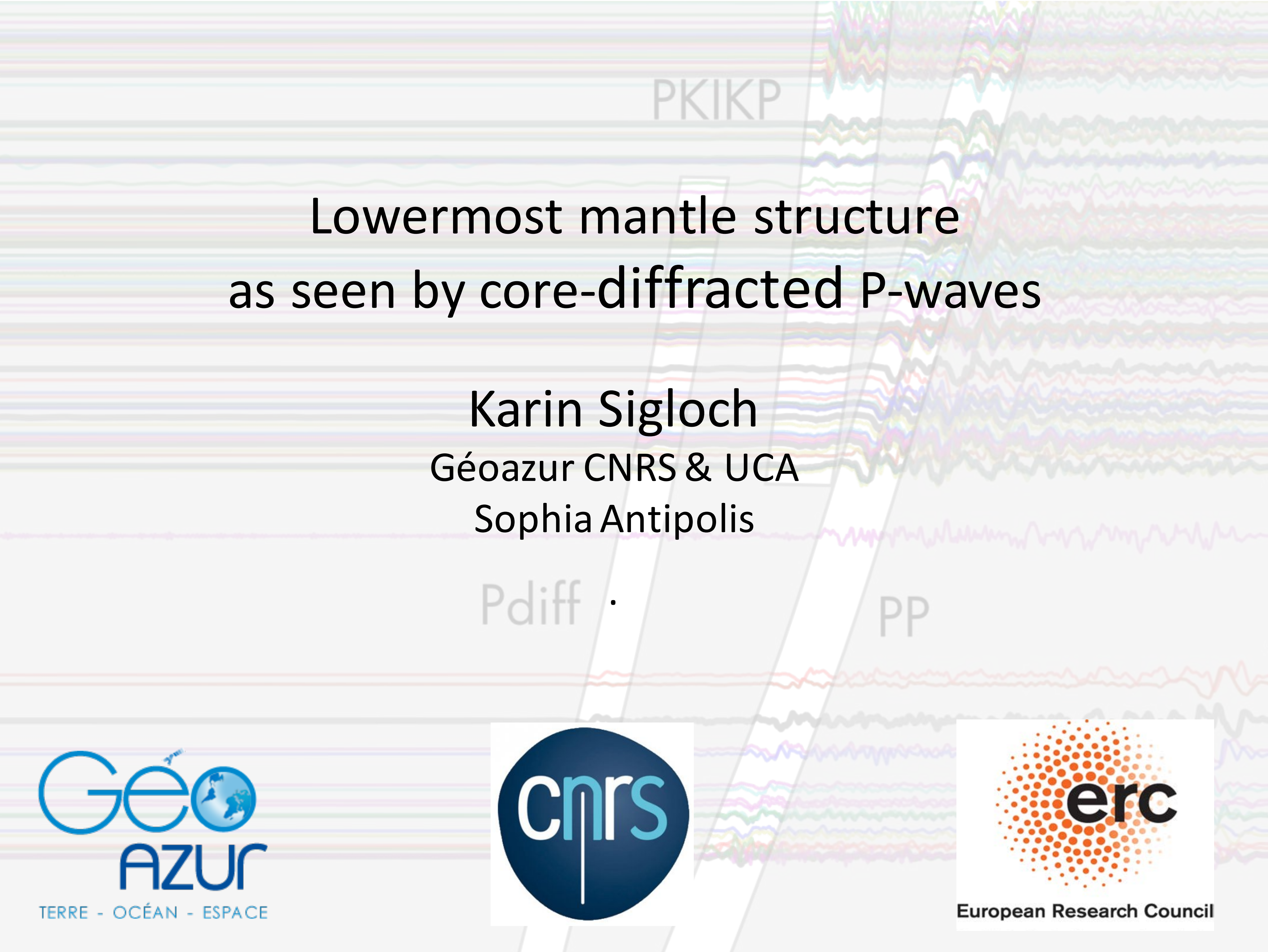

Lowermost mantle structure as seen by core-diffracted P-waves

Karin Sigloch
Géoazur CNRS & UCA
Sophia Antipolis

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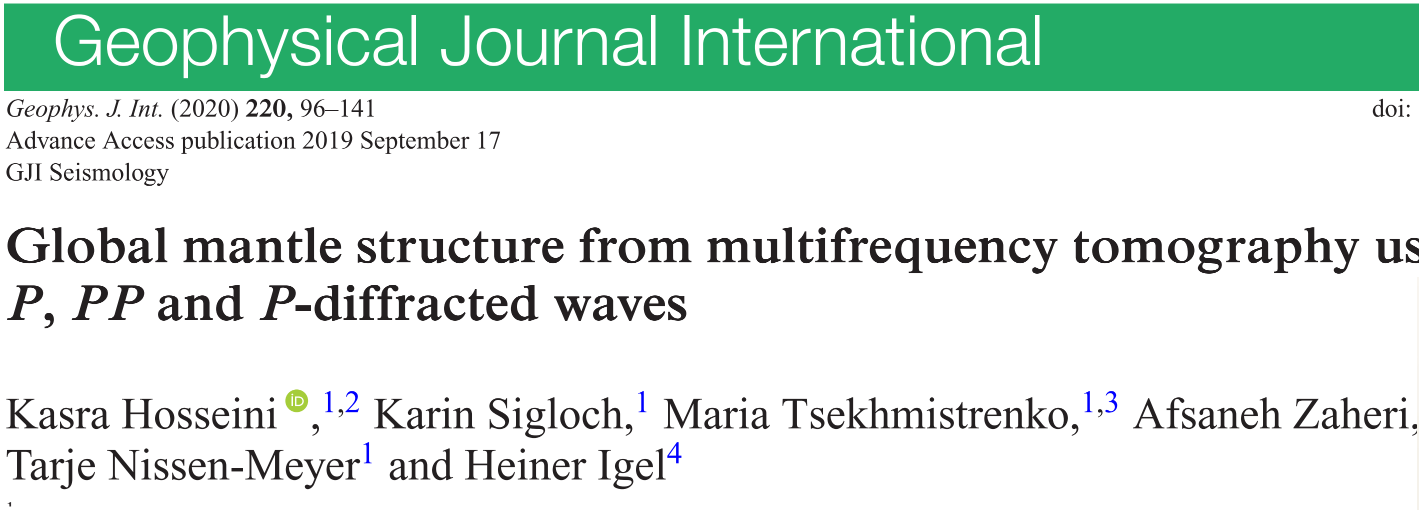


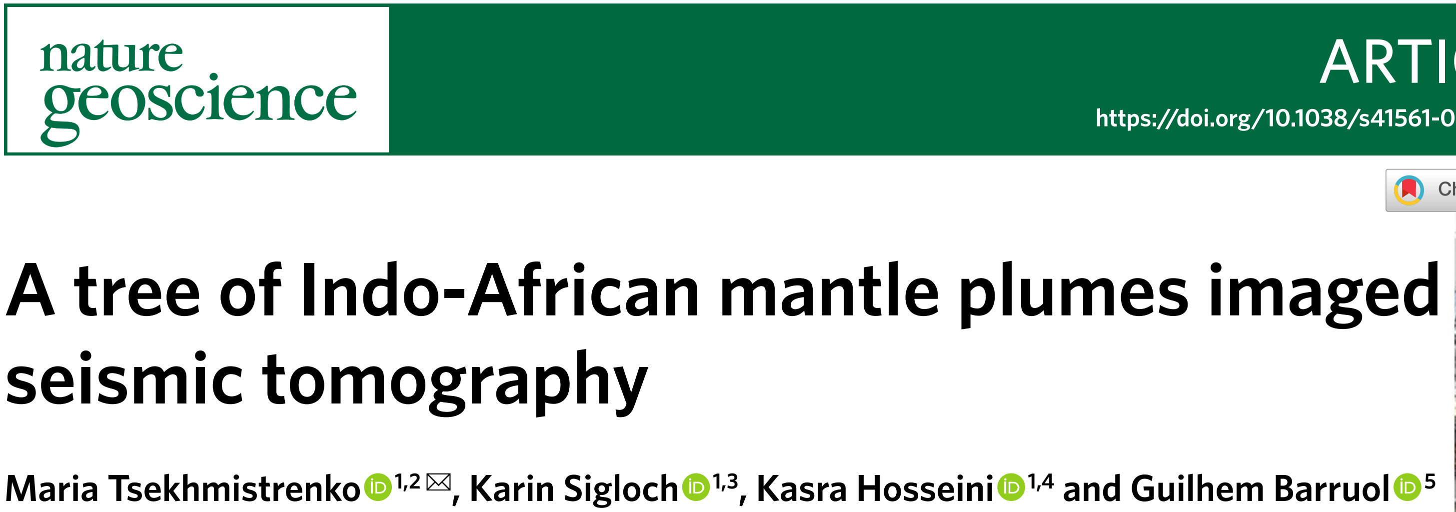
Geophysical Journal International

Geophys. J. Int. (2020) **220,** 96–141
Advance Access publication 2019 September 17
GJI Seismology

doi: 10.1093/gji/ggz394

Global mantle structure from multifrequency tomography using *P*, *PP* and *P*-diffracted waves

Kasra Hosseini,[1,2] Karin Sigloch,[1] Maria Tsekhmistrenko,[1,3] Afsaneh Zaheri,
Tarje Nissen-Meyer[1] and Heiner Igel[4]



nature geoscience

ARTICLES

https://doi.org/10.1038/s41561-021-00762-9

Check for updates

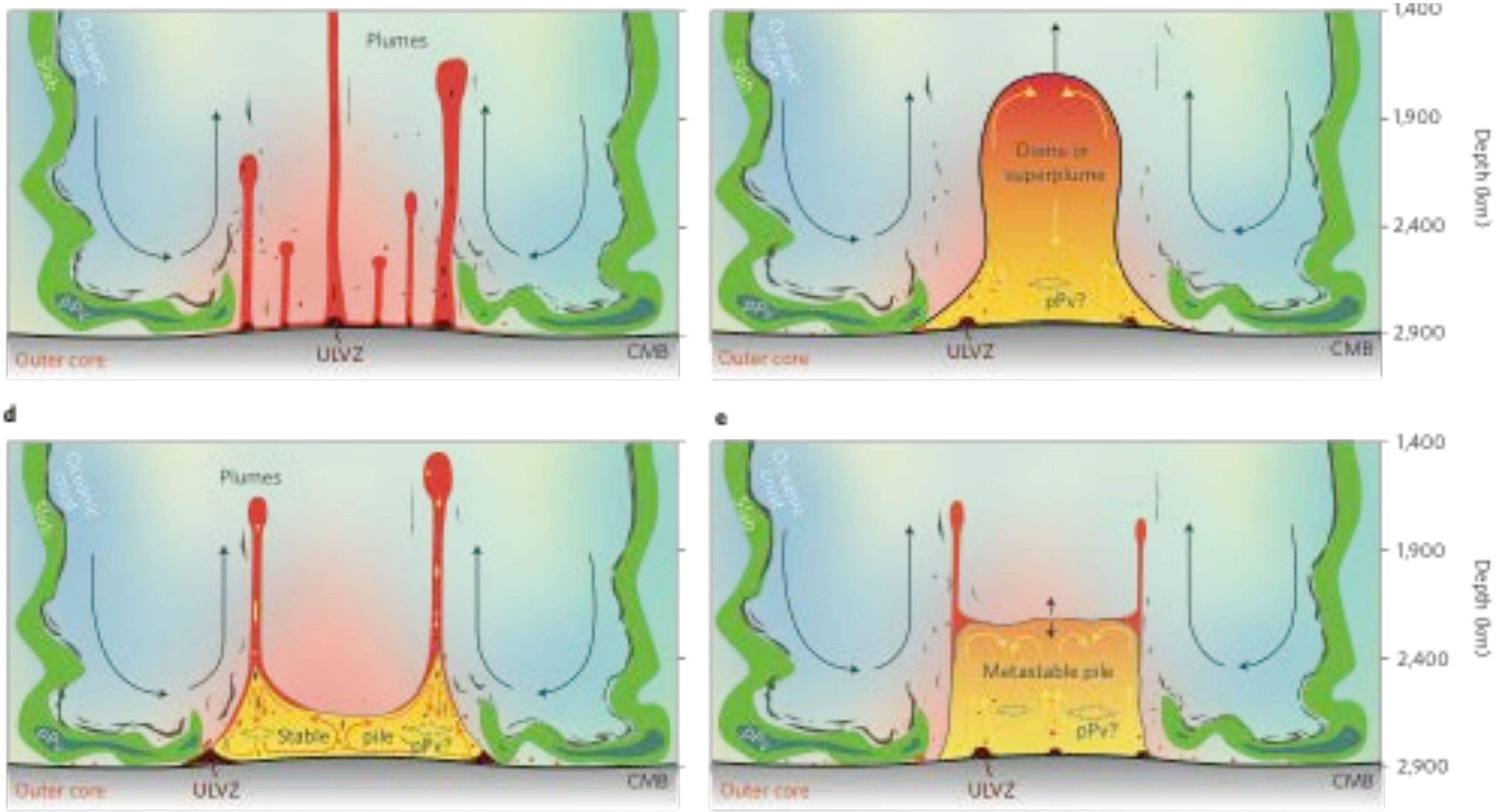
A tree of Indo-African mantle plumes imaged by seismic tomography

Maria Tsekhmistrenko[1,2], Karin Sigloch[1,3], Kasra Hosseini[1,4] and Guilhem Barruol[5]

Lowermost mantle: where slabs end up and plumes begin

Four hypotheses relating plumes, LLVPs and slabs. `
High tomographic resolution is required to rule any of them out.

Garnero et al. 2016 review



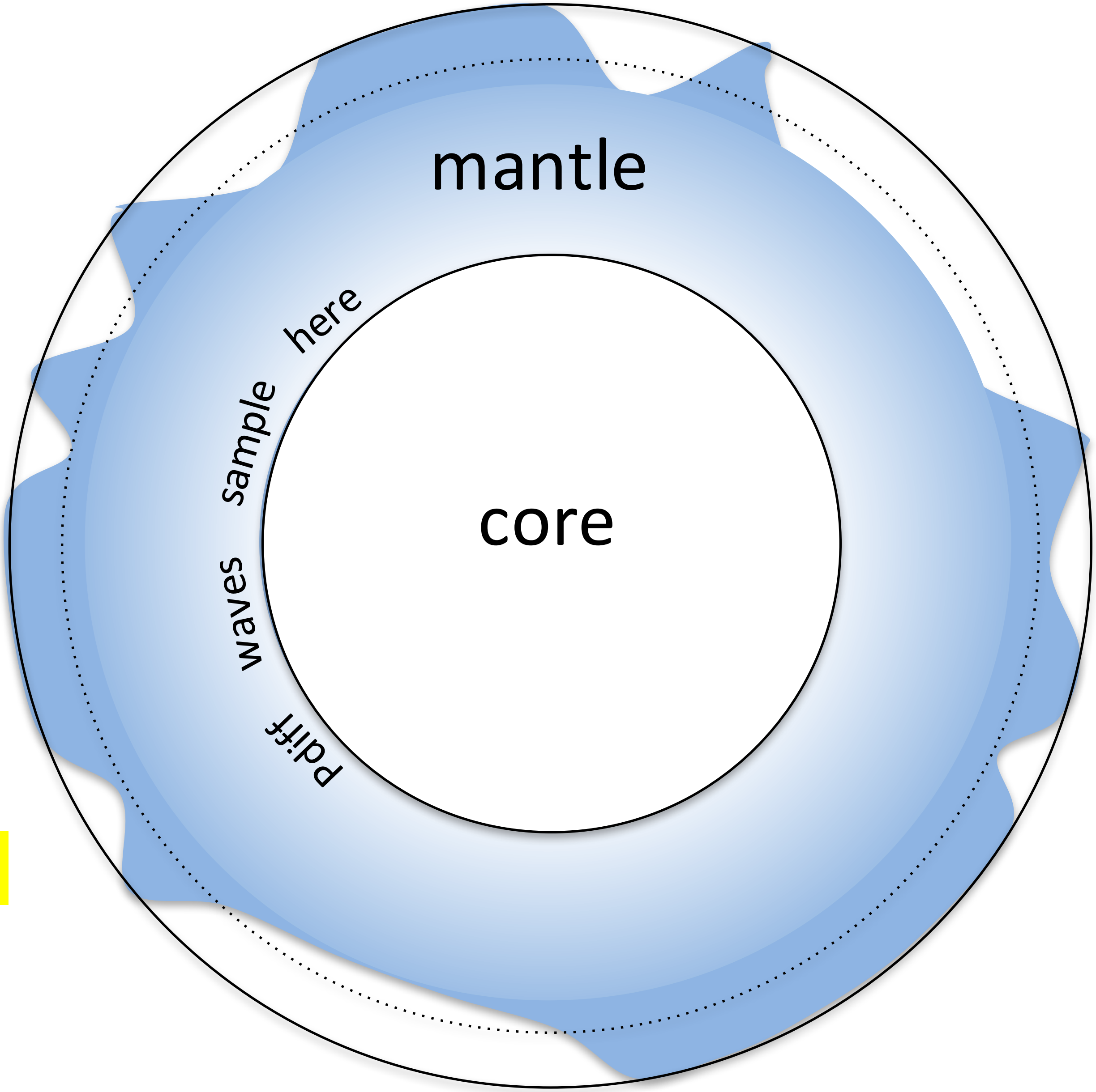
Objective: Use Pdiff waves to fill the illumination gap of body-wave tomography in the lowermost ~1000 km

P-waves

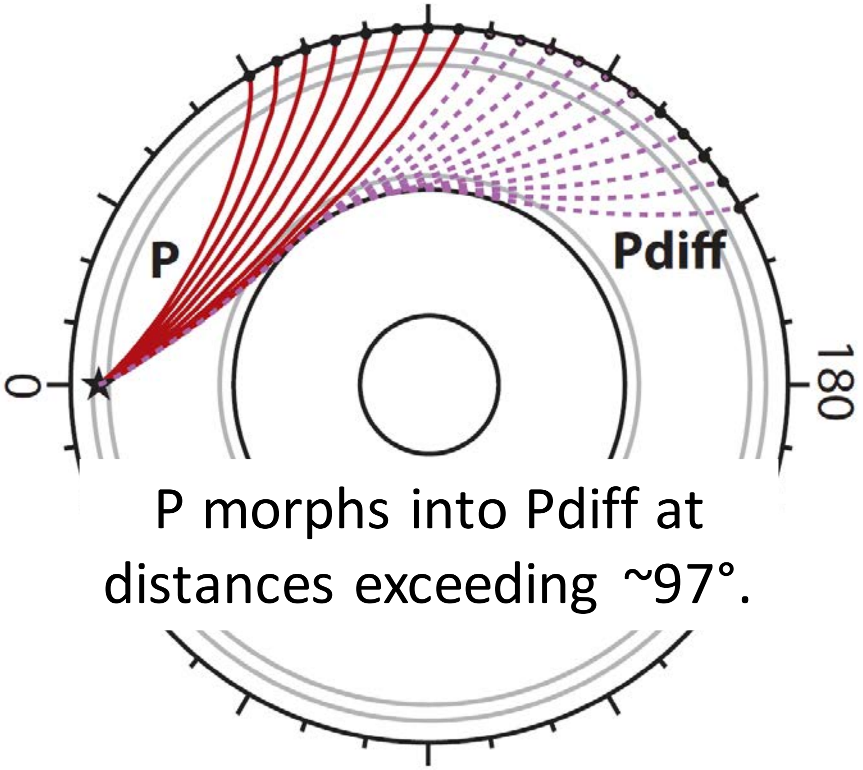
body waves

~~normal modes~~

~~surface waves~~

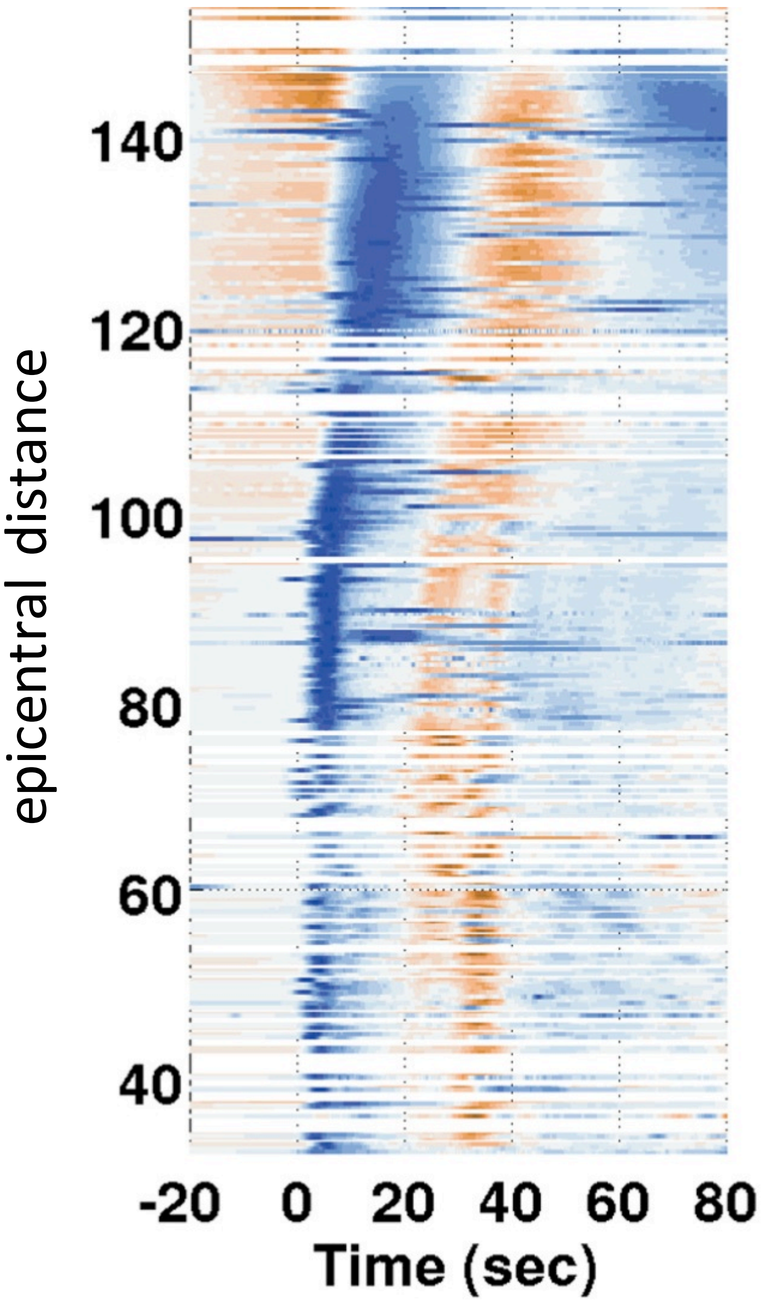


Core-diffracted P-waves sample the deepest mantle extensively.

