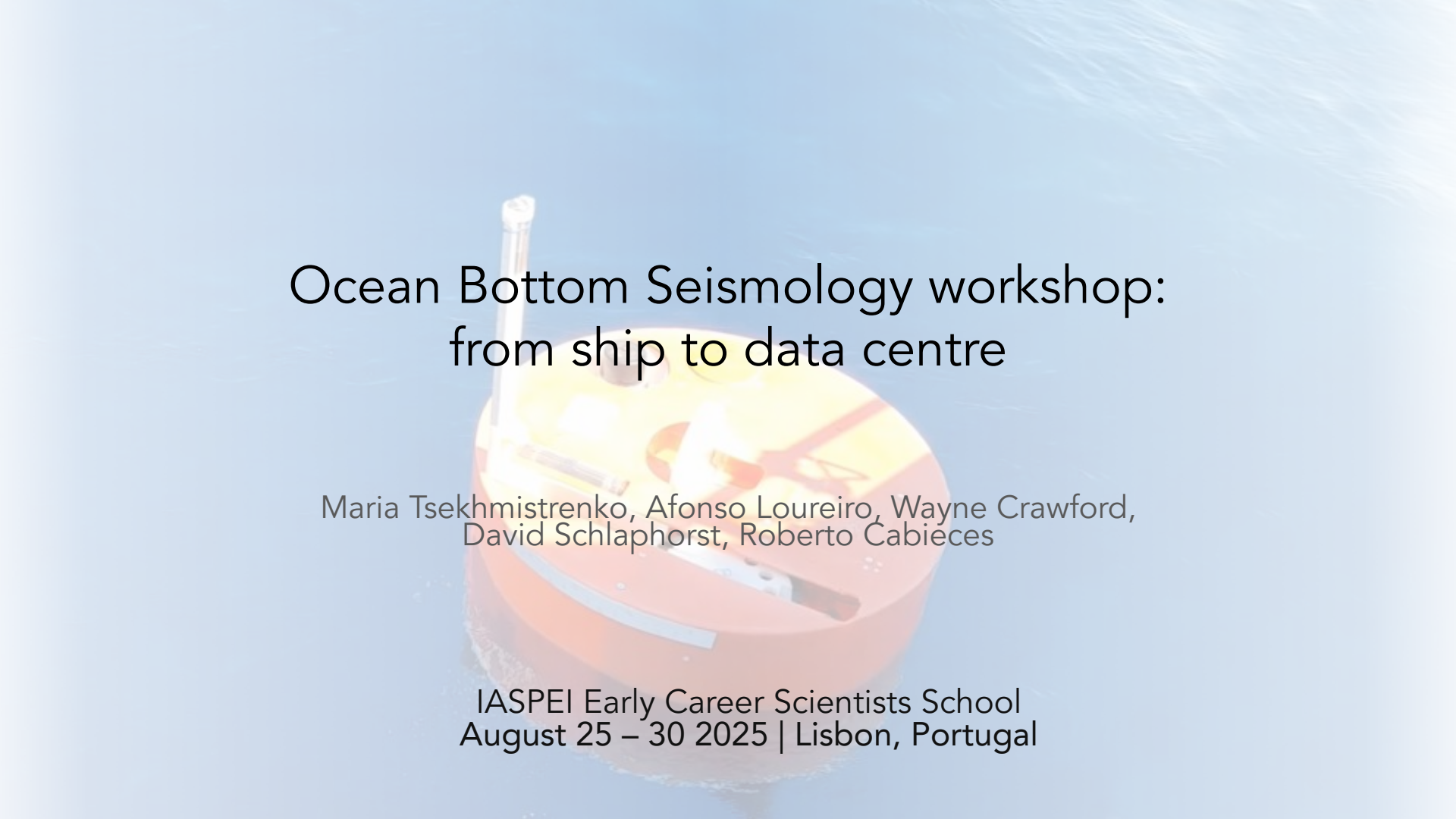
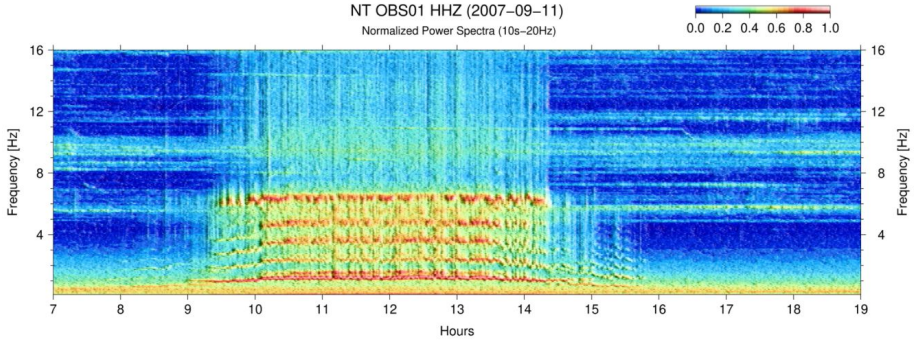


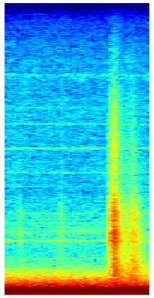
Ocean Bottom Seismology workshop: from ship to data centre

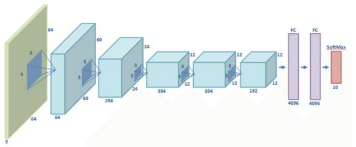
Maria Tsekhmistrenko, Afonso Loureiro, Wayne Crawford, David Schlaphorst, Roberto Cabieces

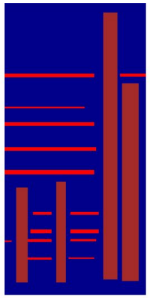
IASPEI Early Career Scientists School
August 25 – 30 2025 | Lisbon, Portugal

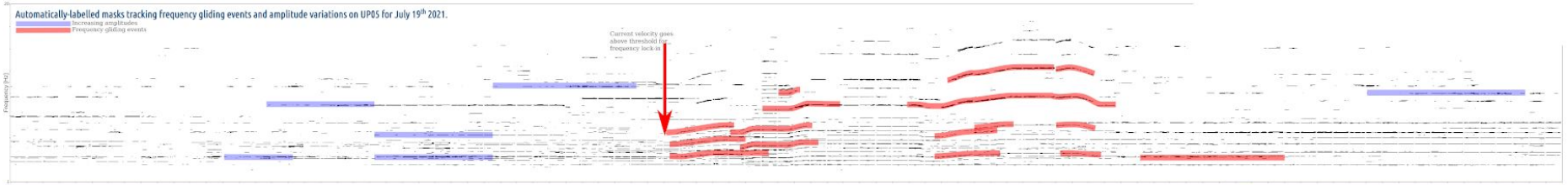
Reverberations

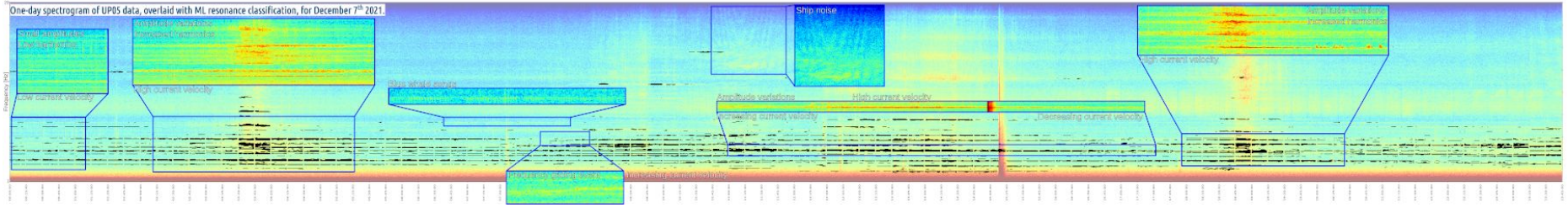

NT OBS01 HHZ (2007–09–11)
Normalized Power Spectra (10s–20Hz)
0.0 0.2 0.4 0.6 0.8 1.0
Frequency [Hz]
Hours

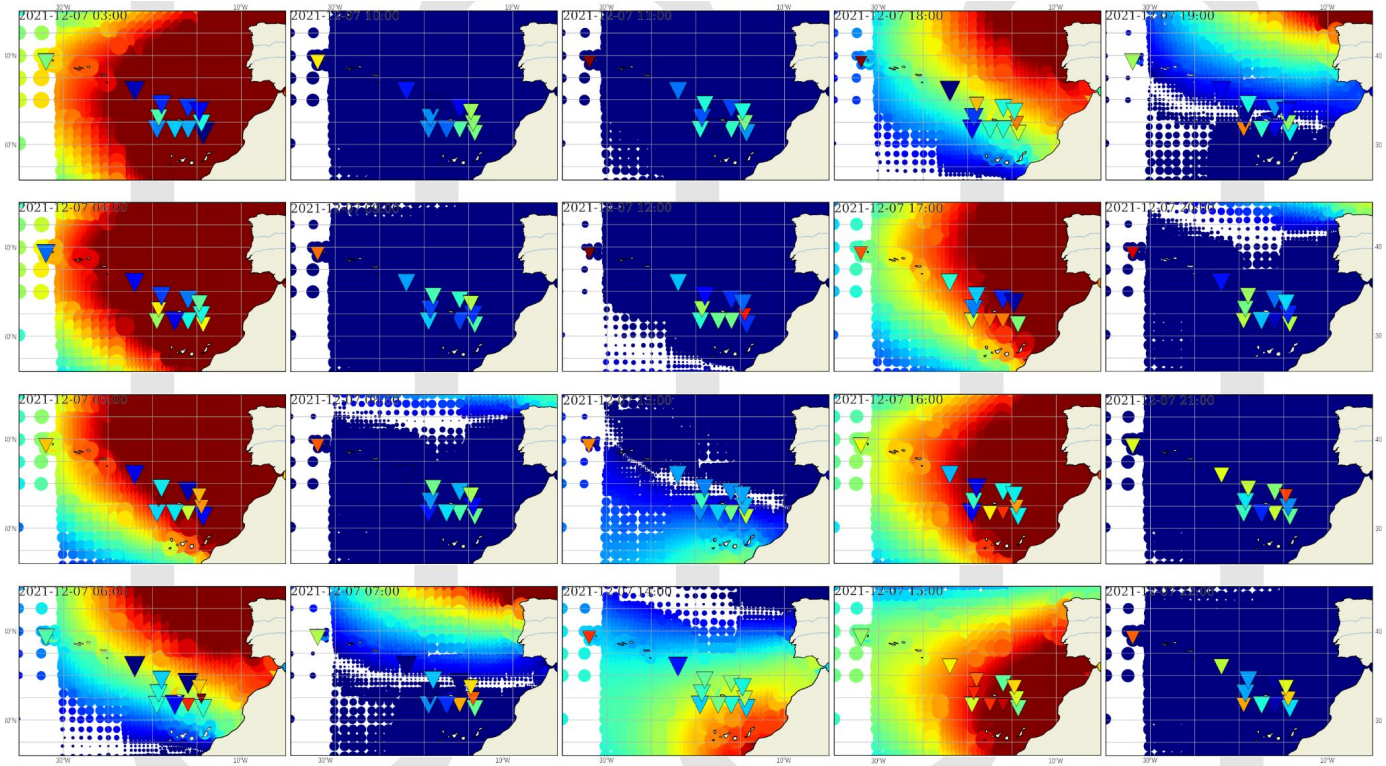



Earthquake
Resonance

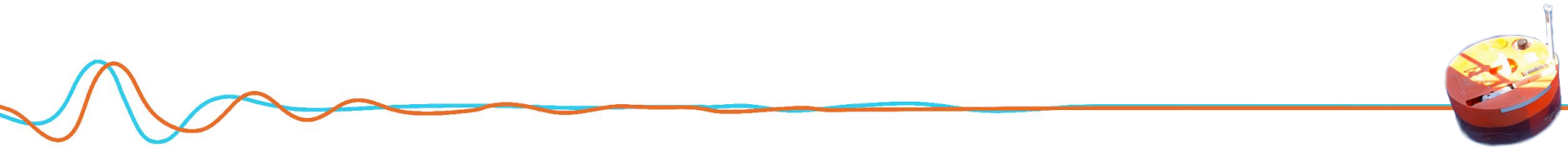



Automatically-labelled masks tracking frequency gliding events and amplitude variations on UP05 for July 19th 2021.
Increasing amplitudes
Frequency gliding events
Current velocity goes above threshold for frequency lock-in

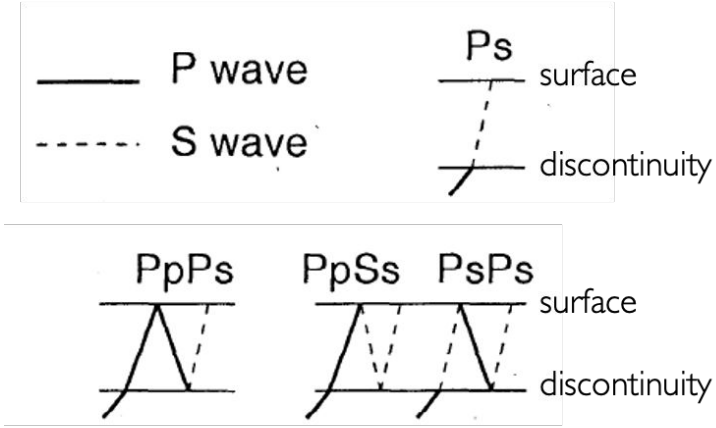

One-day spectrogram of UP05 data, overlaid with ML resonance classification, for December 7th 2021.
Ship noise
Amplitude variations
High current velocity
Increasing current velocity
Decreasing current velocity


2021-12-07 03:00
2021-12-07 18:00
2021-12-07 19:00
2021-12-07 17:00
2021-12-07 16:00
2021-12-07 07:00
2021-12-07 15:00

