Blobs at the base of the mantle

Using HPC to uncover the evolutionary history of great geophysical structures

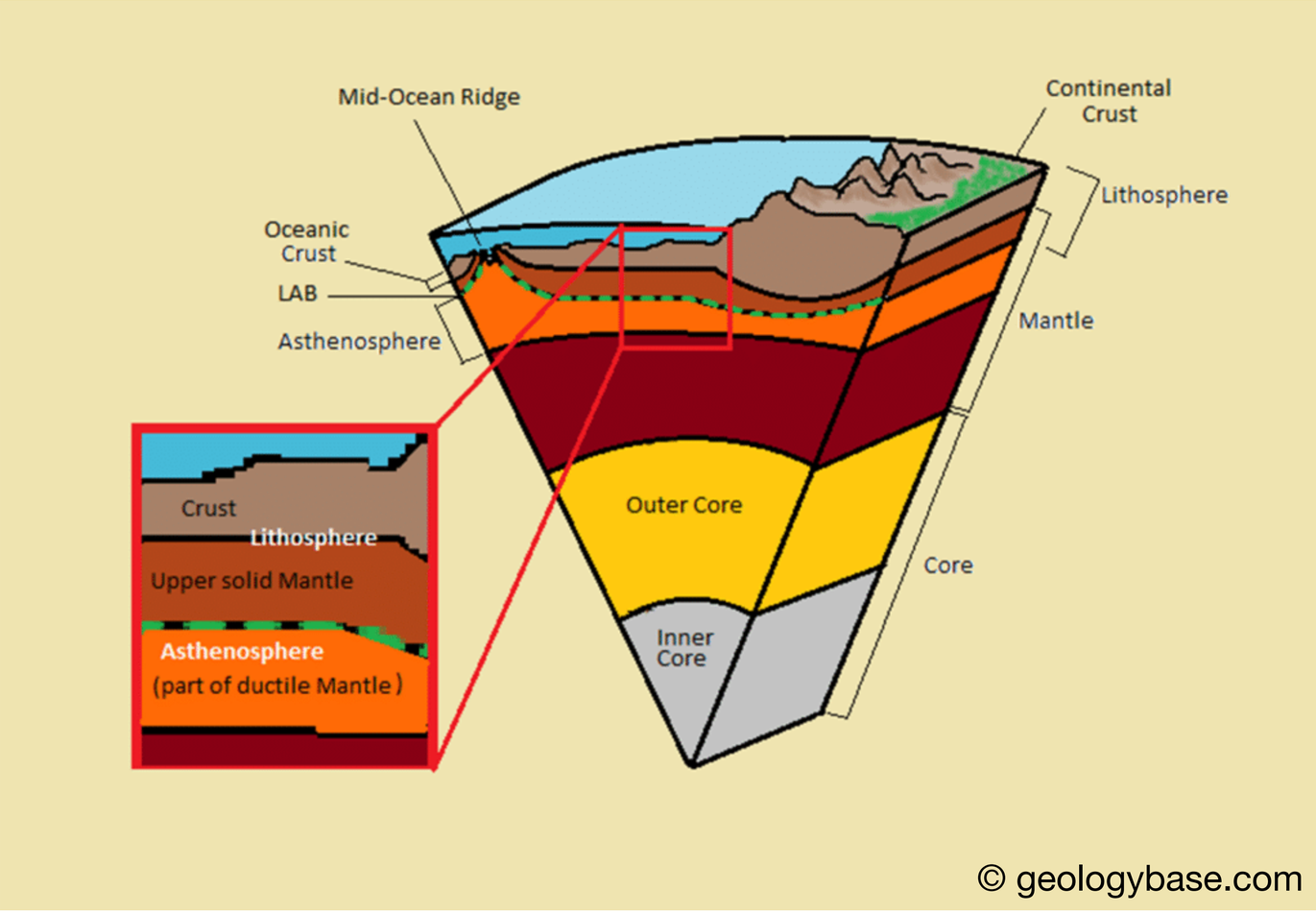
ARCHER2 Celebration of Science 2026

