Mapping global scale mantle flow patterns with seismic anisotropy

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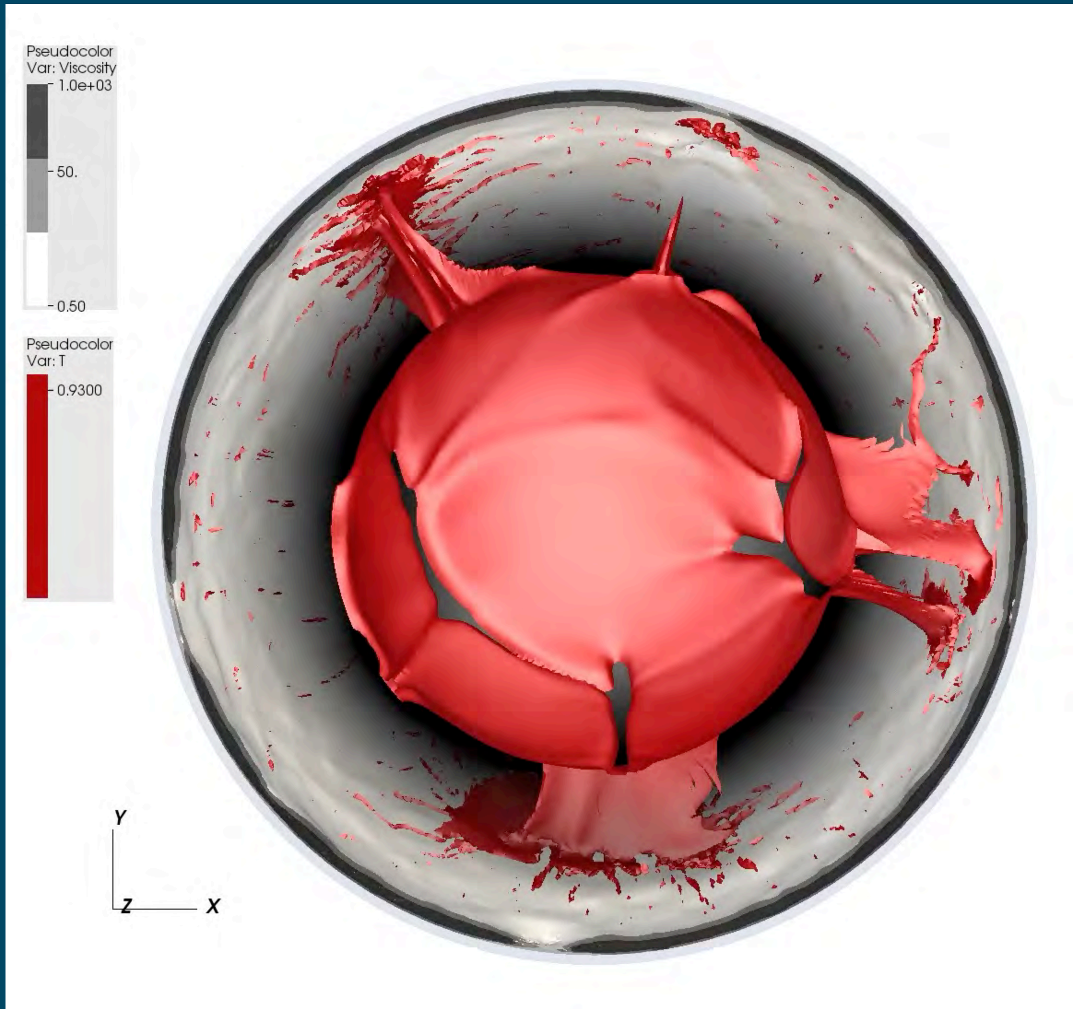
UCL Seismolab

Global mantle flow



Crameri & Tackley, Progress in Earth Planet. Sci., 2016

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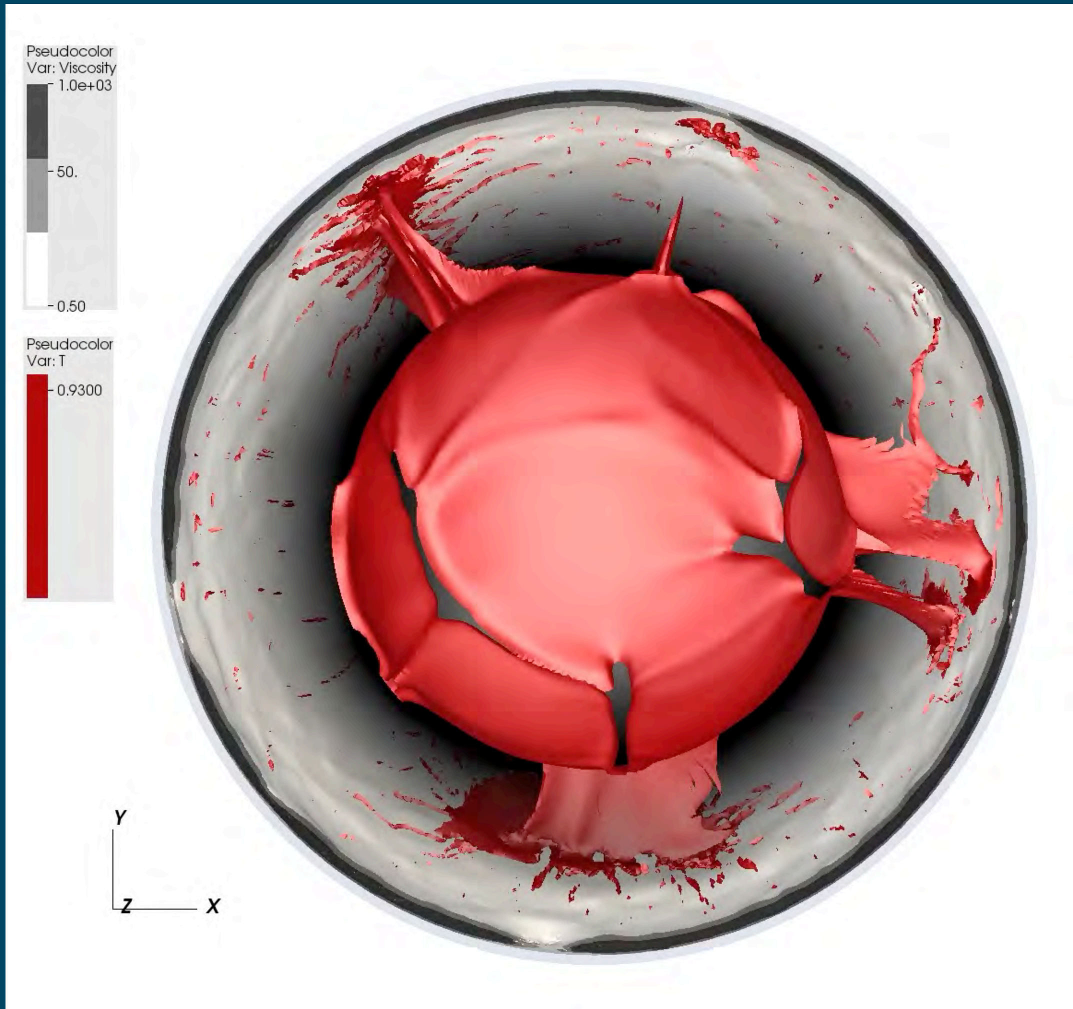

Seismic data: key to constrain geodynamical models

Crameri & Tackley, Progress in Earth Planet. Sci., 2016

Seismic anisotropy

- Directional dependency of seismic wave speed

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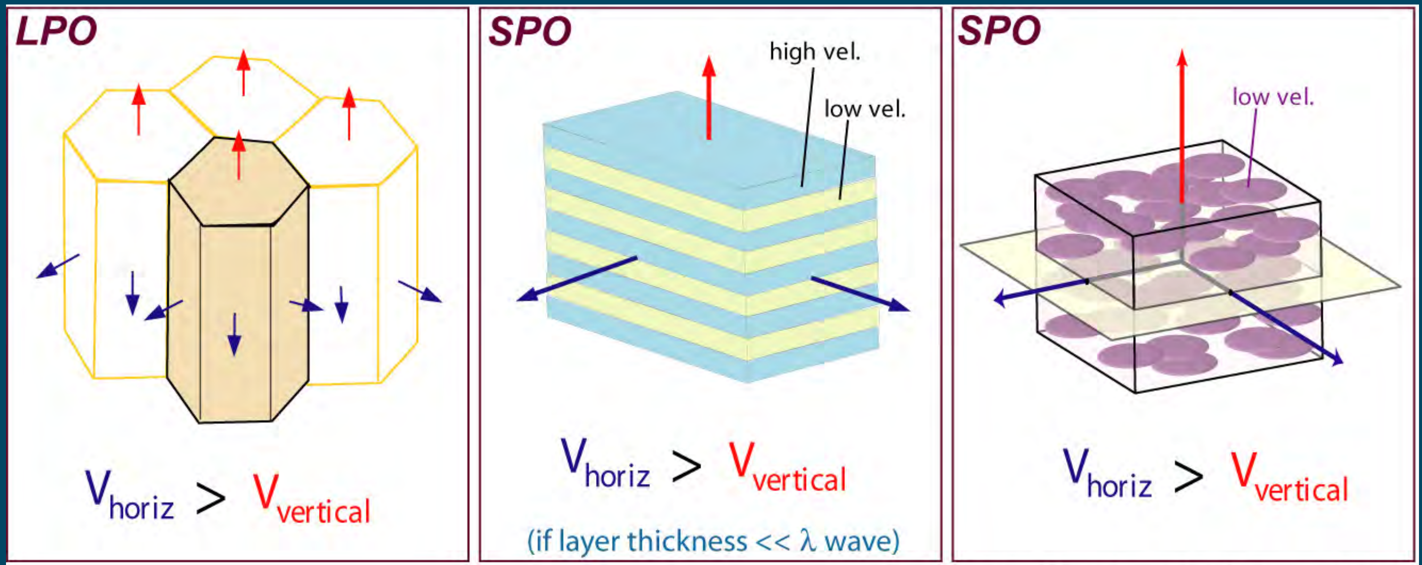
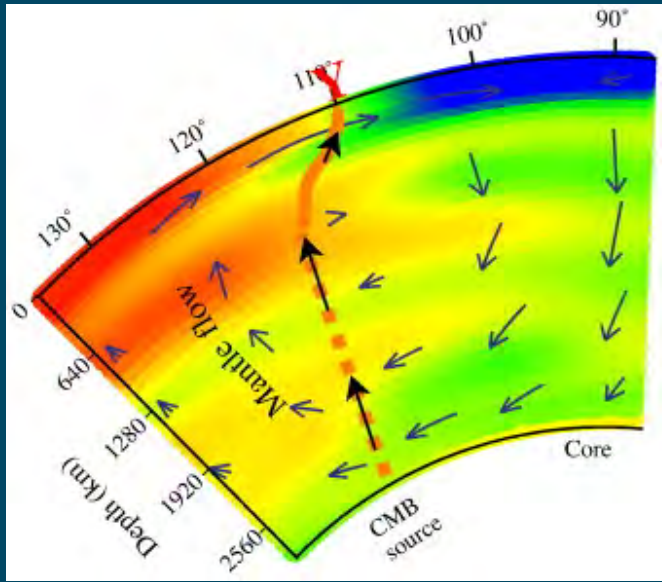
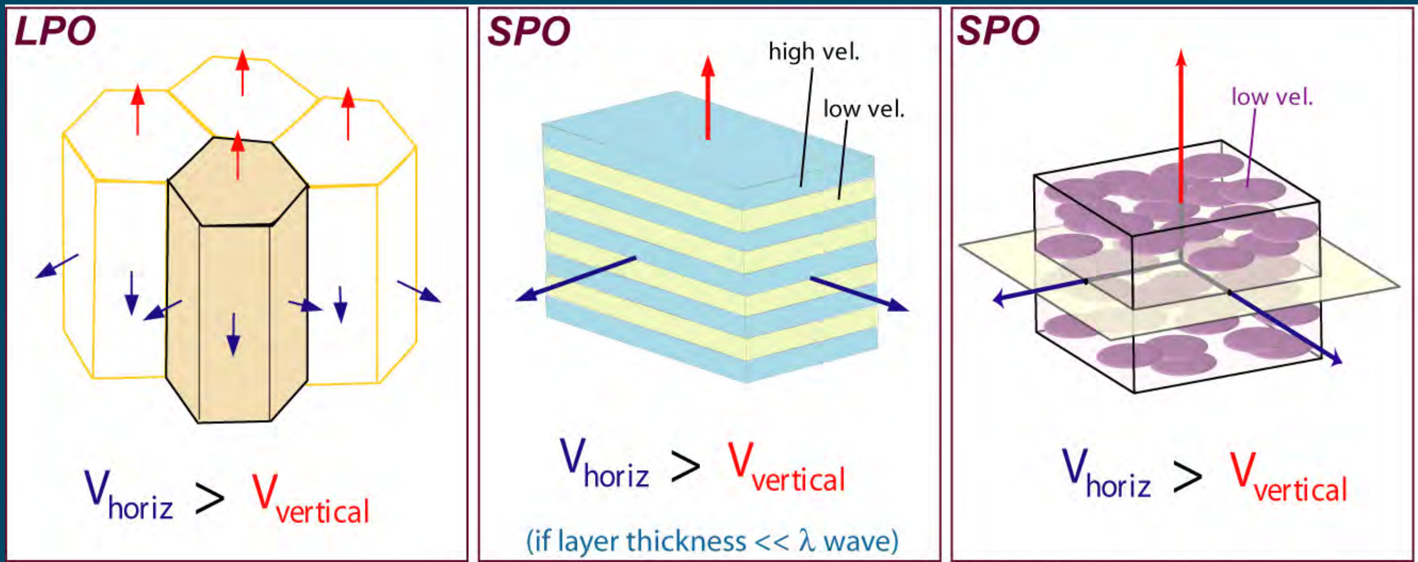