Receiver Functions & Shear Wave Splitting

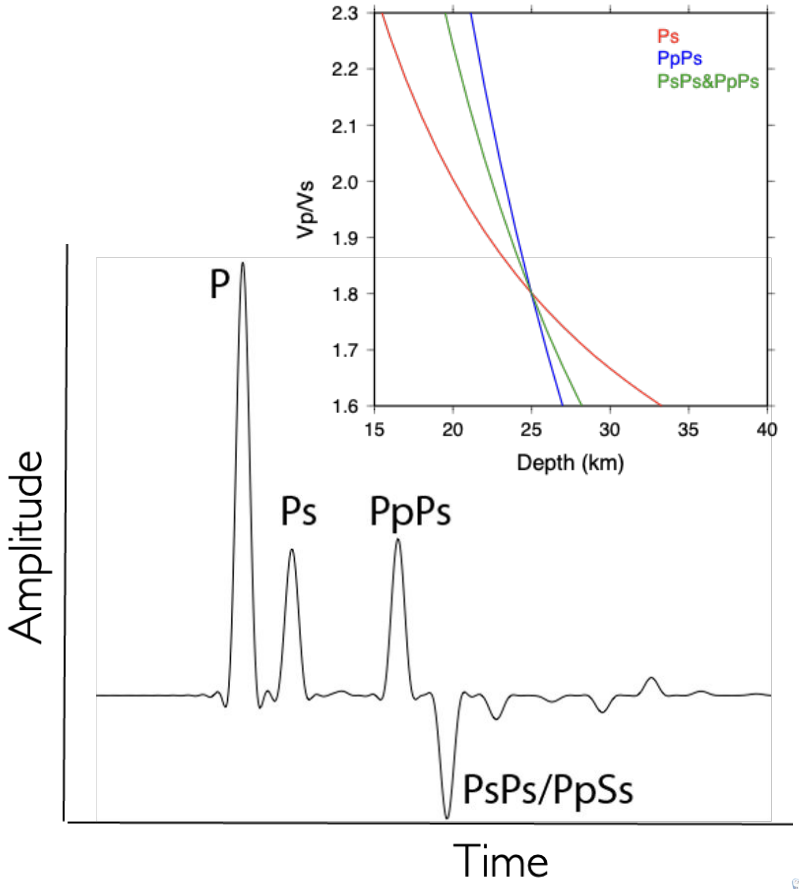


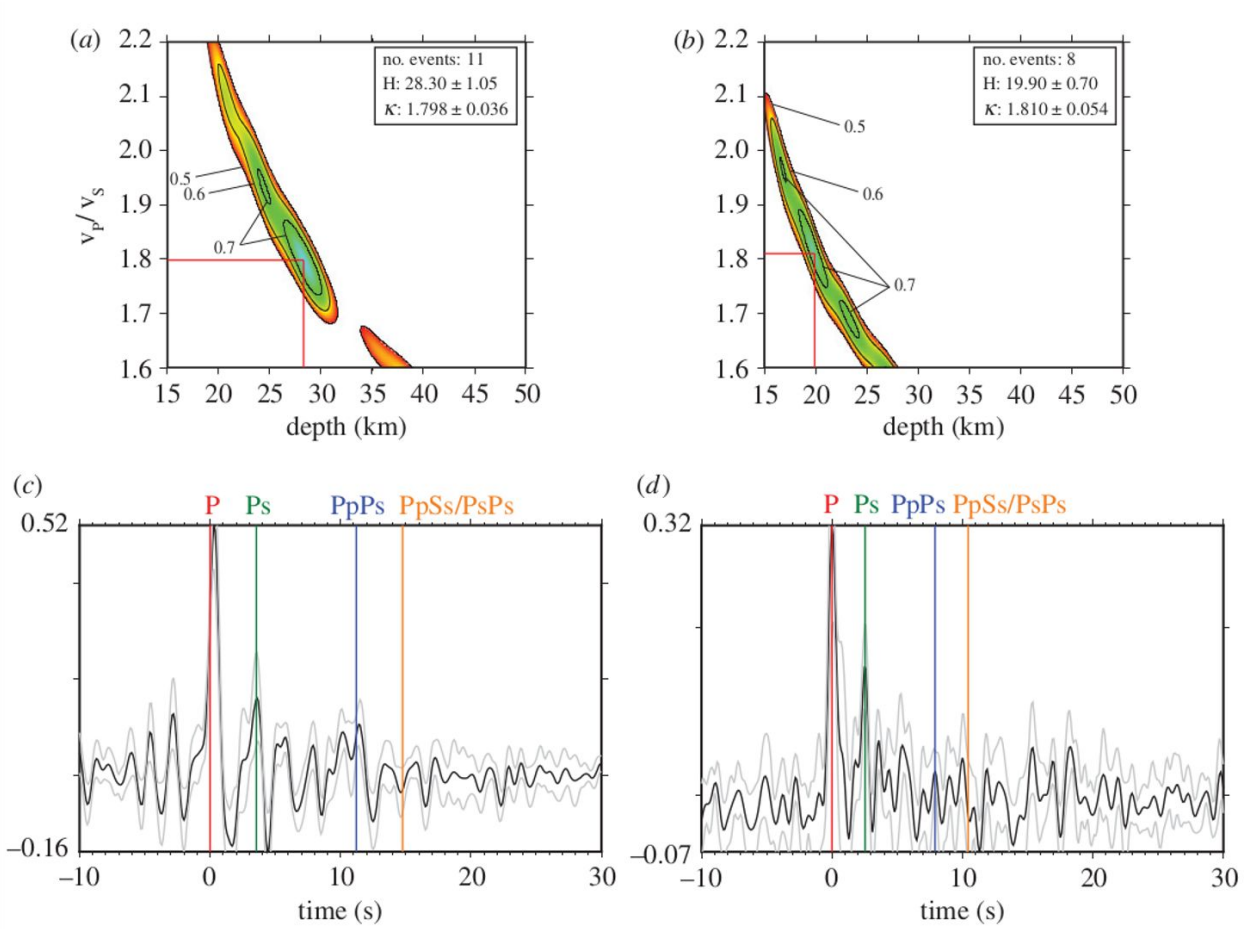
Receiver Functions



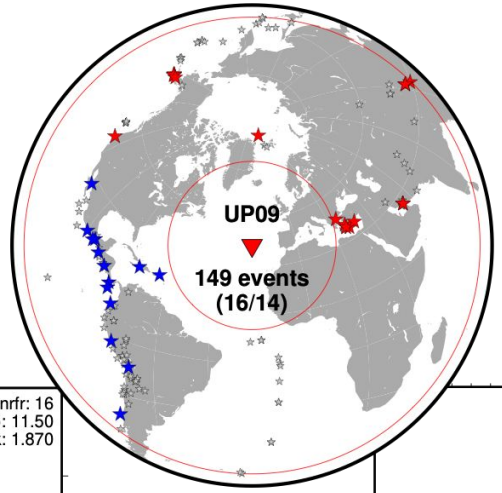
Zhu & Kanamori (2000)

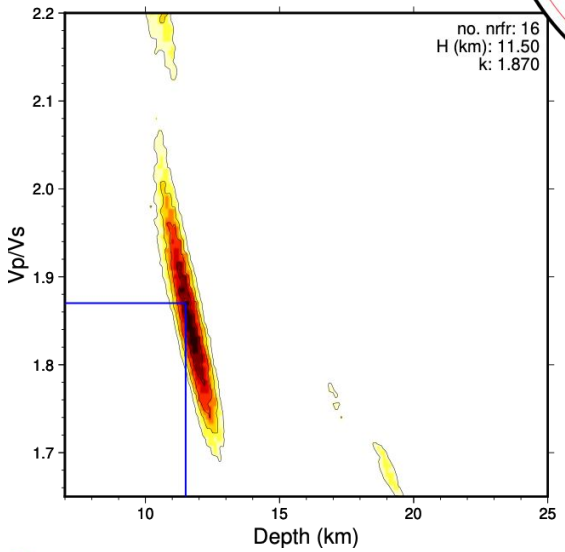
remove source time function with deconvolution

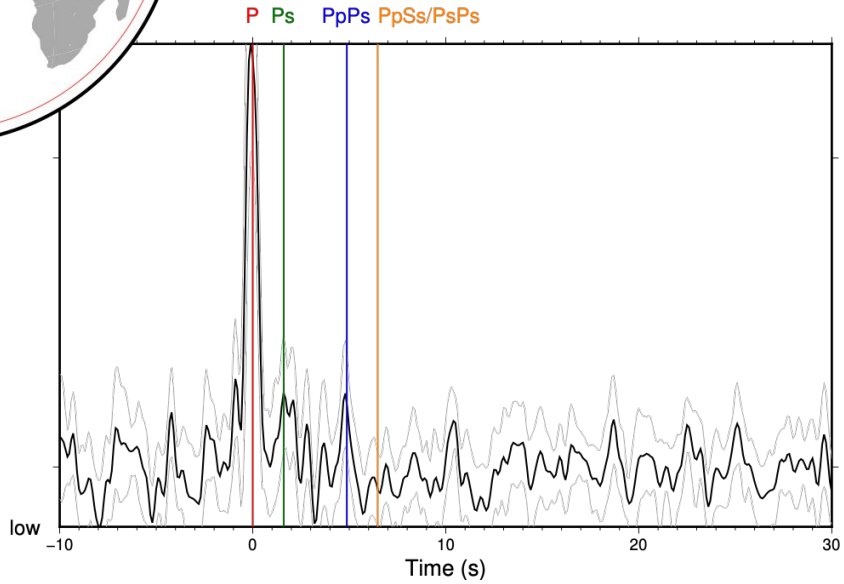


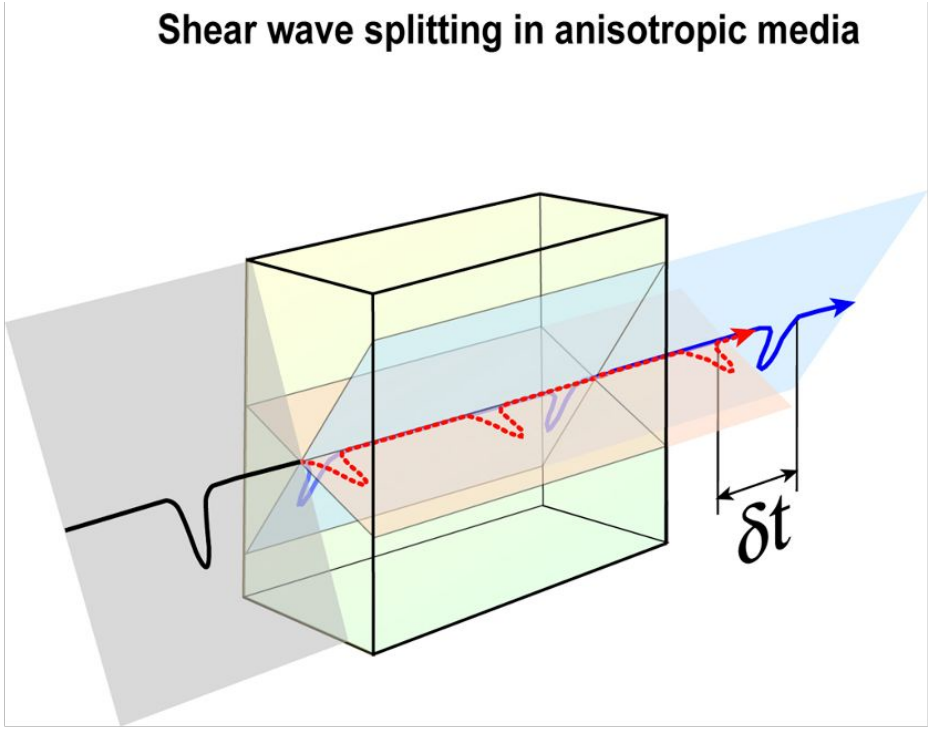


Schlaphorst et al. (2018)


UP09
149 events
(16/14)

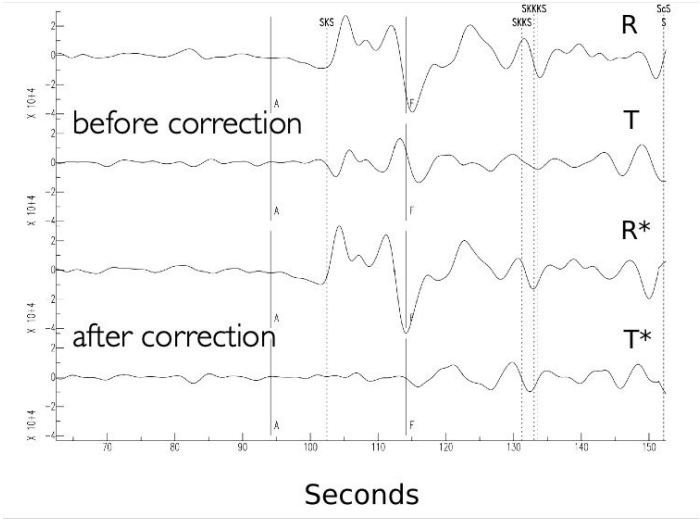

no. nrfr: 16
H (km): 11.50
k: 1.870
Vp/Vs
Depth (km)

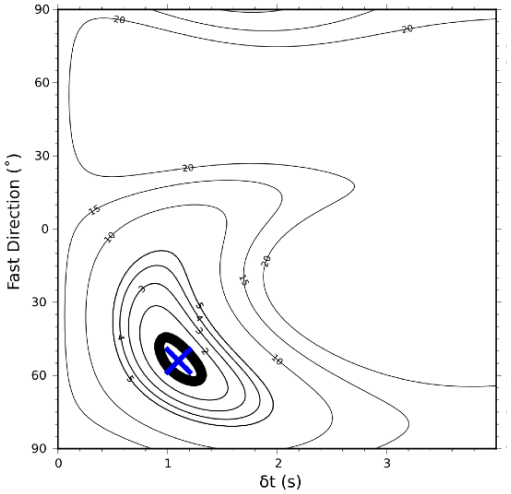

P Ps PpPs PpSs/PsPs
low
Time (s)