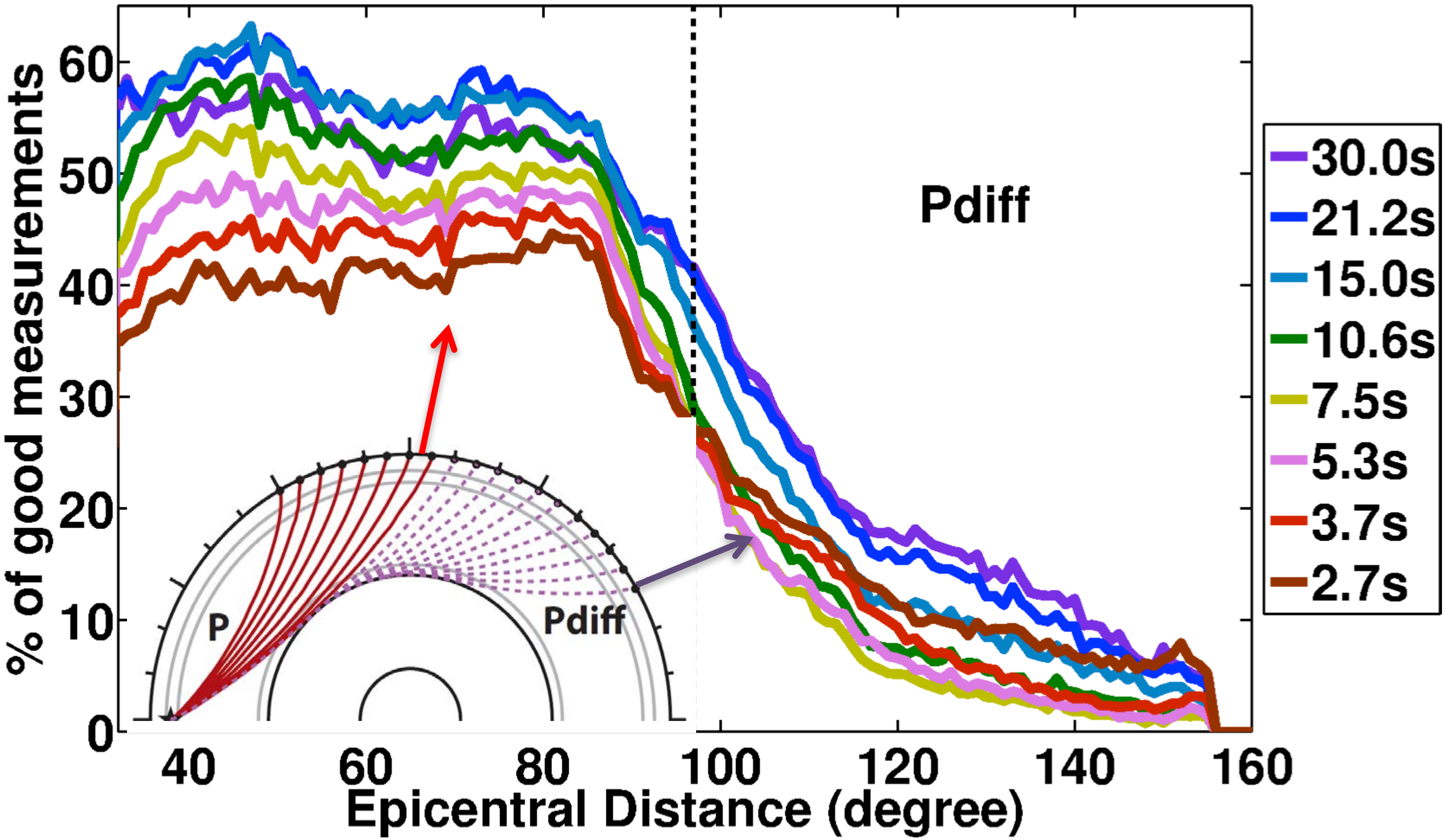


P morphs into Pdiff at distances exceeding ~97°.

Nominal ray paths of Pdiff (or Sdiff) waves. Hardly been used for tomography because ray theoretical modeling would be inadequate.

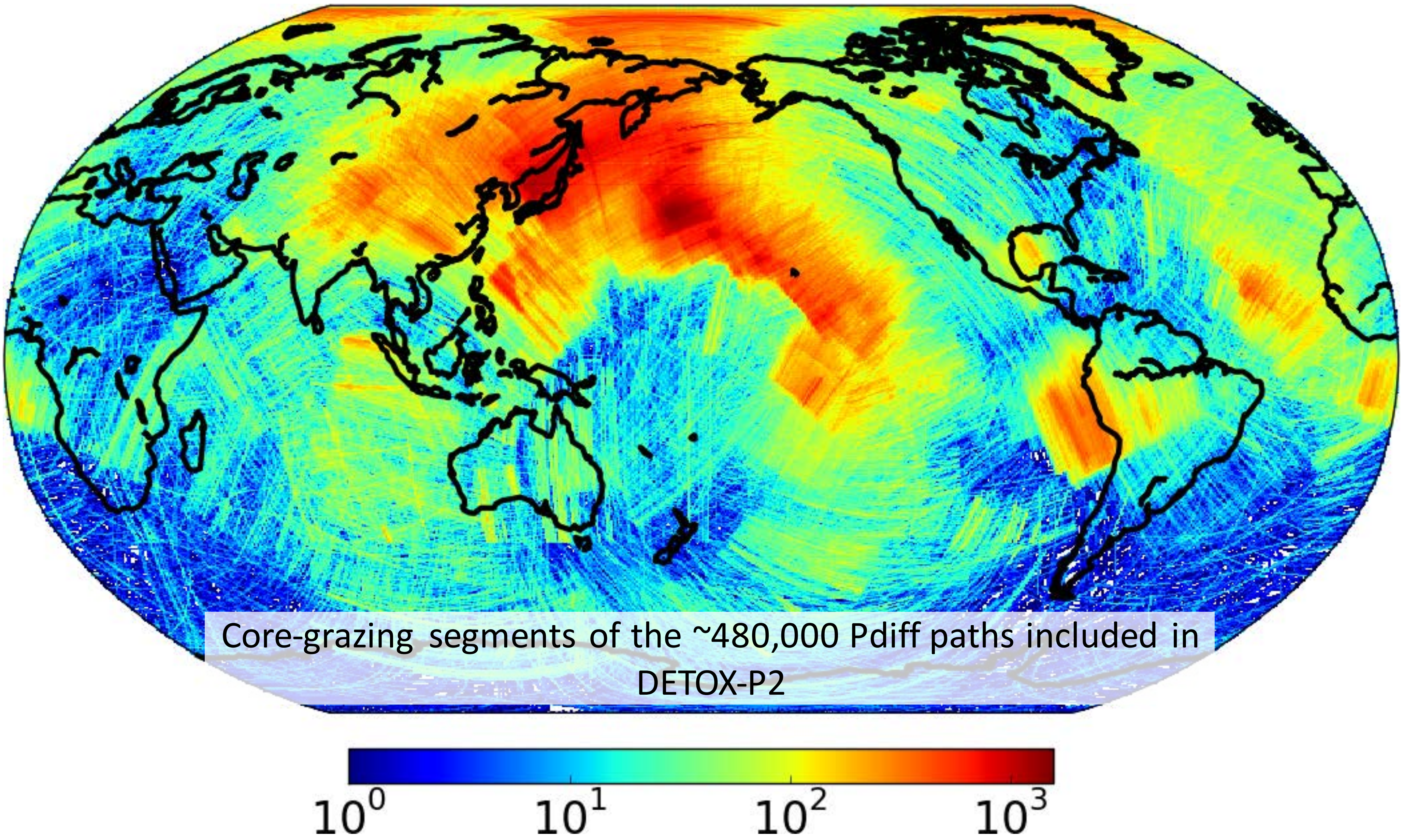


Measurement success on Pdiff waveforms is limited by signal-to-noise ratio.



Hosseini & Sigloch (2015, GJI)

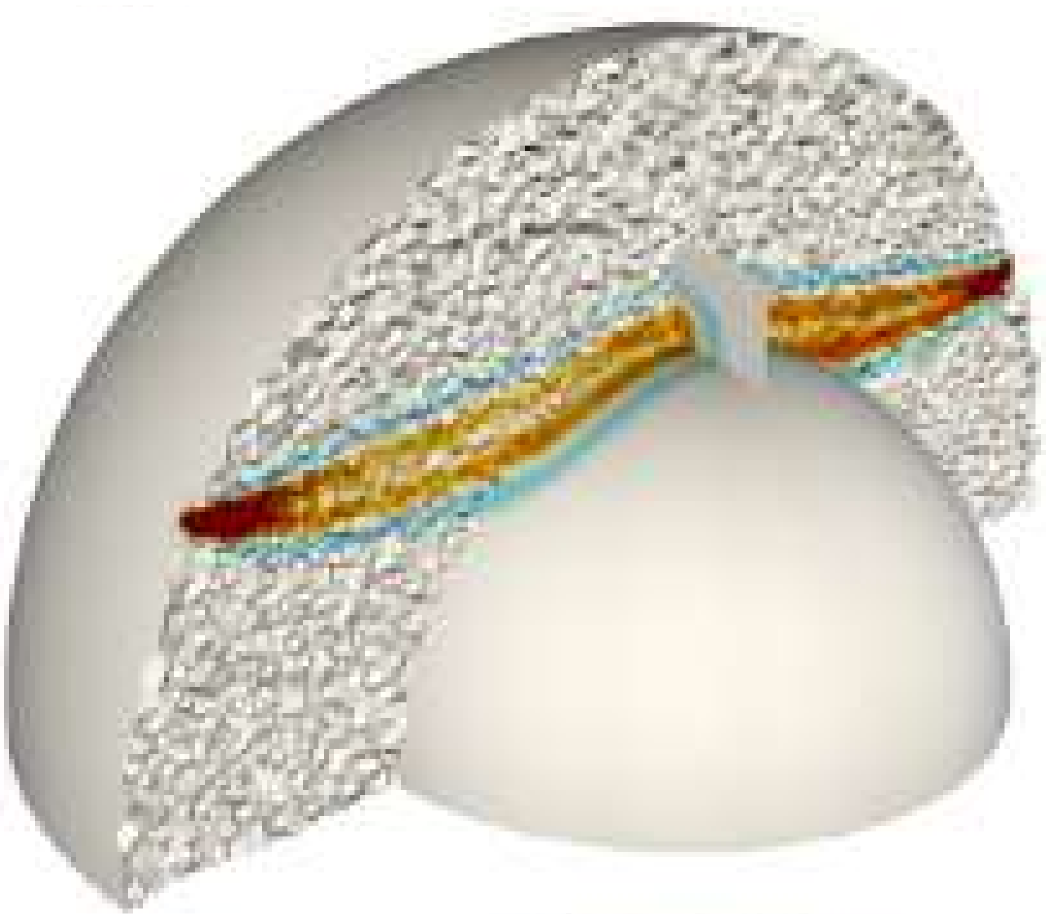
Global P-tomography models DETOX-P2, -P3 are the first to include a large data set of Pdiff data (multi-frequency waveform measurements)



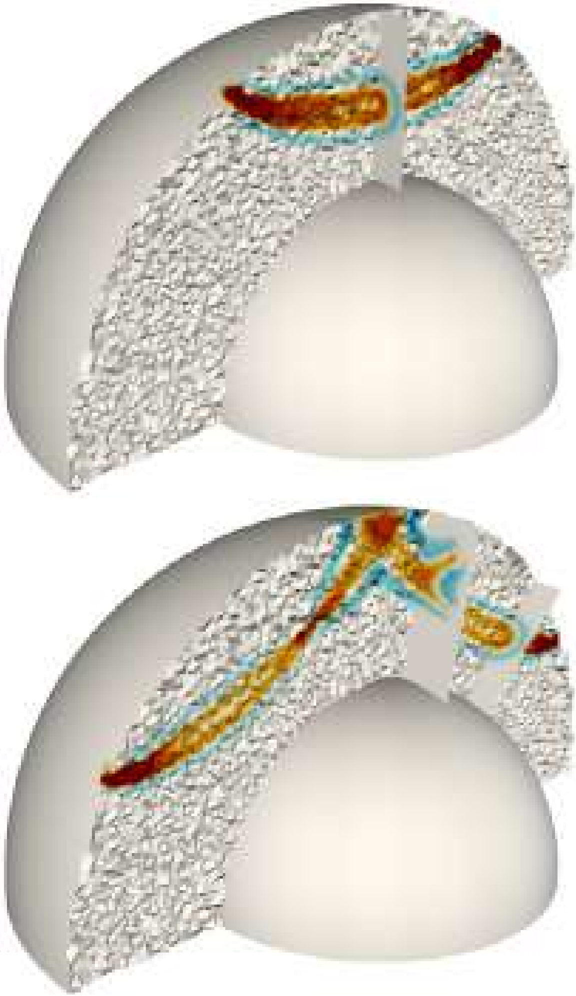
Core-grazing segments of the ~480,000 Pdiff paths included in DETOX-P2

Hosseini et al. 2020 GJI

Sensitivities of the traveltime measurements are modelled by Born kernels.

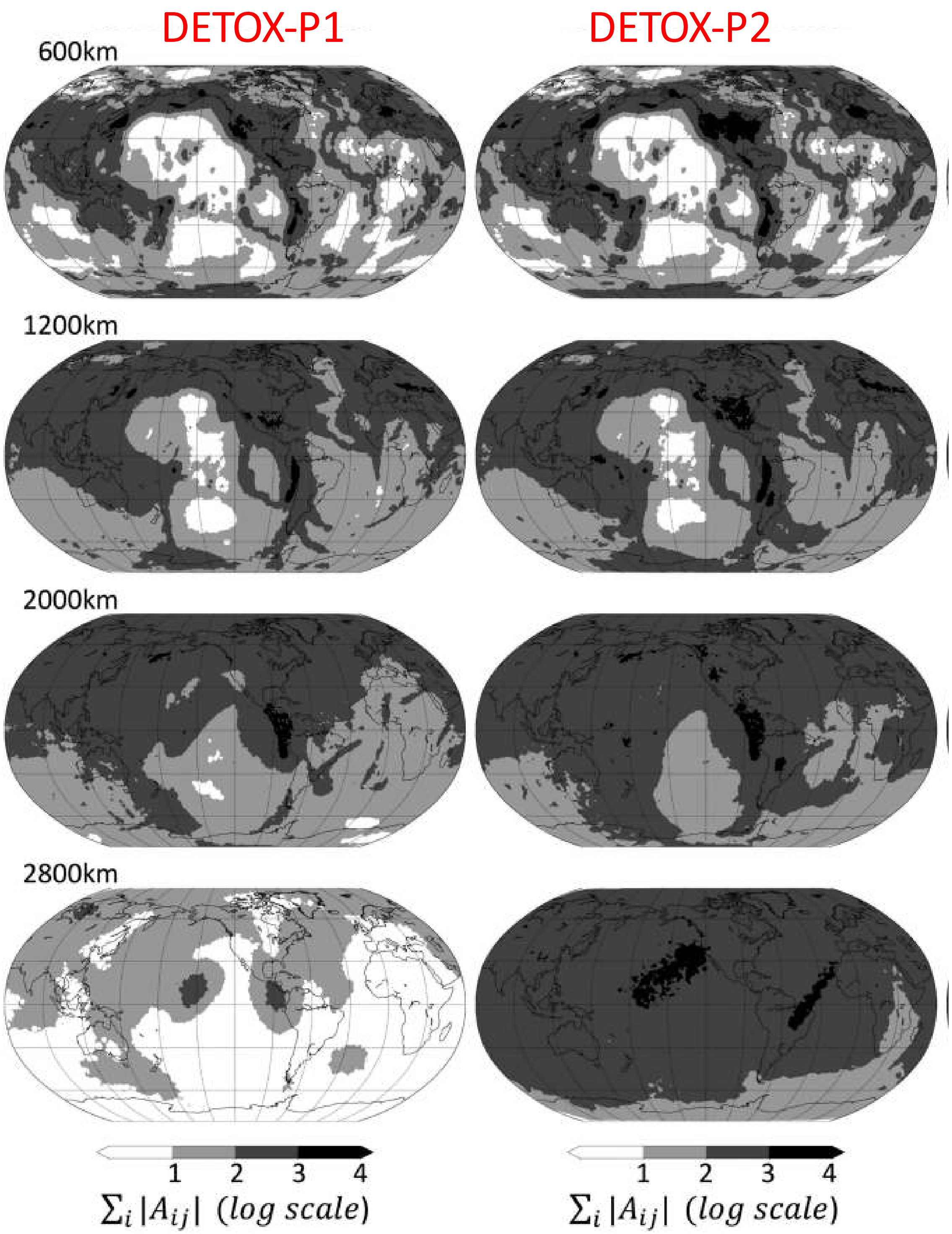


Pdiff-kernel (Δ=120°, T_{dom}=21 s), computed by full wave propagation (AxiSEM software, Tarje Nissen-Meyer).



P and PP kernels are computed by the much cheaper method of Dahlen et al. 2000.
ISC picks are modeled by ray theory (super cheap).

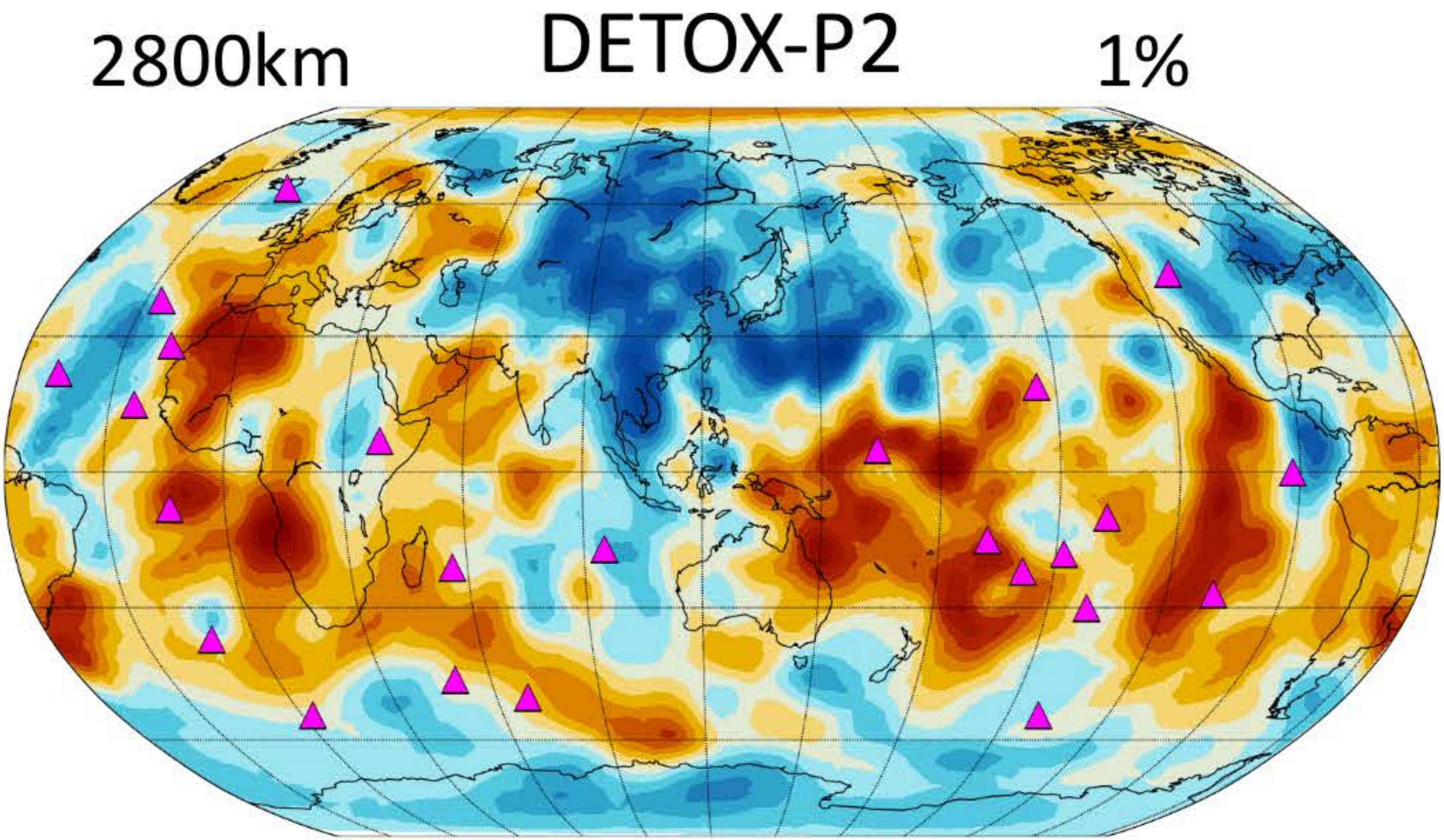
A step change in sensing the lowermost mantle with P-waves



Showing the wave path coverage of:
DETOX-P1 (a "normal", teleseismic P-wave model) versus DETOX-P2 (which adds Pdiff).

Hosseini et al. 2020 GJI

Result: Core-mantle boundary as seen by Pdiff & P waves



2800km DETOX-P2 1%

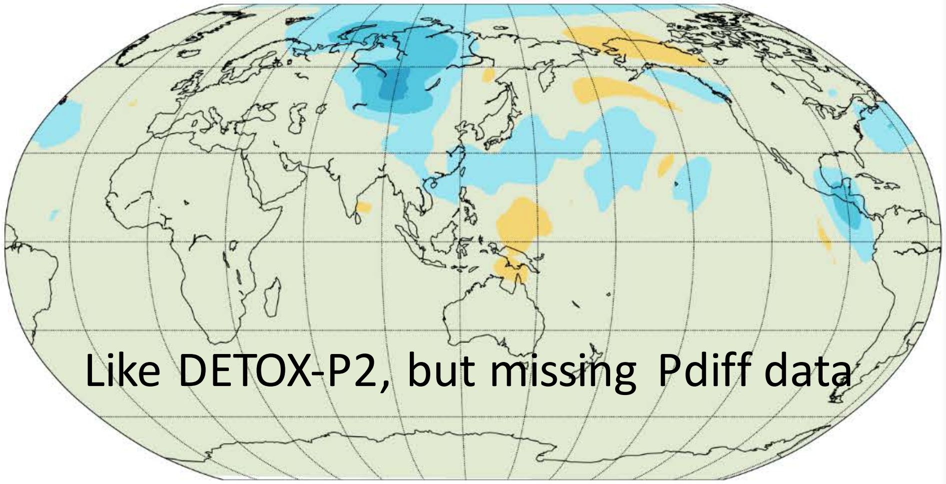
red: seismically slow (~hot) – blue: seismically fast (cold, slab)

△ : hotspots

Hosseini et al. 2020 GJI

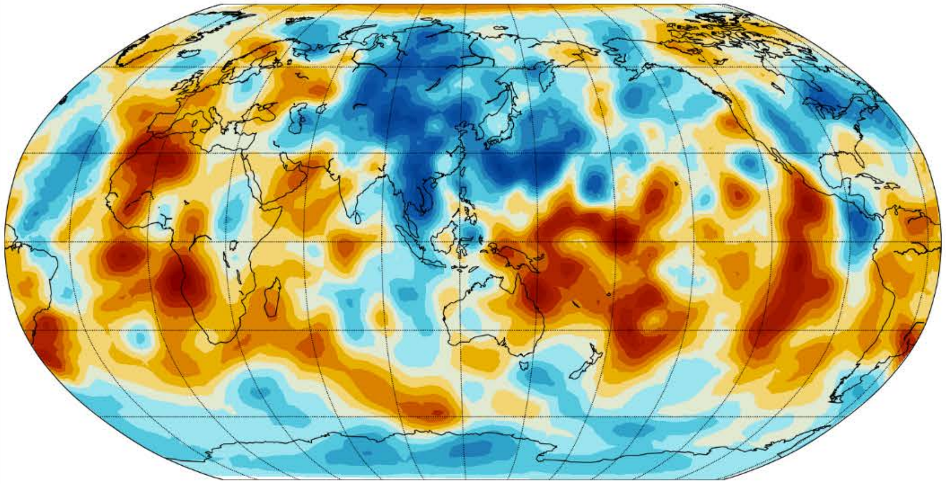
Comparison with other global P-wave tomographies