[after Moore,Garnero,Lay,Williams, JGR, 2004]

Seismic anisotropy

- Directional dependency of seismic wave speed
- May be due to LPO or SPO
- Key to constrain mantle flow





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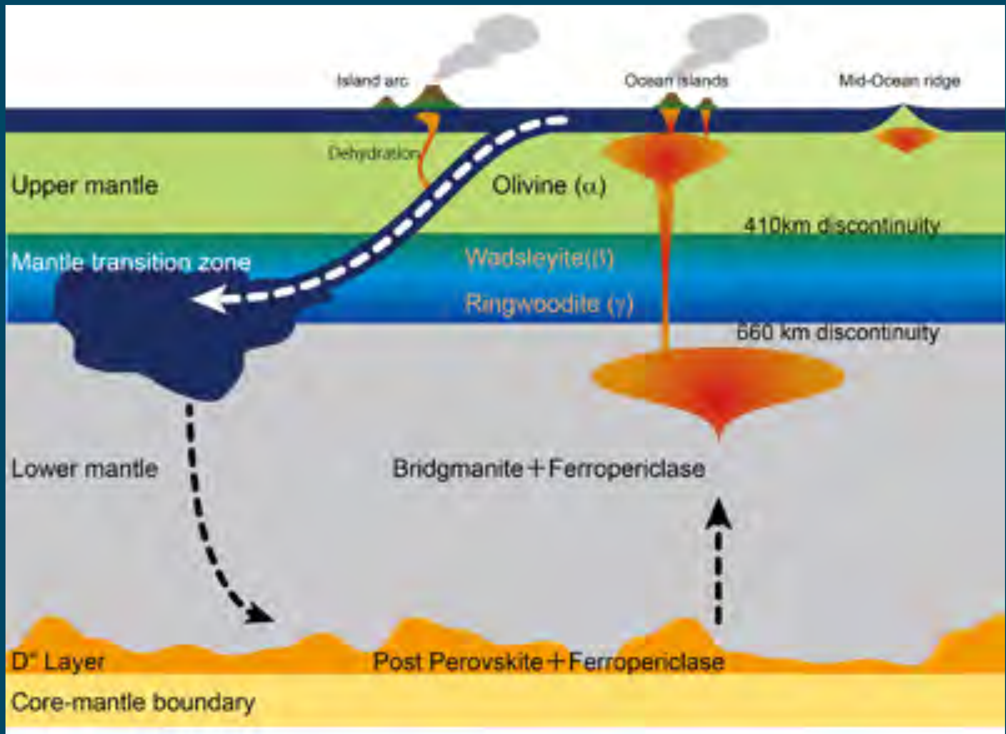
Seismic anisotropy: where?



http://www.grc.ehime-u.ac.jp/en/research/details

- Upper mantle:

  Well-established

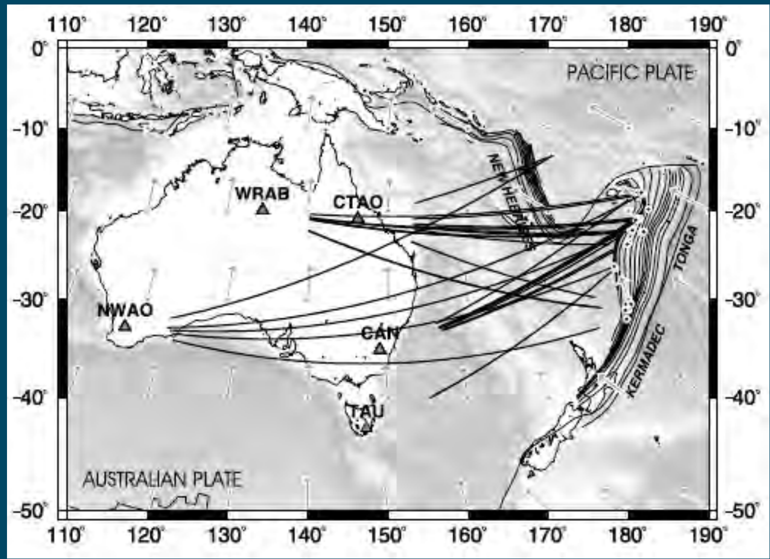
18%

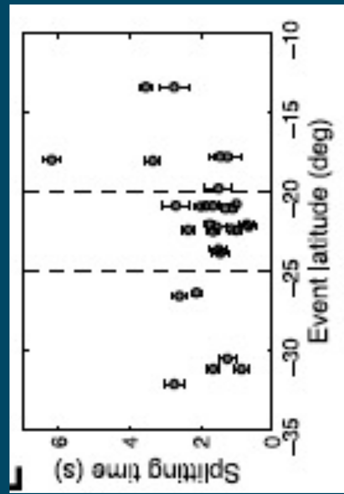
- Transition zone & lower mantle:

  - More debated
  - Stagnating slabs
  - Laterally spreading plumes
  - Water reservoir ?
  - Boundary layer ?

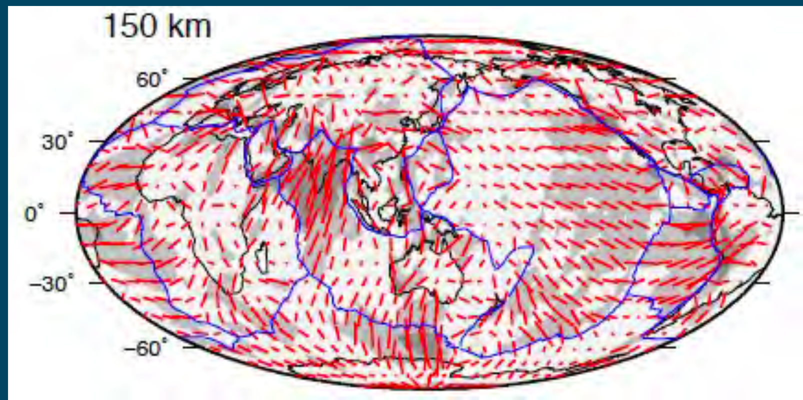
Seismic anisotropy: how do we map it?

- Shear wave splitting
- Radial and azimuthal anisotropy tomography
- Polarities of body wave reflections





Wookey & Kendall, JGR, 2004



Debayle et al., GRL, 2016

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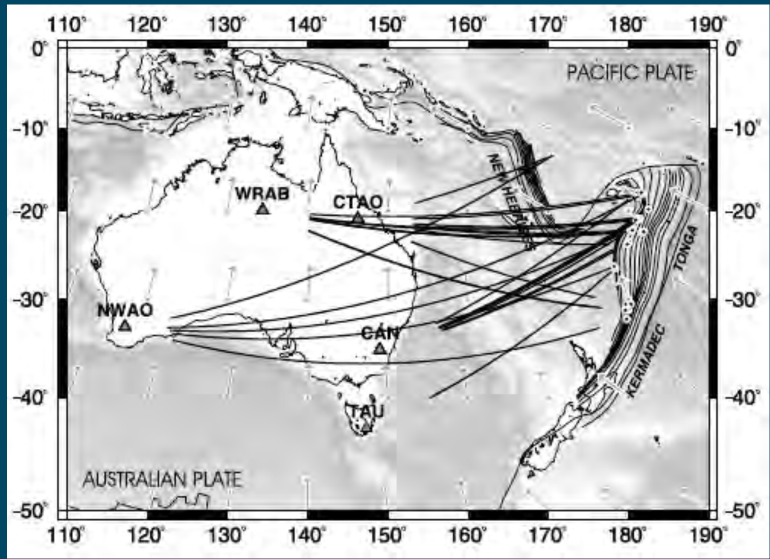

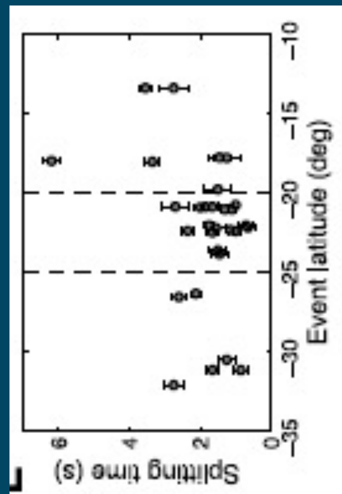

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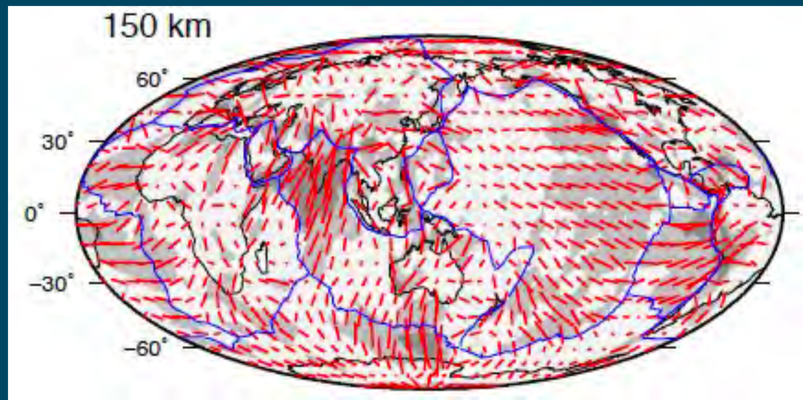