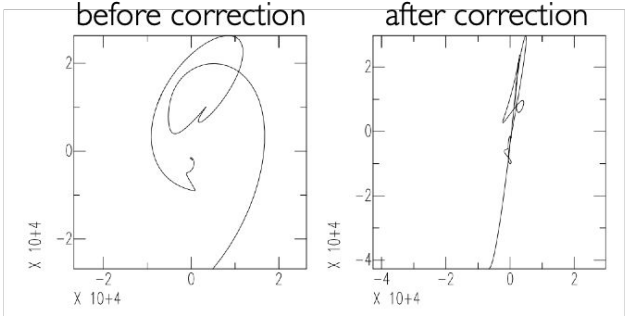


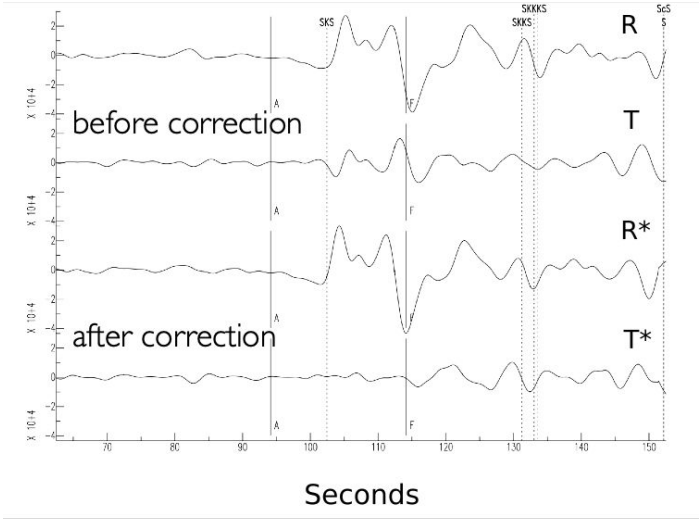
(by Ed Garnero)

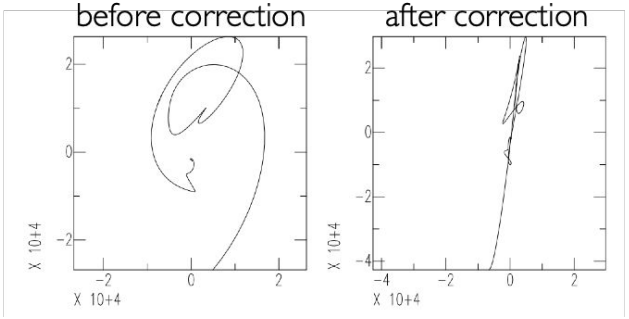
- Shear-wave has certain incoming polarisation.
- In anisotropic medium splits in two shear-waves with orthogonal polarisation (can be different to initial polarisation).
- One wave travels faster than the other.
- After leaving the anisotropic region, waves retain polarisation and time difference.
- At the surface, using a broadband 3-component seismic station, splitting parameters can be measured (i.e. fast shear wave polarisation direction (FPD), φ, and time delay, δt) – see Silver & Chan (1991, JGR).

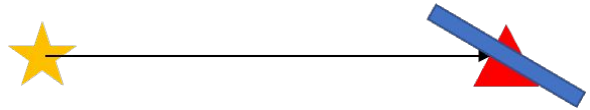

SKS
SKKKS
SKKS
ScS
S
R
T
R*
T*
before correction
after correction
A
F
X 10+4
70
80
90
100
110
120
130
140
150
Seconds

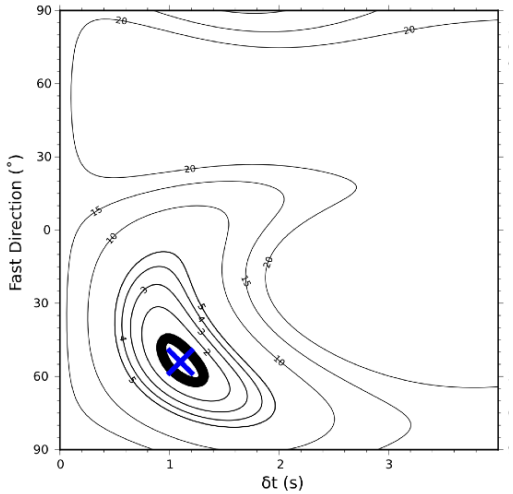

Fast Direction (°)
δt (s)
90
60
30
0
30
60
90
0
1
2
3
20
15
10
5
4
3
2
1

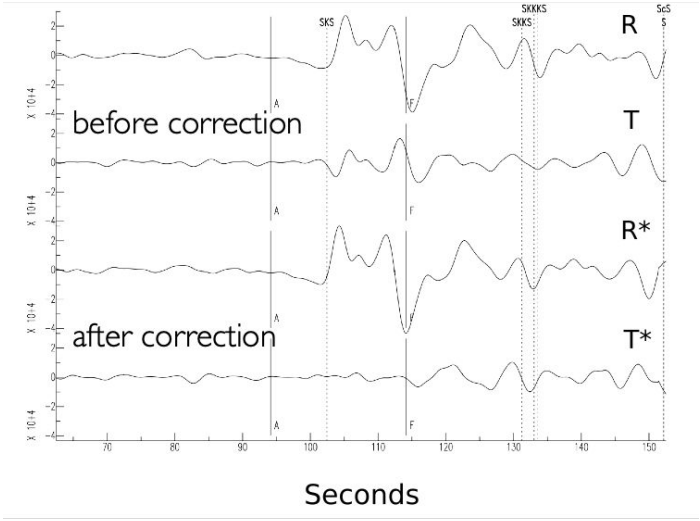

before correction
after correction
X 10+4
X 10+4
X 10+4
X 10+4

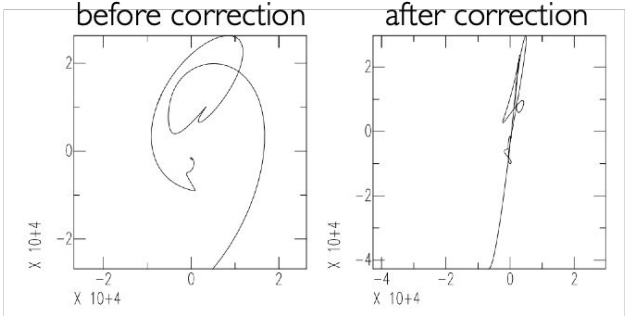

SKS
SKKKS
SKKS
ScS
S
R
T
R*
T*
before correction
after correction
A
F
X 10+4
70
80
90
100
110
120
130
140
150
Seconds

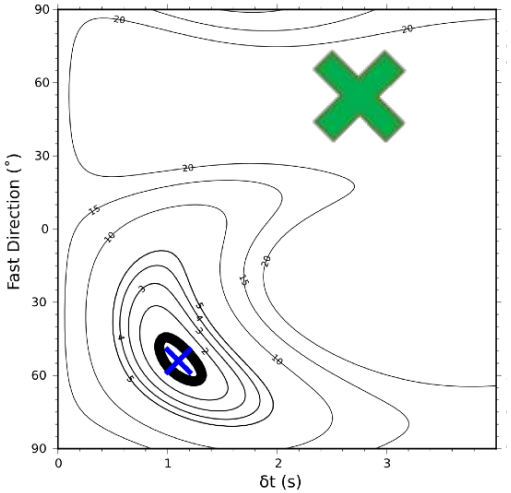

before correction
after correction
X 10+4
X 10+4
X 10+4
X 10+4

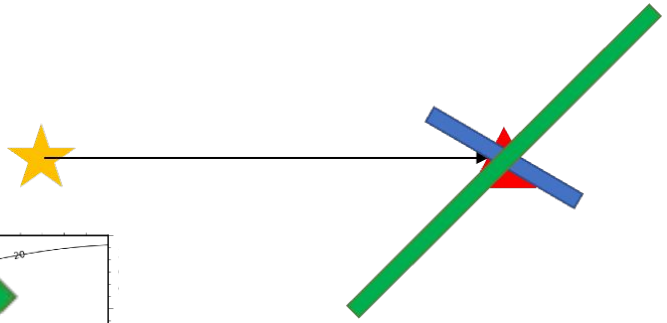


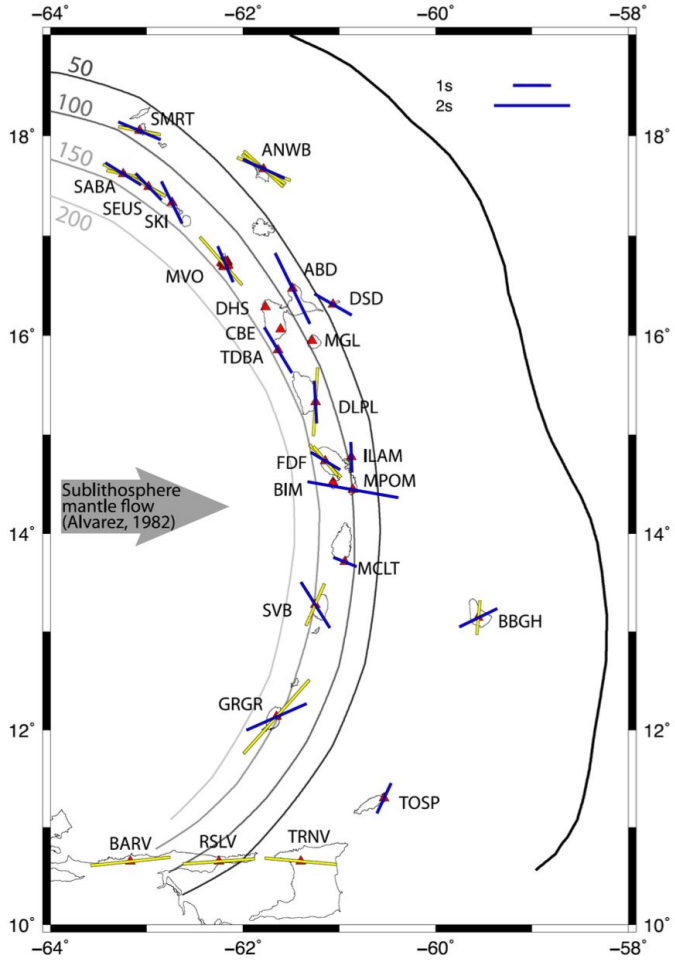

Fast Direction (°)
δt (s)
90
60
30
0
30
60
90
0
1
2
3
20
15
10
5
4
3
2
1


SKS
SKKKS
SKKS
ScS
S
R
T
R*
T*
before correction
after correction
A
F
X 10+4
70
80
90
100
110
120
130
140
150
Seconds