James Panton - Cardiff University / University of Cologne

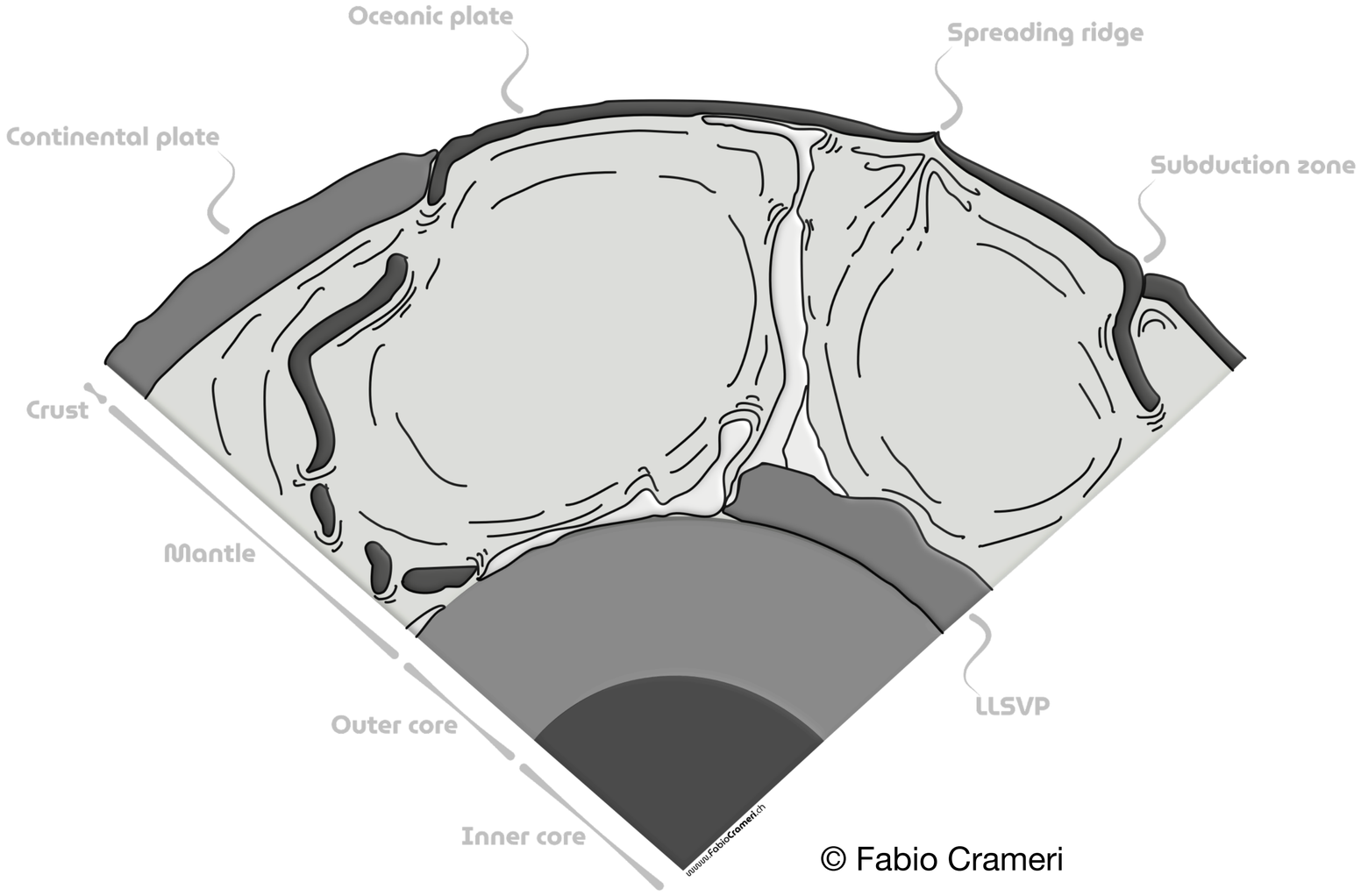
School of Earth and Environmental Sciences
Ysgol Gwyddorau'r Ddaear a'r Amgylchedd