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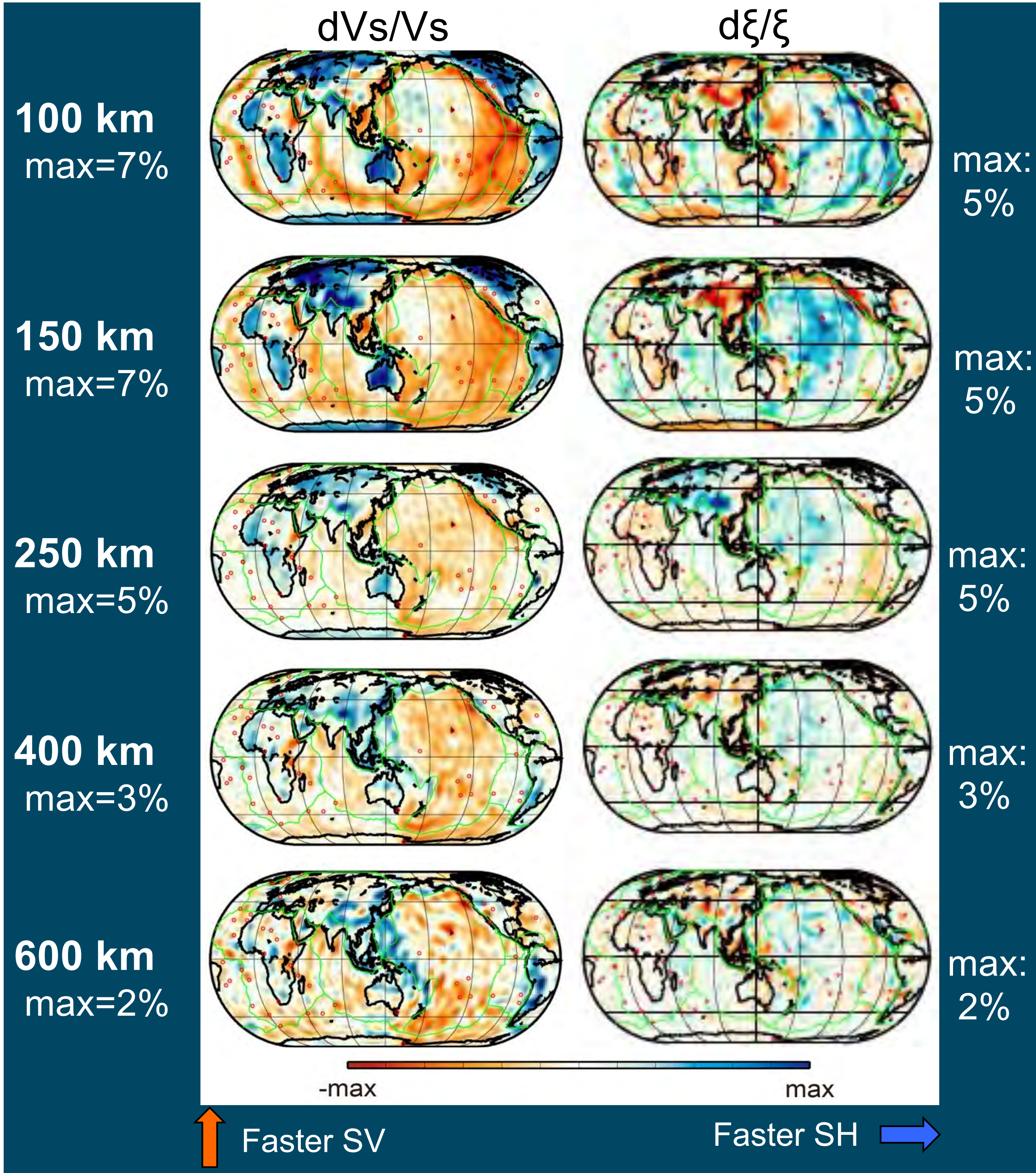
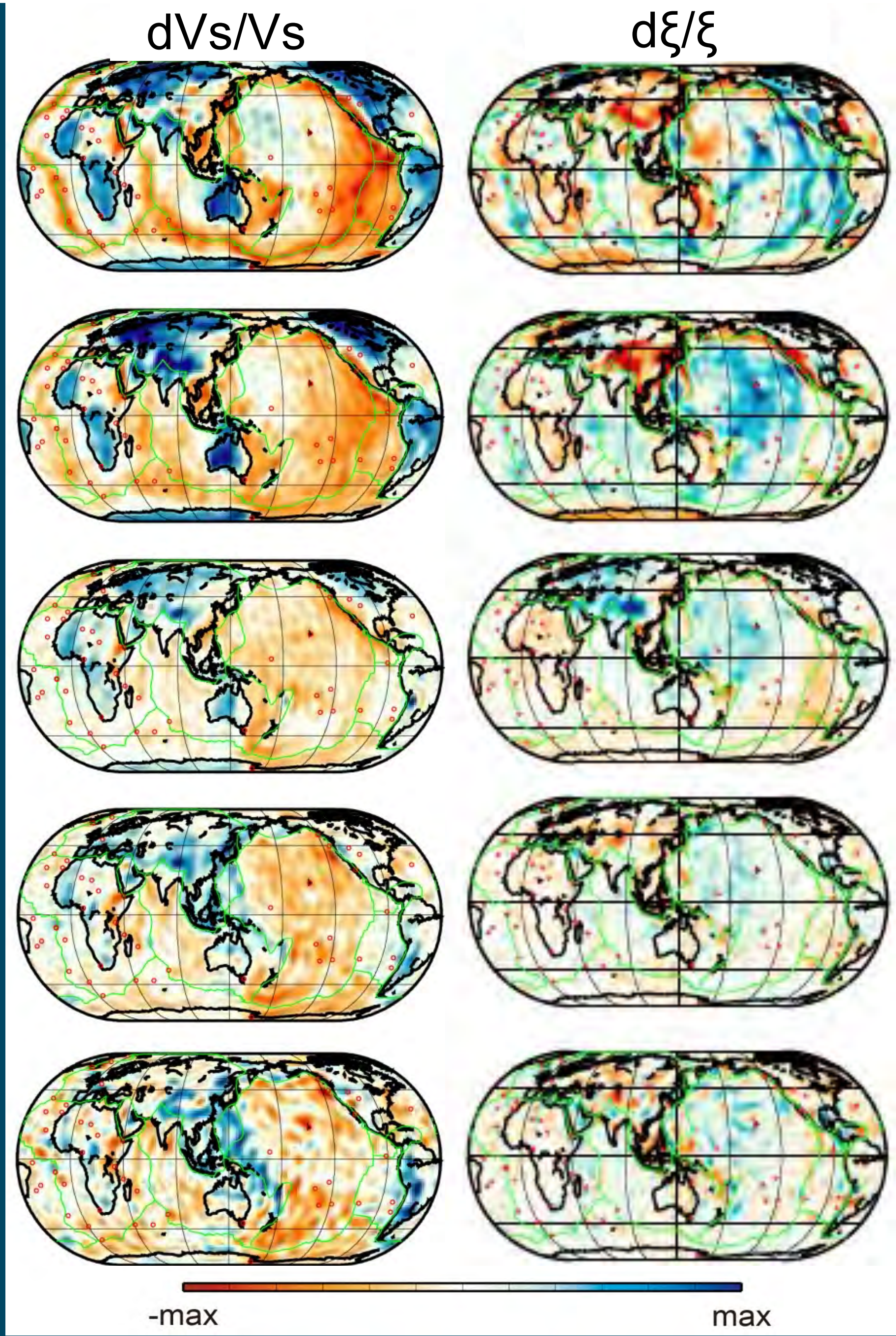
SGLOBE-rani

a global whole-mantle radially anisotropic model



Chang, Ferreira et al., JGR, 2015



100 km max=7% | max: 5%

150 km max=7% | max: 5%

250 km max=5% | max: 5%

400 km max=3% | max: 3%

600 km max=2% | max: 2%

Faster SV   Faster SH

Chang, Ferreira et al., JGR, 2015

SGLOBE-rani

a global whole-mantle radially anisotropic model

- Huge set of surface wave and body wave data (>55M)
- Sensitivity from crust to lowermost mantle
- Joint inversions for crustal and mantle structure

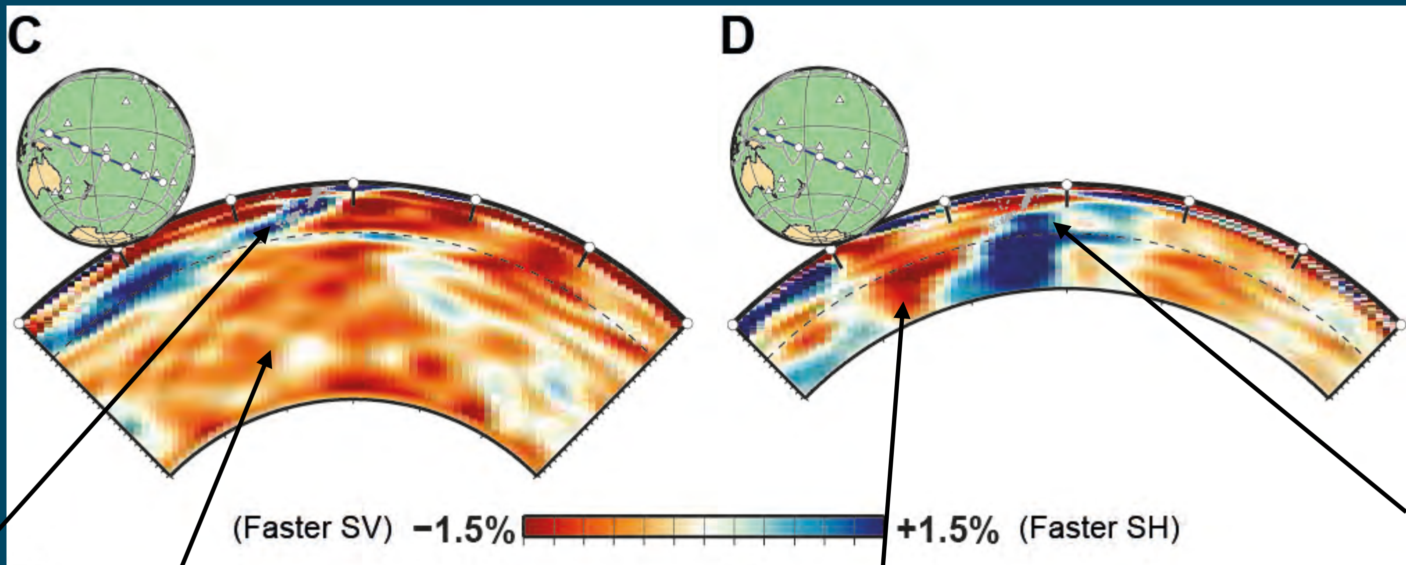
Plume-slab interactions

Red: Slow
Blue: Fast

Isotropy **Anisotropy**

Red: ↑
Faster vert.-

Blue: ➡
Faster horiz.-



Tonga slab stagnates in the upper mantle

Anisotropy anomaly behind slab following the upwelling

Large scale upwelling (Samoan plume) from the bottom of the mantle

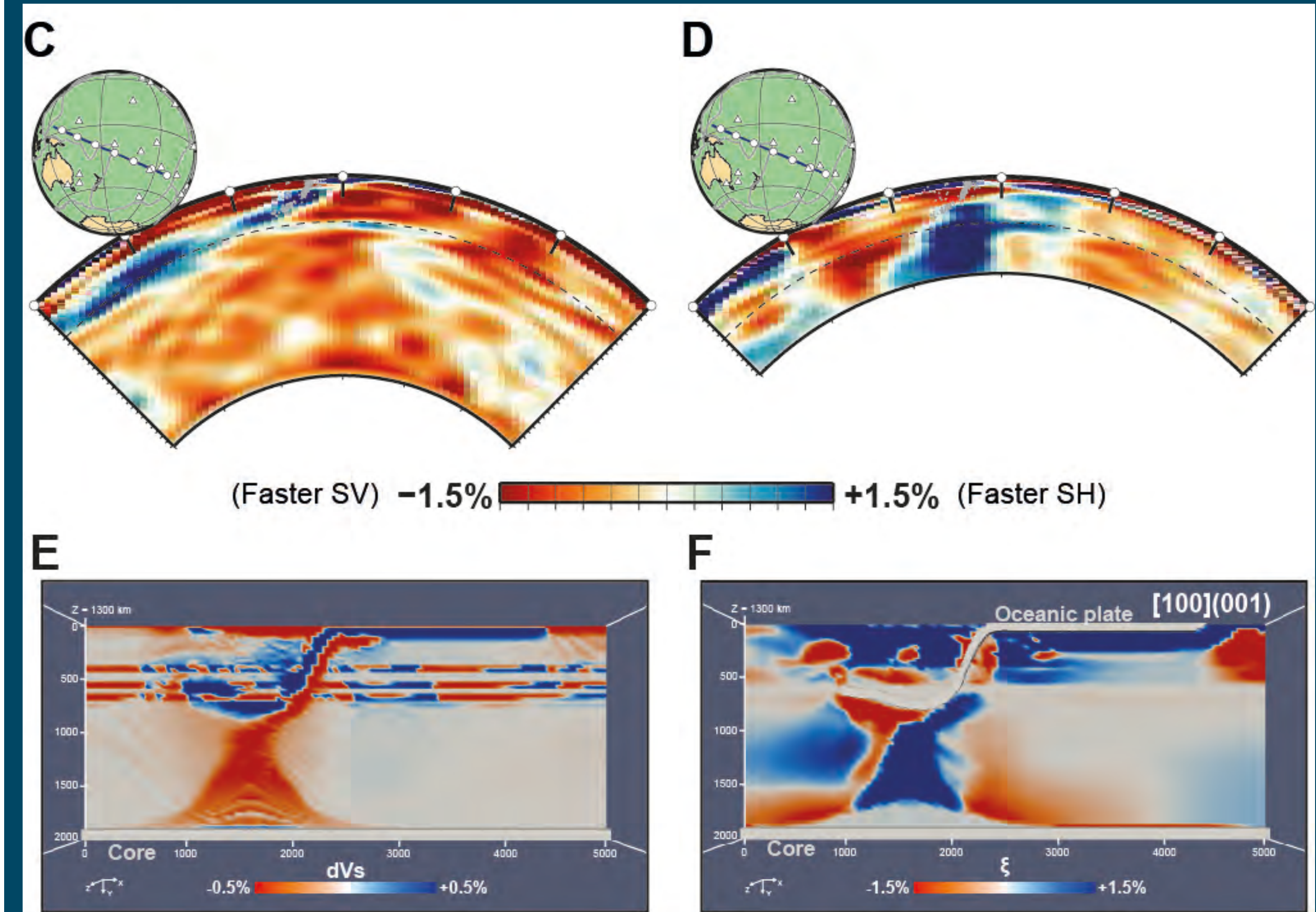
Anisotropy anomalies associated with slabs

Deep plume-slab collision !