2800km DETOX-P1 1%

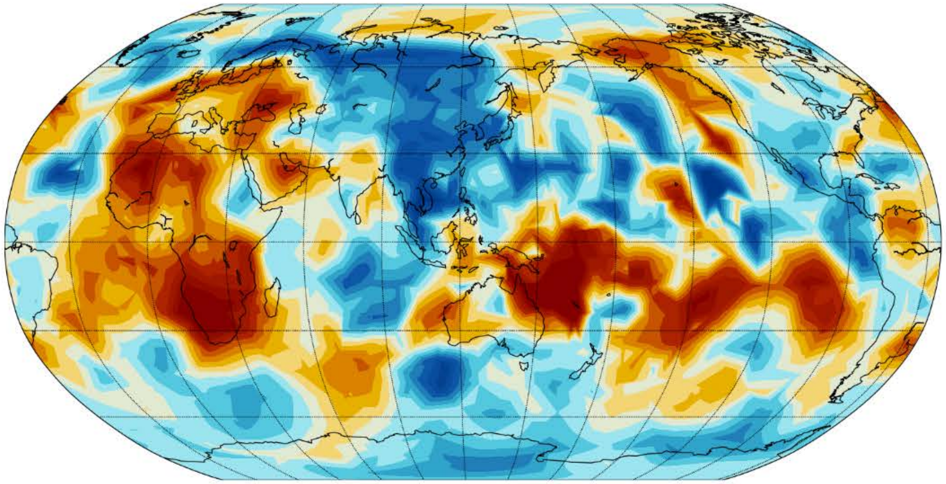


Like DETOX-P2, but missing Pdiff data

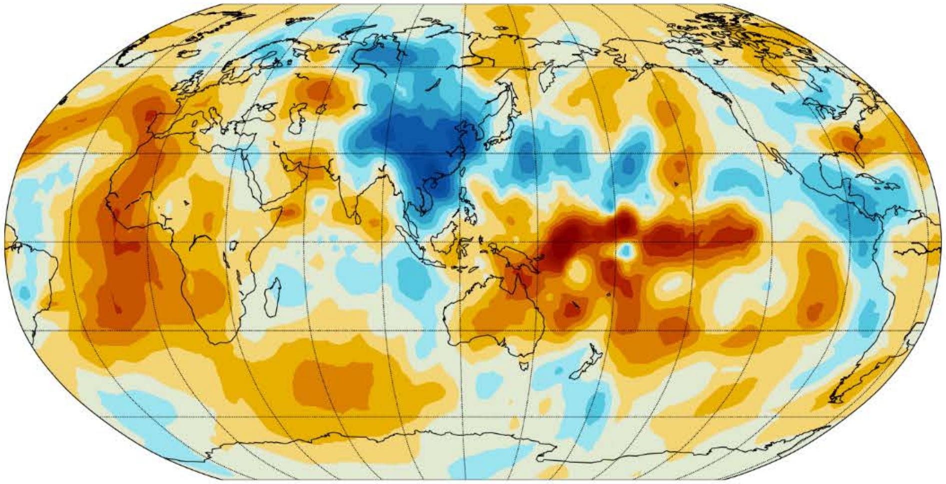
DETOX-P2 1%



2800km PRI-P05 1%

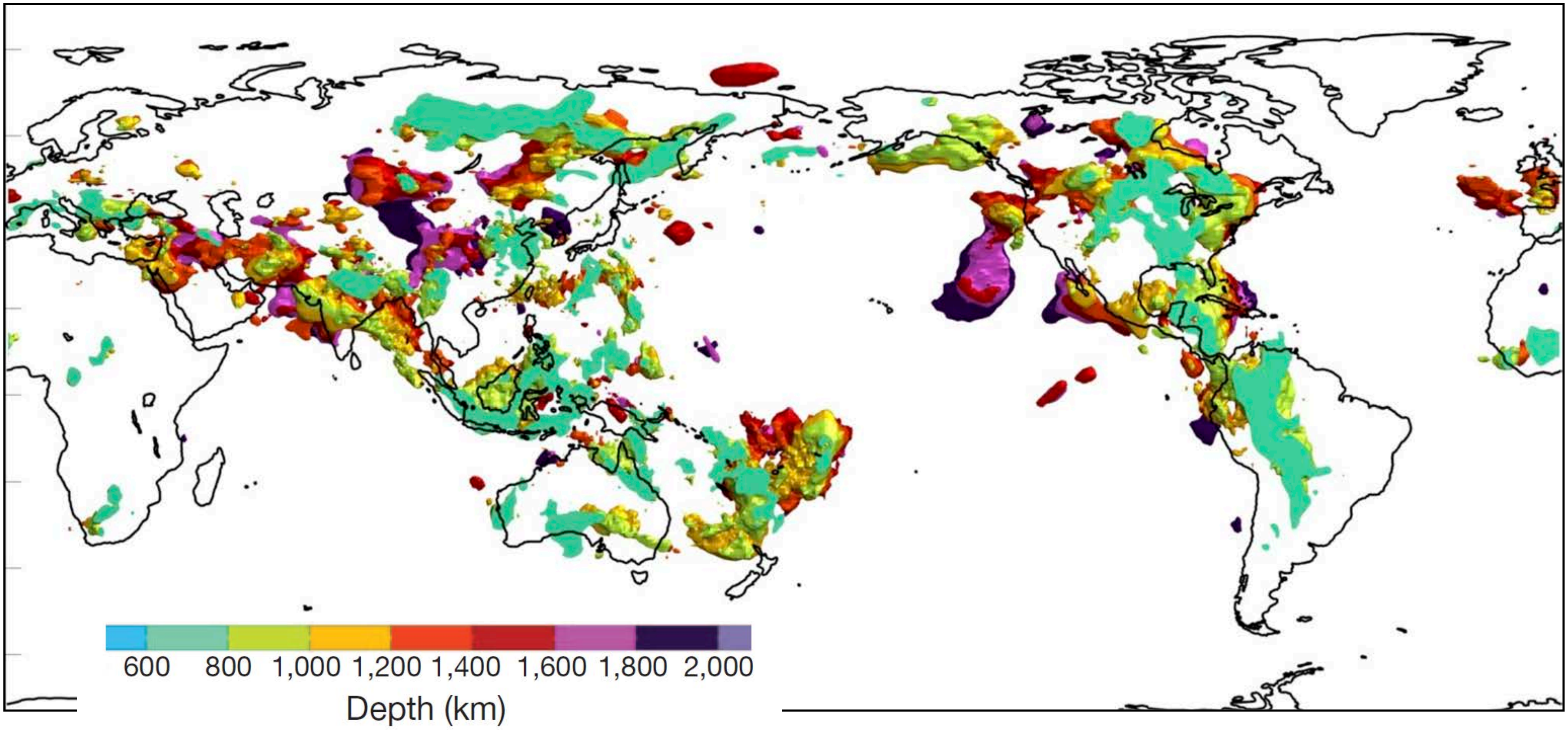


MITP08 1%



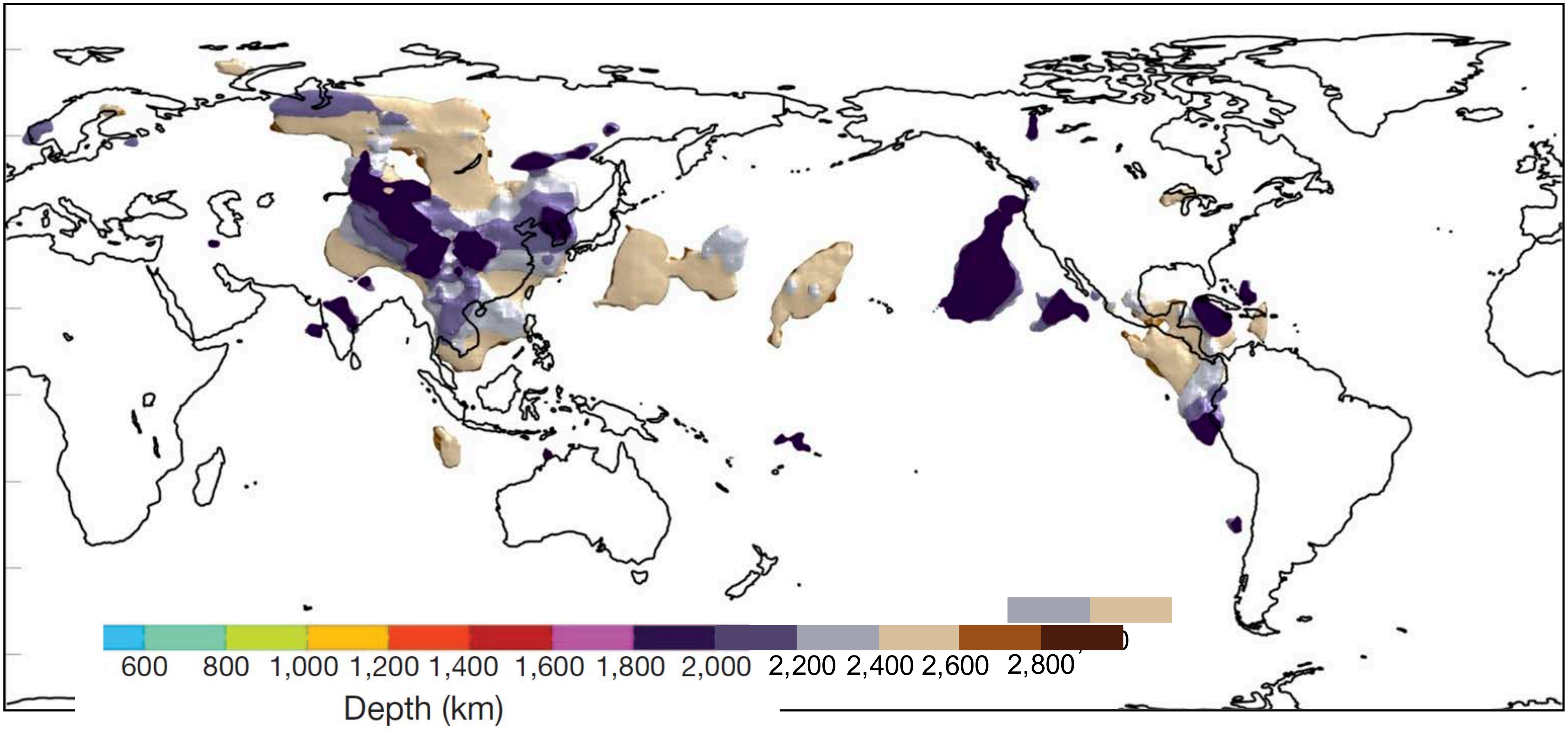
Other P-models are made of basically the same teleseismic-P data as DETOX-P1 (showing Princeton 2005 and MIT 2008 models).

Fast anomalies (slabs) from 800-2000 km depth in model MIT-P08 (teleseismic; no Pdiff data)



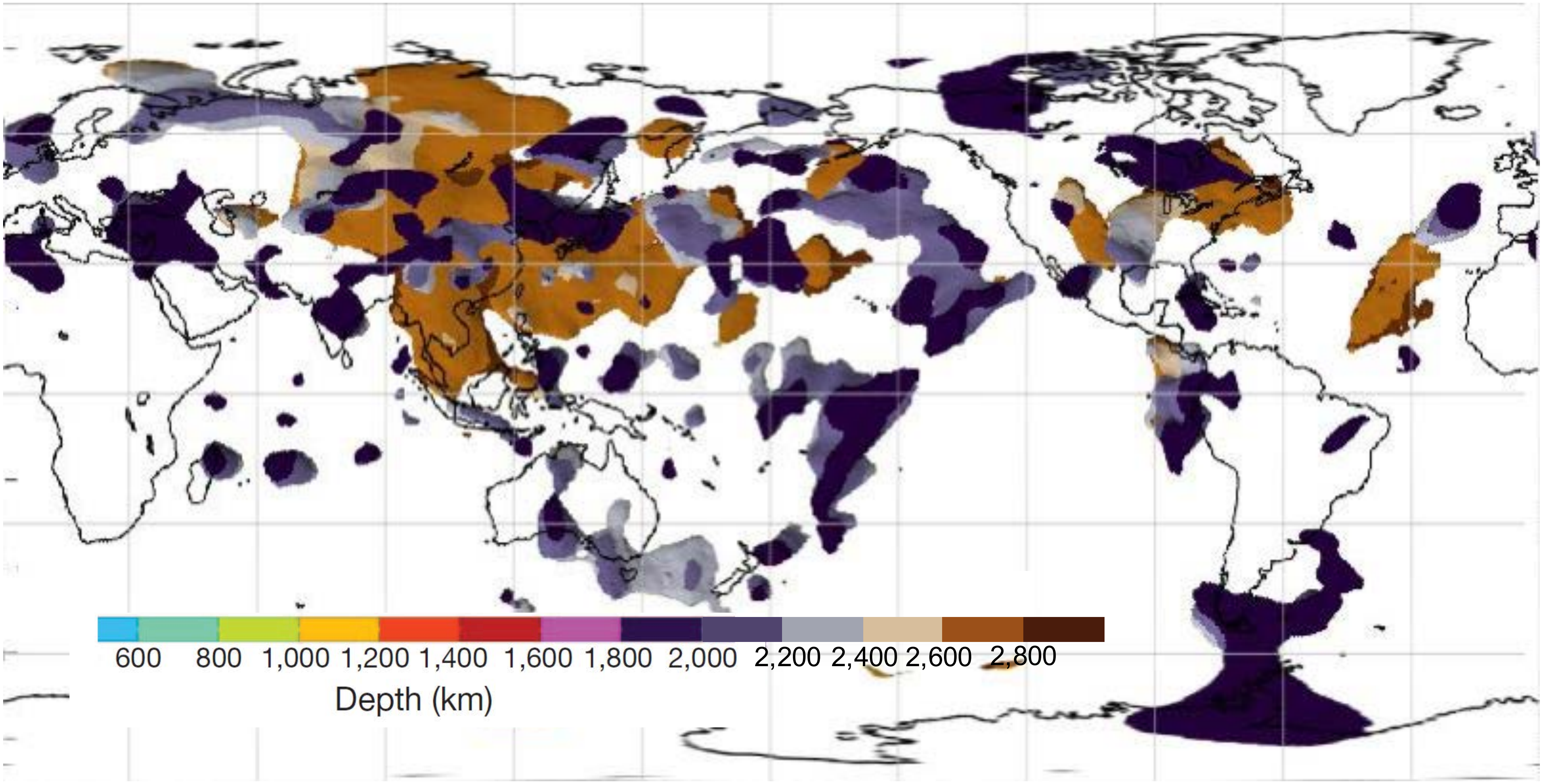
- Li et al. 2008, a P-wave model well used for slab interpretation.
- 3-D isosurface rendering. Colour means depth, changes every 200 km.

Fast anomalies (slabs) below 2000 km depth in model MIT-P08 (teleseismic, no Pdiff data)



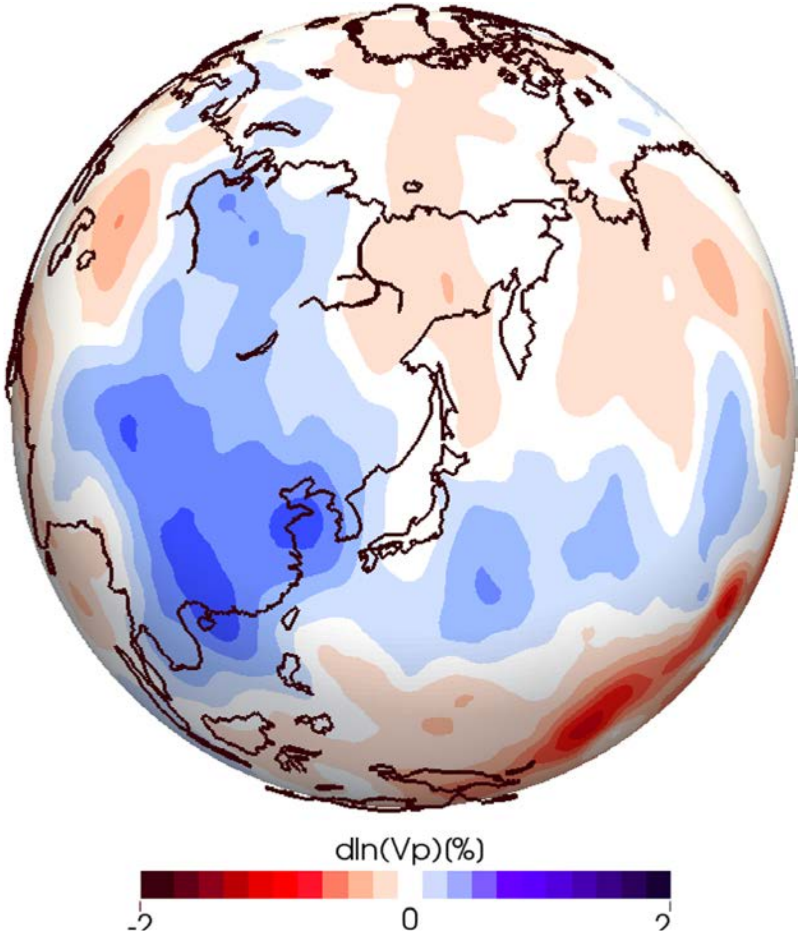
- Li et al. 2008, a P-wave model well used for slab interpretation.
- 3-D isosurface rendering. Colour means depth, changes every 200 km.

Fast anomalies (slabs) below 2000 km depth
Model DETOX-P2 (**P + ~500,000 Pdiff data**)

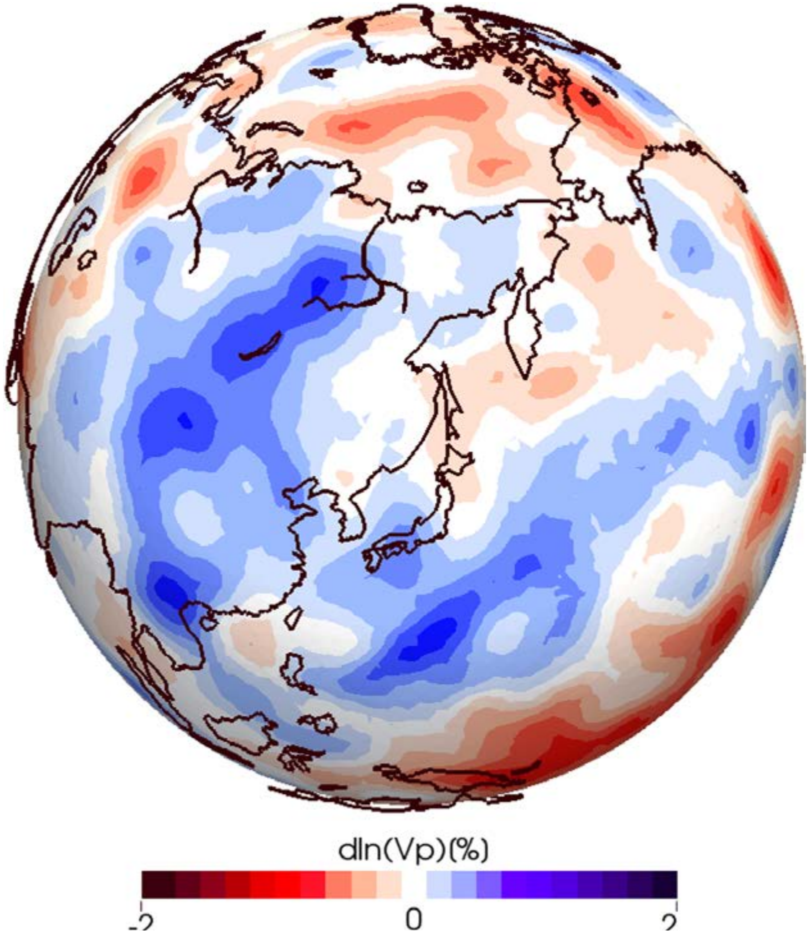


- 3-D isosurface rendering. Colour means depth, changes every 200 km.

Deepest slabs now appear elongated and crisp, like in the upper/mid-mantle.



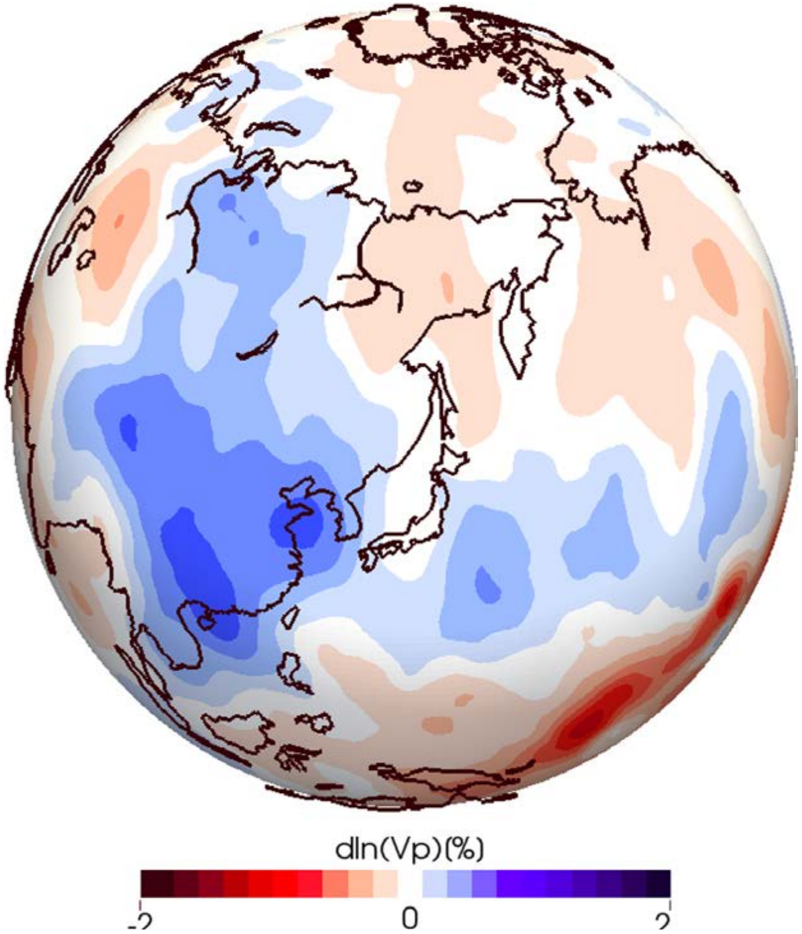
MIT-P08 (Li et al. 2008)



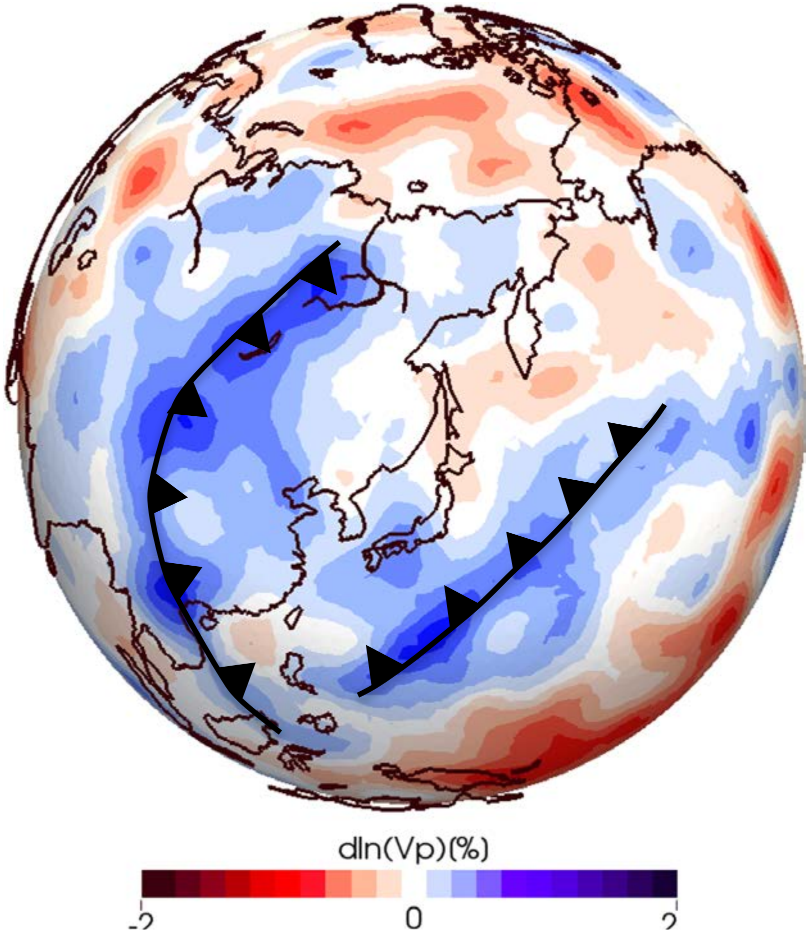
DETOX-P2 (Hosseini et al. 2020)

Deepest slabs now appear elongated and crisp, like in the upper/mid-mantle.

Inferring the strikes of paleo-trenches becomes a reasonable exercise. Example: at 2800 km under East Asia.



