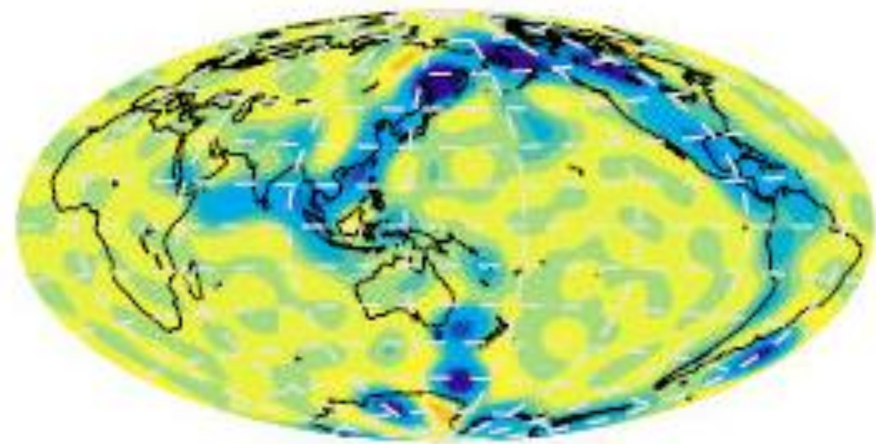


150 - 300 Ma



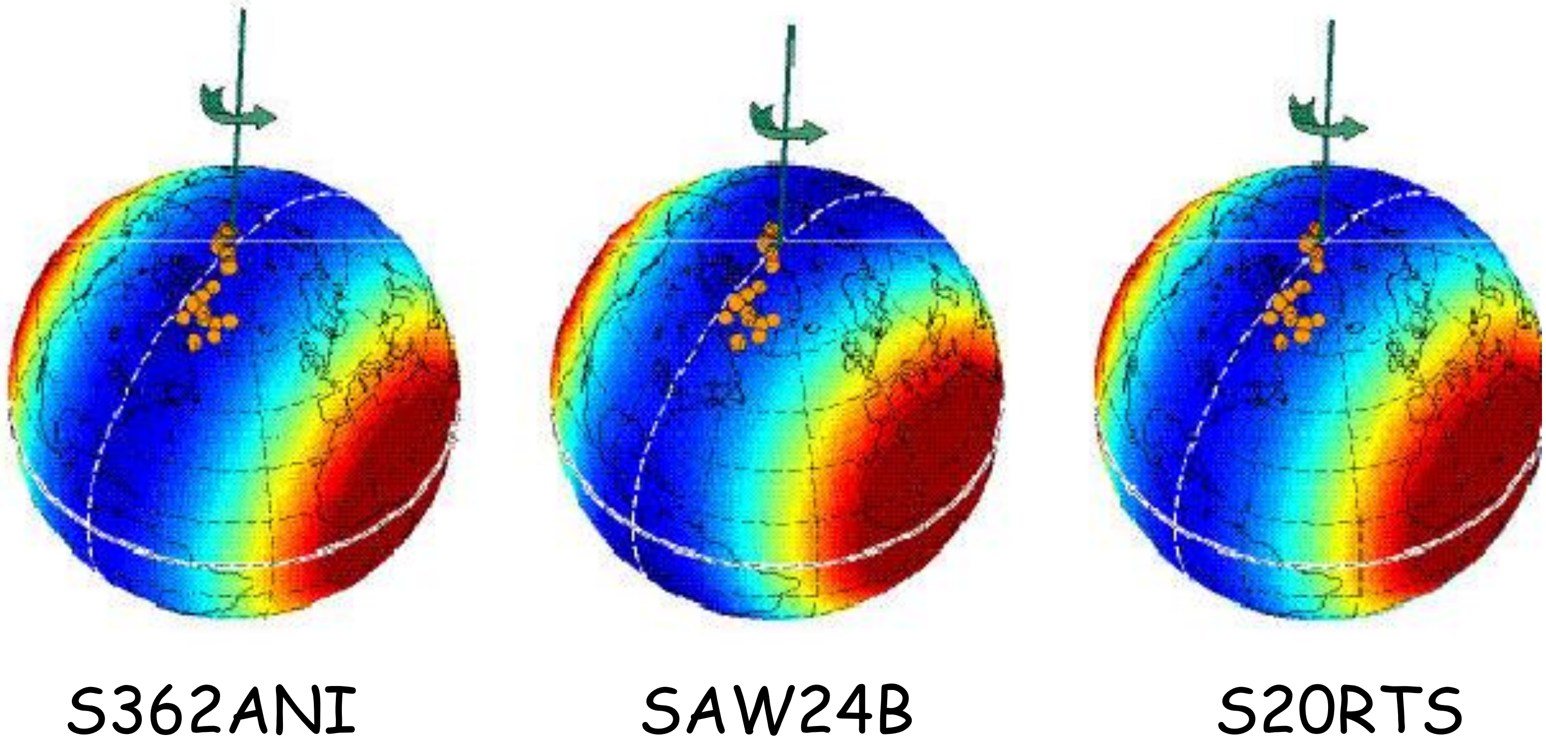
Steinberger and Torsvik (2010)

Integrated Subduction ; 0 120 Ma



After Lithgow-Bertolloni And Richards (1998)

Degree 2 velocity anomalies at 2800 km, the Earth's rotation axis and TPW paths of Besse and Courtillot (2002)



Conclusions I

“Tomographic stratigraphy” complemented by geodynamic observations on plate motions, subduction history and true polar wonder sets three distinct regions in the Earth’s mantle:

1. **Heterosphere.** Moho to 250 – 300 km depth. Shorter wavelength (strongest is degree 5),very heterogeneous: 90% of volume integrated power. Represents present day tectonics. Time scale: about 30 Ma.

Conclusions II

2. Extended Transition Zone. 250 – 300 km to 650 or 1000 km. Relatively white spectrum, except for distinct increase in degree 2 power above the 650 km discontinuity, where subducted slabs may pond; few slabs penetrate the 650 km discontinuity but flatten out at 1000 km; with one possible exception. Time scale: at least the same as "Heterosphere"

3, Superplume (LLVSP) Zone. 650 or 1000 km to CMB. Strong heterogeneity at CMB dominated by degrees 2 and 3 continues up to 1000 km depth but with decreasing amplitude. "Abyssal Zone" shows very steep gradient from CMB to

Conclusions III

500 km above CMB. This is where the plumes and ULVZ structures are likely to be born. The time is longer than 200 Ma but may be much larger, as indicated by some True Polar Wonder results. The origin of the structure may point to an early stage in the Earth's evolution