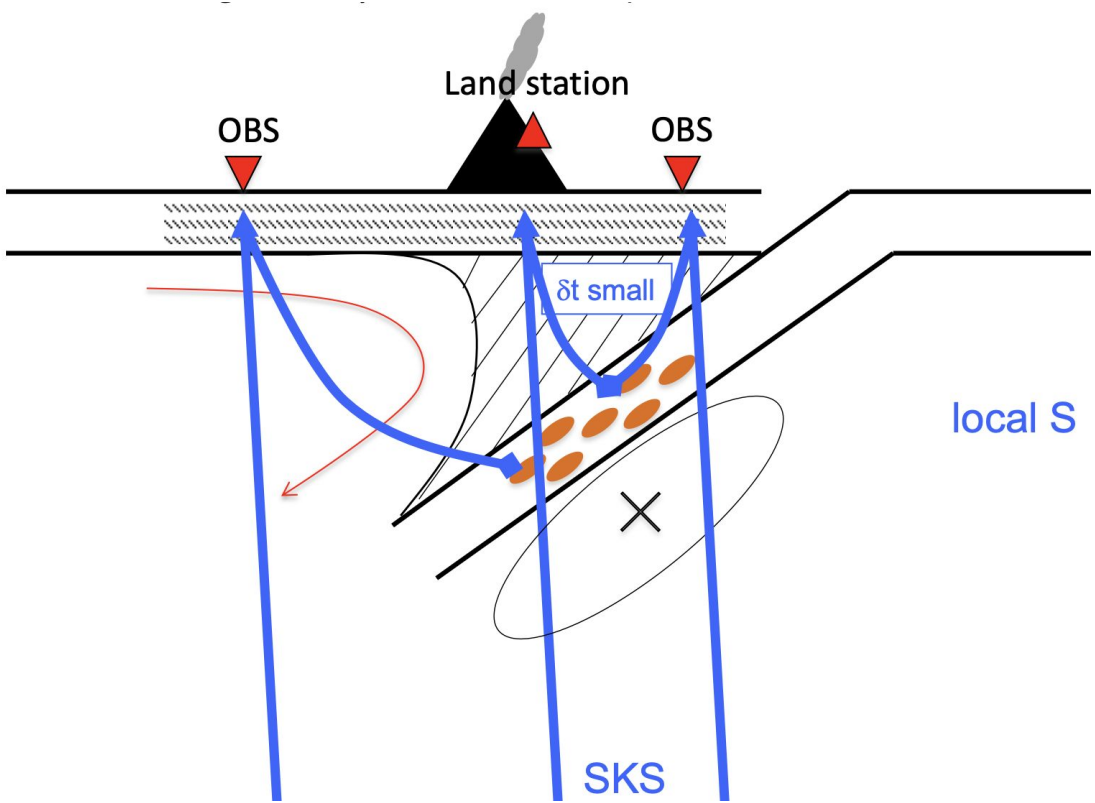

before correction
after correction
X 10+4
X 10+4
X 10+4
X 10+4

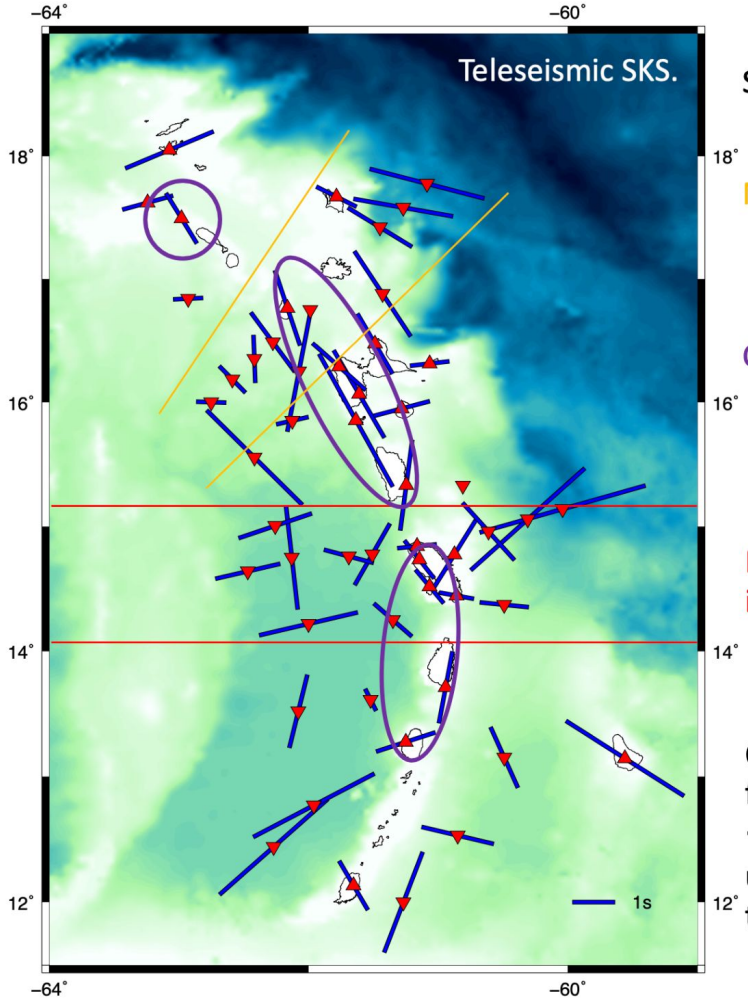

Fast Direction (°)
δt (s)
90
60
30
0
30
60
90
0
1
2
3





Schlaphorst et al. (2017)
Including results (yellow) from Russo et al. (1996), Benford et al. (2012), Meighan and Pulliam (2013) and Hodges and Miller (2015).


Land station
OBS
OBS
δt small
local S
SKS



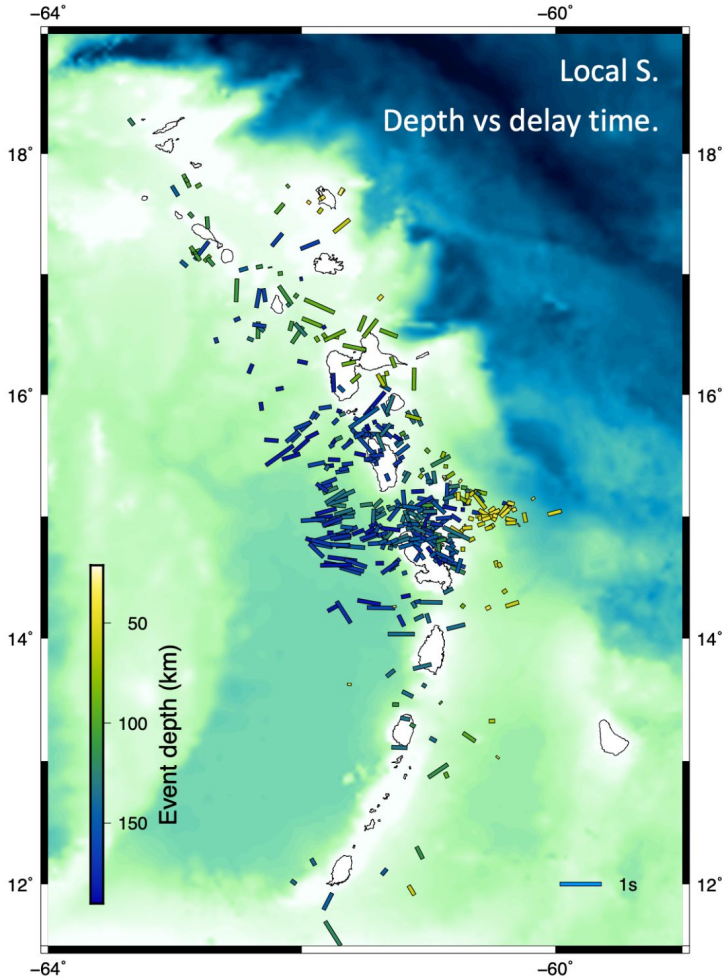
Some general patterns can be observed:

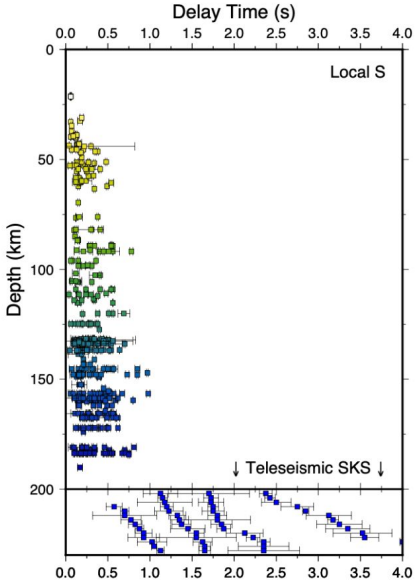
Mostly || around northern LAA.

Close to || on many islands.

Mostly ⊥ around mid LAA (even on some island stations).

Orientation on the arc often very different from orientation off the arc.
→Important and interesting for better understanding of arc structure and dynamics to include OBS from fore- and backarc regions.





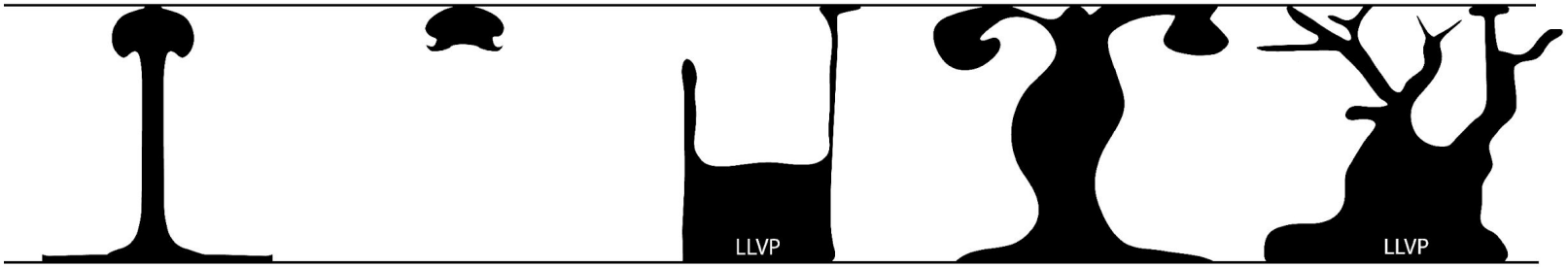
To avoid confusion:

1) SKS does not have a depth attributed to it. If SKS delay times are bigger than S that means that an anisotropic region has to be located beneath the epicentre of the local event.
2) SKS is ordered for visibility reasons, the pattern does not mean anything.

Also, in general, depth increase in this area means going into backarc, since events are located deeper there.

Seismic Tomography:
Mantle plumes around Africa

Mantle plumes through time



Thin, bouyant conduits
Morgan, 1971

Only upper mantle
anomalies
Foulger et al. 2000

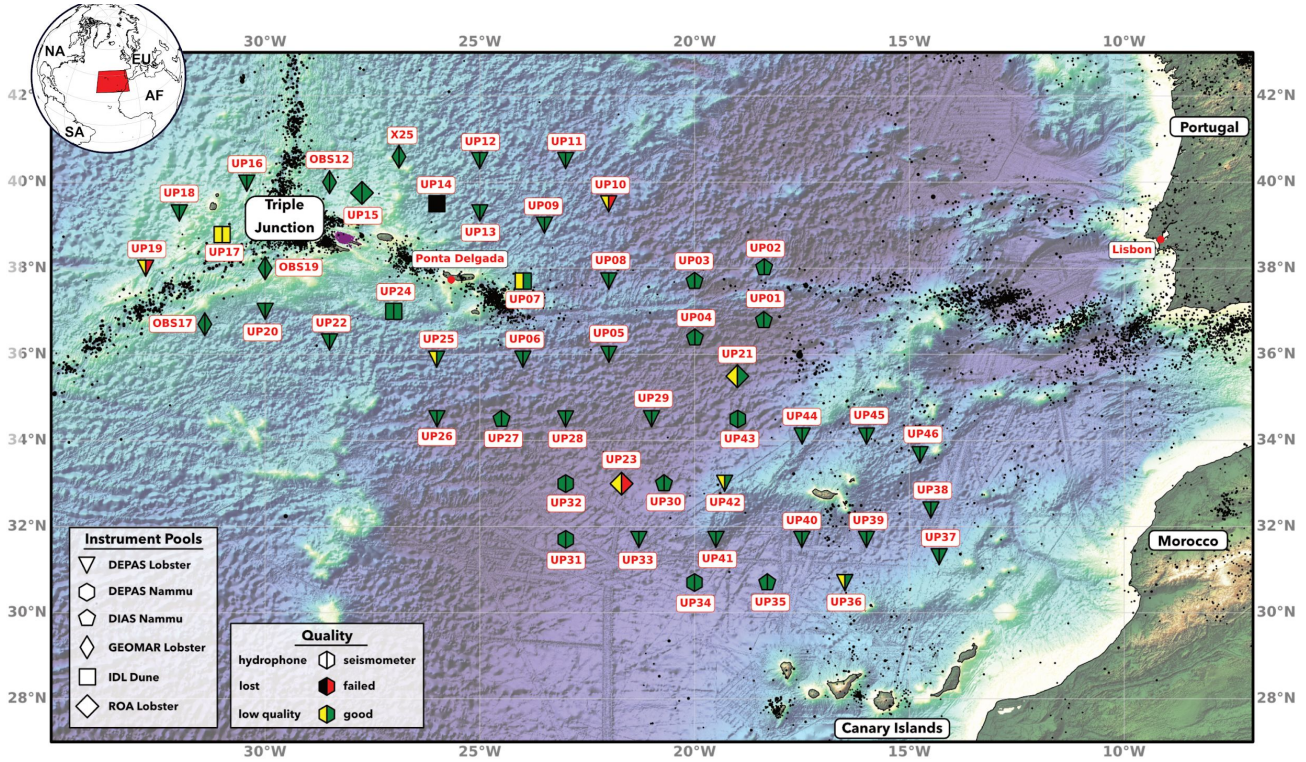
Plumes from the edge
of the LLVPs
Torsvik et al., 2010

Fat mantle plumes
French & Romanowicz, 2015

UPFLOW

Upward mantle flow from novel seismic observations

- ERC (2021-2026) funded
- PI Ana Ferreira (UCL) and co-I Migueal Miranda (IPMA)
- Passive seismology large-scale experiment in the Azores-Madeira-Canary region



UPFLOW

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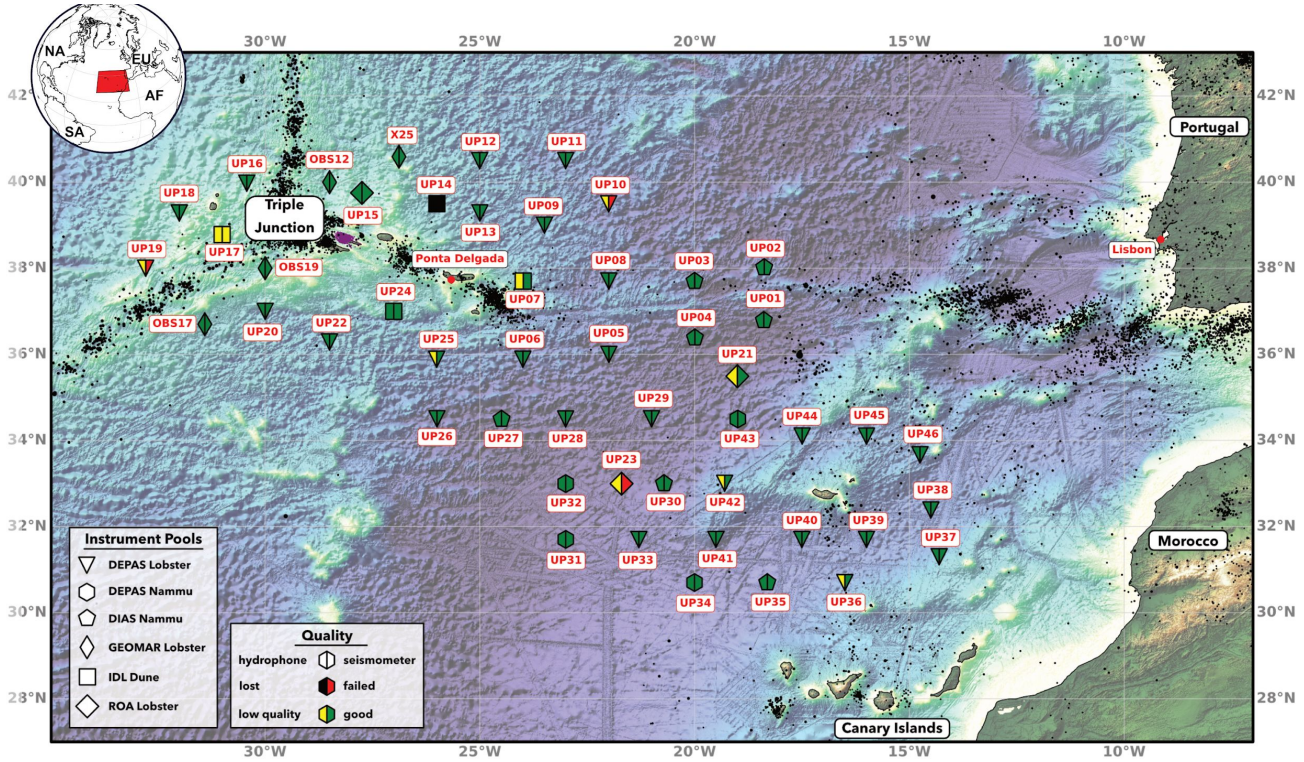
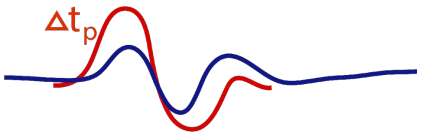
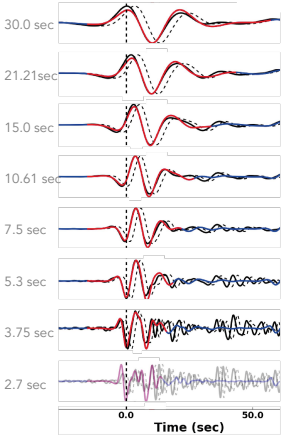
- Passive seismology large-scale experiment in the Azores-Madeira-Canary region
- 49 (out of 50) OBSs recovered in a ~1,000×2,000 km^2 area
- >40 land stations in the Azores and Madeira (plus > 20 in the Canaries)
- > 25 having been deployed in the Azores by CIVISA, IDL and UCL following the Sao Jorge crisis in 2022