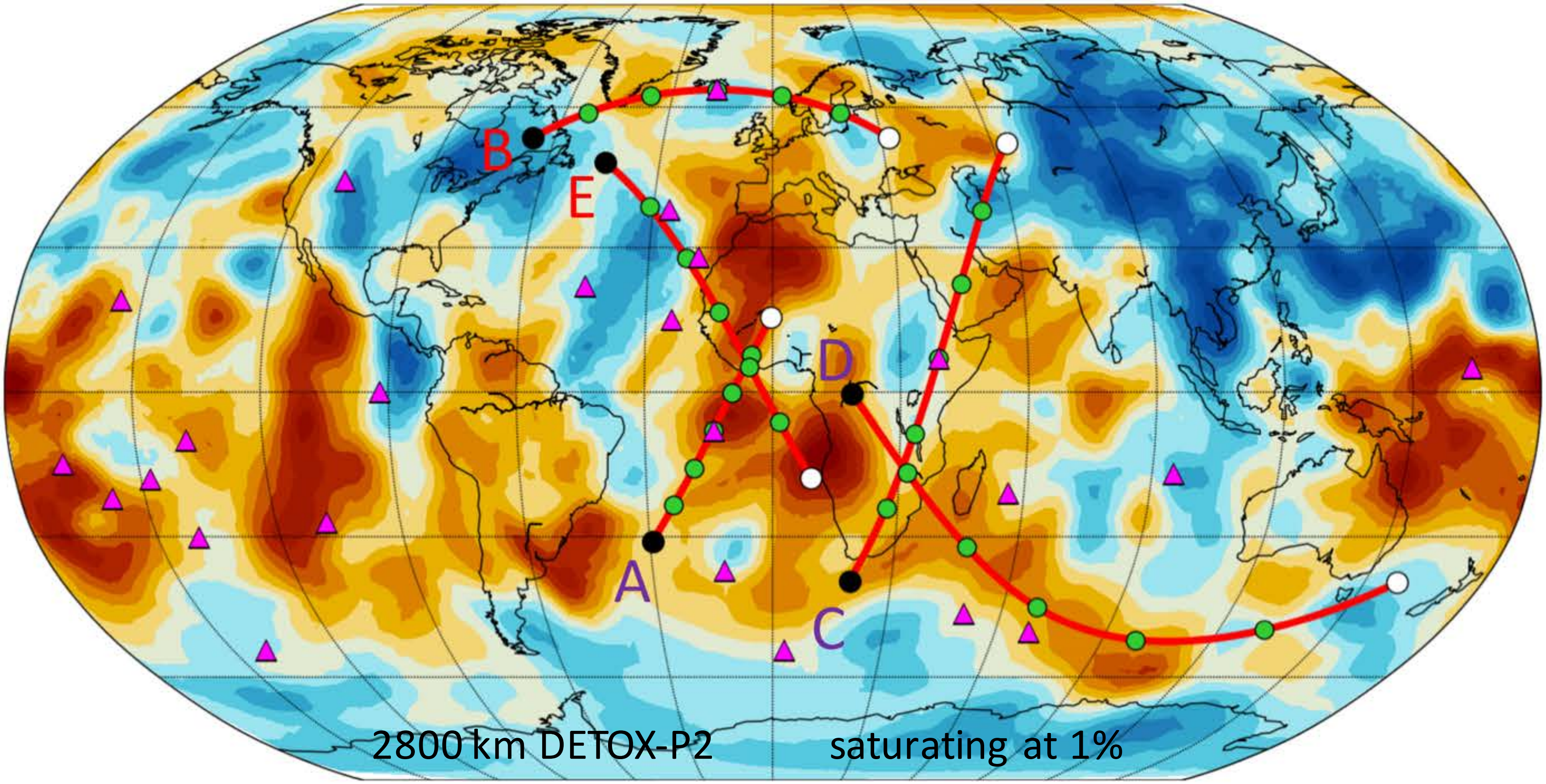
MIT-P08 (Li et al. 2008)



DETOX-P2 (Hosseini et al. 2020)

Large Low Velocity Provinces as seen by P-waves

LLVPs = about **a dozen very slow patches (600-1400 km in diameter)**, embedded in a moderately slow background.



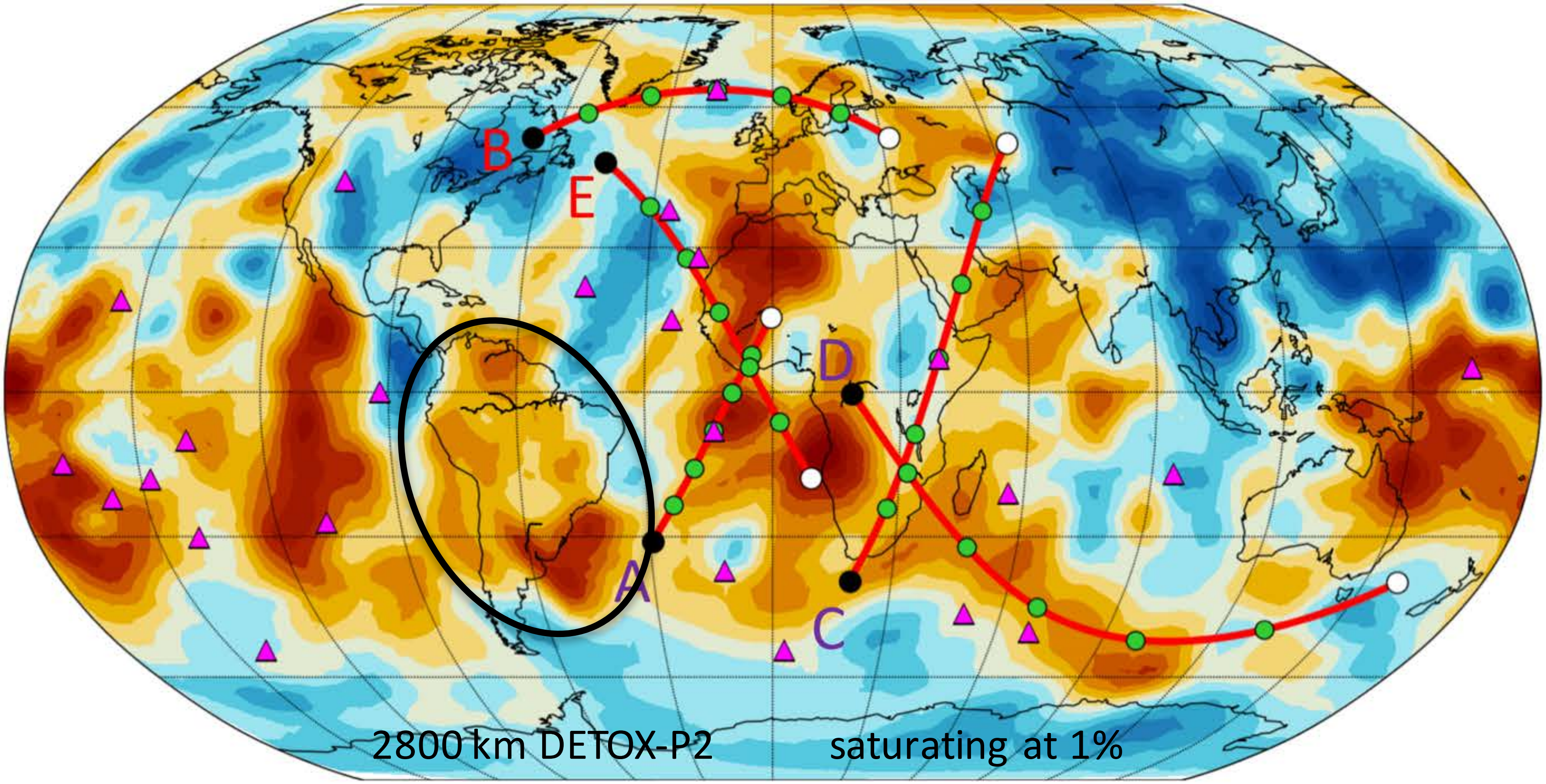
2800 km DETOX-P2 saturating at 1%

Hosseini et al. 2020 GJI

Large Low Velocity Provinces as seen by P-waves

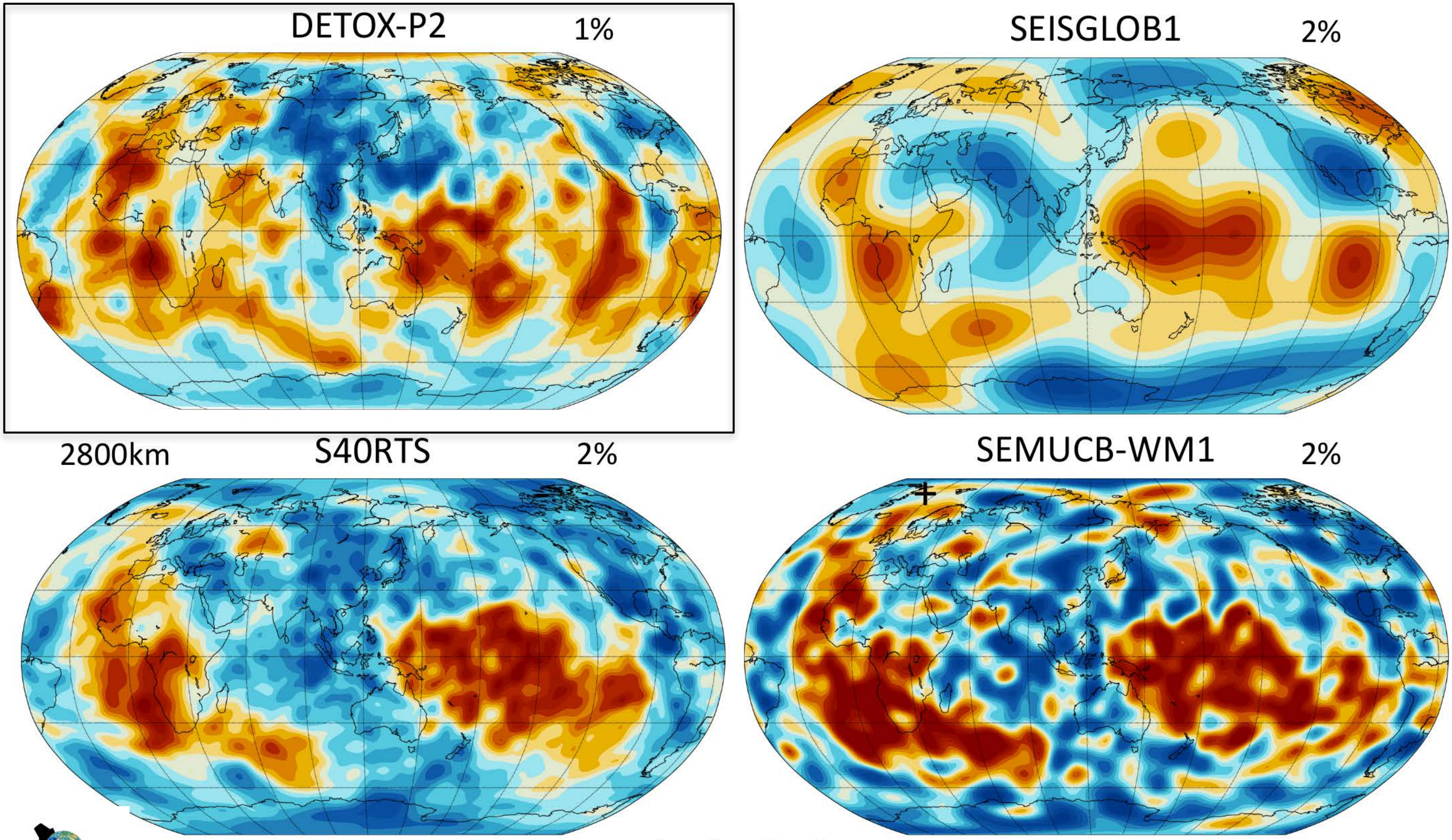
LLVPs = about **a dozen very slow patches (600-1400 km in diameter)**, embedded in a moderately slow background.

Newly imaged, only by P-waves: LLVP-like patches under South America. They **connect** the African and Pacific LLVPs into a longitudinal belt that almost circles the globe at southern and equatorial latitudes.



Hosseini et al. 2020 GJI

Comparison with global S-wave tomographies at CMB

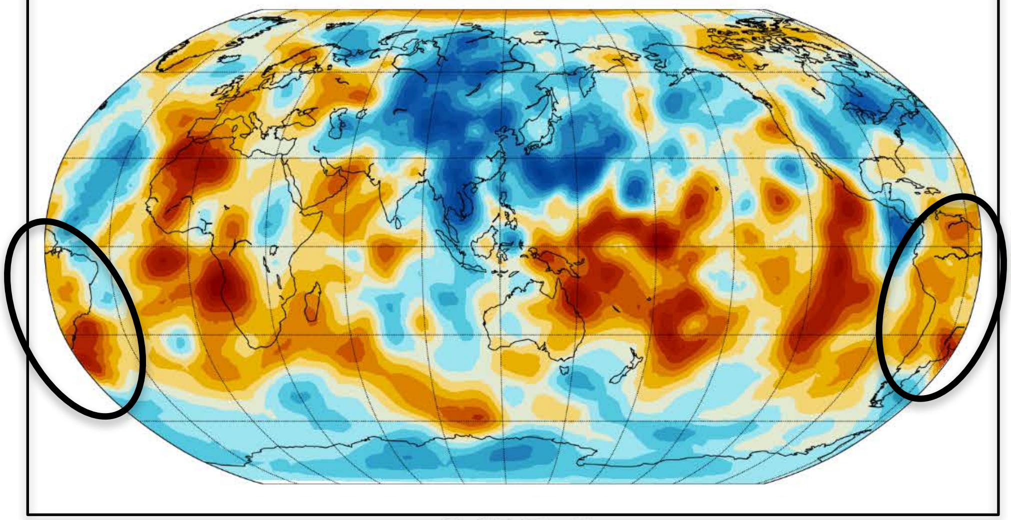


SubMachine

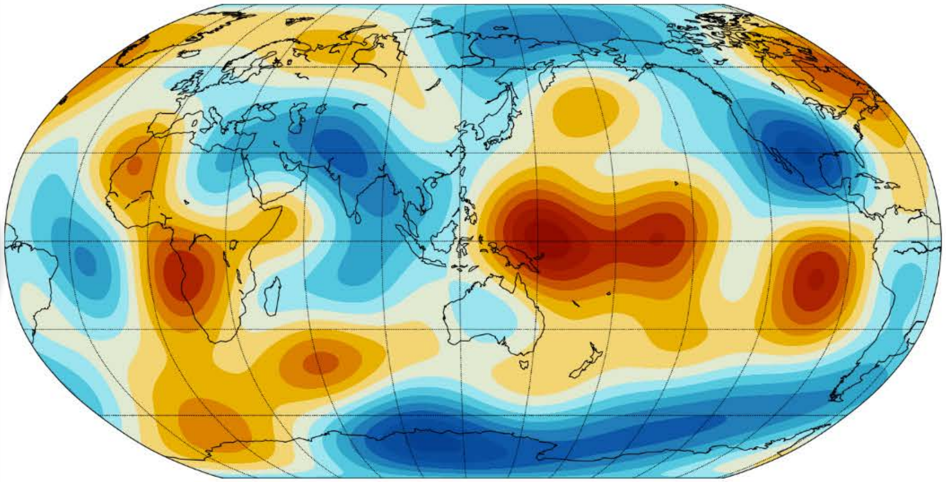
Plot your own model comparisons with SubMachine: www.earth.ox.ac.uk/~smachine

Comparison with global S-wave tomographies at CMB

DETOX-P2 1%

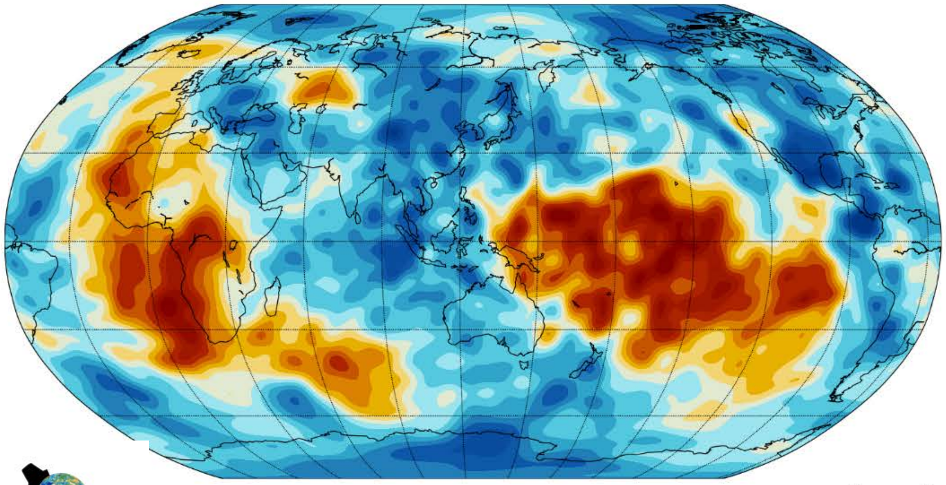


SEISGLOB1 2%

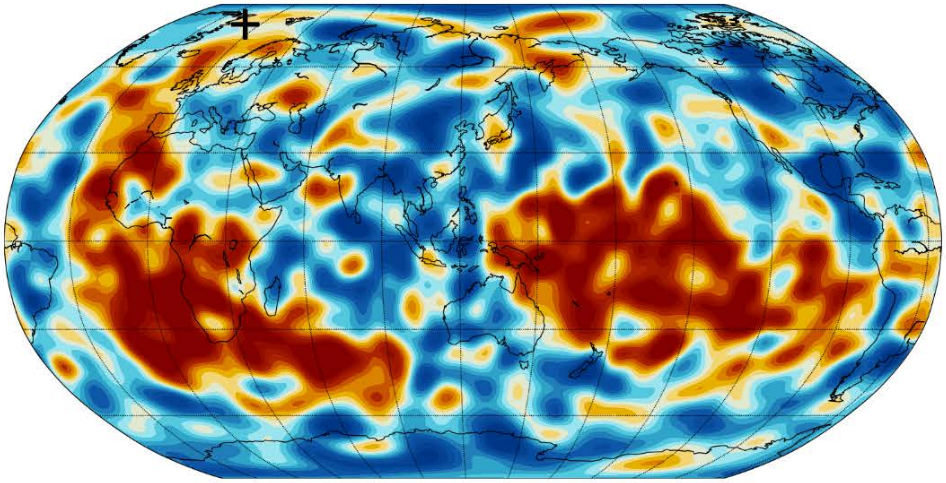


2800km

S40RTS 2%



SEMUCB-WM1 2%



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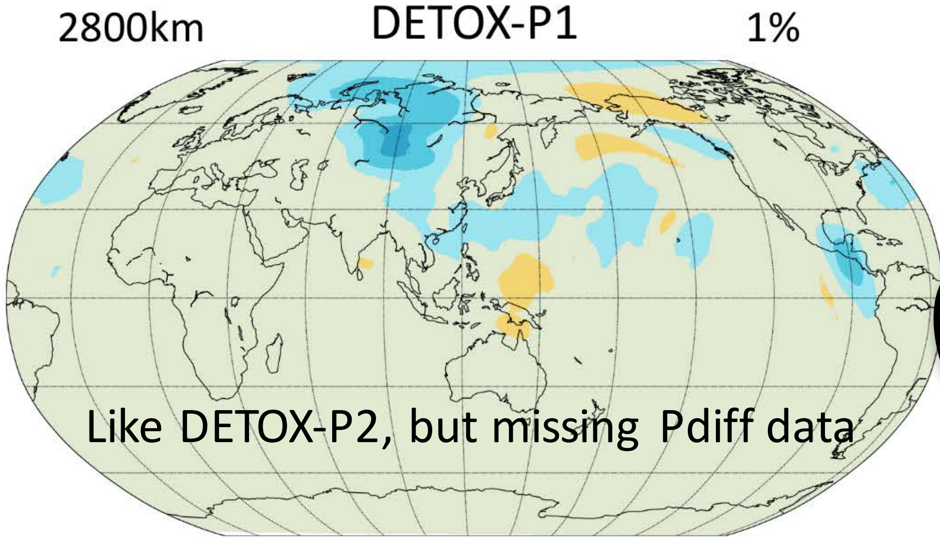
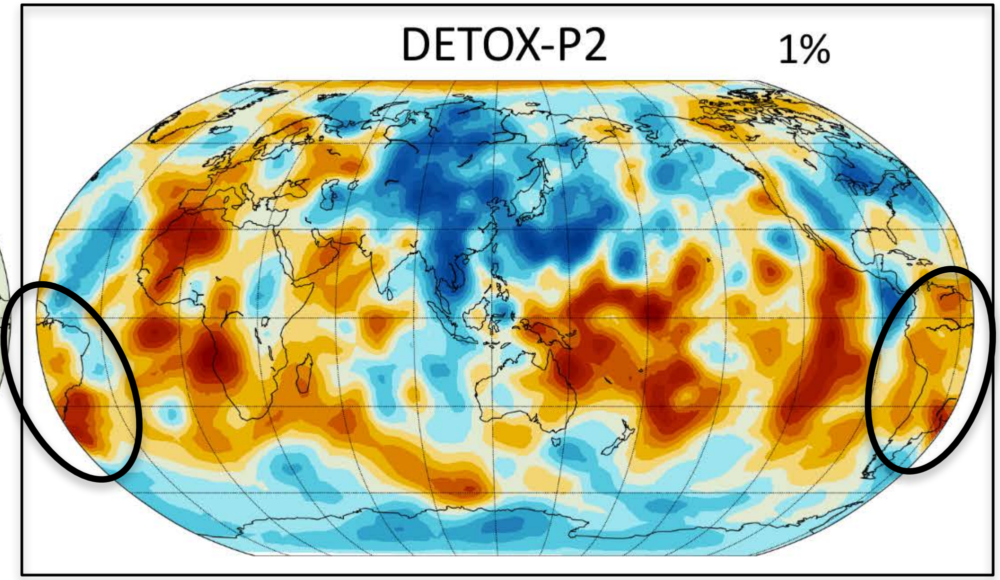
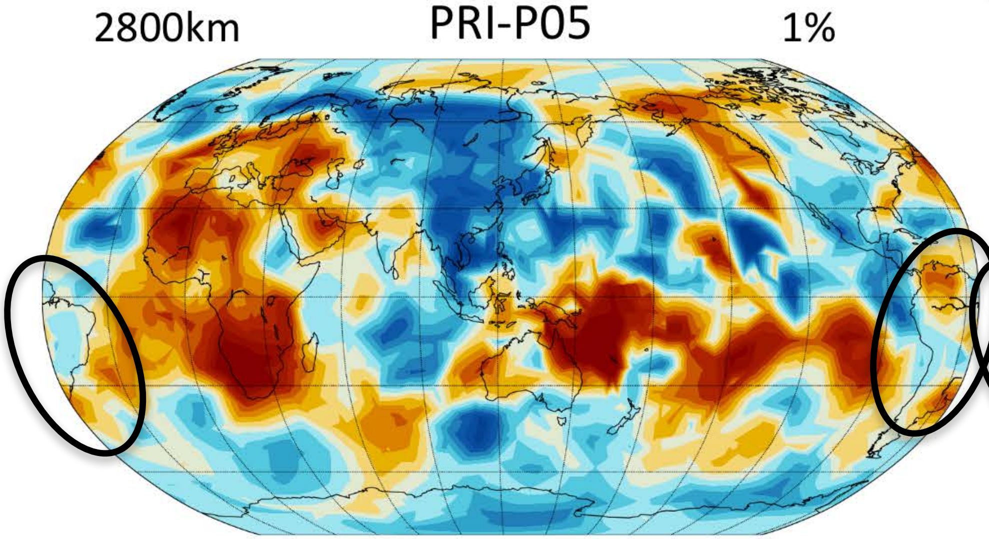
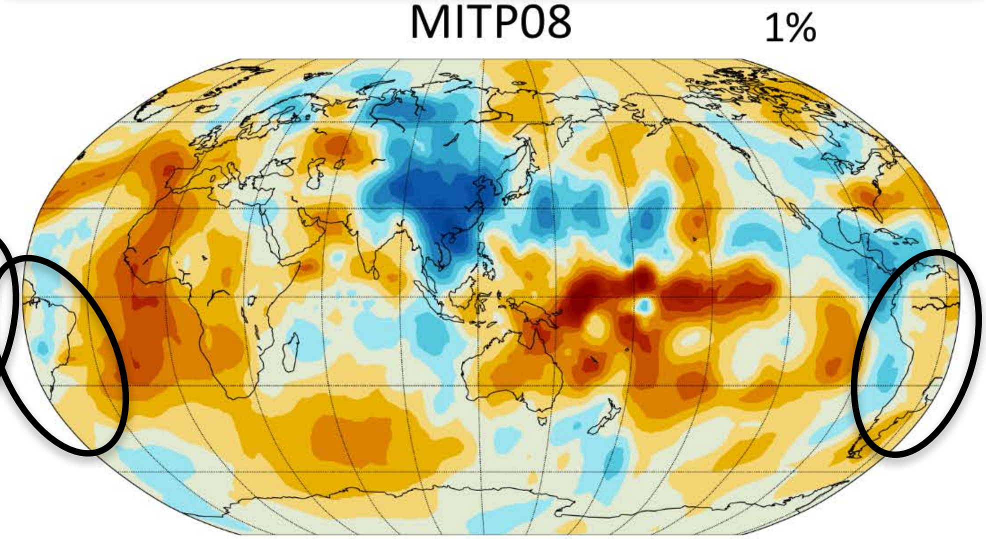
Comparison with other global P-wave tomographies