Chang, Ferreira & Faccenda, Nature Comms., 2016

Plume-slab interactions

Isotropy   Anisotropy



Seismo-geodynamics interpretation:

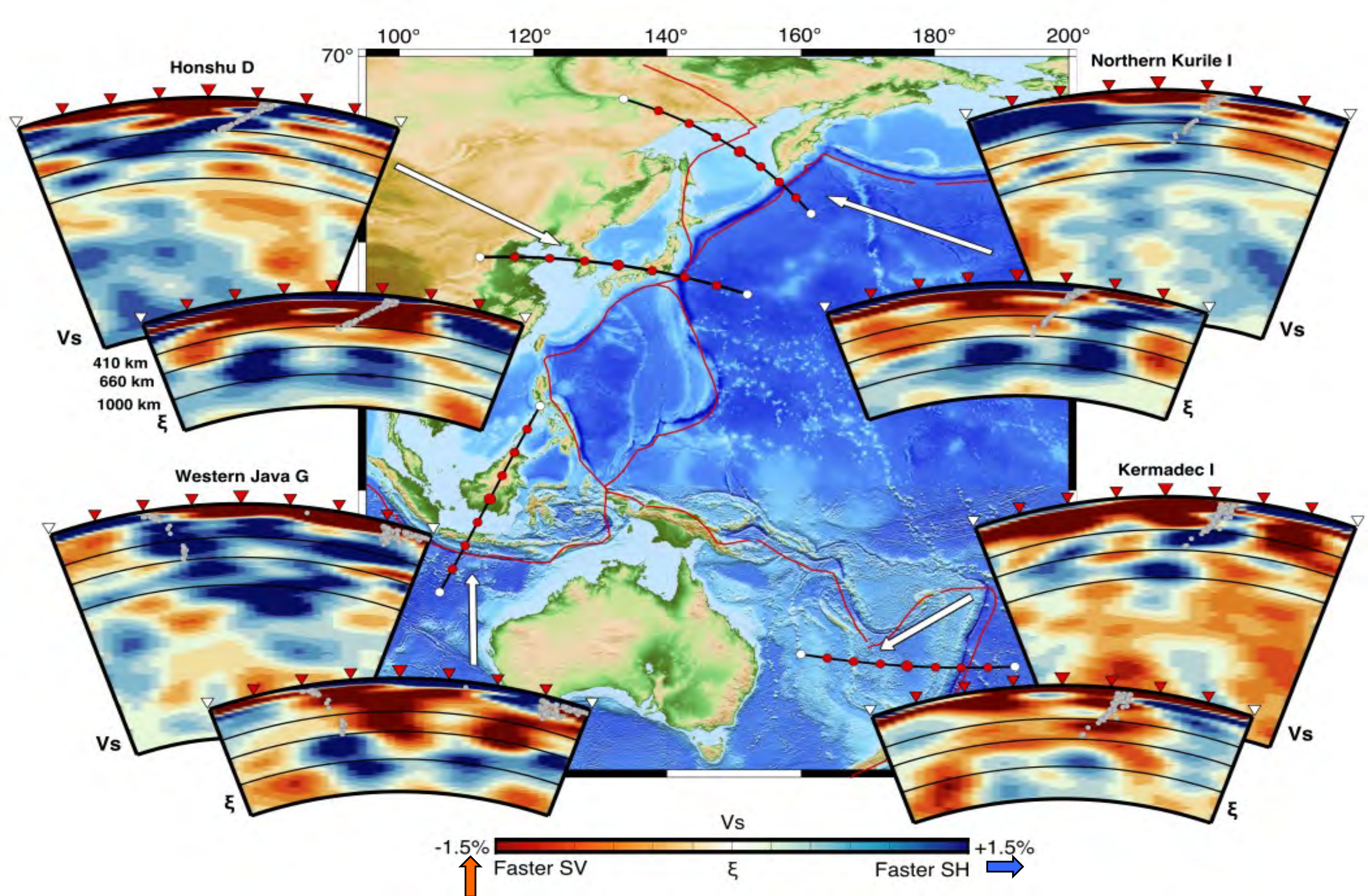
Slab-plume interaction beneath Tonga – **a deep collision ~700 km beneath our feet:**

- The upwelling plume favors stagnancy of the slab
- Coupled plume-fast slab retreat effect

Chang, Ferreira & Faccenda, Nature Comms., 2016

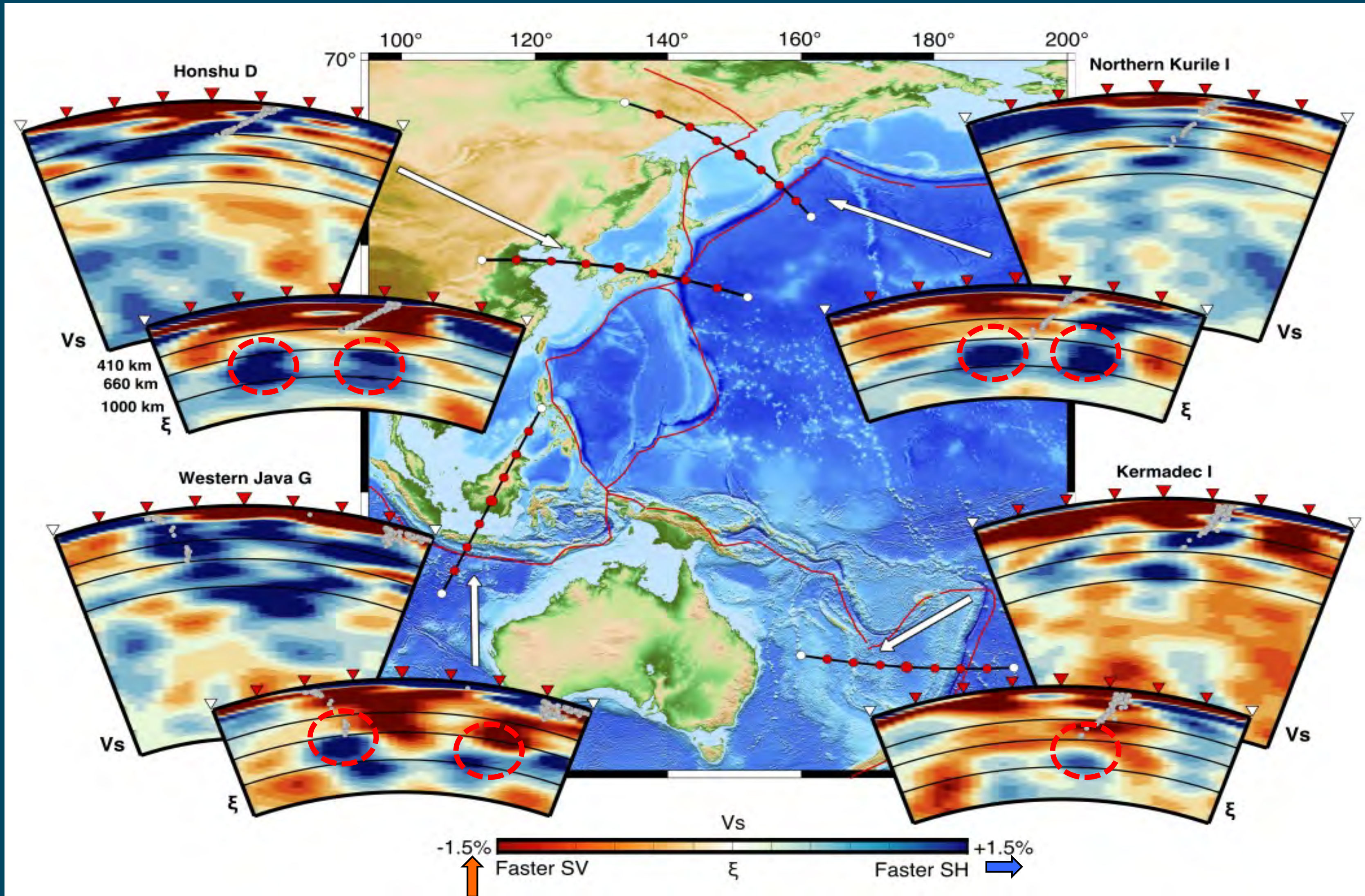
Upwelling is very dynamic !

Uppermost lower mantle anisotropy



Ubiquitous presence of anisotropy in top of lower mantle

Uppermost lower mantle anisotropy

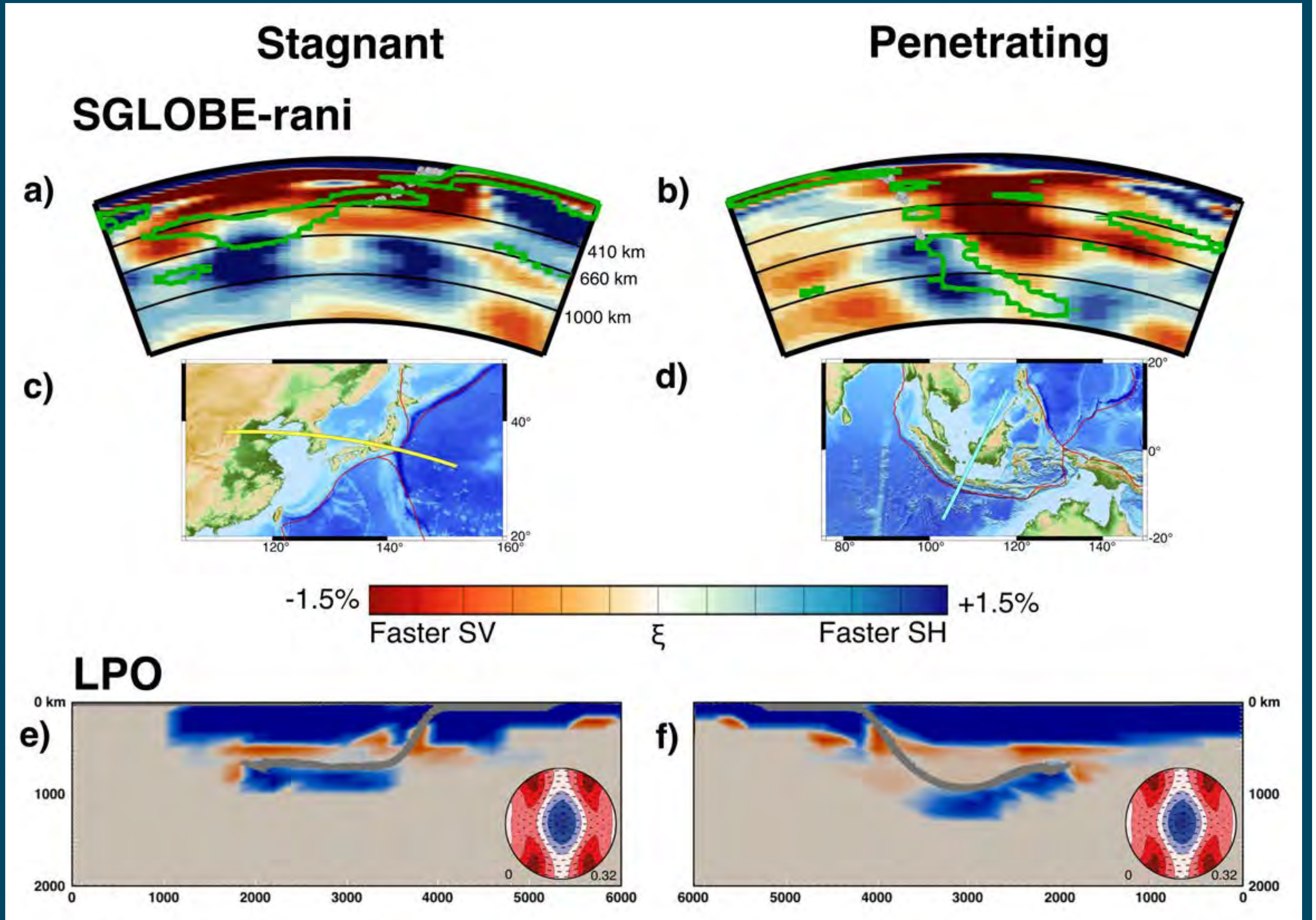


Ubiquitous presence of anisotropy in top of lower mantle

Uppermost lower mantle anisotropy

Four possible bridgmanite slip systems:

[100](010)
[010](100)
<110> {-110}
[001](100)



The anomalies are consistent with dislocation creep in the lower mantle

Ferreira et al., Nature Geo., 2019

Challenges

- Uncertainty and model appraisal quantification

- Quantitative seismo-geodynamics integration

- Data, data, data

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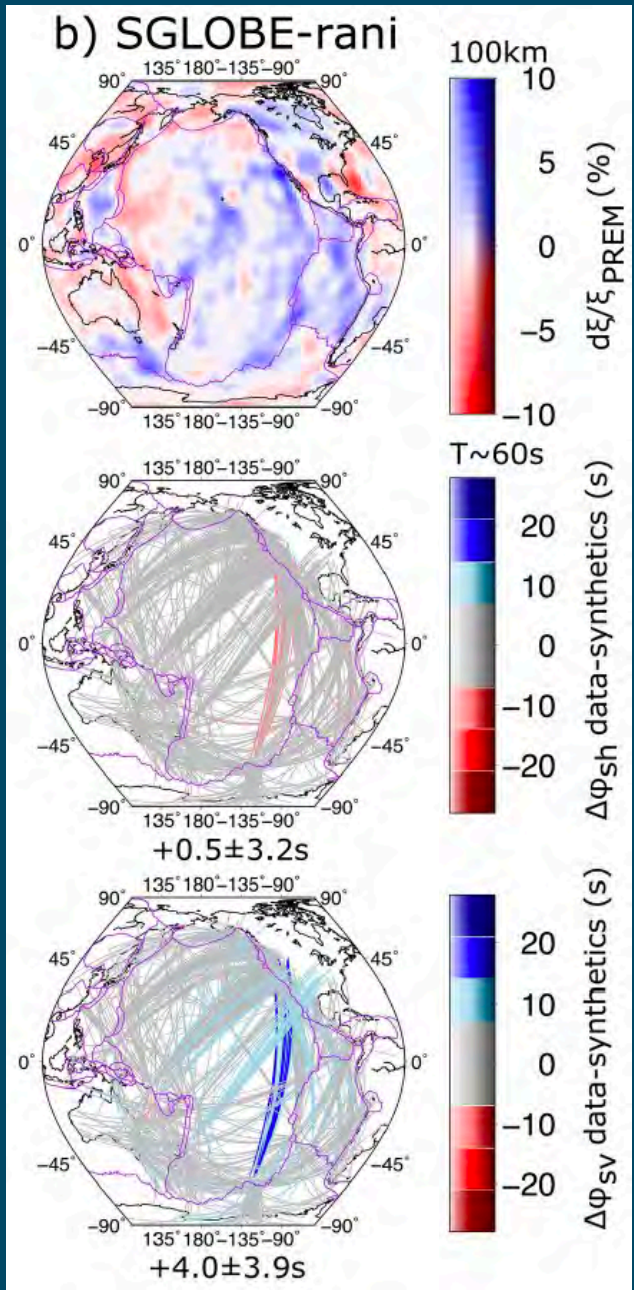
Quantitative model appraisal