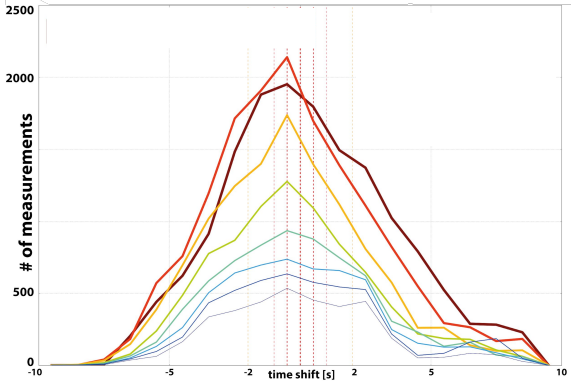


(Fast) workflow

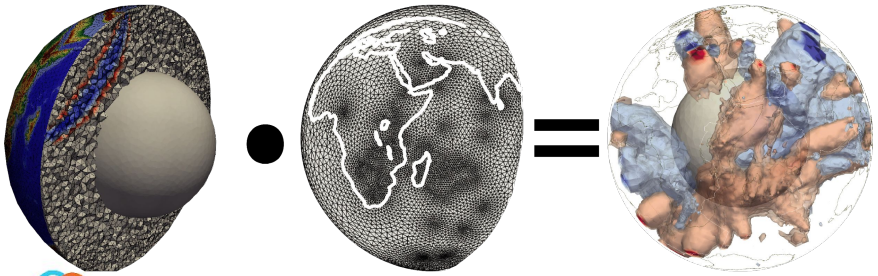


Multi Frequency Measurements





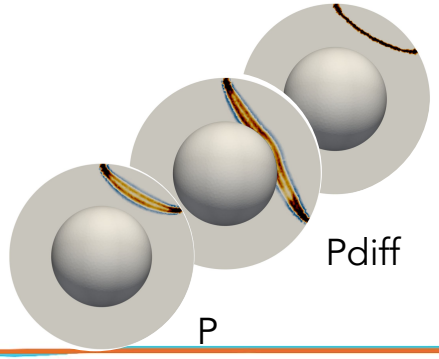
G . m = d



kernels

model parameters

data



Synthetic waveform

*

=

Source Time Function

Body waves are emerging from an earthquake, the shape of the body waves is defined as a source time function.

Greens Function

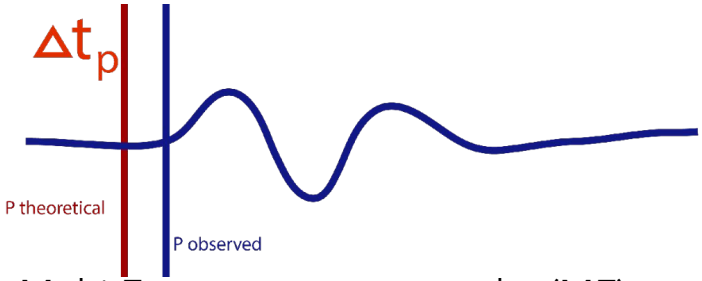
The Green's function is the response of the Earth model to a Dirac function.

Synthetic Waveform

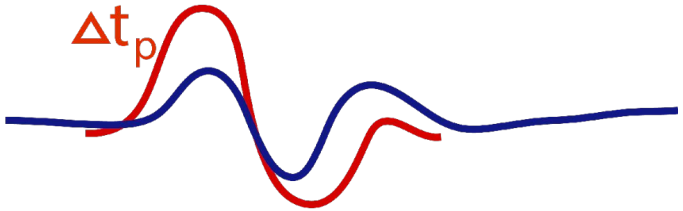
Theoretical, synthetic waveform or matched filter

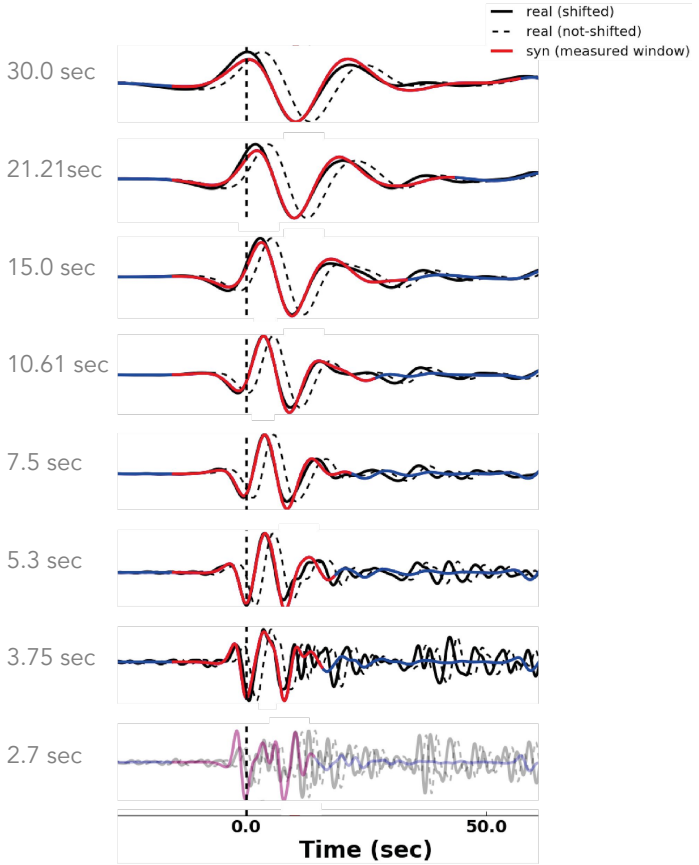
Ray vs. multi-frequency (MF)

Ray based tomography

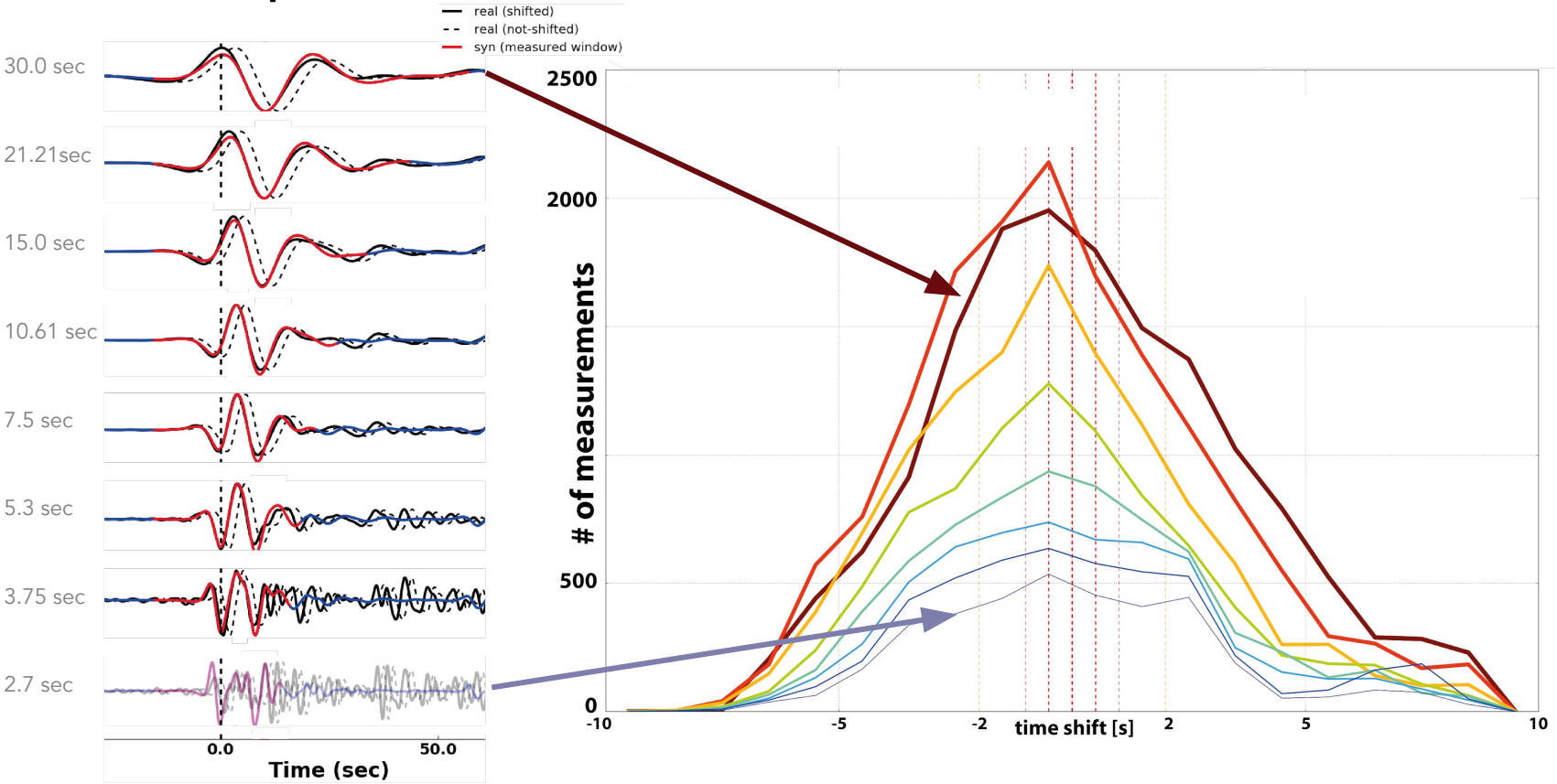


Multi Frequency tomography (MF)





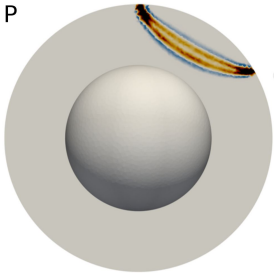
Multifrequency measurements



Data in numbers

	Multi Frequency	Pdiff	ISC	All
measurements	55,657	[illegible]	[illegible]	2,587,717

increase resolution around **La Reunion and western Indian Ocean**

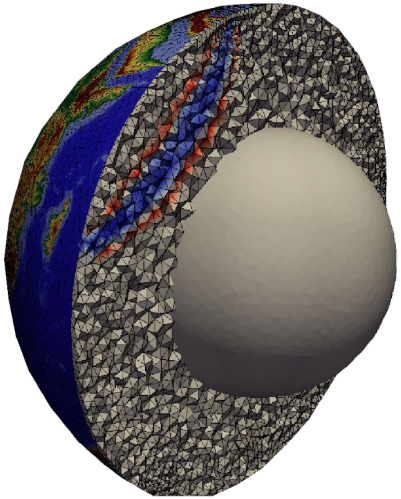


coverage down to the **core mantle boundary** (globally)

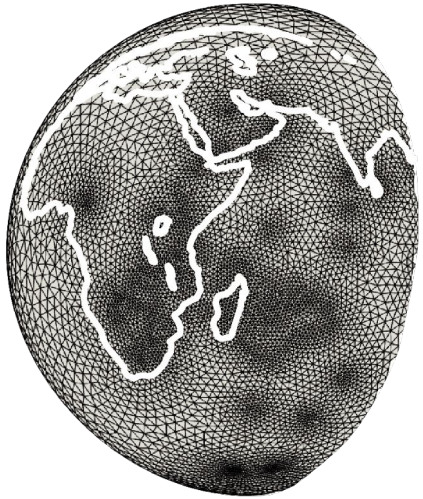
constrain **borders of region of interest** (globally)