Like DETOX-P2, but missing Pdiff data







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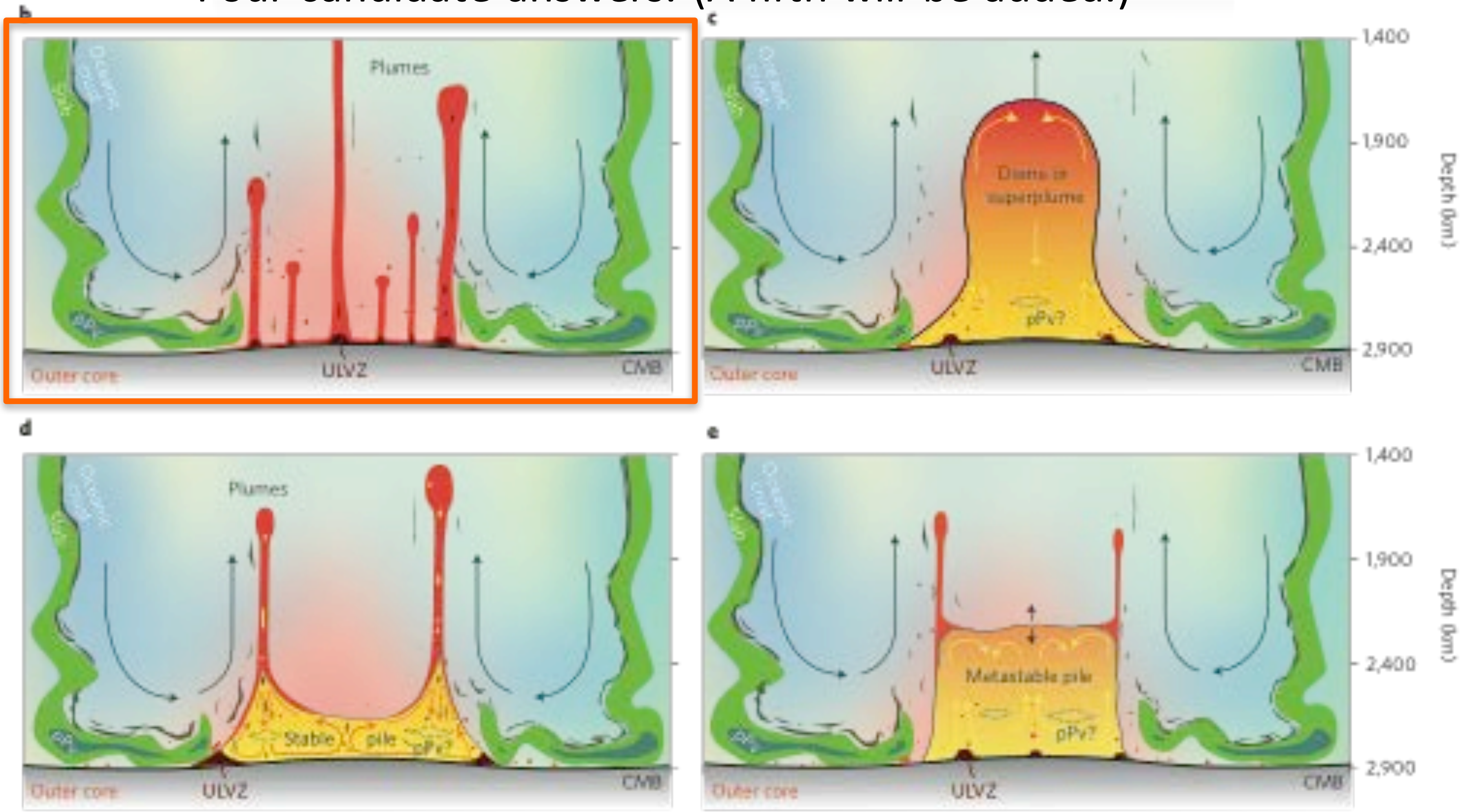
Relationship between LLVPs and plumes?

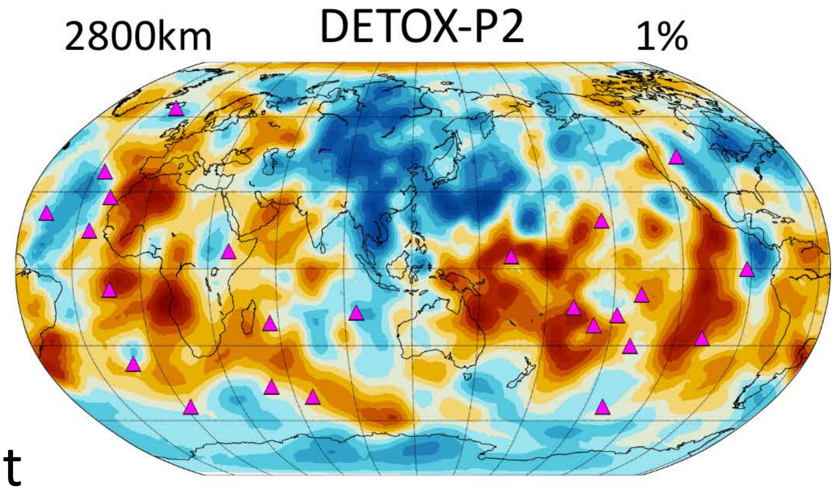
Four candidate answers. (A fifth will be added.)



Garnero et al. 2016 review

Figure 2 | LLSVP observations and interpretations. a, Surface features (upper panel) and seismically determined lower-mantle phenomena (lower panel). See text for details. **b–e**, Idealized possibilities proposed to explain LLSVPs. In all cases, subducted material (possibly including post-perovskite, pPv) surrounds the structure of interest that maps as the LLSVP. **b**, Plume cluster. **c**, Thermochemical superplume. **d**, Stable thermochemical pile. **e**, Metastable thermochemical pile. LIPs, large igneous provinces; CMB, core–mantle boundary; ULVZs, ultralow velocity zones.

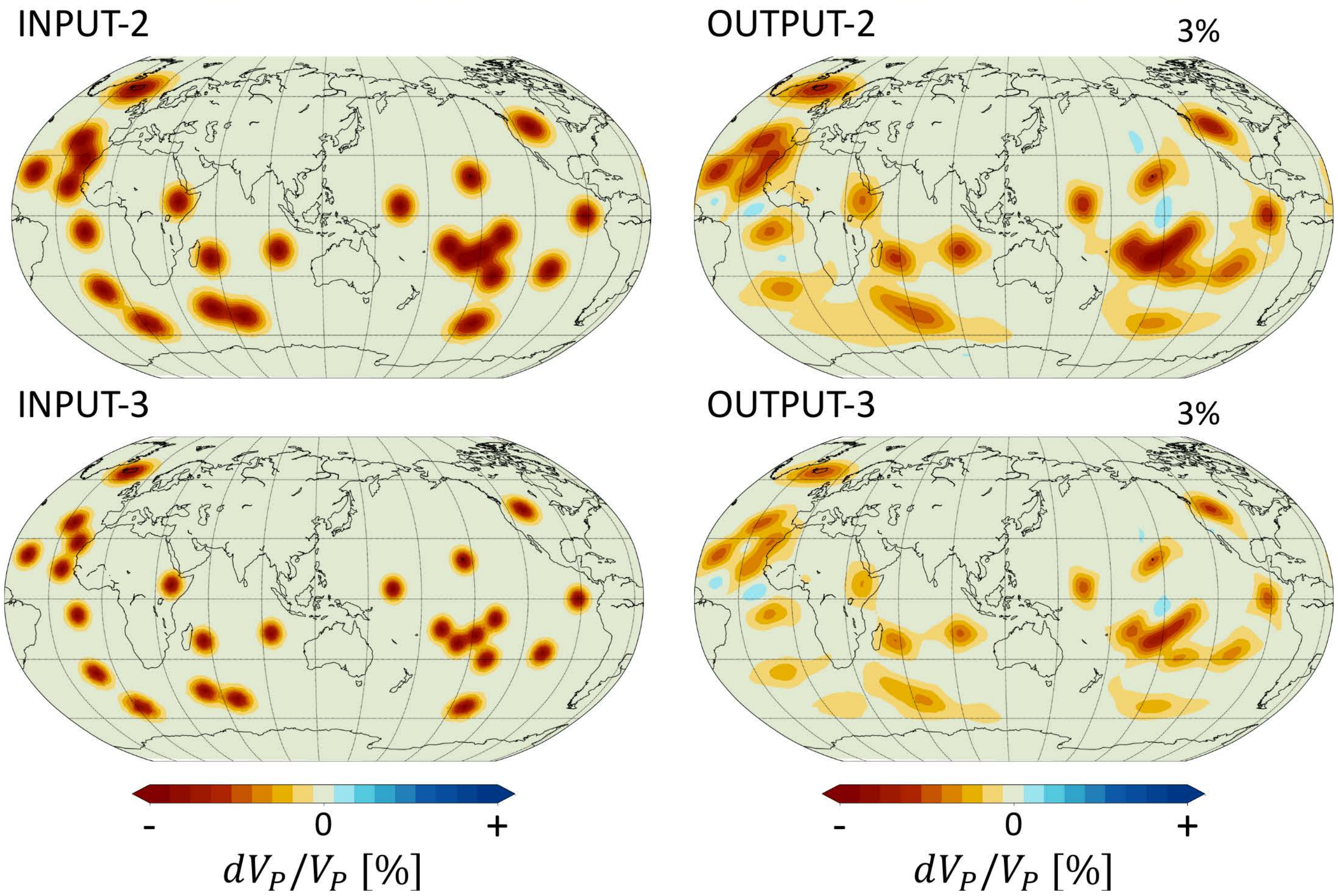
Resolution tests at the CMB: How much would the bases of individual plumes blur together?



Input: vertical “plume conduits” at all hotspot locations.

Radii = 400 km

Radii = 300 km



Hosseini et al. 2020 GJI

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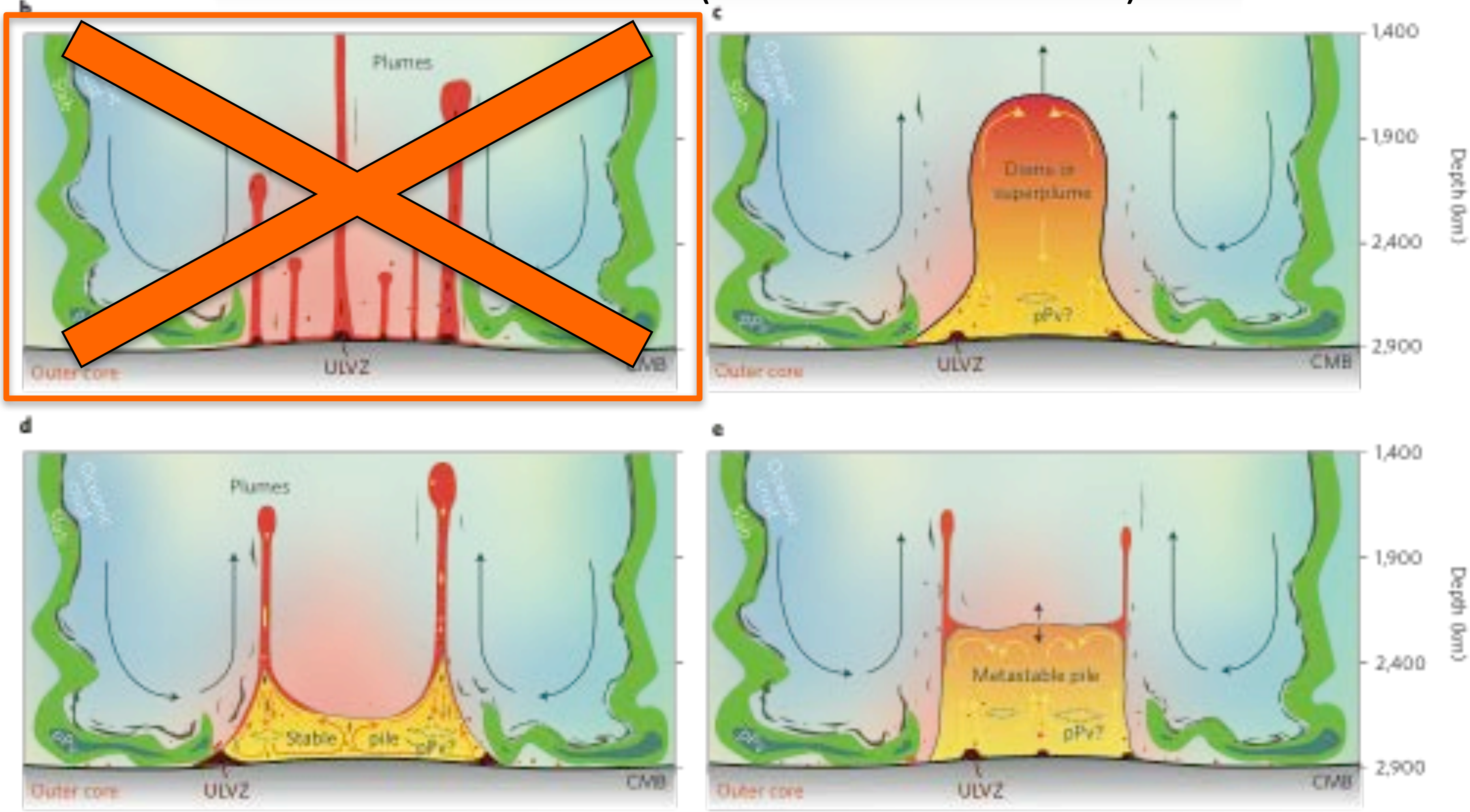

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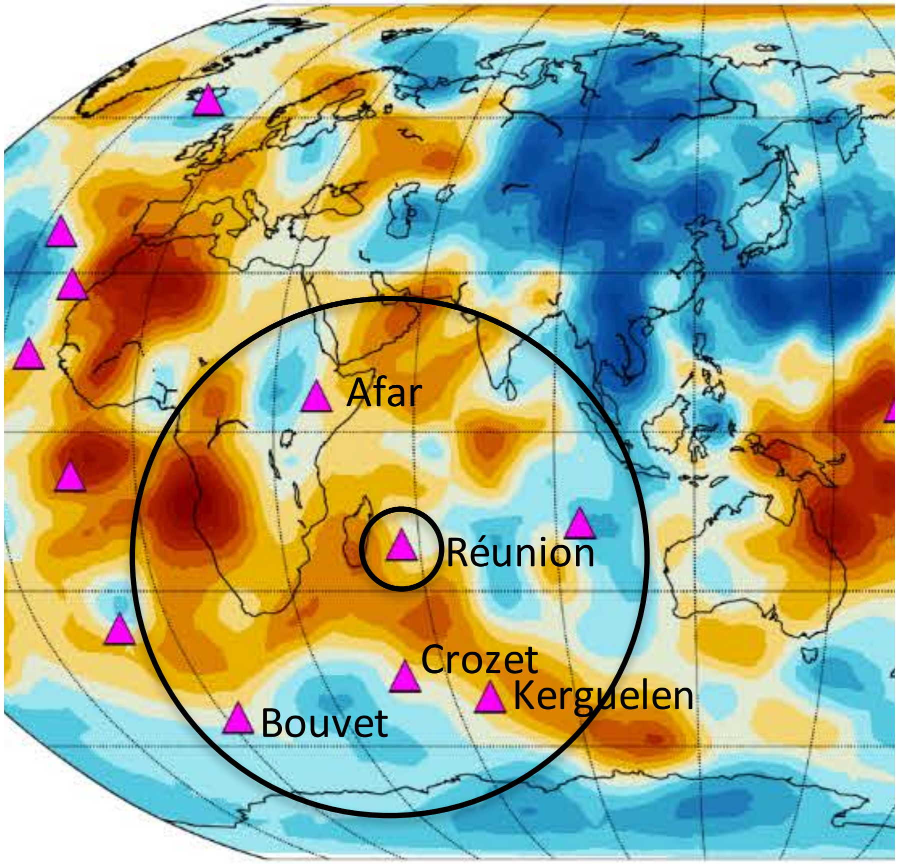
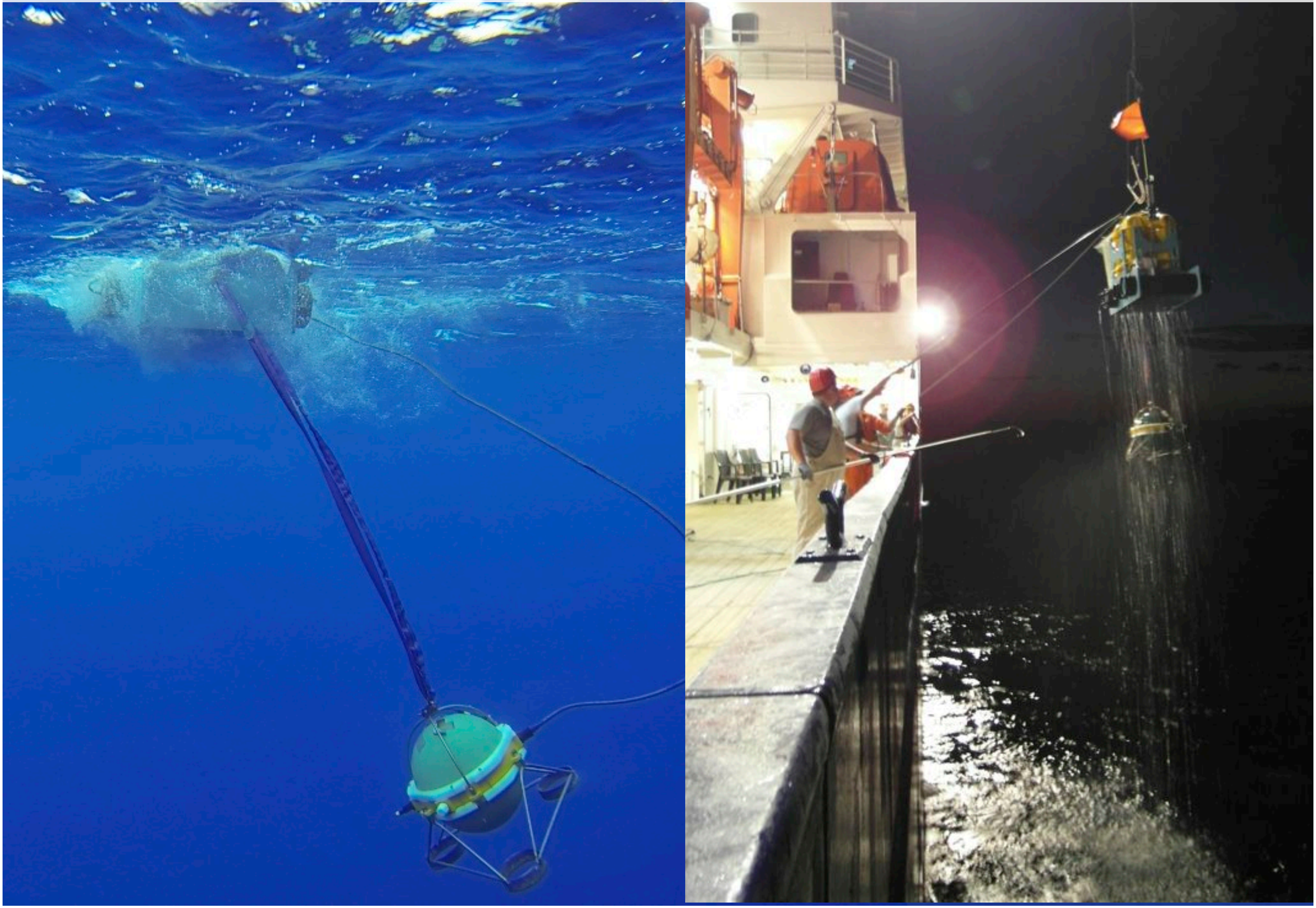
Part 2: Imaging the African“superplume” (southeastern half) from the CMB to the upper mantle

- Oceanic area, numerous hotspots, plus South Africa sitting higher than expected.
- Oceans are hardly instrumented ➔Upper mantle under hotspots is poorly sampled.
- We managed to instrument one hotspot: La Réunion (Barruol & Sigloch 2014 EOS)

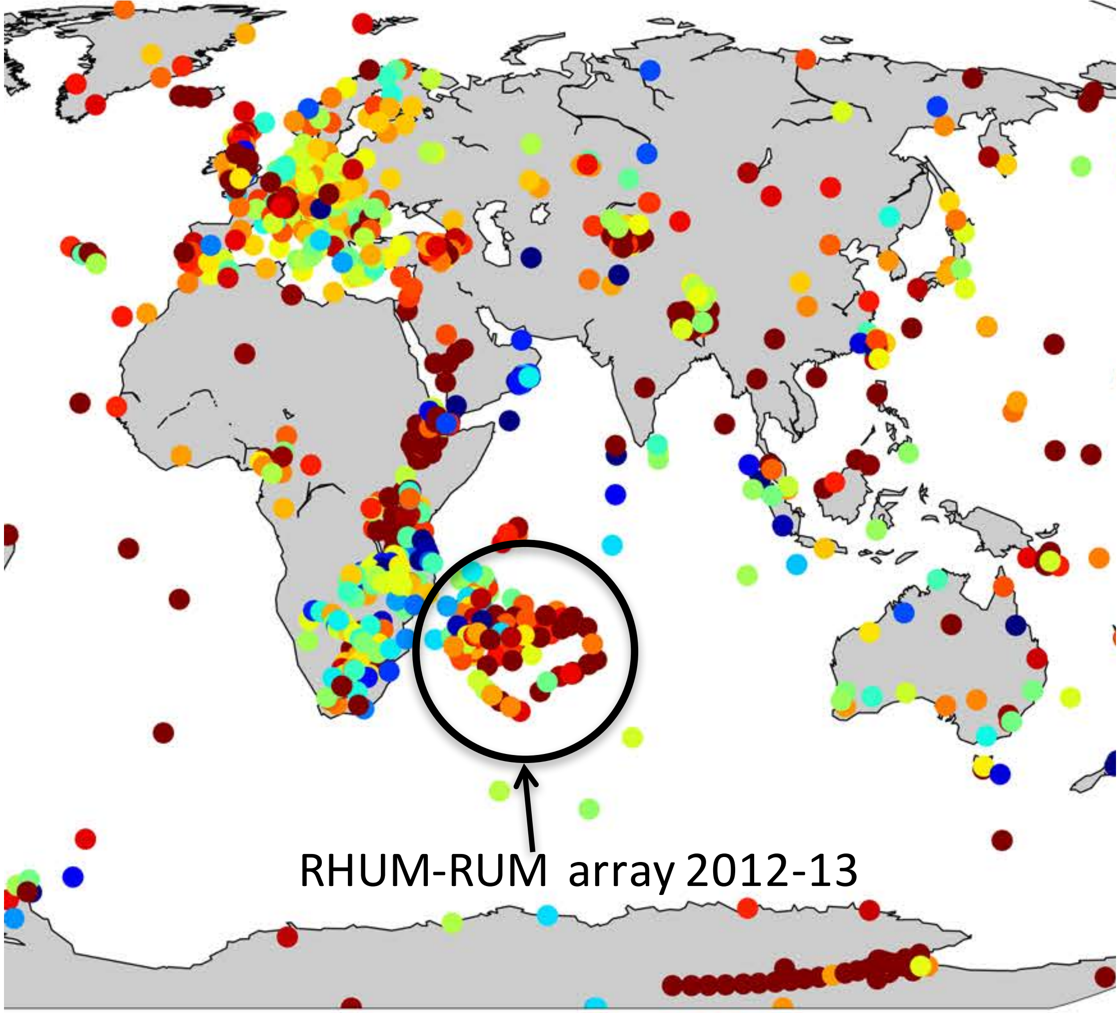


The RHUM-RUM experiment deployed 57 BB OBS for 13 months



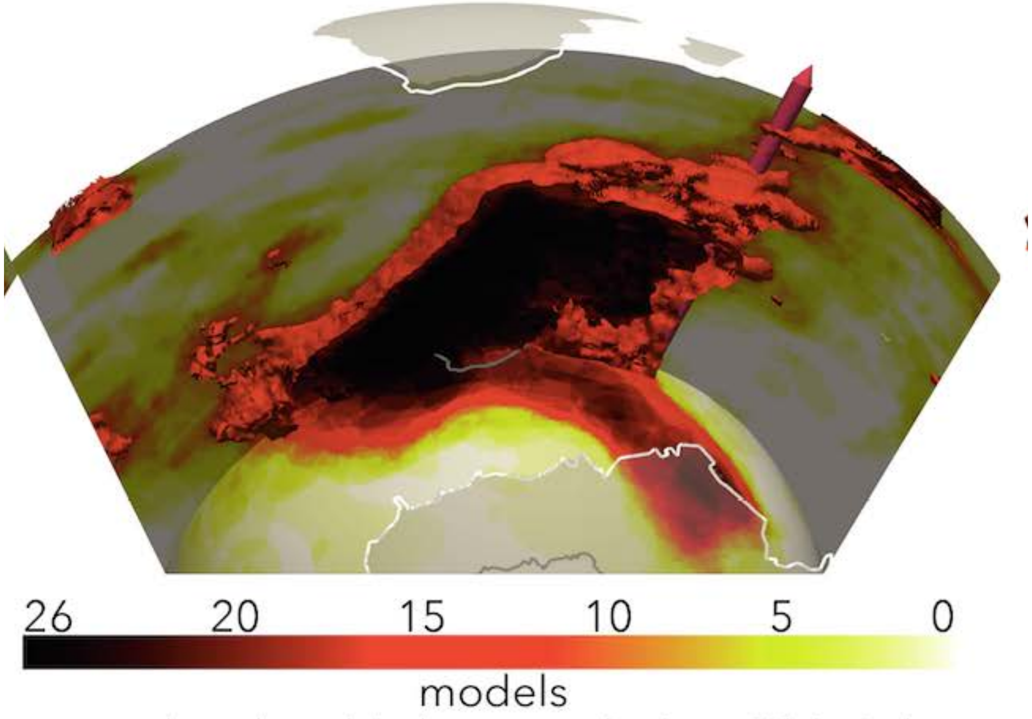
Whole-mantle views of the African LLVP

- Upper mantle resolved by RHUM-RUM's ~57 OBS and 30 land stations (but only under La Réunion hotspot)
- Lower and lowermost mantle resolved primarily through P and Pdiff – finite-frequency traveltimes and ISC picks.