Love

Rayleigh



Kendall, Ferreira et al., JGR, 2021

- Compiled an independent seismic dataset (2,307 waveforms from 36 quakes)
- Computed synthetic waveforms using the spectral element method for SGLOBE-rani
- Compared the synthetic waveforms with real data: compute phase misfits

Quantitative model appraisal

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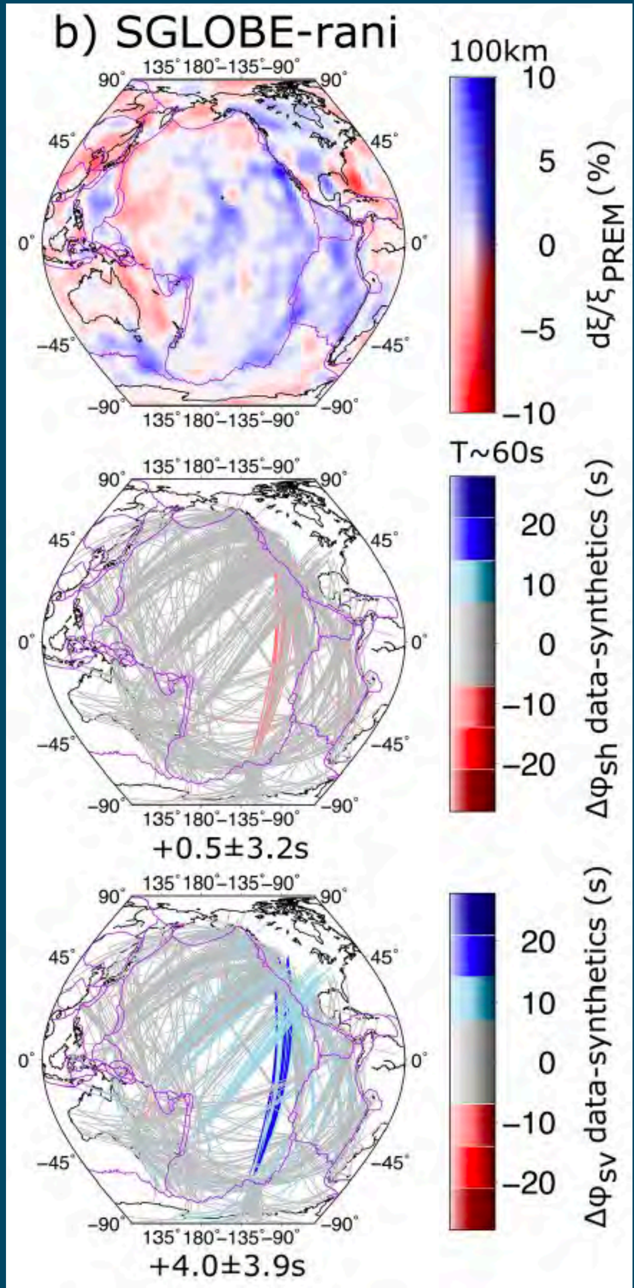

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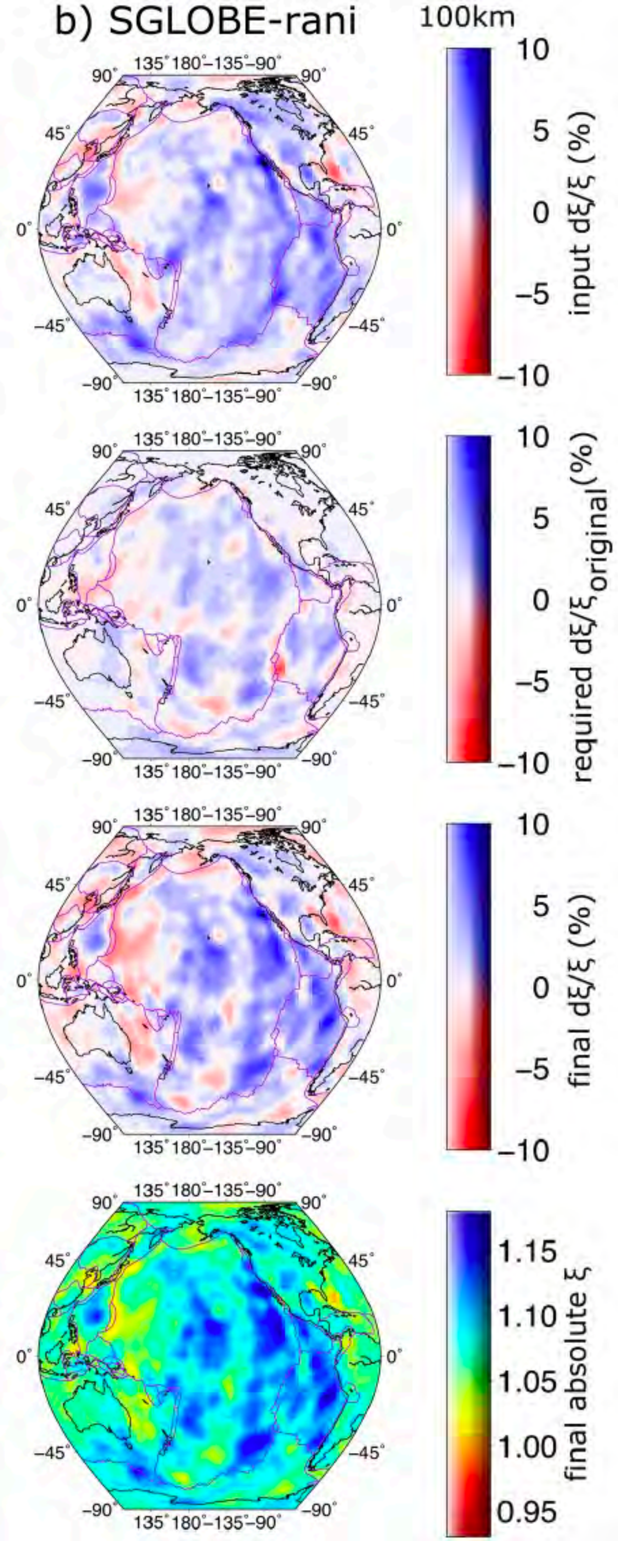
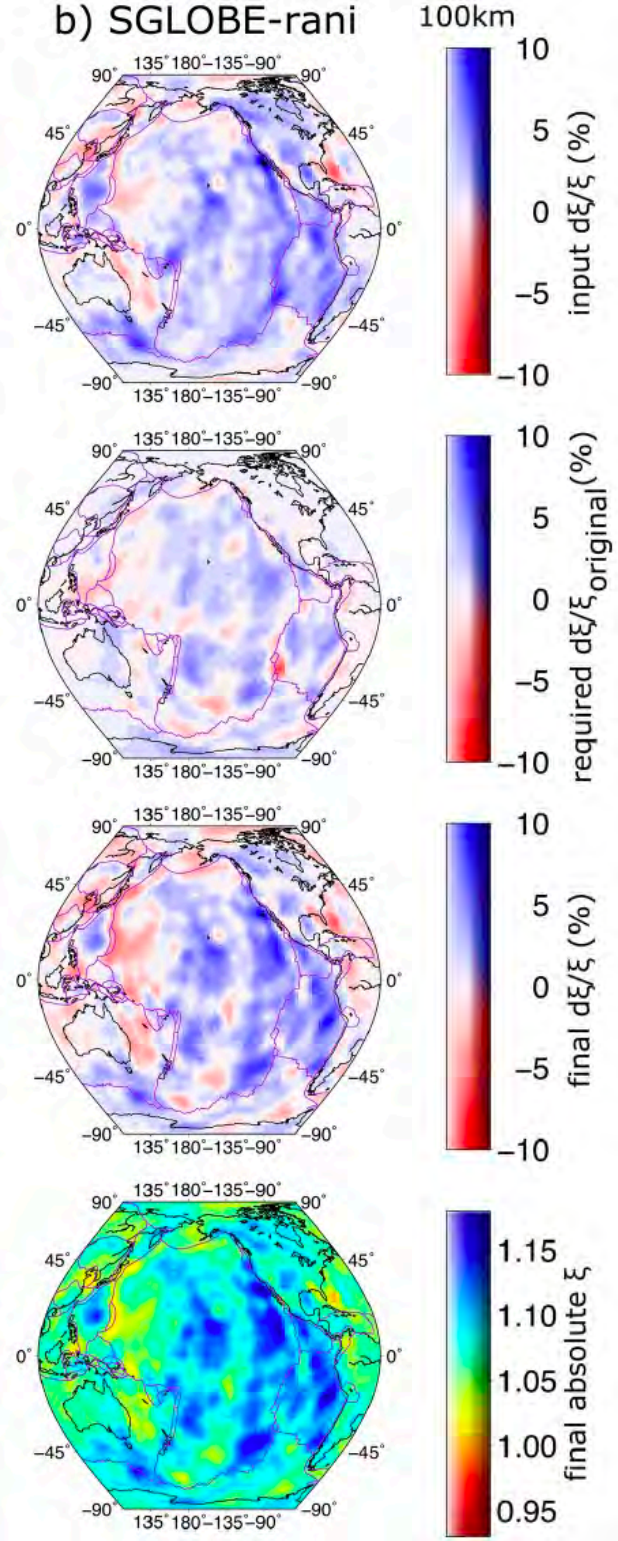
- Inverted the phase misfits for Vs and radial anisotropy using SGLOBE-rani as starting 3-D model



SPacific-rani

- The data require an asymmetry at the East Pacific rise, requiring stronger radial anisotropy to the W of the EPR than to the E



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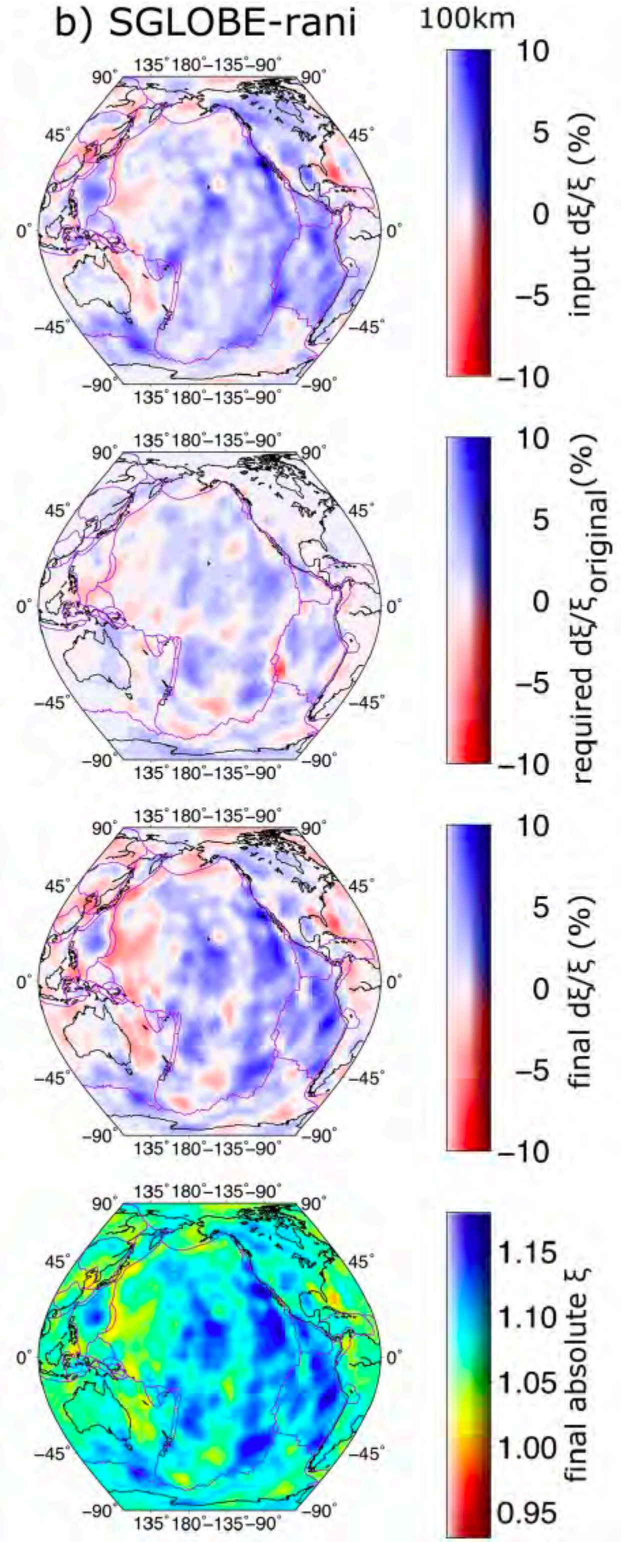
- This is possibly due to LPO produced by shear-driven asthenospheric flow beneath the S Pacific Superswell