Inversion

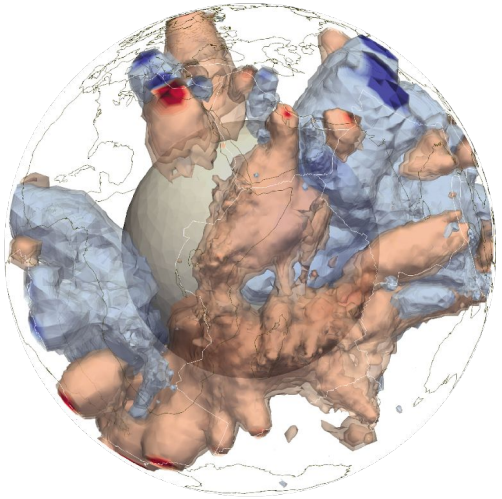
G . **m** = **d**



kernels



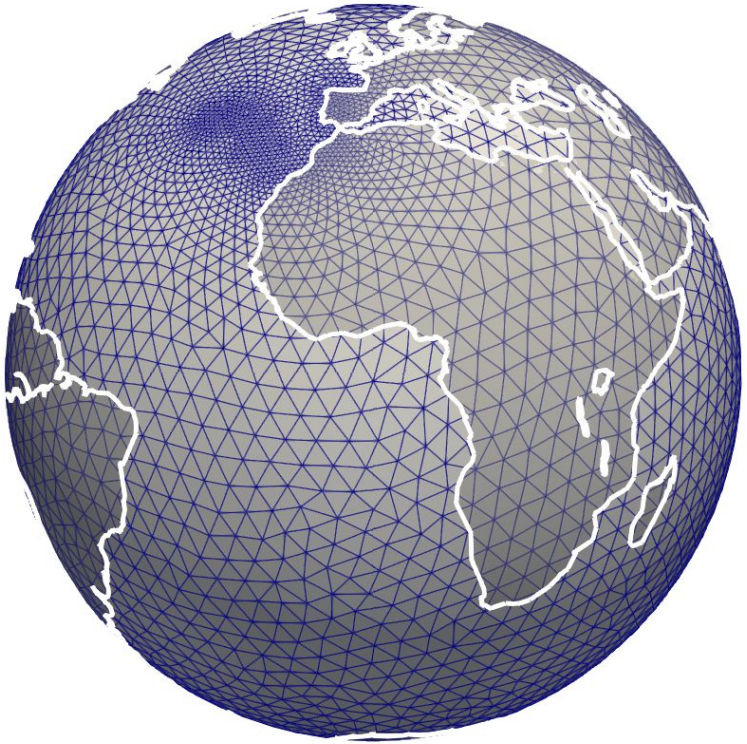
model parameters



data

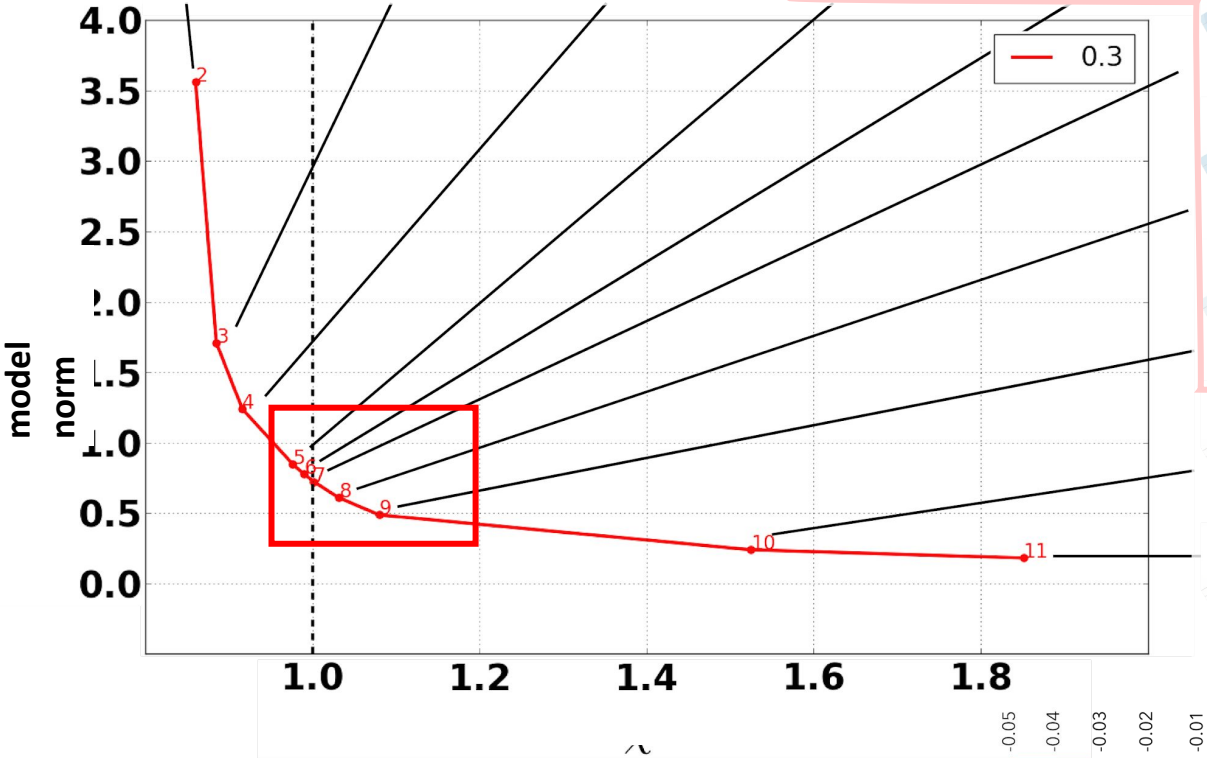
UPFLOW mesh UPv1

22323 model parameters



L - curve

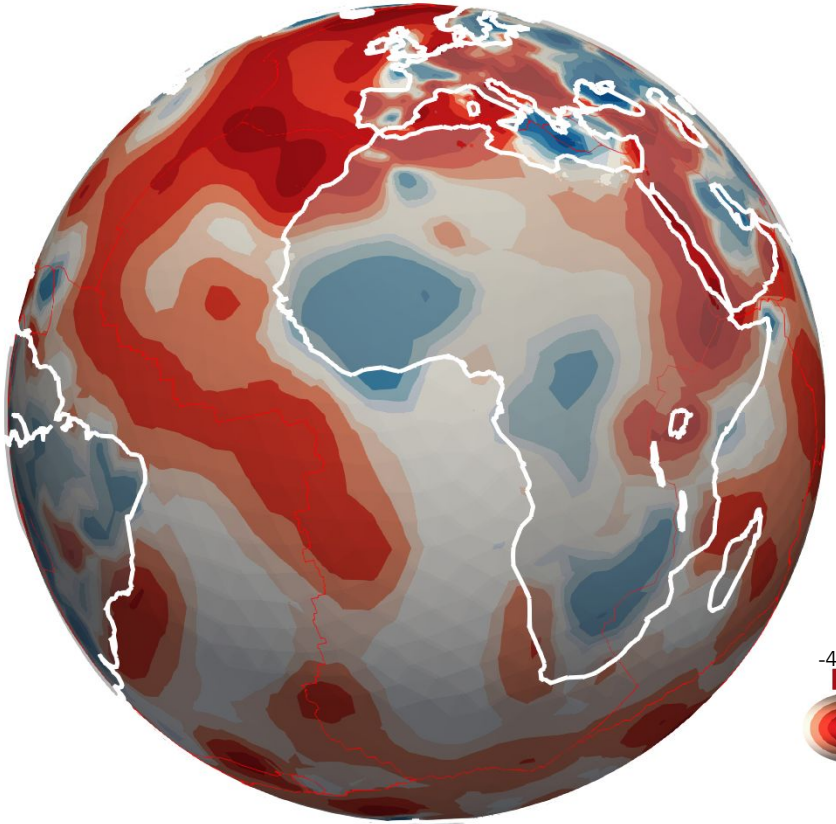
The L-curve shows the trade-off between model norm and data fit: 3 times more smoothing than damping is applied

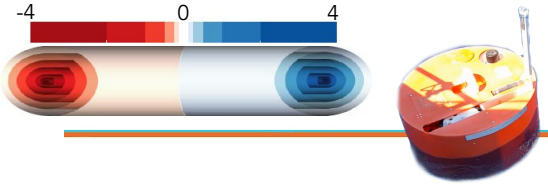


ISC tomography

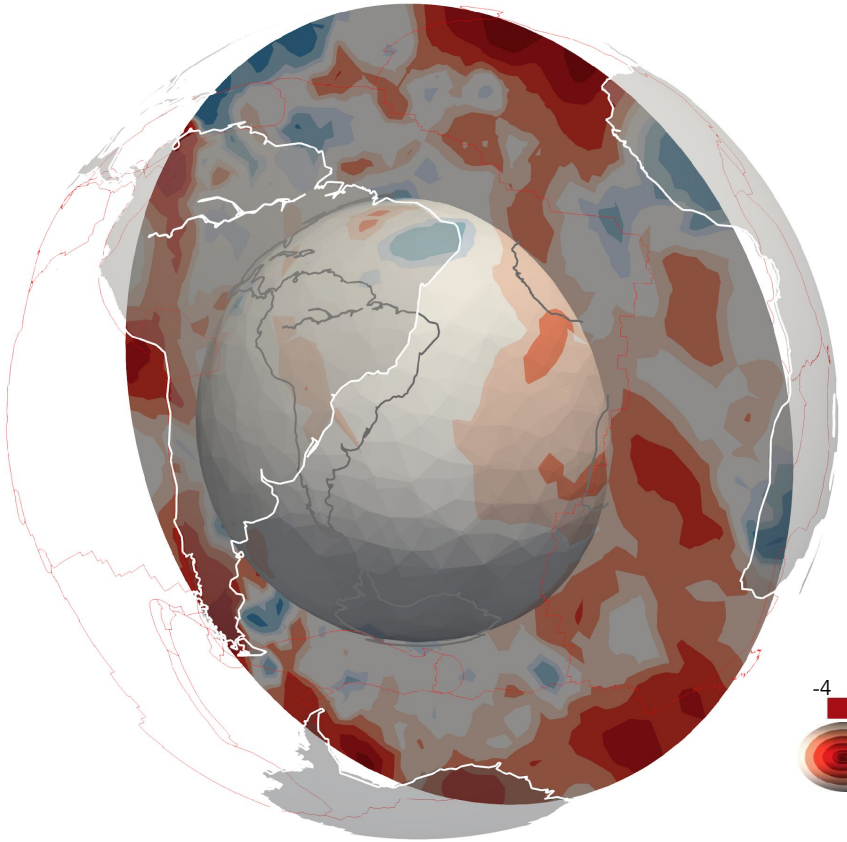
The ISC-EHB Dataset is a groomed version of the ISC Bulletin, and contains 199578 Seismic events from 1964 to 2020, where the period 1964-2008 has been rebuilt. The total number of 44,711,525 time-defining seismic phases are associated with the ISC-EHB dataset.

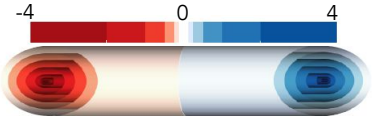
Number of picked P phase arrival times: 5,658,315





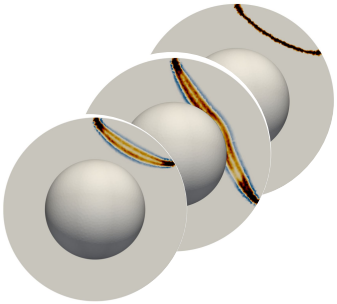
ISC tomography

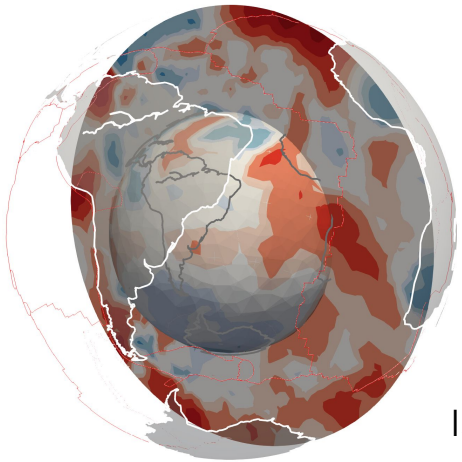


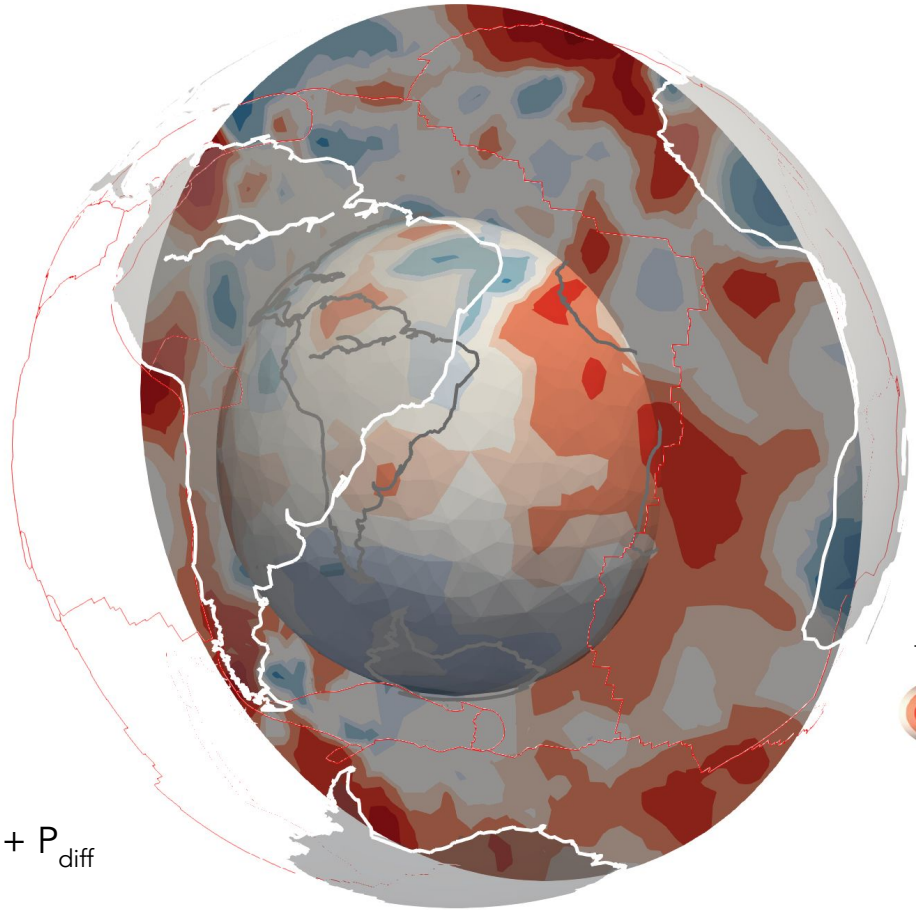


ISC + Pdiff + NA + UP

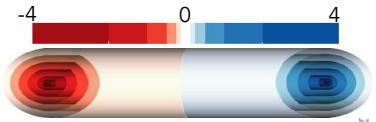
- Total of 5,942,476 combined arrival times
- 109,937 added multifrequency measurements from UPFLOW and other temporal experiments in that area