RHUM-RUM array 2012-13

Dots are stations that yielded finite-frequency waveform measurements.

Global models (without RHUM-RUM data) were in good agreement in the lower mantle, but poor agreement in the upper mantle.



“Vote map” of 26 global P- and S-wave models on which mantle areas are seismically slow. Each model gets one “vote” (per lat/lon voxel). Colour codes the vote count. Ex: “13” means that half of the models see a place as slow

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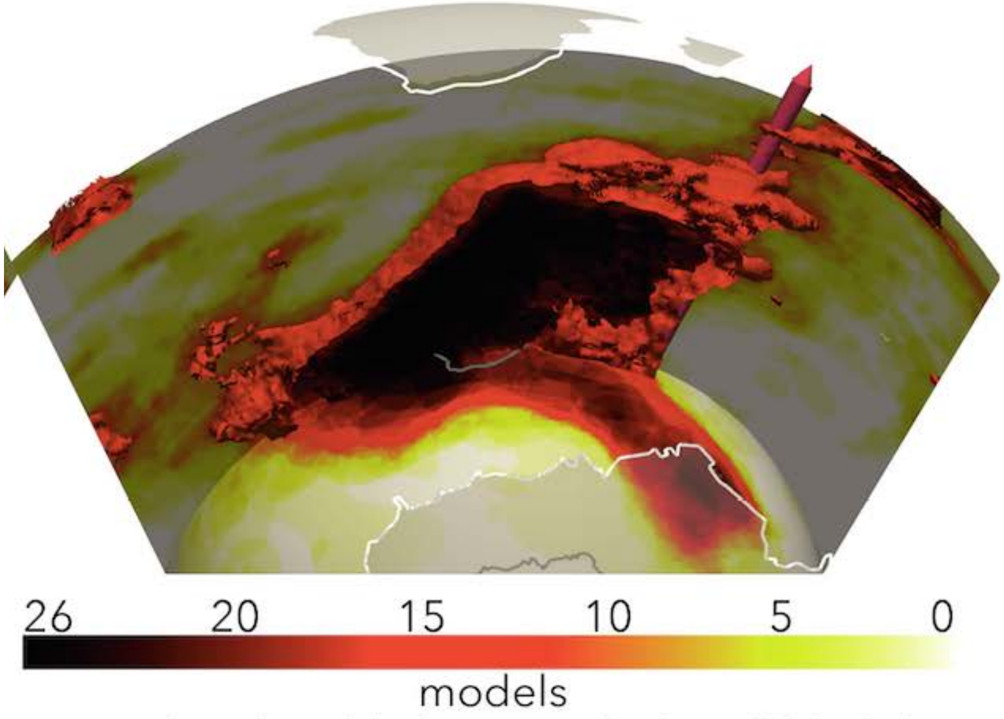

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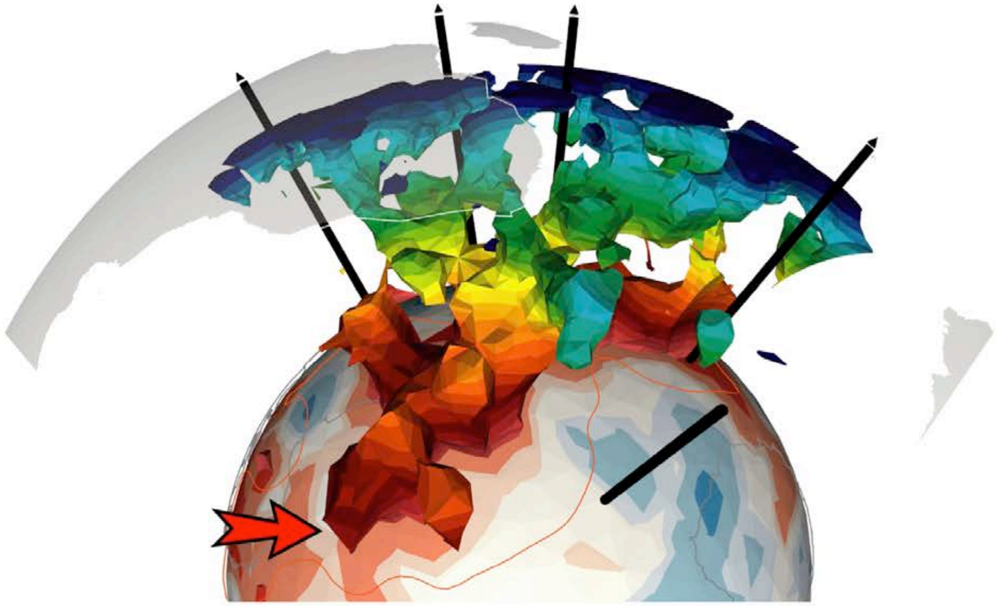
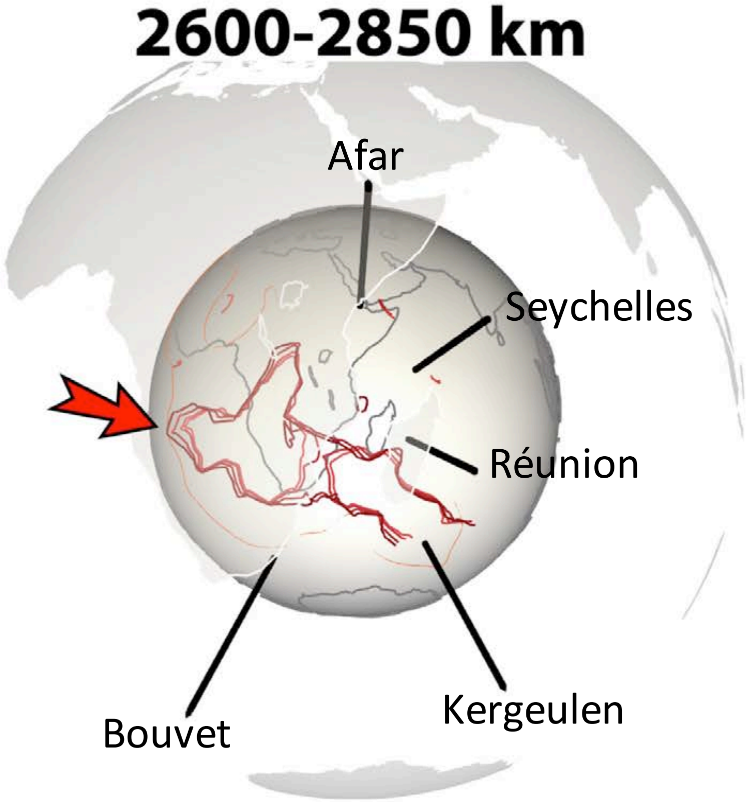
With RHUM-RUM, P and Pdiff data (Tsekhmistrenko et al. 2021 NatGeo)

Seismically slow structure associated with the LLVP



Seismically slow material is enclosed by an isosurface. Colour signals depth and changes every 100 km.



Seismically slow material is contoured. One contour line every 100 km. Line colour signals depth.

Tsekhmistrenko et al. 2021

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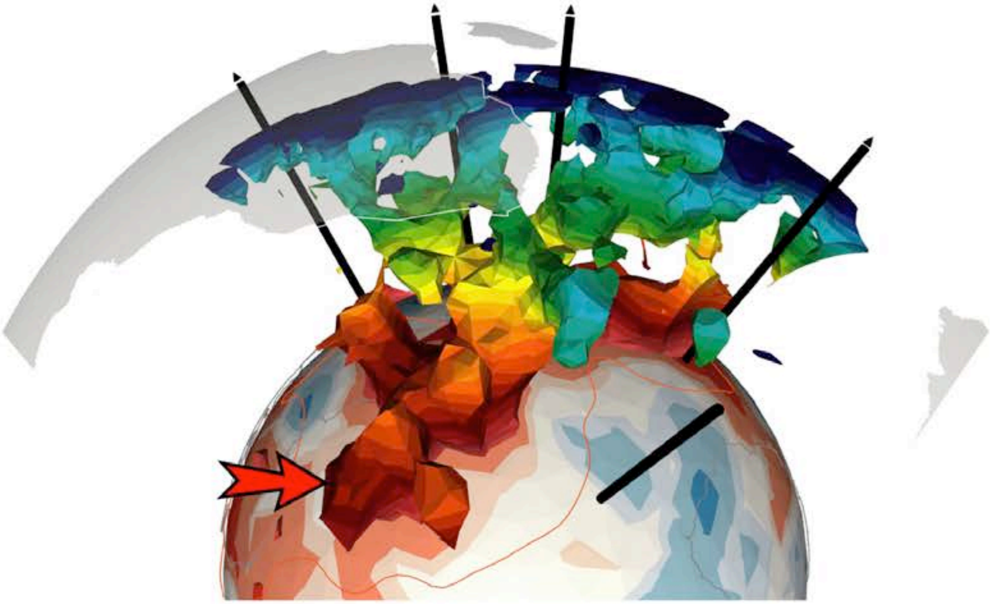

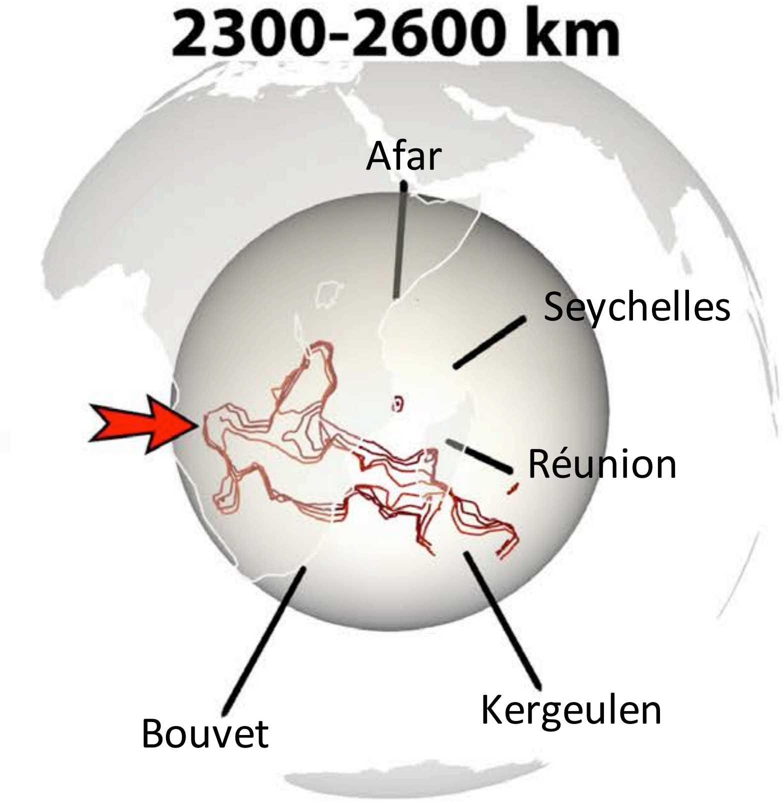

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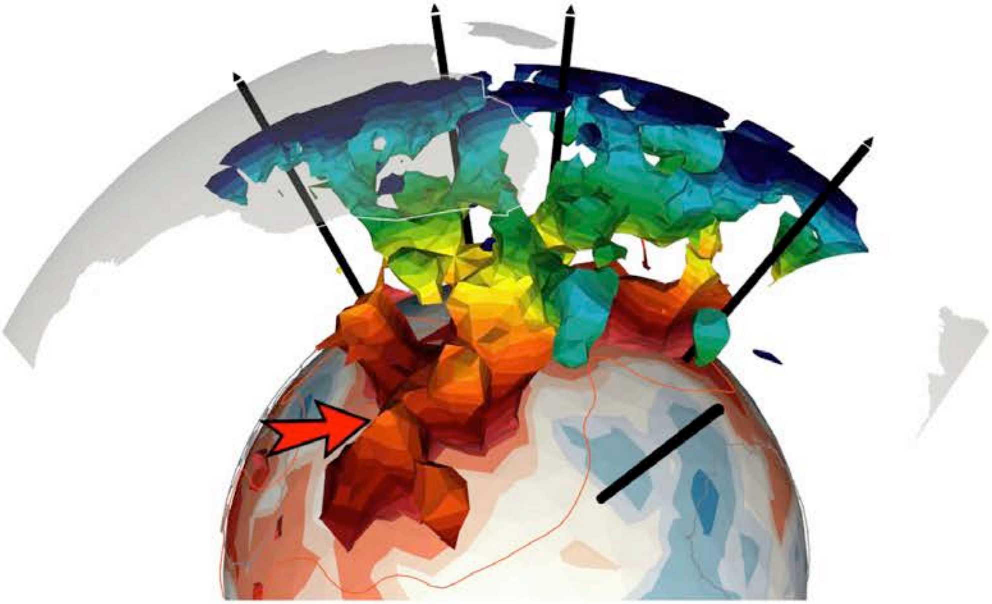

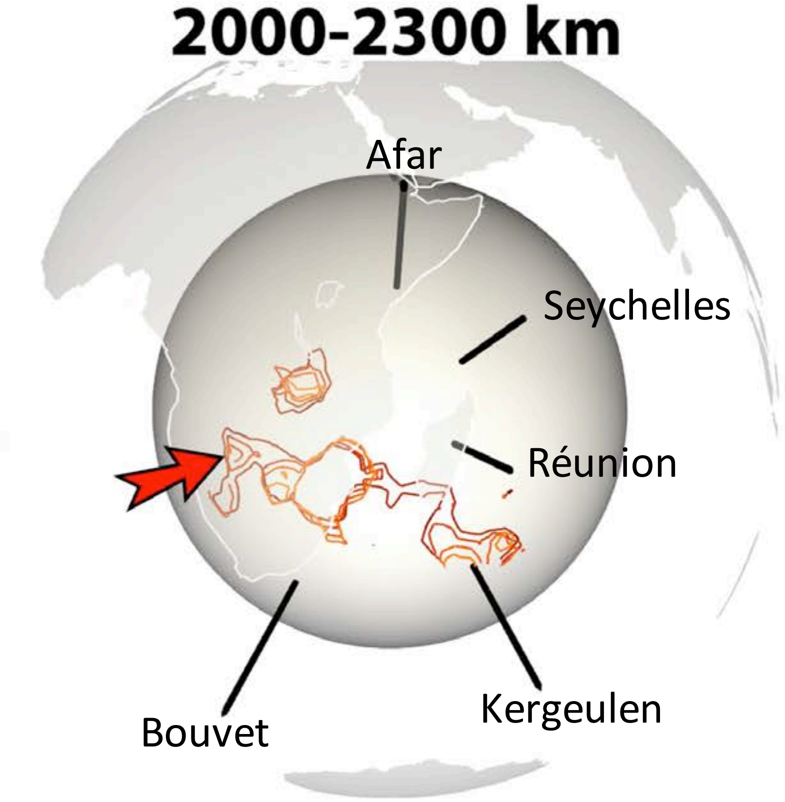

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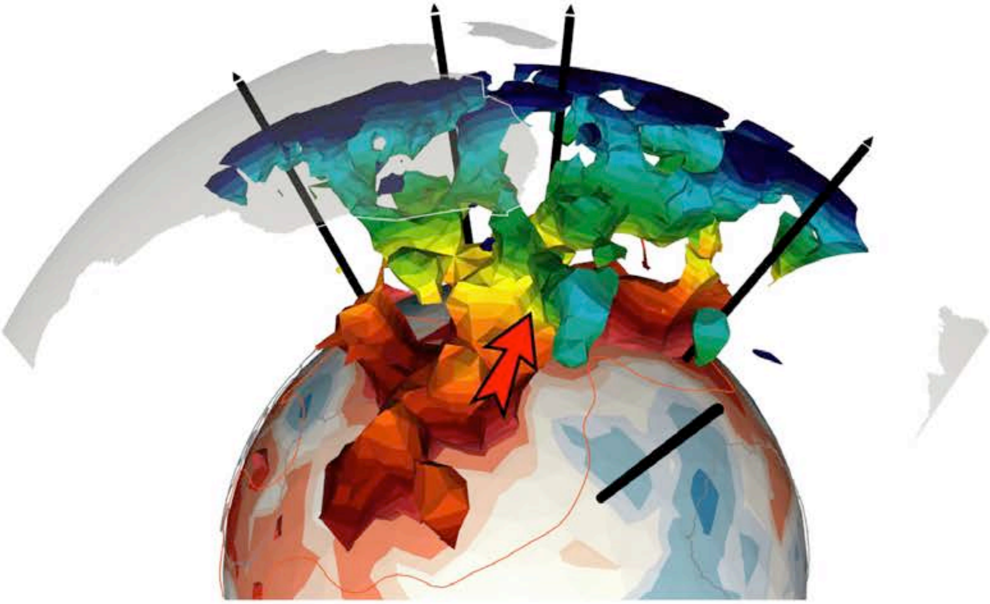
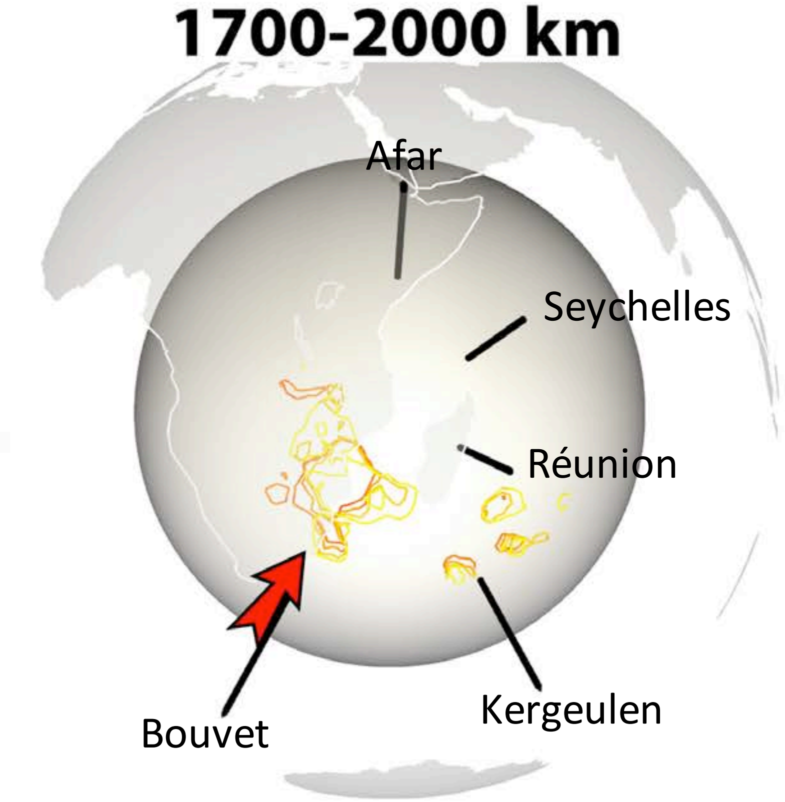


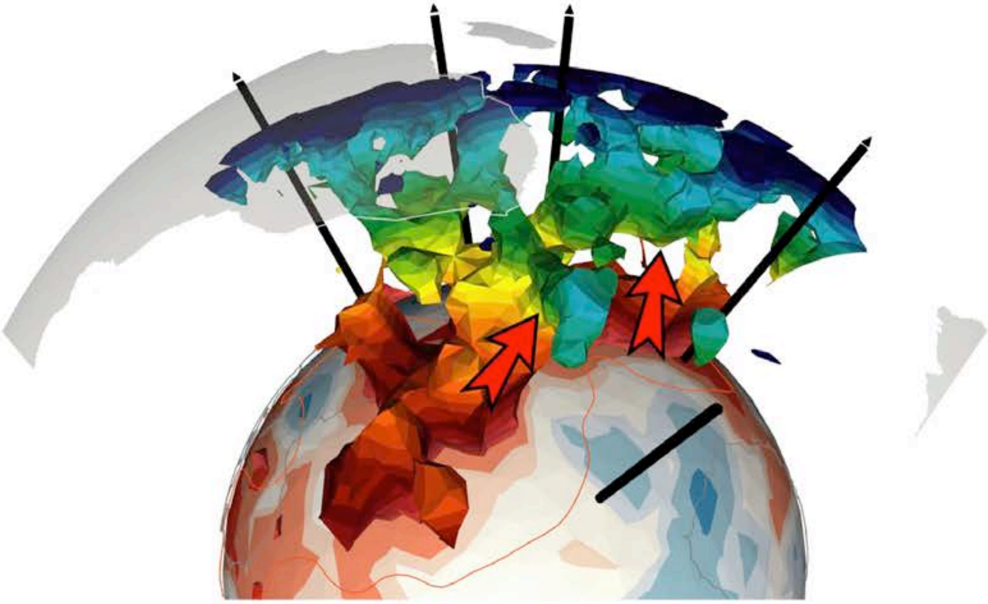


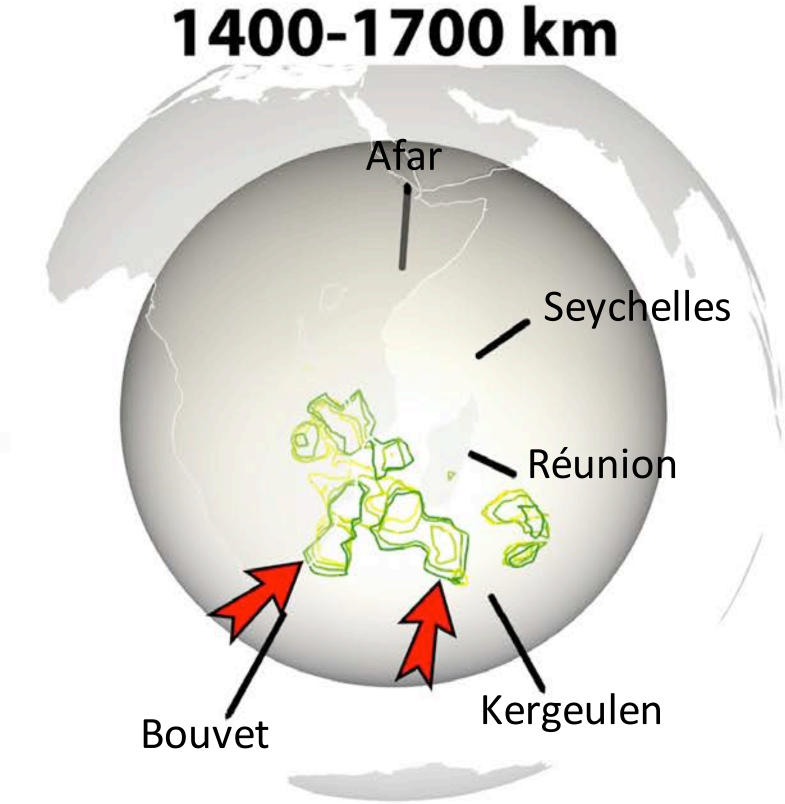
Seismically slow material is enclosed by an isosurface. Colour signals depth and changes every 100 km.