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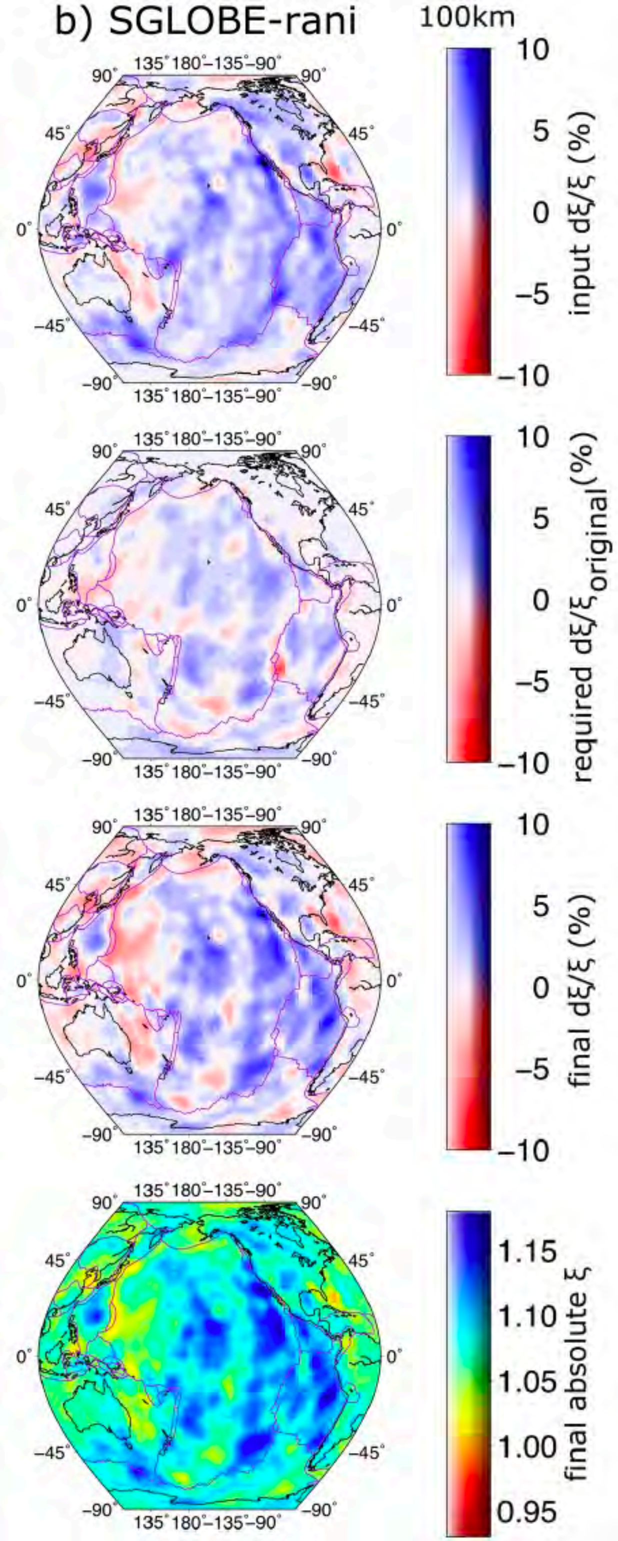

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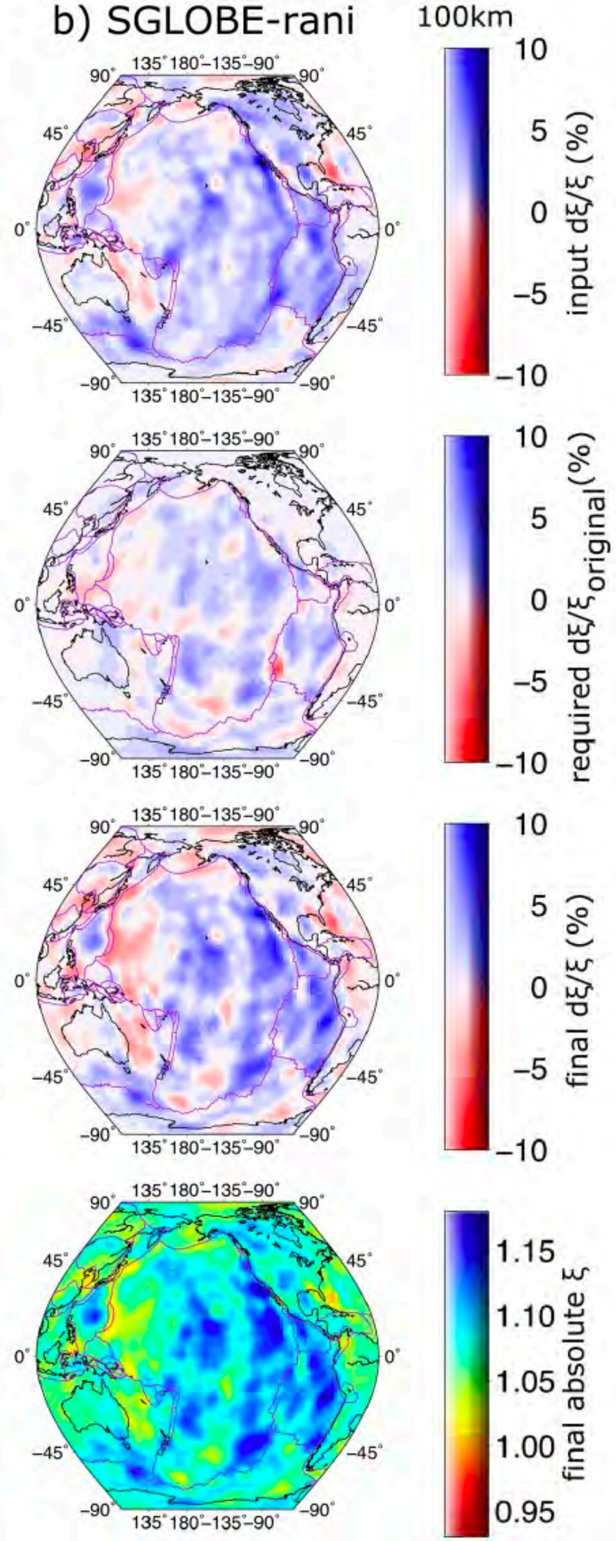

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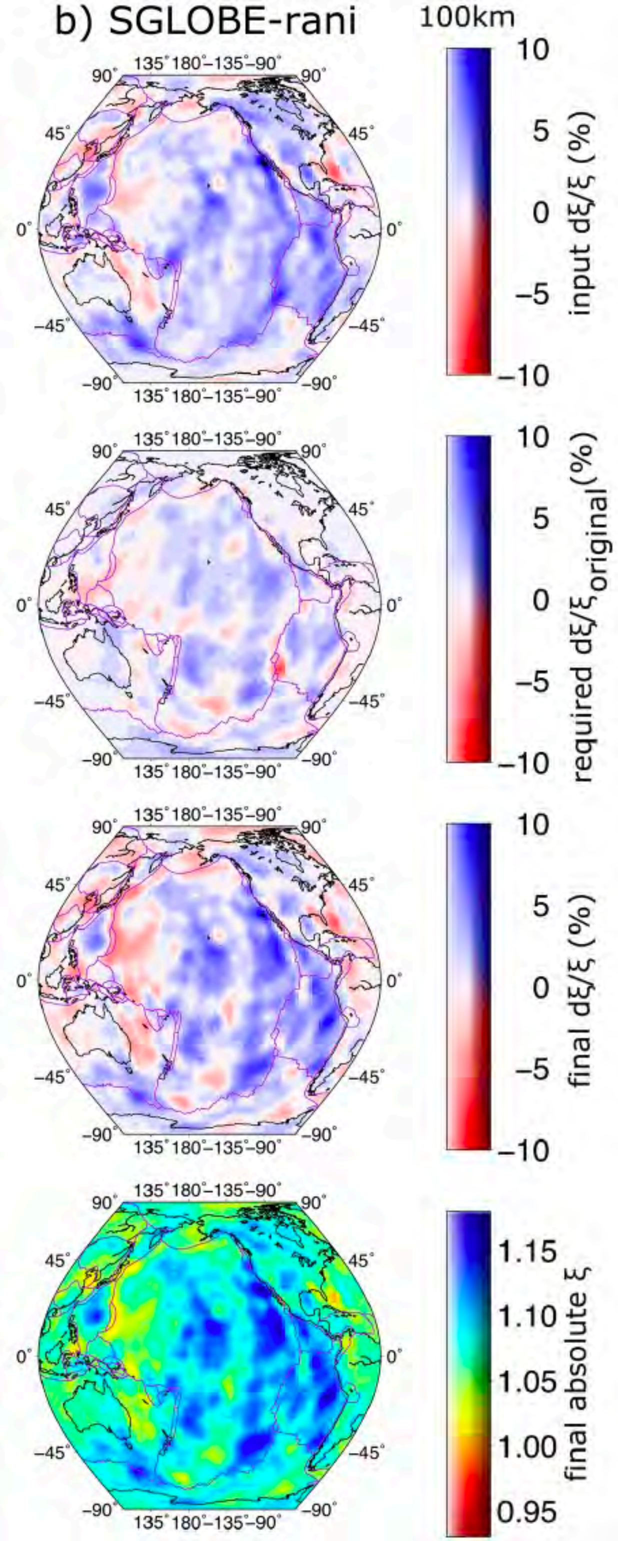
Quantitative model appraisal and data assimilation approach



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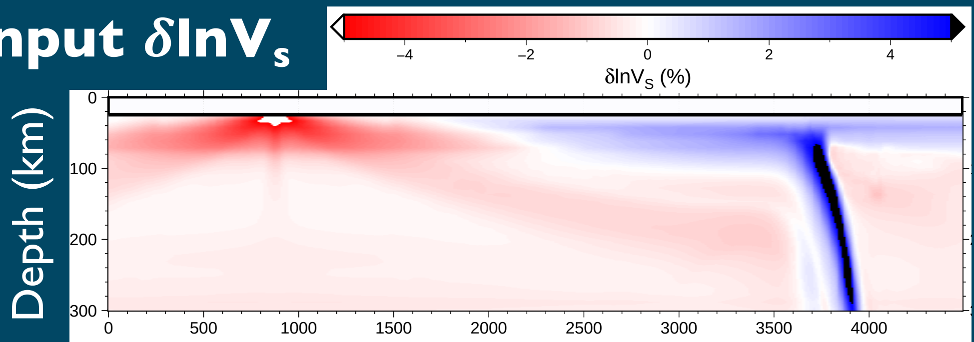
Check out Auggie Marignier's poster:
Proximal MCMC – towards a sparse Earth model

Challenges

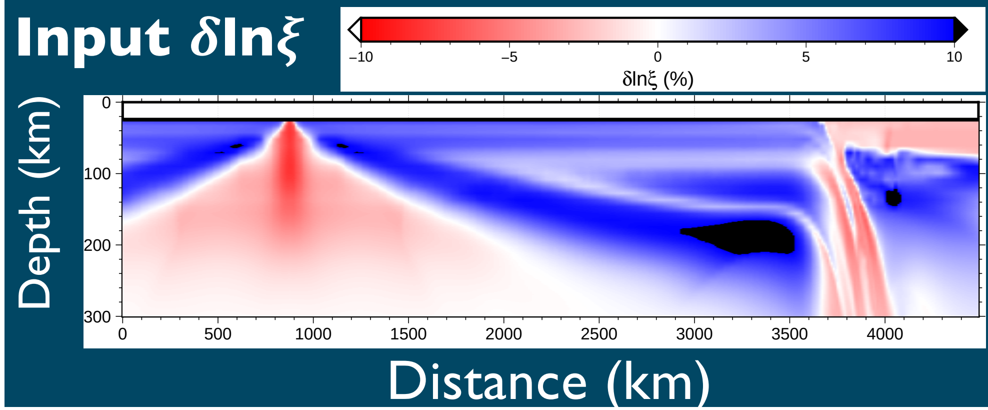
- Uncertainty and model appraisal quantification
- **Quantitative seismo-geodynamics integration**
- Data, data, data