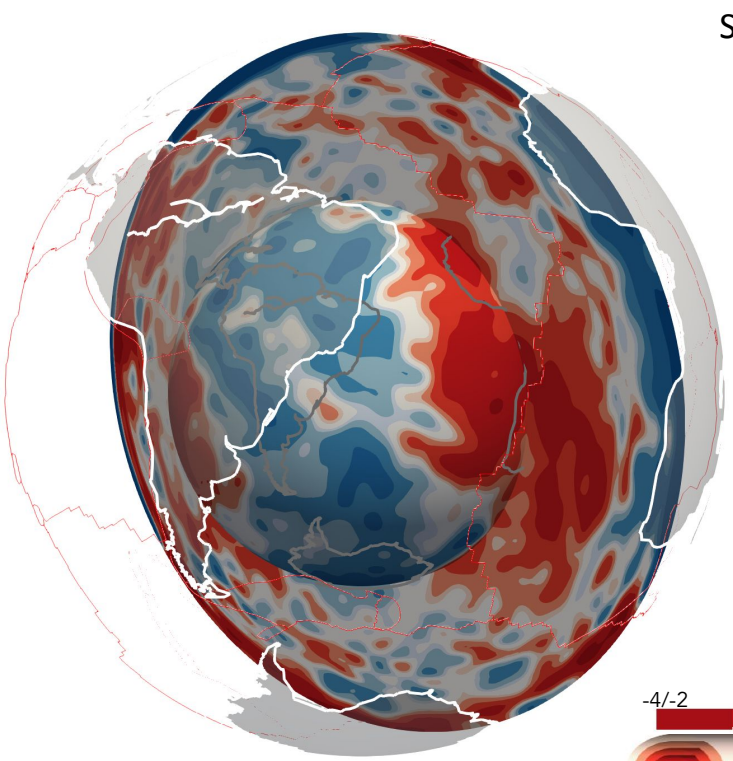


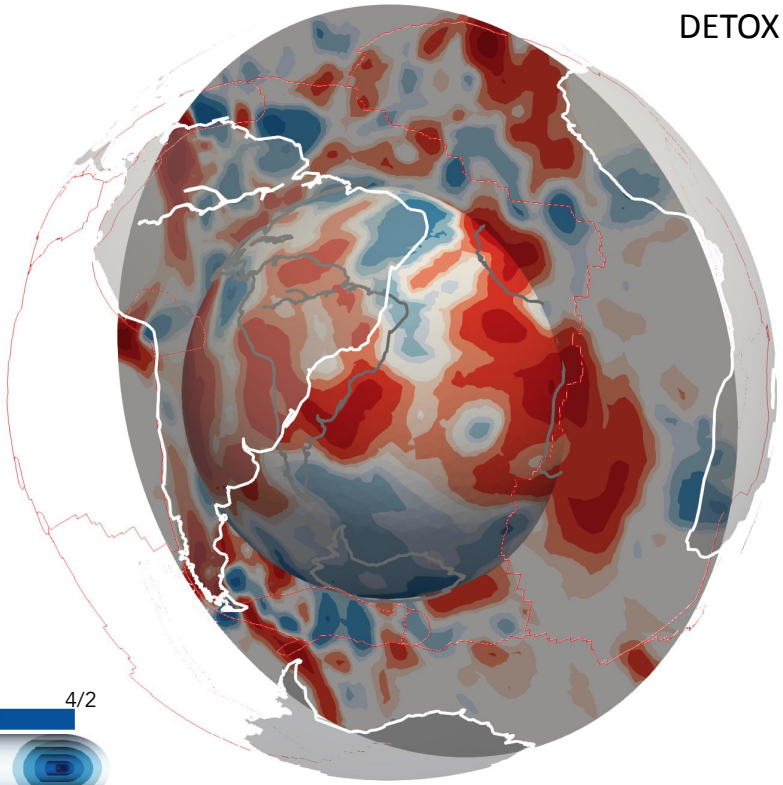


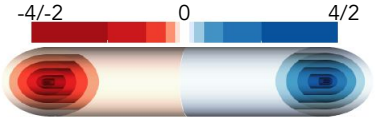
ISC + P_{diff}

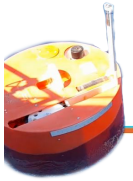


Compare to other models





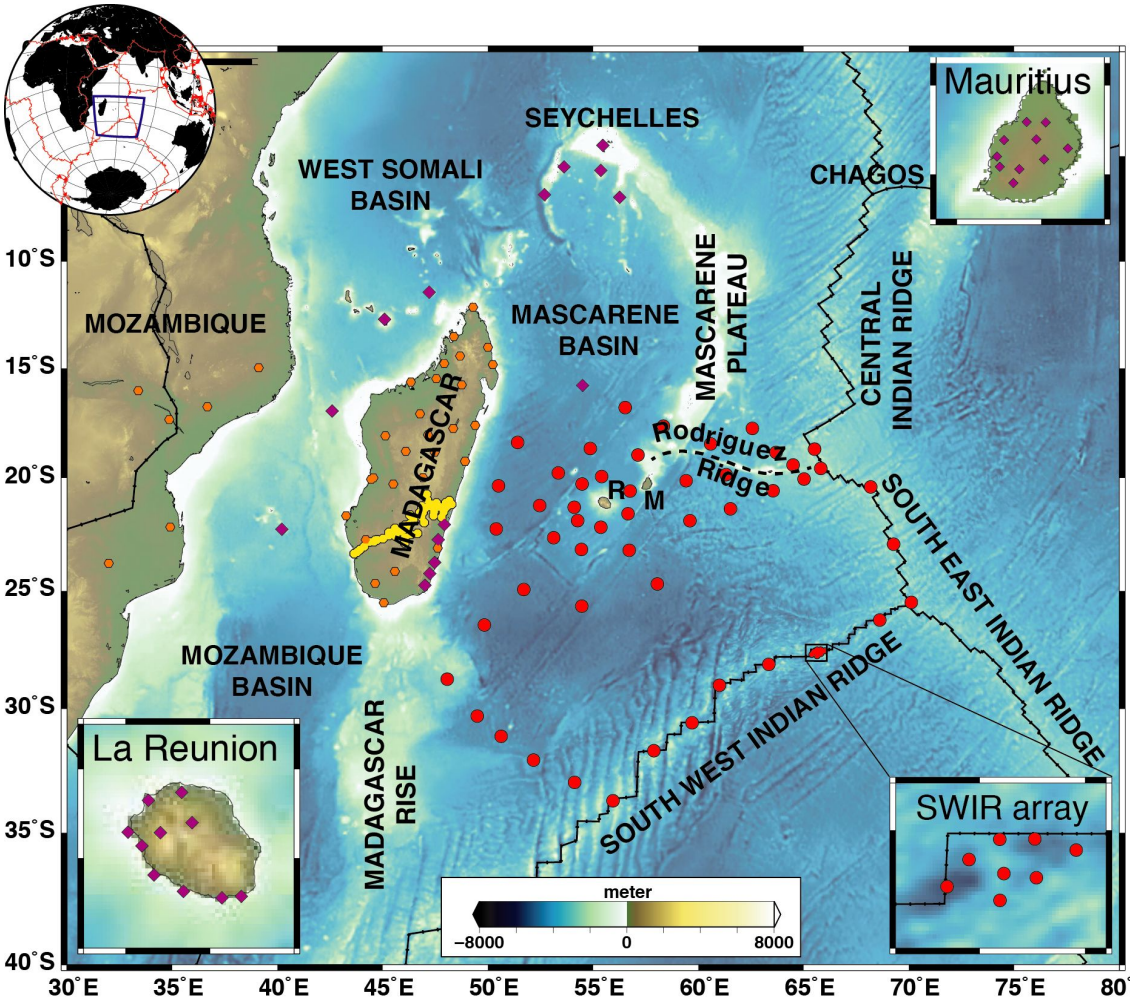




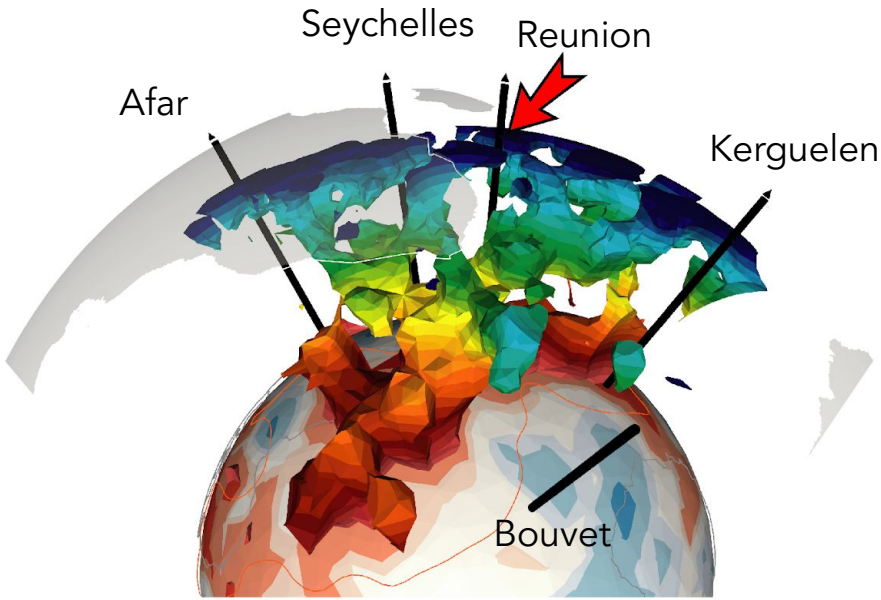
RHUM-RUM

Reunion Hot-Spot Upper Mantle – Reunions Unterer Mantel

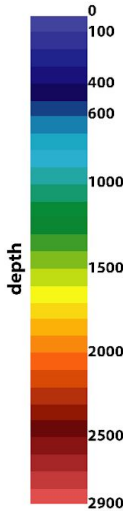
- 57 Ocean Bottom (2012 -2013)
- island stations on Reunion, Rodriguez, Gloriso Islands, Juan de Nova, Europa Island, Tromelin Island, Mayotte & Madagascar
- MACOMO (M. Wysession)
- SELESOMA (F. Tilman - GFZ)
- MAURITIUS/SEYCHELLES (G. Rümpker)