Seismically slow material is contoured. One contour line every 100 km. Line colour signals depth.

Tsekhmistrenko et al. 2021

Seismically slow structure associated with the LLVP





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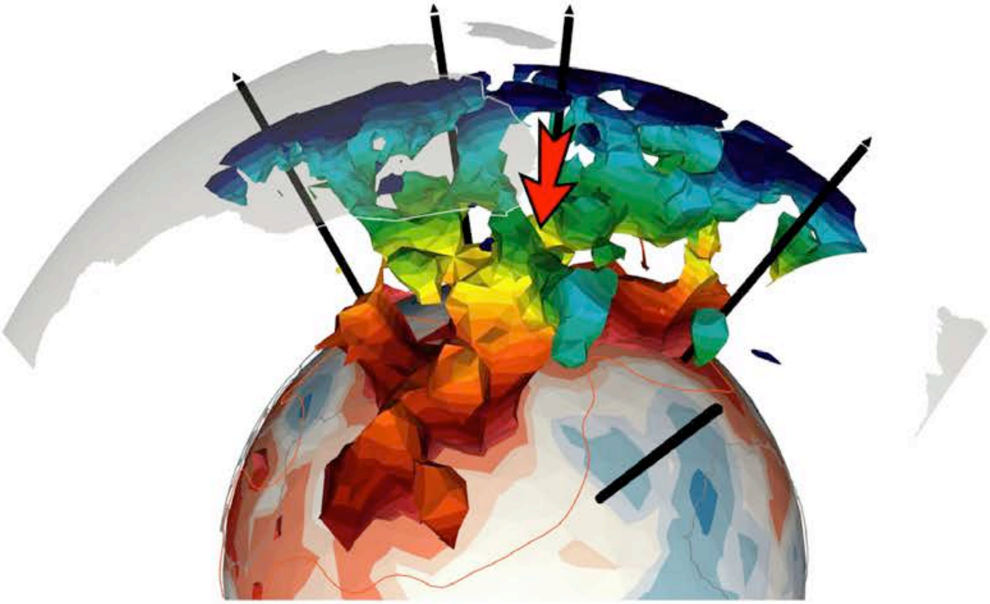

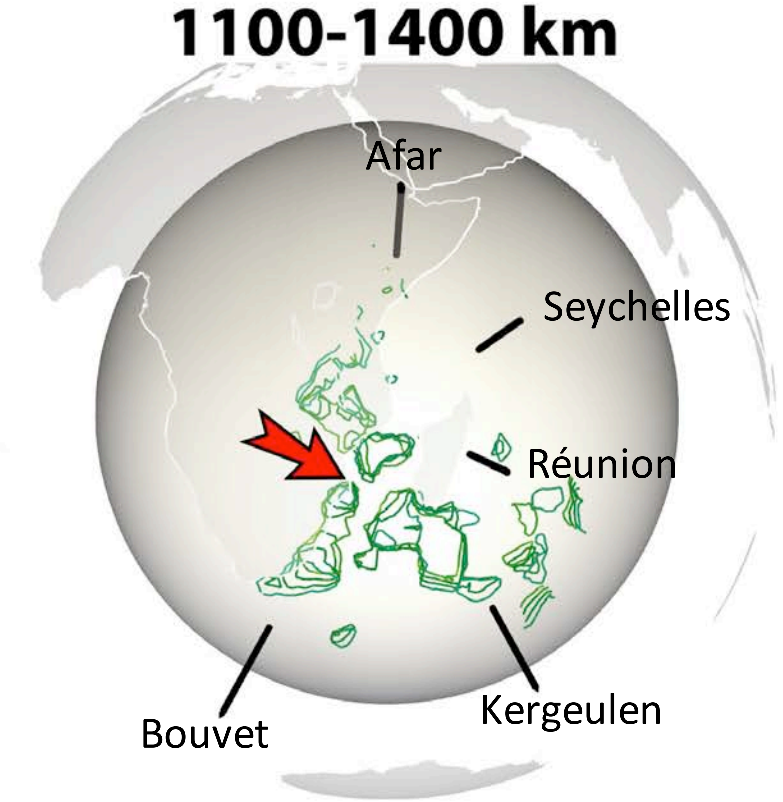

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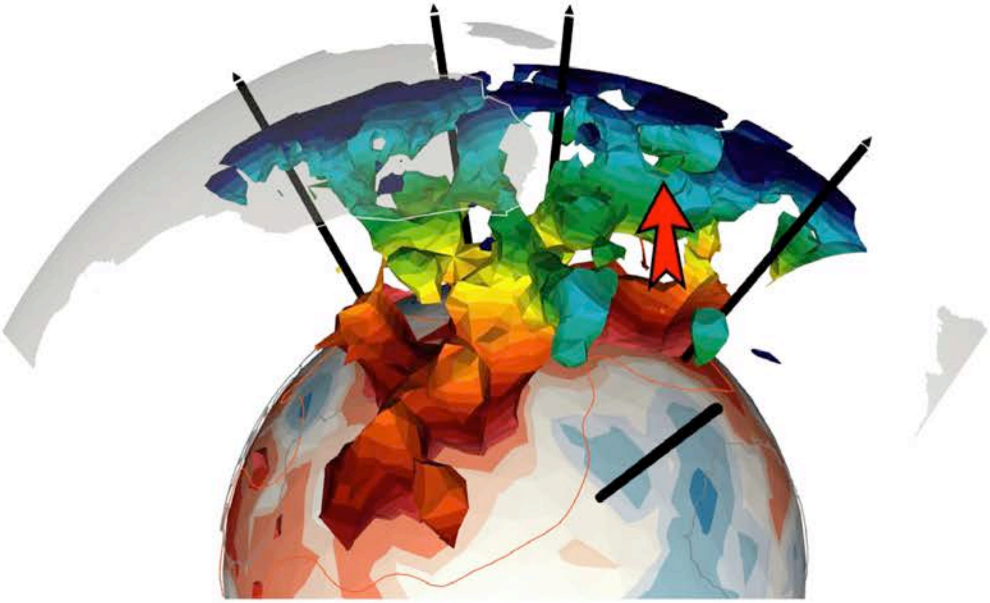

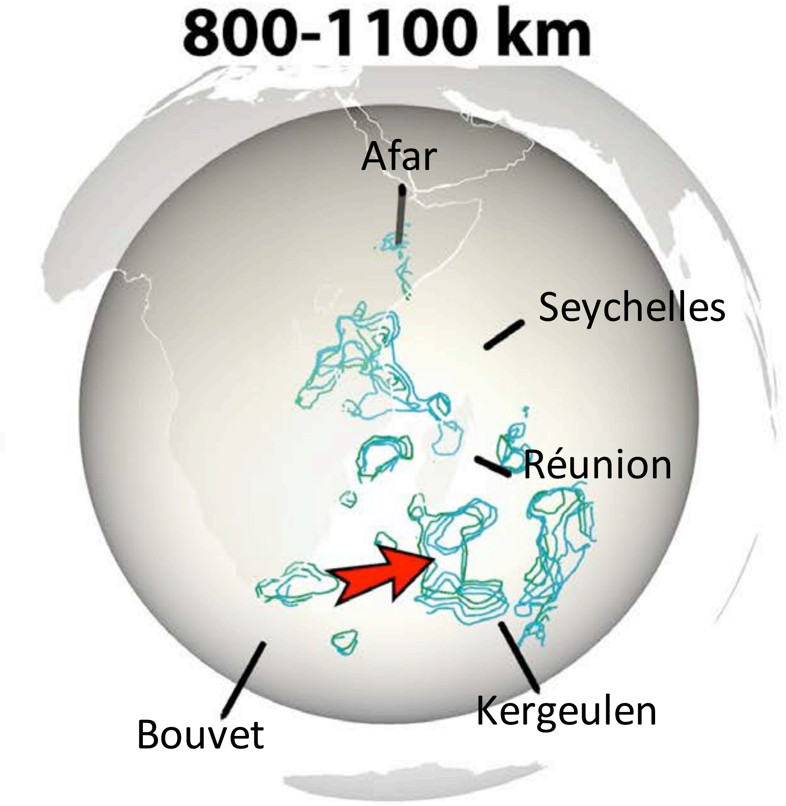

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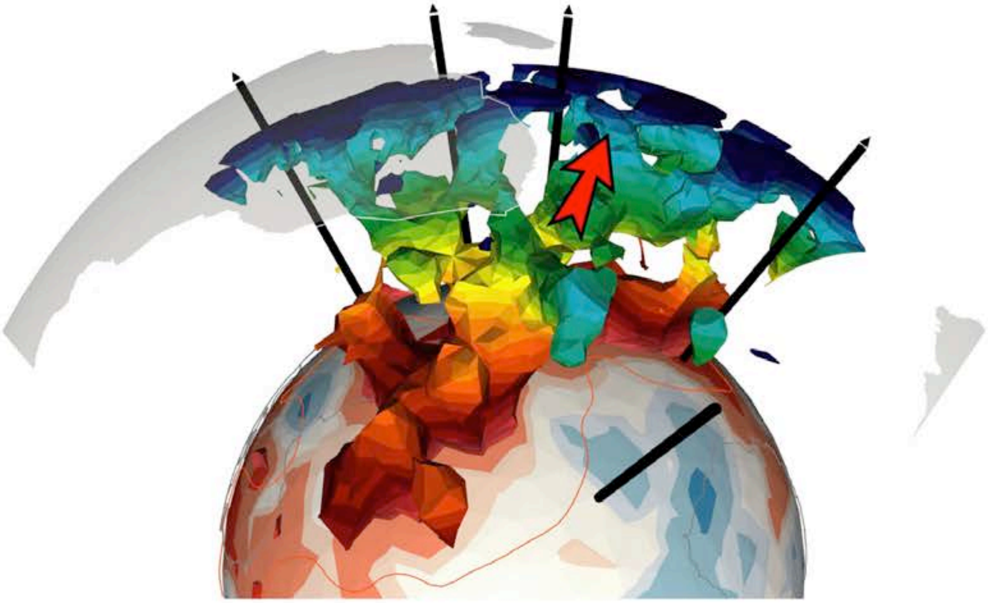

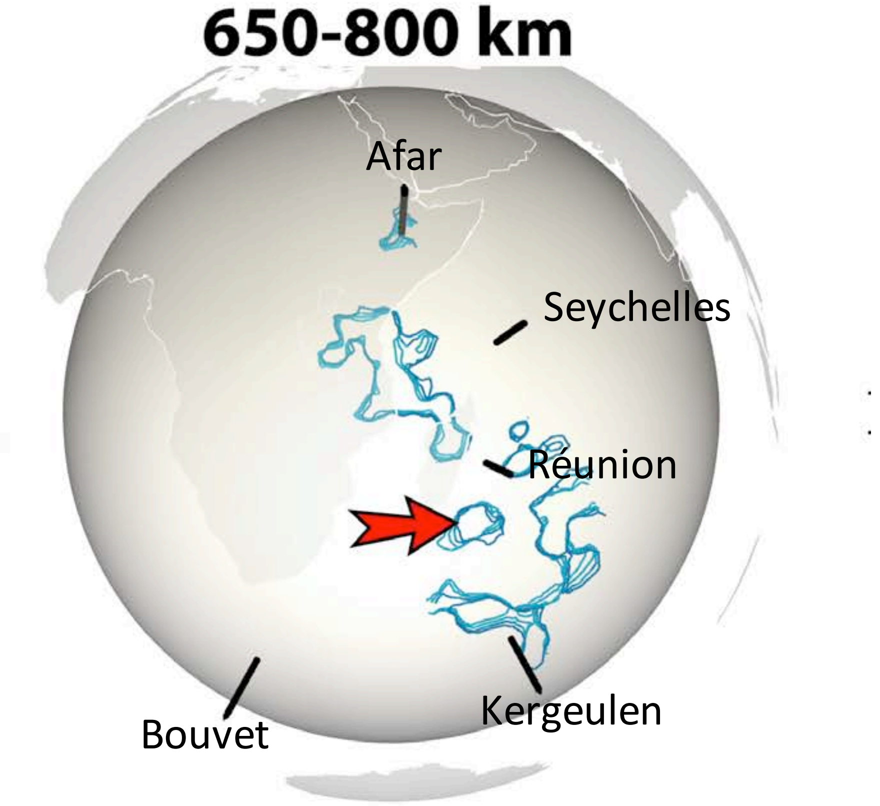

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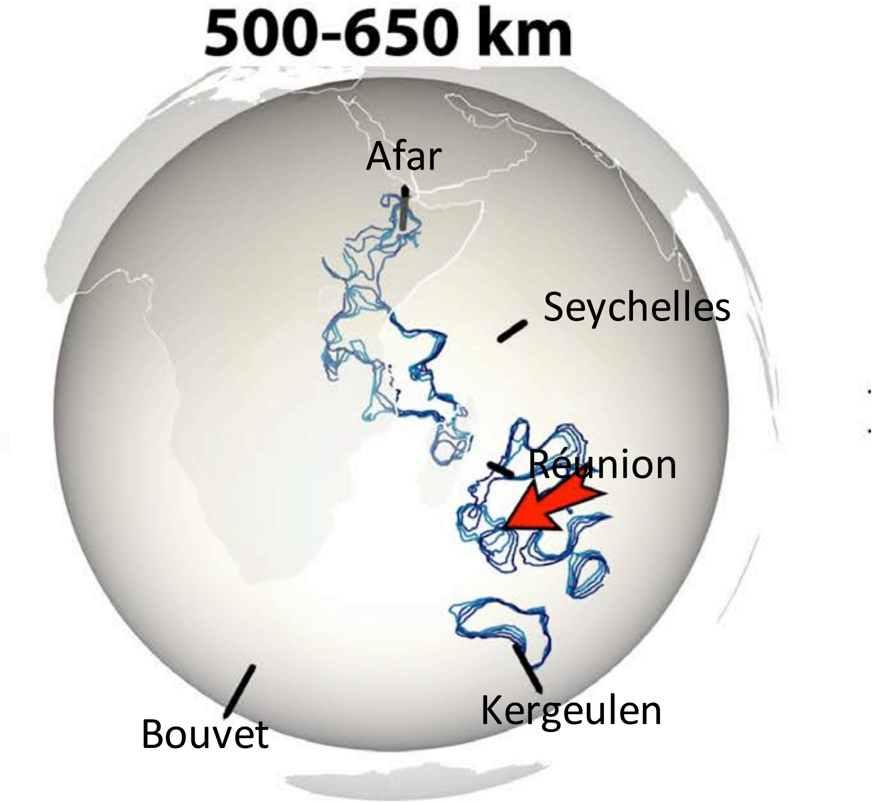

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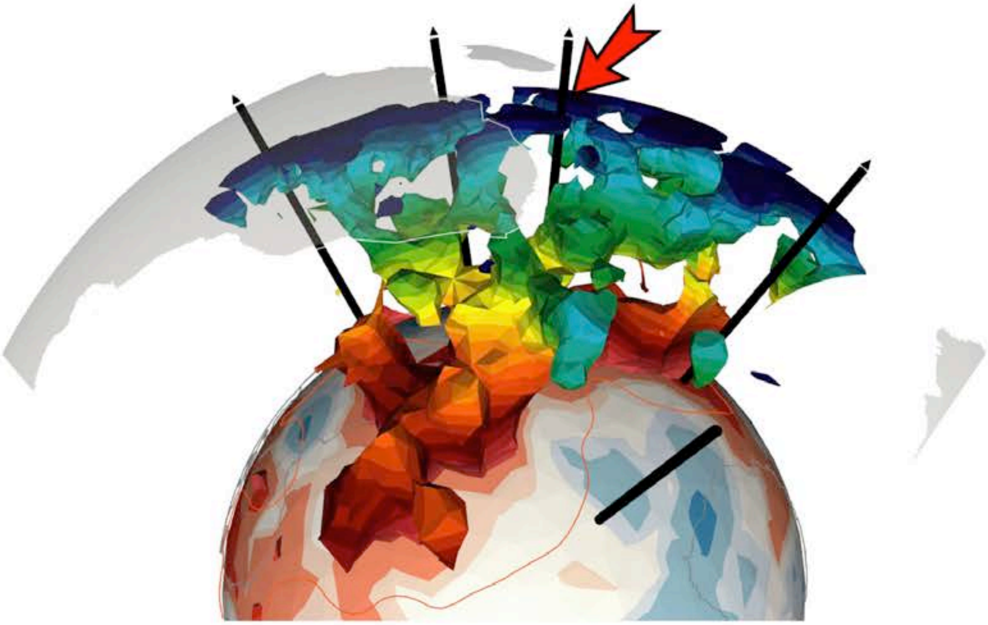

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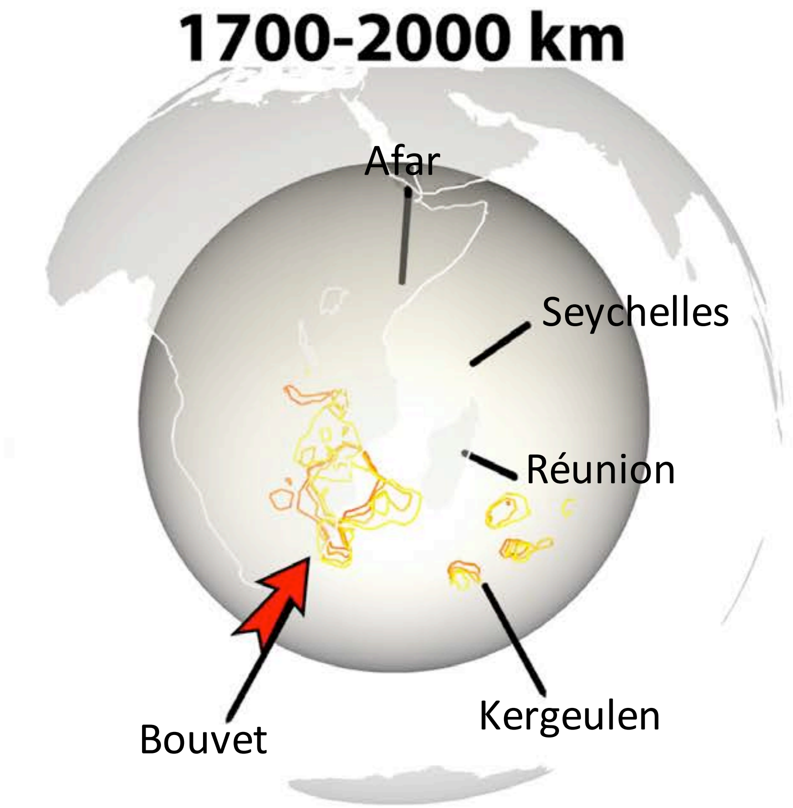
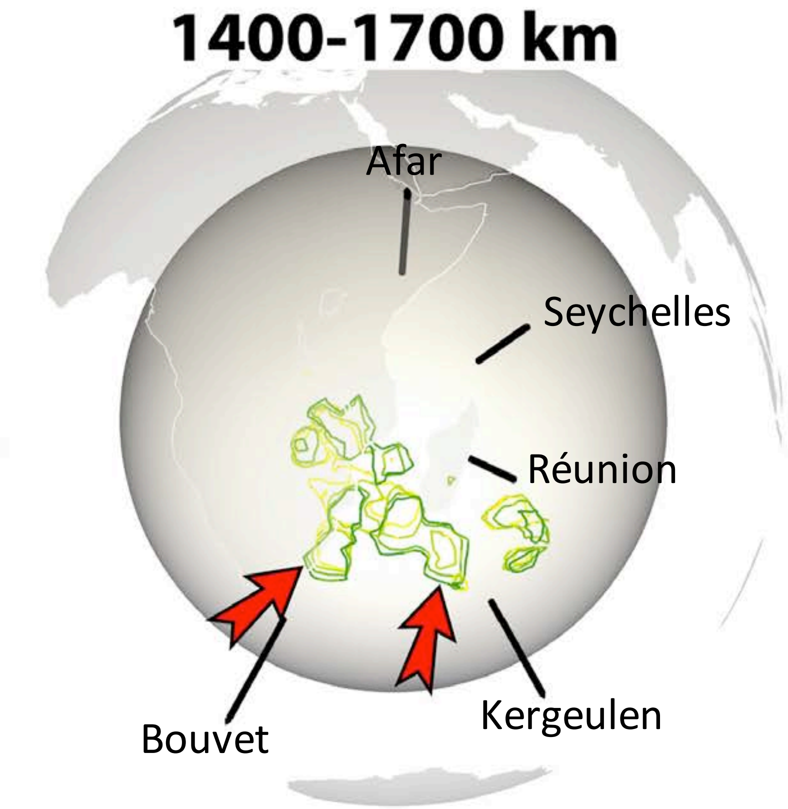
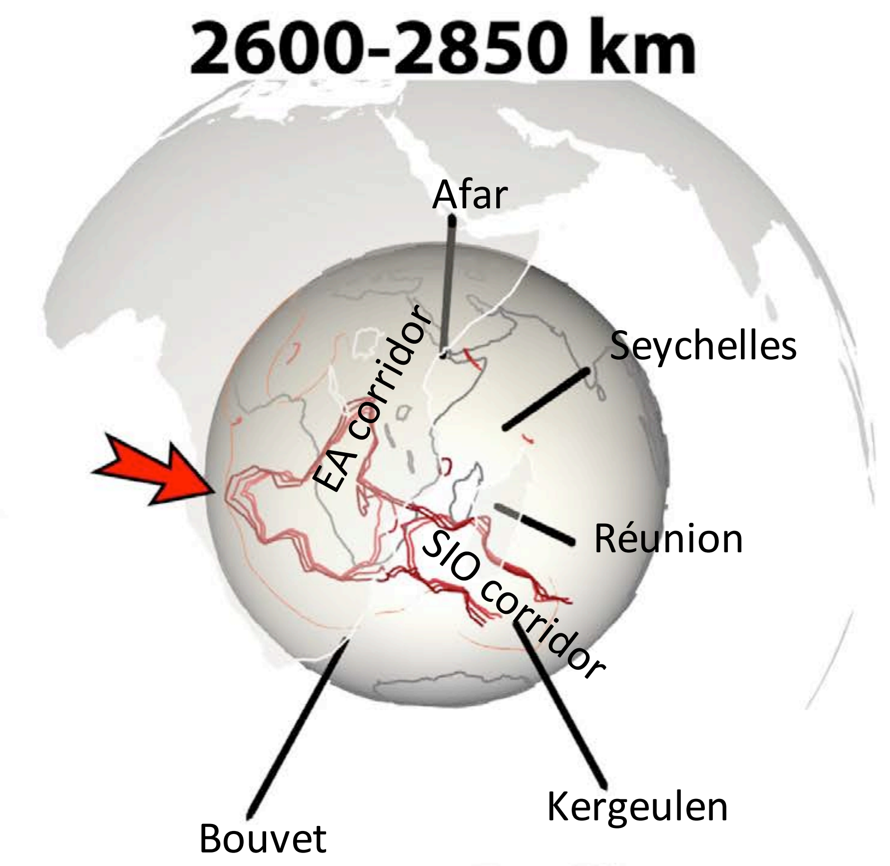
The LLVP's central dome cusps at ~1700 km depth, under the Mozambique Channel → the upper boundary of the LLVP.