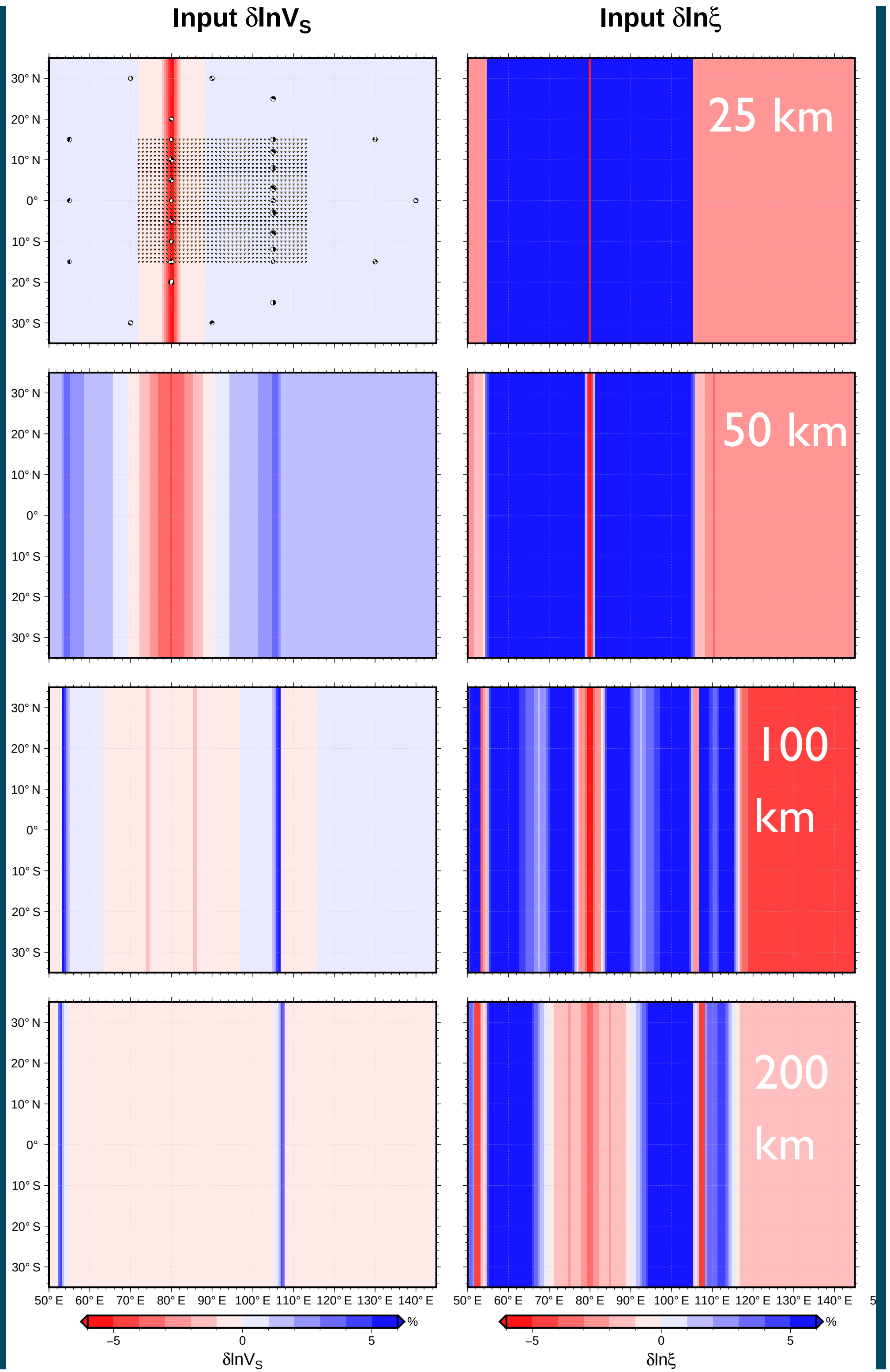
Input model:
2-D ridge to slab geodynamical model + fabrics calculations
(21 elastic constants)

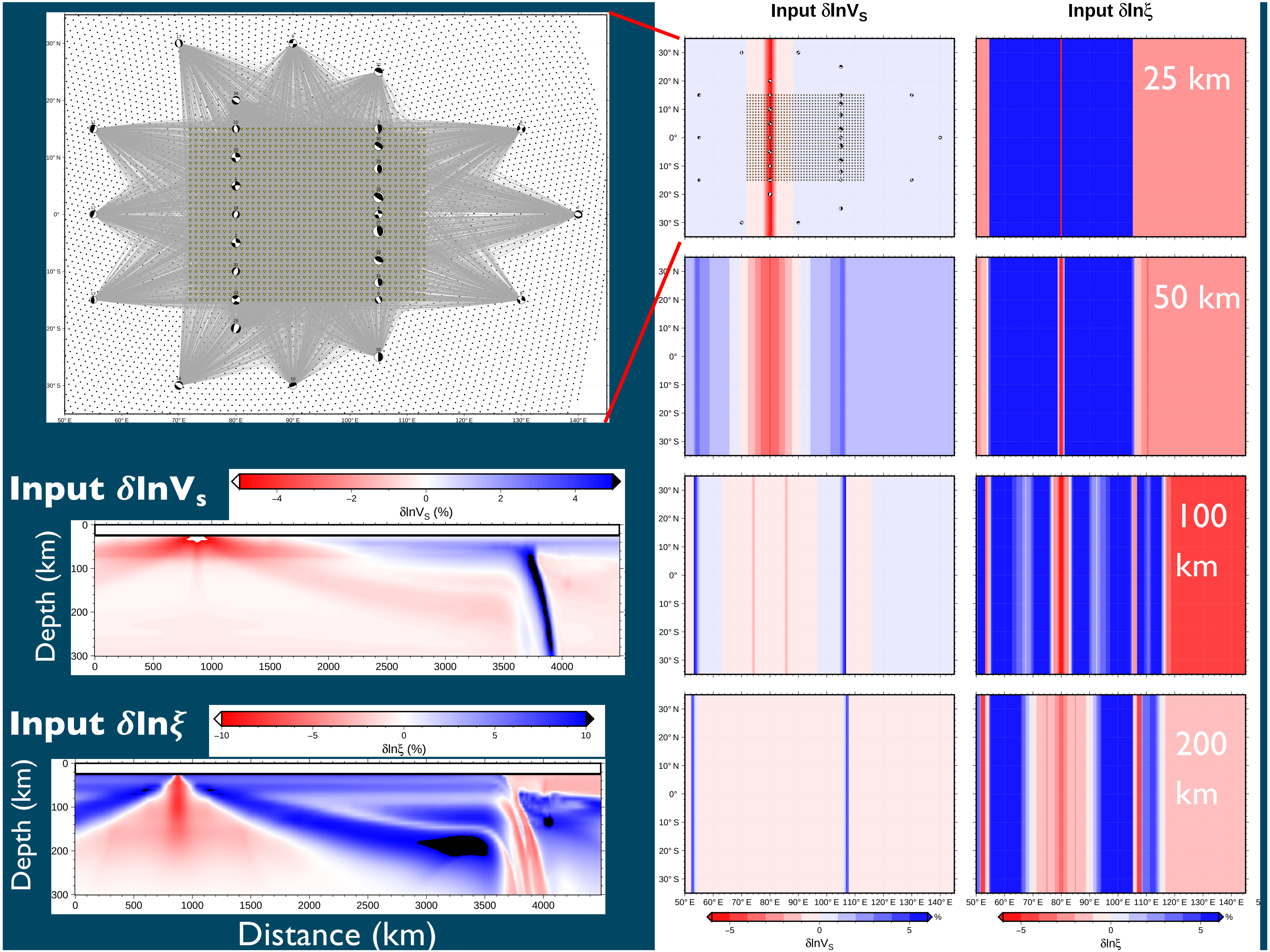
Input $\delta \ln V_s$



Input $\delta \ln \xi$



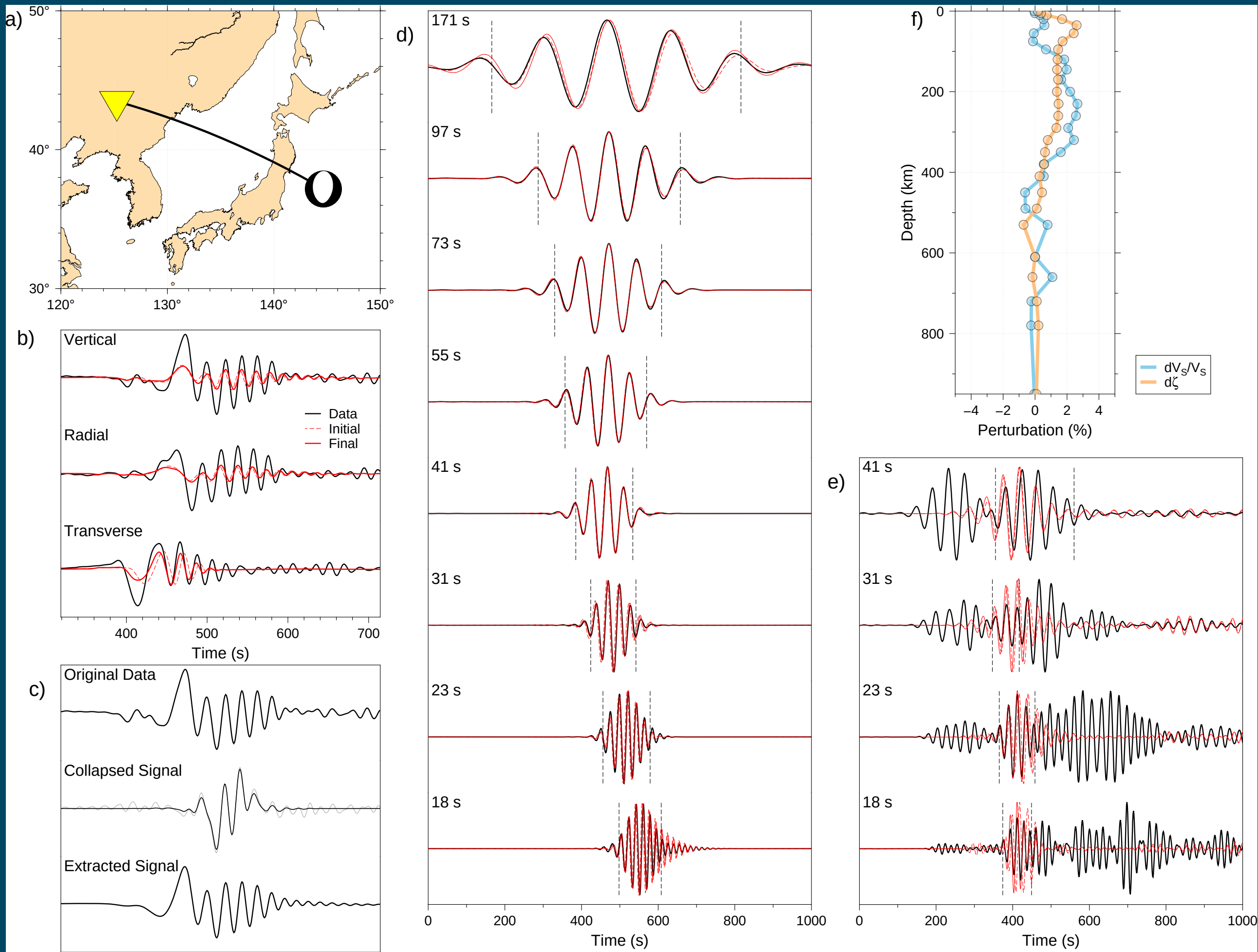




Input δlnV_S
Input δlnξ
25 km
50 km
100 km
200 km
30° N
20° N
10° N
0°
10° S
20° S
30° S
50° E
60° E
70° E
80° E
90° E
100° E
110° E
120° E
130° E
140° E
δlnV_S
δlnξ
%
Input δlnV_s
δlnV_S (%)
Depth (km)
Input δlnξ
δlnξ (%)
Distance (km)