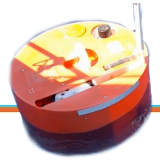


Depth slices the Western Indian Ocean

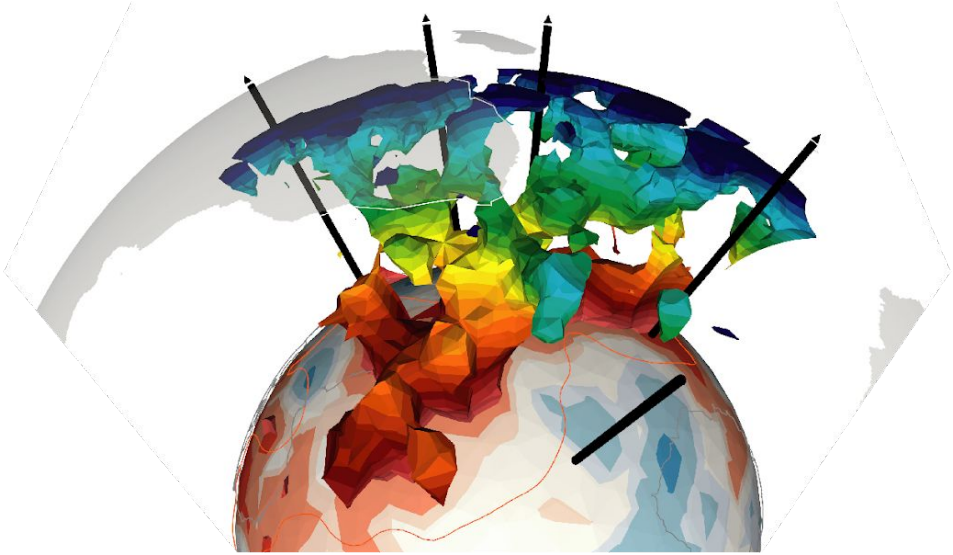


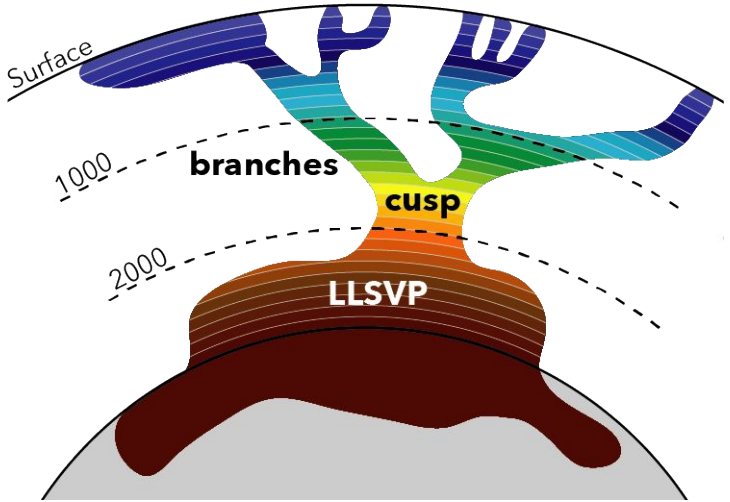
Volume is rendered for:
< -0.5%



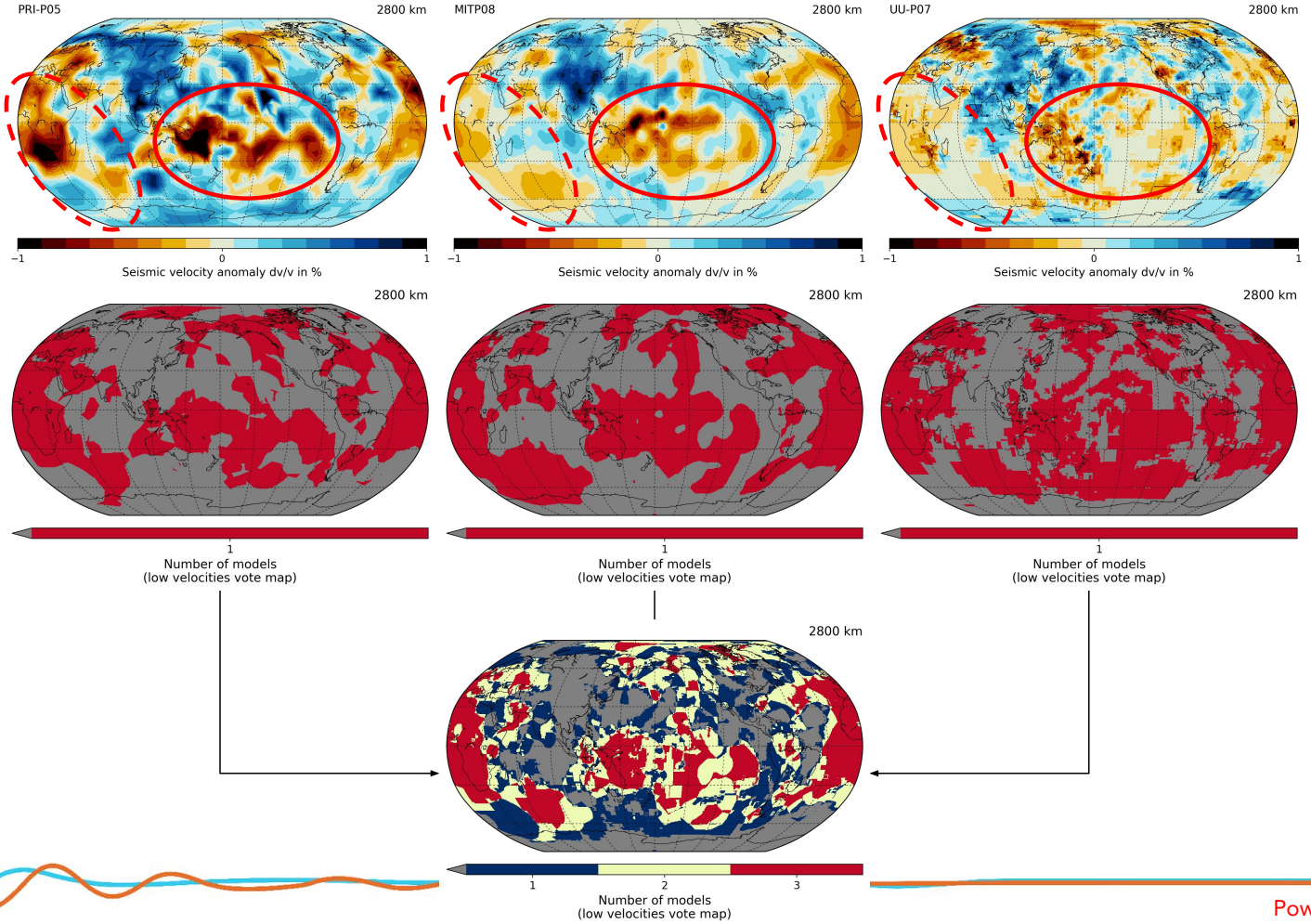


Tree like structure beneath La Reunion

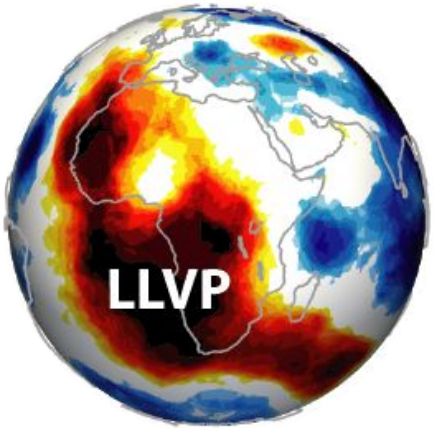




Vote-maps (2800 km)

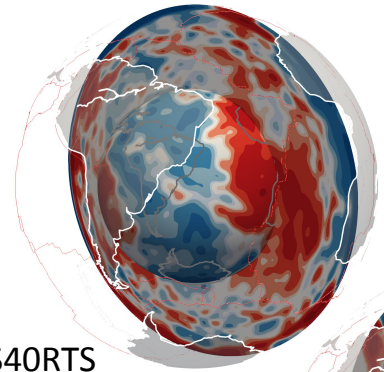


Complex mantle structures

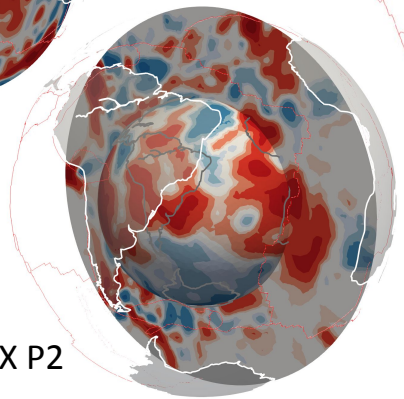


Vote map

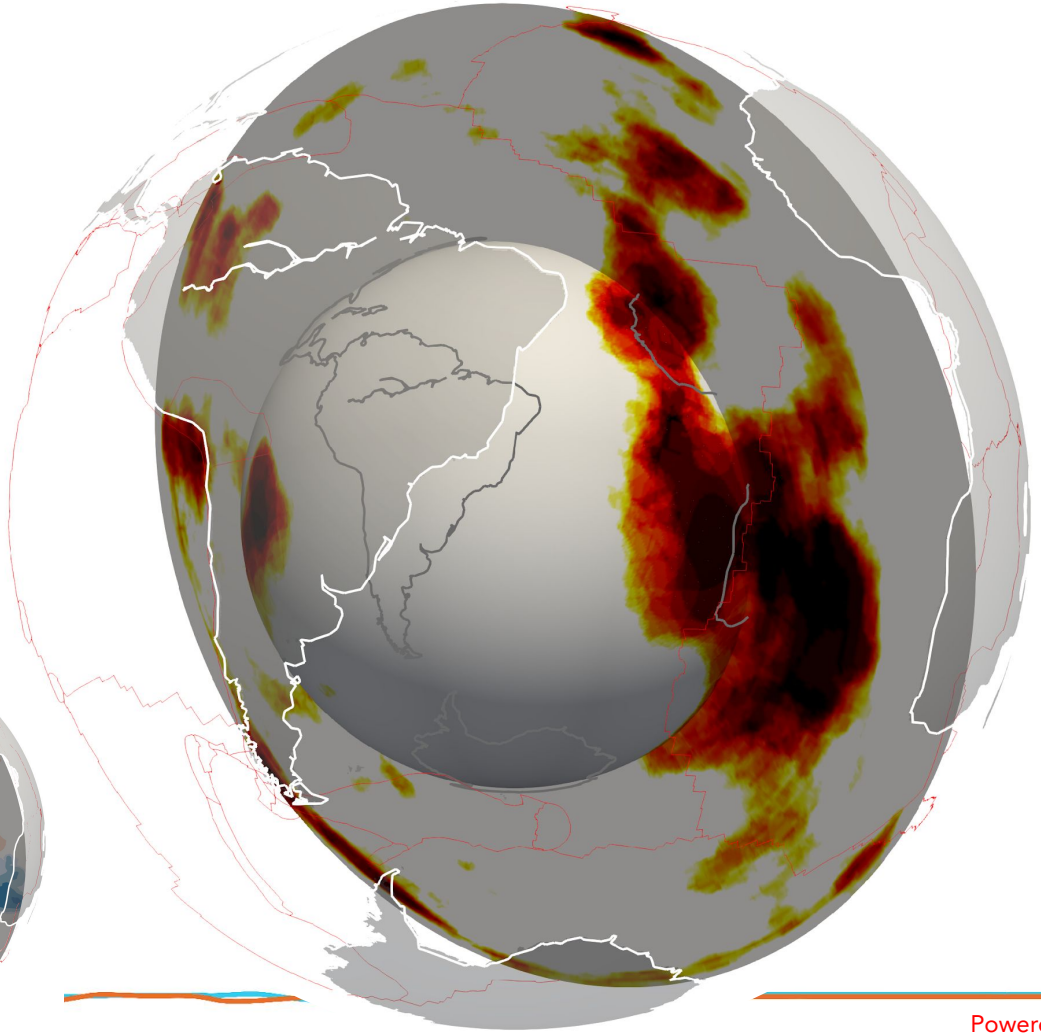
26 models combined; color bar starts from 13 models



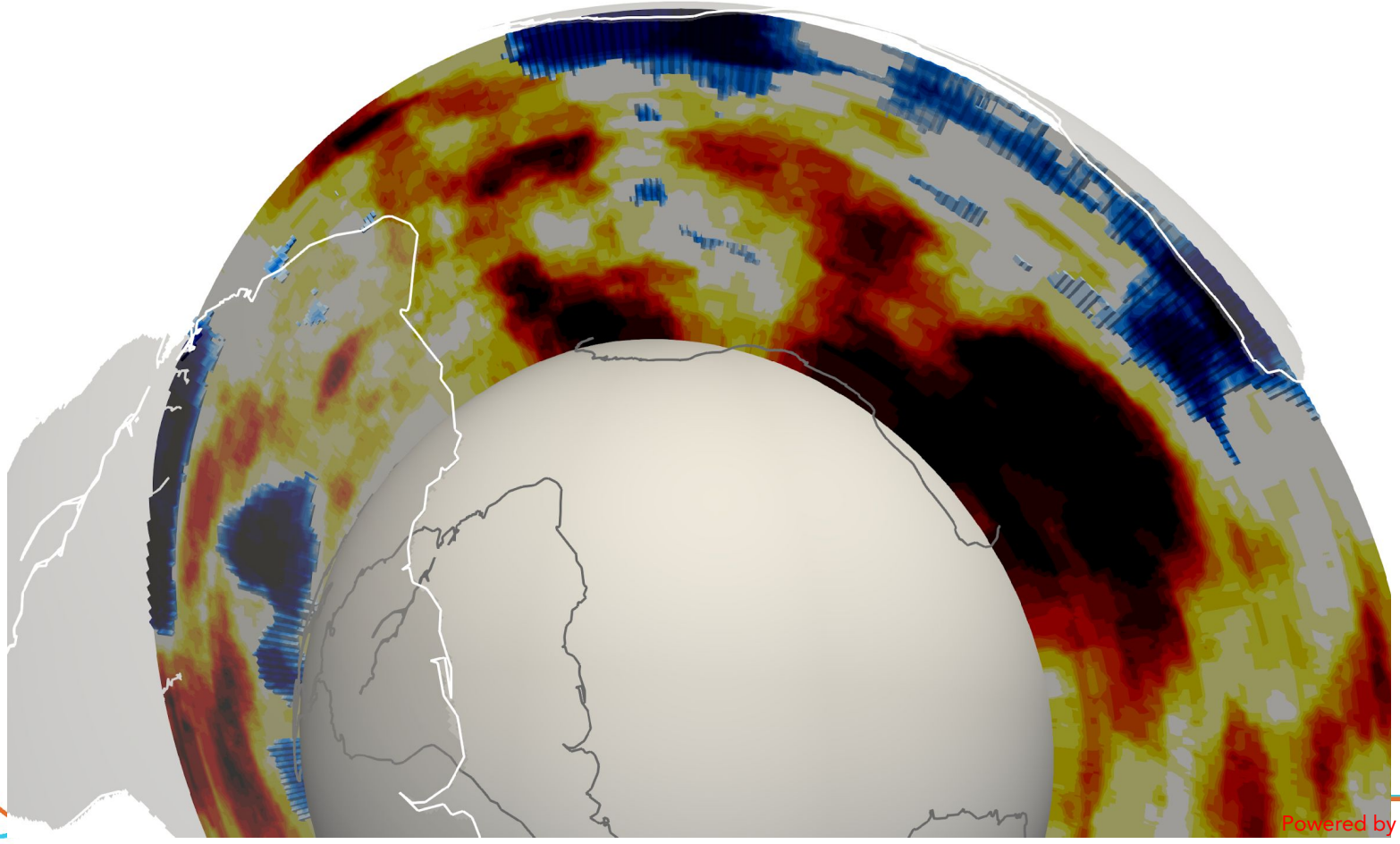
S40RTS



DETOX P2

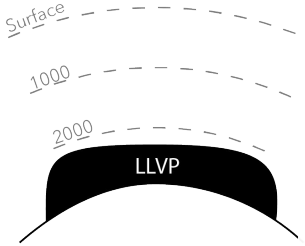


Complex mantle structures



Origin of complex structures?

1. Conduits rise **from border** (e.g. Torsvik, 2010) and propagate through time inwards
2. Doming at center and branching **out- and upward** (e.g. Farnetani and Samuel, 2005)
3. Unstable **thermochemical boarders** release blobs creating appearance of branches (e.g. Olson and Singer 1985)



Outlook

- The UPFLOW experiment collected a large, high-quality and unique OBS dataset in the mid-Atlantic region
- The RHUM-RUM experiment improved the illumination beneath the Western Indian Ocean.
- Both experiments contribute to better imaging around Africa but gaps remain.
- Structures are more complex around Africa than previously considered and need to be further investigated.
- A. Ferreira's initiative of an Atlantic Array may provide a platform to illuminate beneath the whole Atlantic.

Thank you!