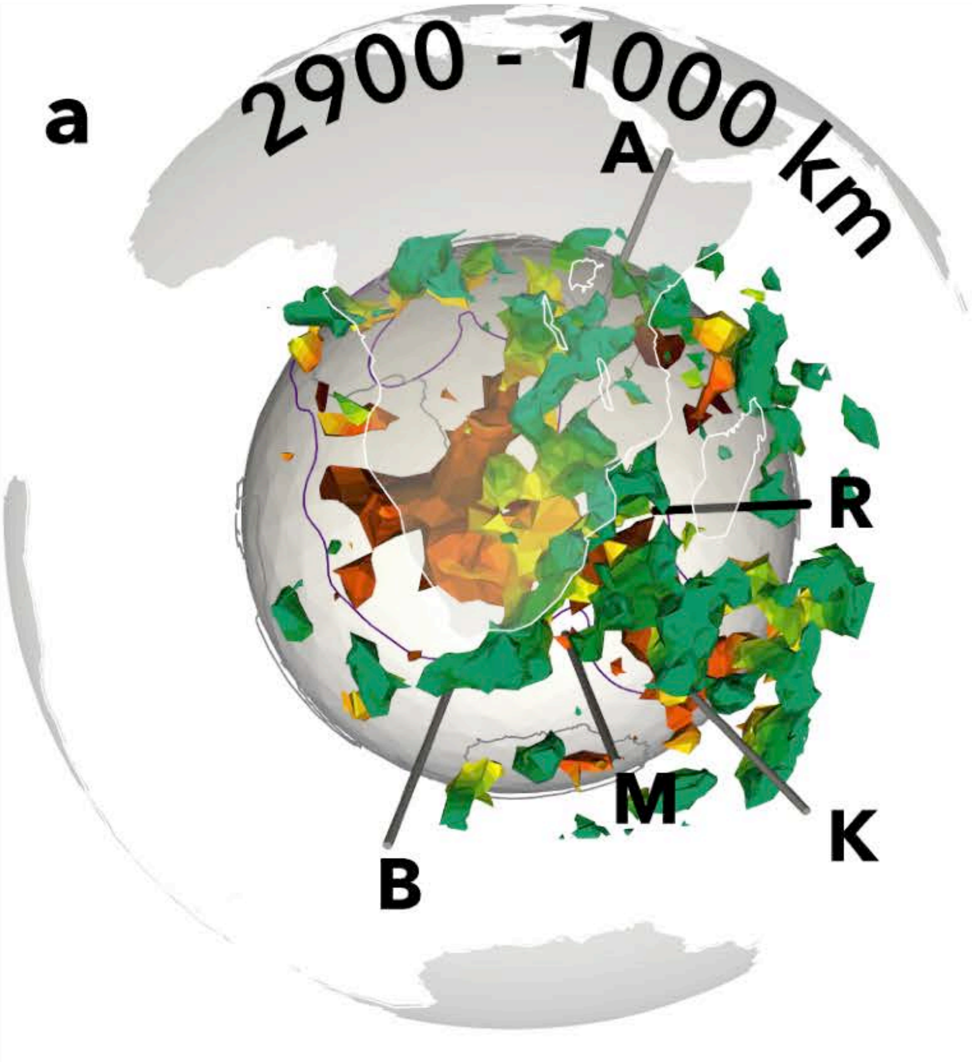




The three diverging branches look clearly different from what is underneath, hence they should probably not be considered LLVP. But what are they?

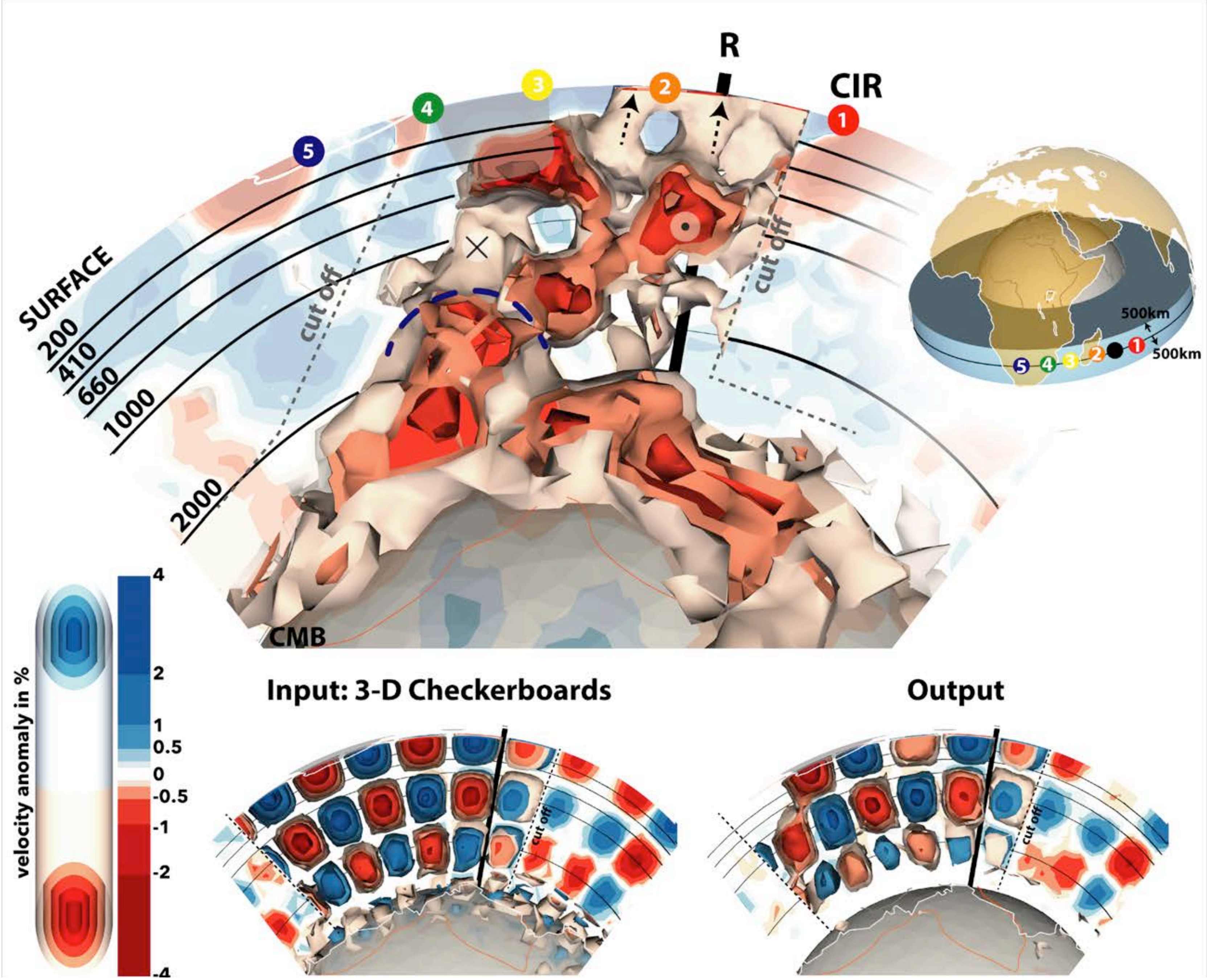
The African LLVP and its three branches





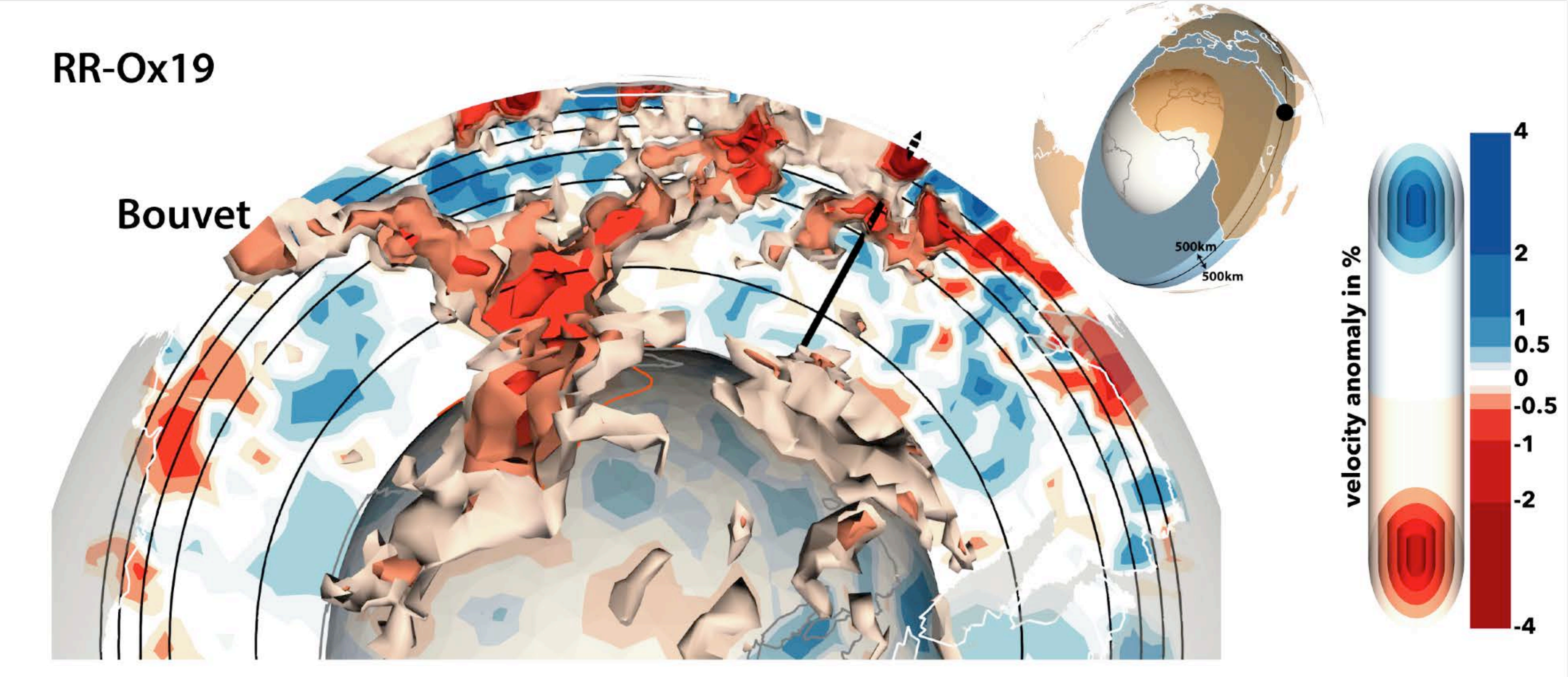
- The small-scale splashiness (or canopy of the “tree”) does not overlie the central LLVP. It is observed vertically above the Kerguelen and East African CMB corridors.

Southern Indian Ocean branch: Low-velocity anomalies in a west-east section through South Africa and La Réunion



Tsekhmistrenko et al. (2021)

Bouvet branch & East Africa branch

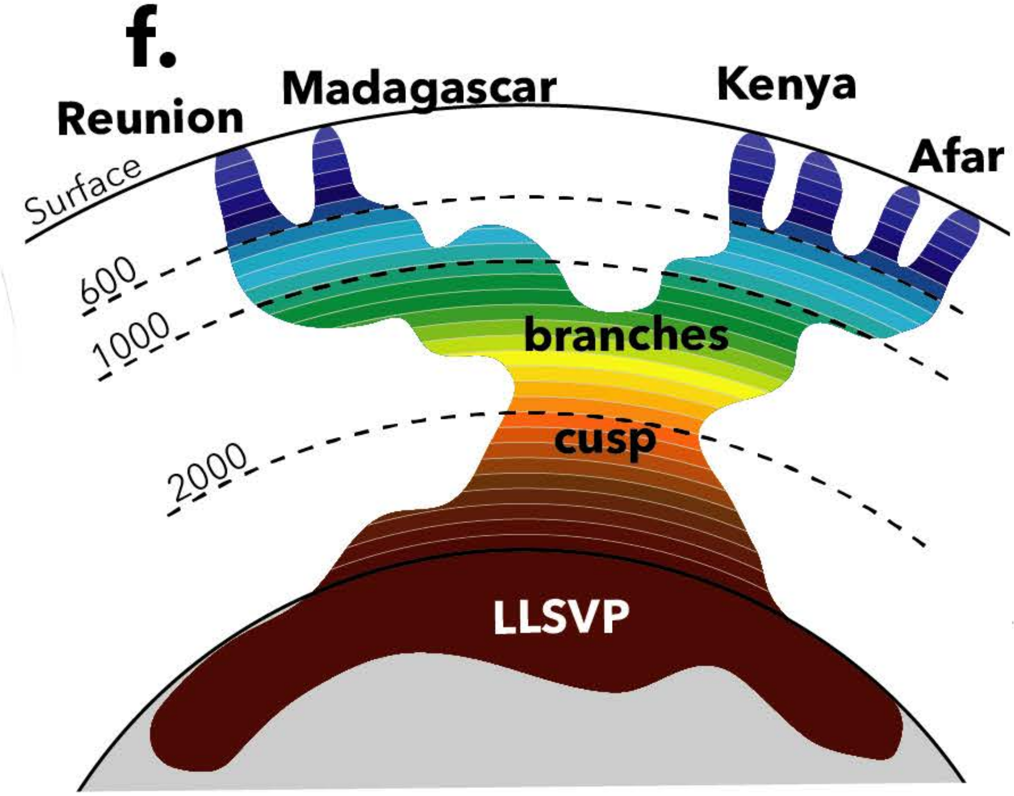


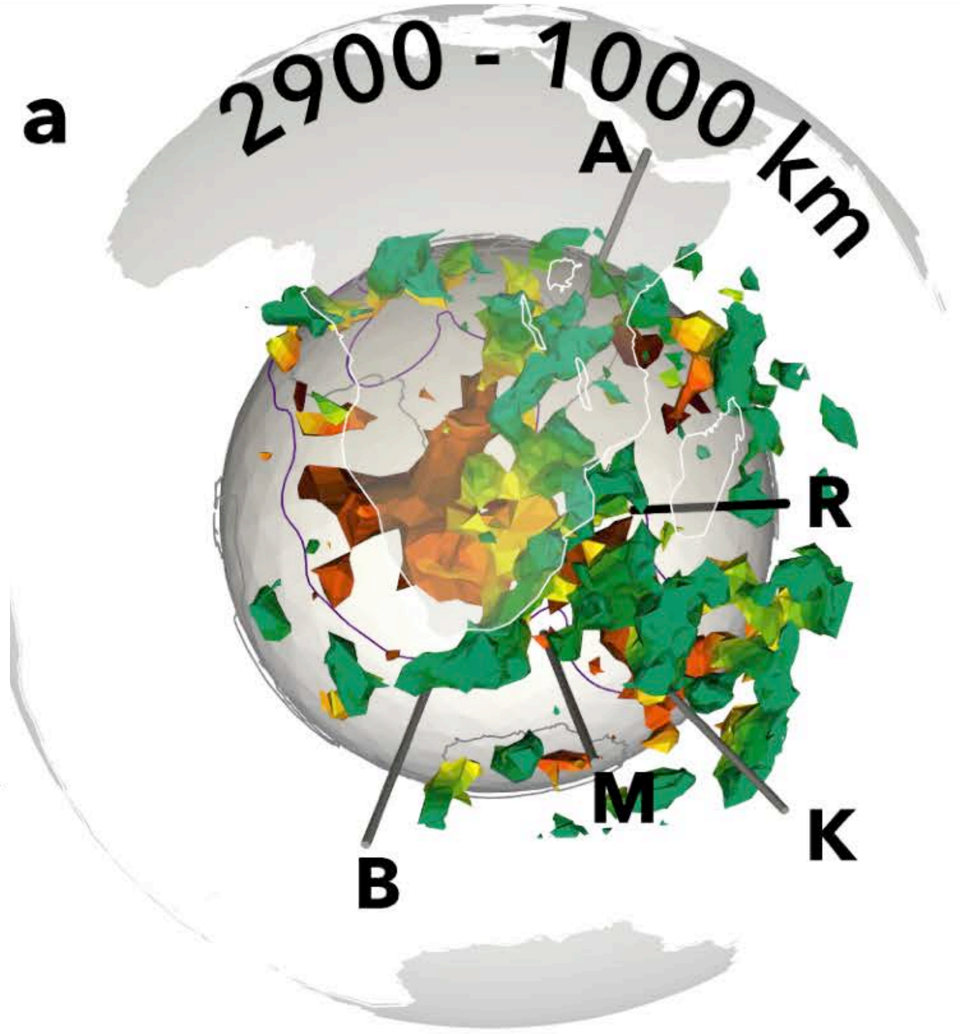
Tsekhmistrenko et al. (2021)

The East African branch is also underlain by a CMB corridor. (It reaches northward only to Kenya, which was overlain by the Afar region around 30 Ma, when the LIP erupted.)

No CMB corridor observed under Bouvet branch, but would be expected to remain unresolved.

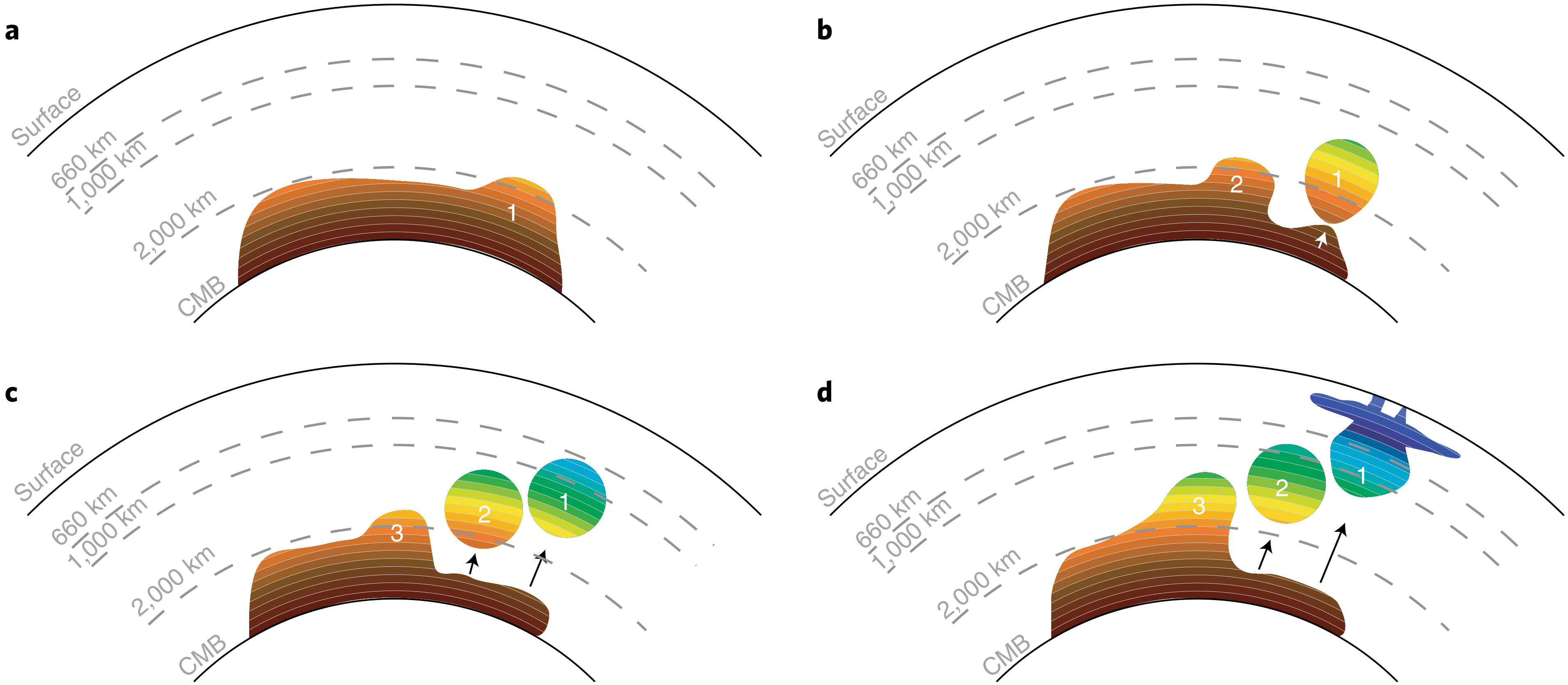
The African LLVP and its three branches





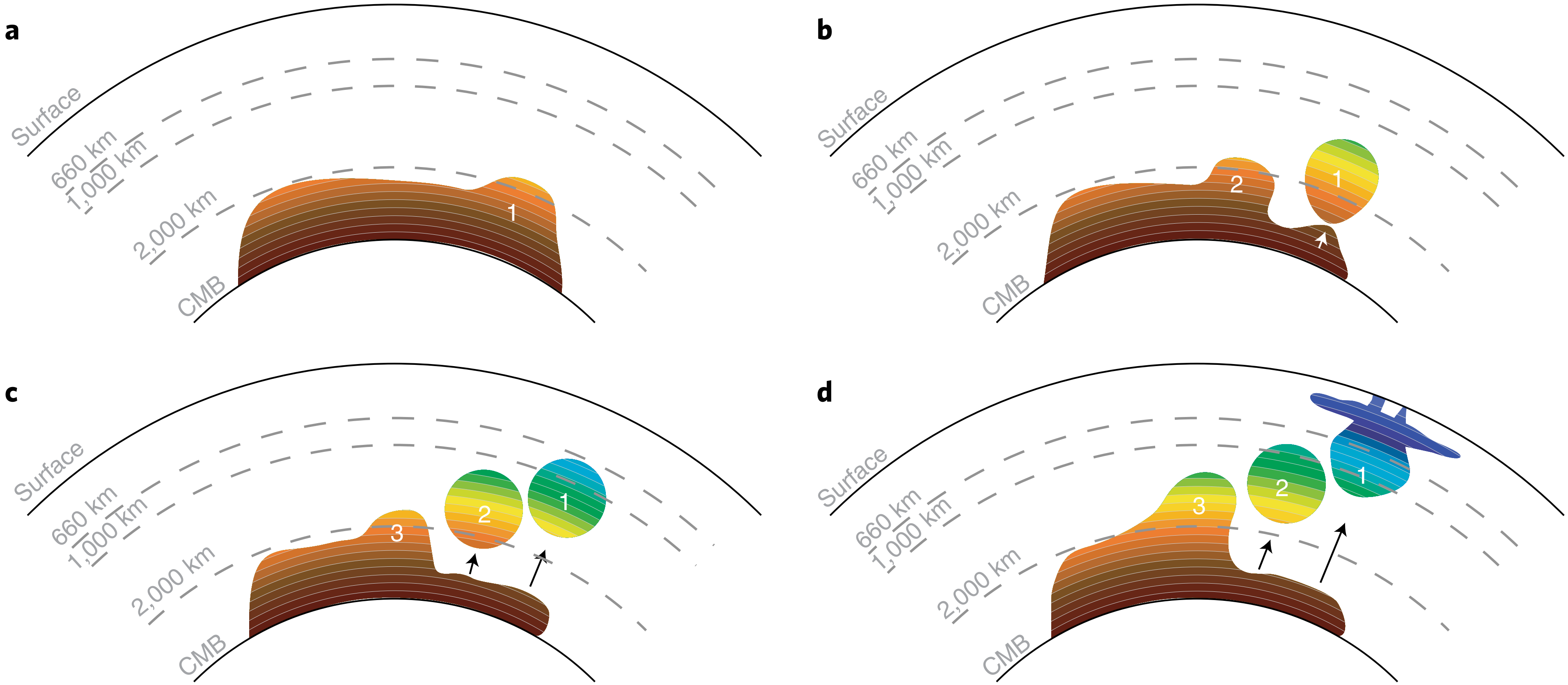
- Structure is complex, but passes resolution tests and plausibility checks.

Proposed relationship between a CMB corridor and a mid-mantle branch: vertically upwelling blobs, offset in time.



- In simulations, upwellings have strong tendency to rise (almost) vertically (e.g. work by Davaille, Steinberger).
- Consistent with our observations: Why else would the mid-mantle branches be found vertically above the CMB corridors (and not elsewhere)?

Proposed relationship between a CMB corridor and a mid-mantle branch: vertically upwelling blobs, offset in time.



- Blobs that rose vertically but detached sequentially would create the diagonally rising appearance. (Tomo does resolve individual blobs.)
- Thin “classical” plumes are spawned only upon arrival at the upper mantle. They remain rooted in their mid-mantle blob.

CMB corridor in the Southern Indian Ocean: the cause or facilitator of Indian Ocean opening?

A sequence of 3 LIPs (3 blob detachments?) unzipped India from Gondwana, and opened the Indian Ocean: Kerguelen ~120 Ma; Marion ~90 Ma; La Réunion (Deccan) ~65 Ma.

➔ Corresponds to an inward sweep of blobs along the SIO corridor.

➔ East African rifting may be a sequence in progress.

➔ Geological significance of the convergence of branches under South Africa/Mozambique Channel?