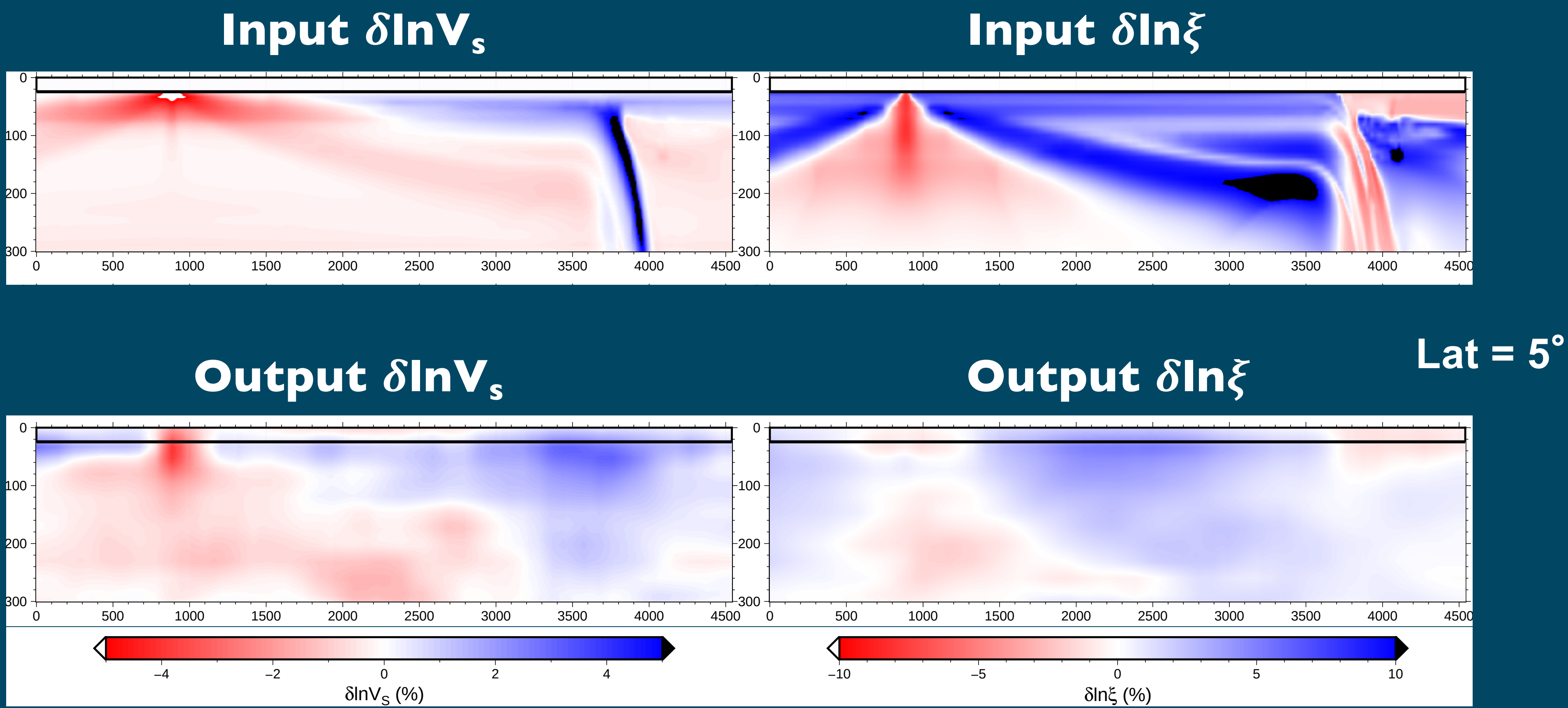
Approach

- Compute synthetic seismograms using the spectral element method (10,000 paths; T>24 s)
- Use the surface waveform partitioned inversion method to invert the synthetics for isotropic and radially anisotropic structure
- Joint inversions for crustal and mantle structure



Witek et al., GJI, 2021 (in review)

Inversion results – very preliminary!



- Substantial smearing of anomalies, notably of slab's high Vs anomalies
- First-order anisotropy features are all resolved, but no details
- Small-scale structure is poorly resolved

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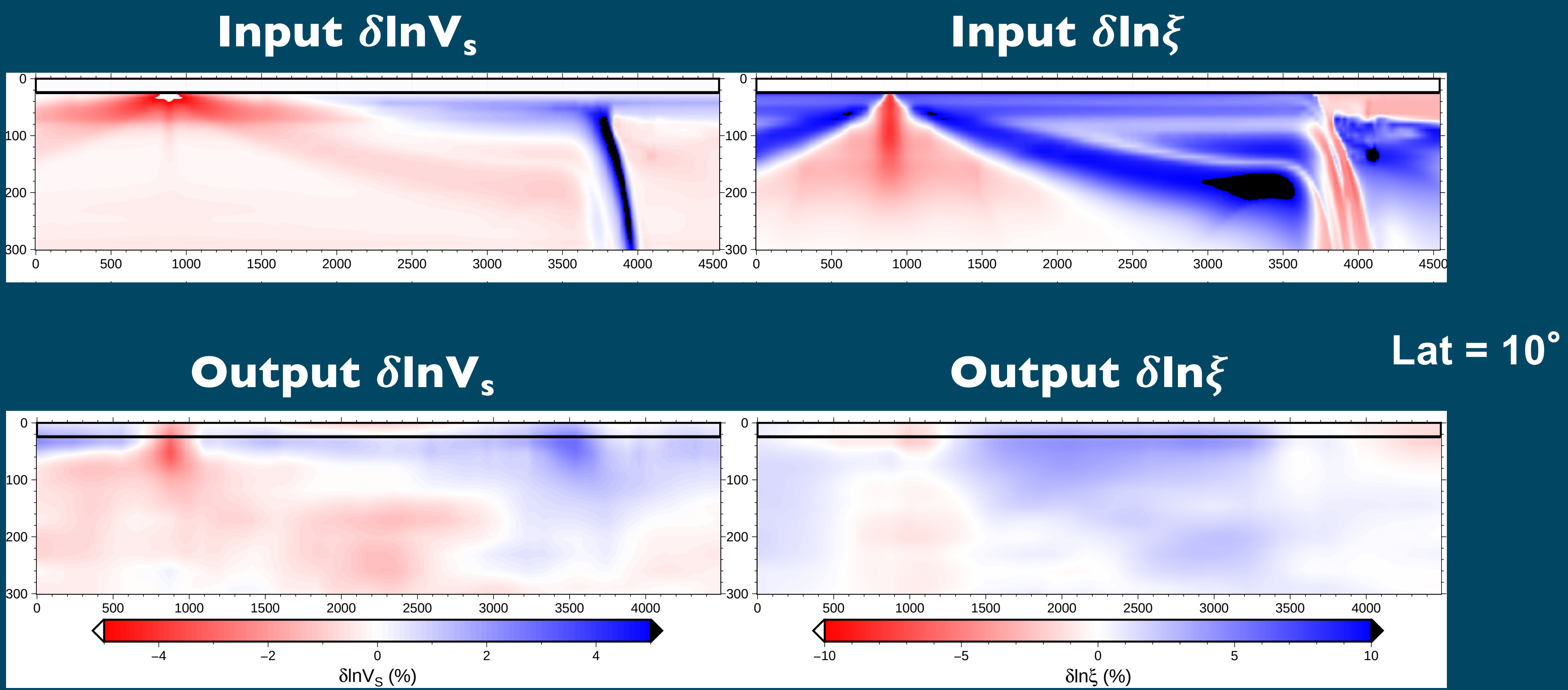

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Check out Federica Restelli's poster:
Normal mode observability of seismic anisotropy

Data, data, data

UPFLOW: Upward mantle flow from novel seismic observables

Data, data, data

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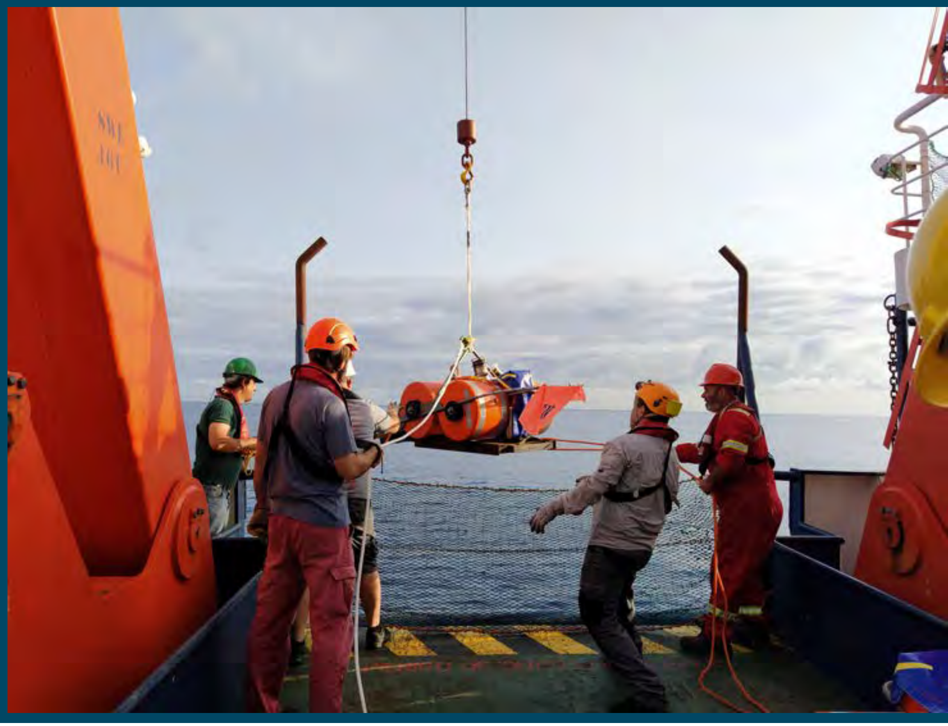
Large-scale ocean bottom seismometer expedition (mid-Atlantic)



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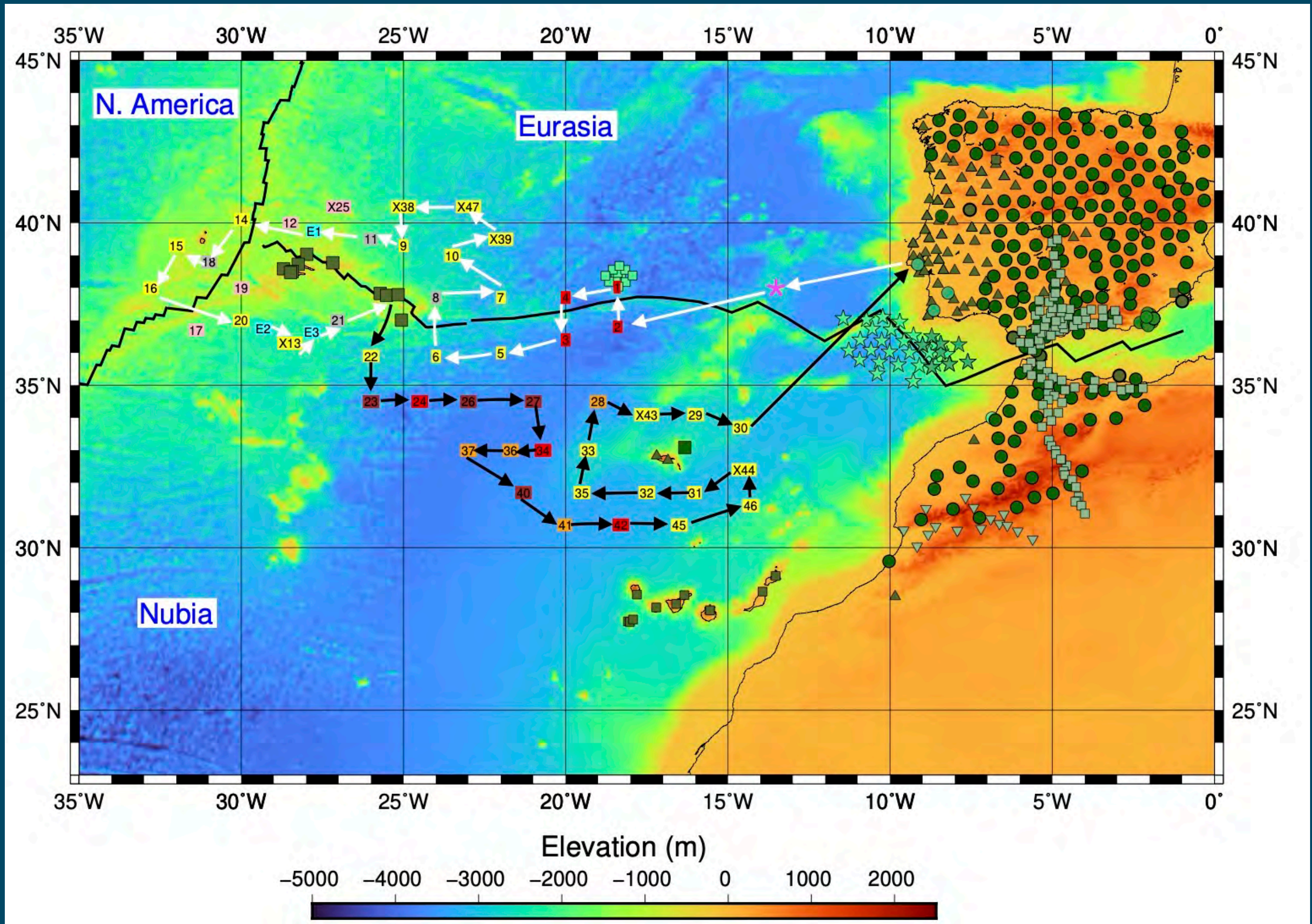

- 50 OBSs
- ~4 weeks at sea
- 5300.6 nautical miles (~9800 km)
- 15 scientists
- 17 ship crew
- 1 yr of recordings

https://upflow-eu.github.io/

Twitter, instagram: @upfloweu

Conclusions

✦ SGLOBE-rani, a global radially anisotropic model:

- Signature of a deep plume-slab interaction between the Samoa plume and the Tonga slab.

- Fast SH anomalies in the ~660 km – 1200 km depth region beneath subduction zones consistent with a lower mantle deformation mechanism dominated by dislocation creep.

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- New data set on the way from the mid-Atlantic!


Thank you for your attention!