UNIVERSITY OF COLOGNE

Earth structure refresher

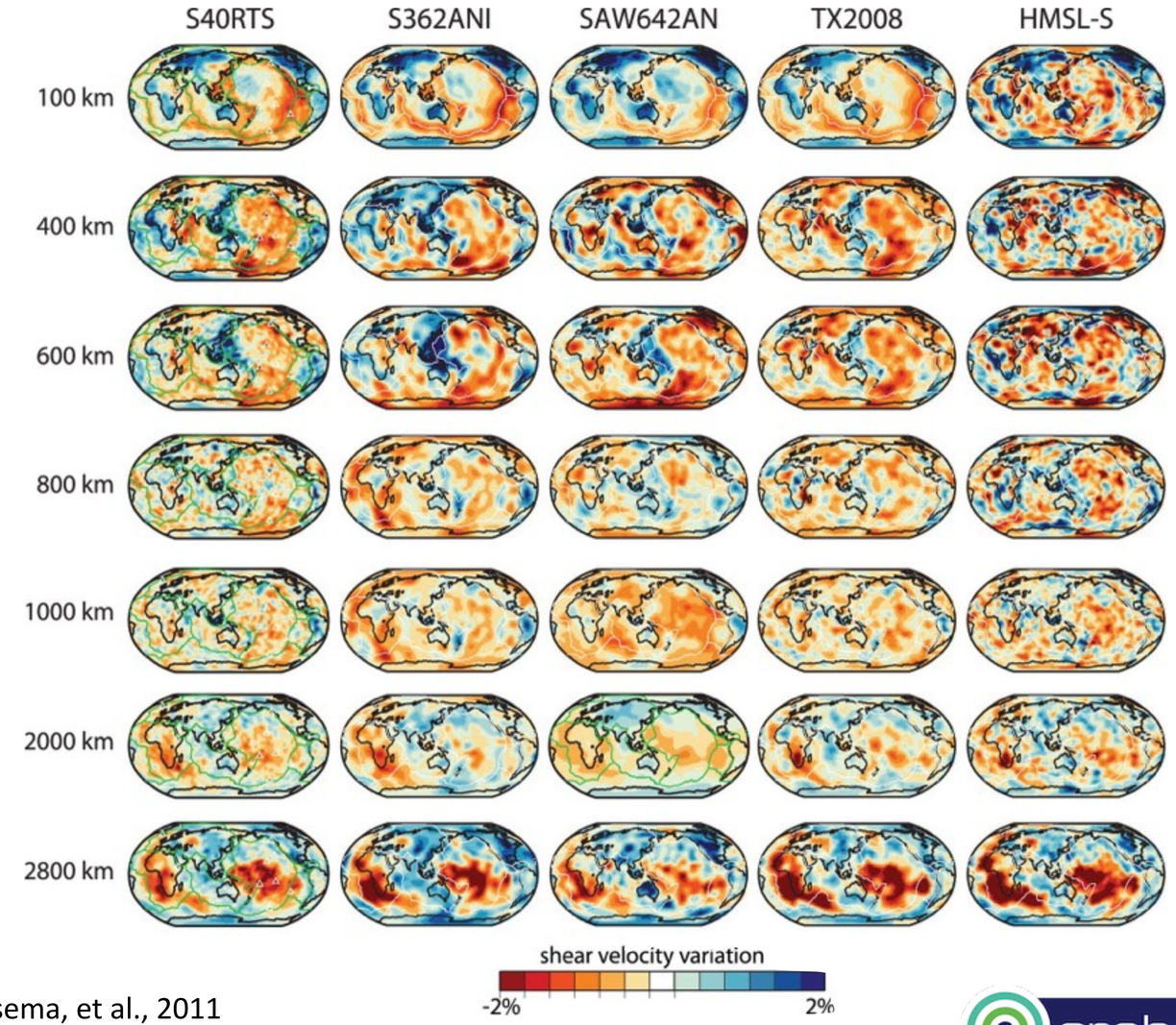


Earth structure refresher



Insights from seismic tomography

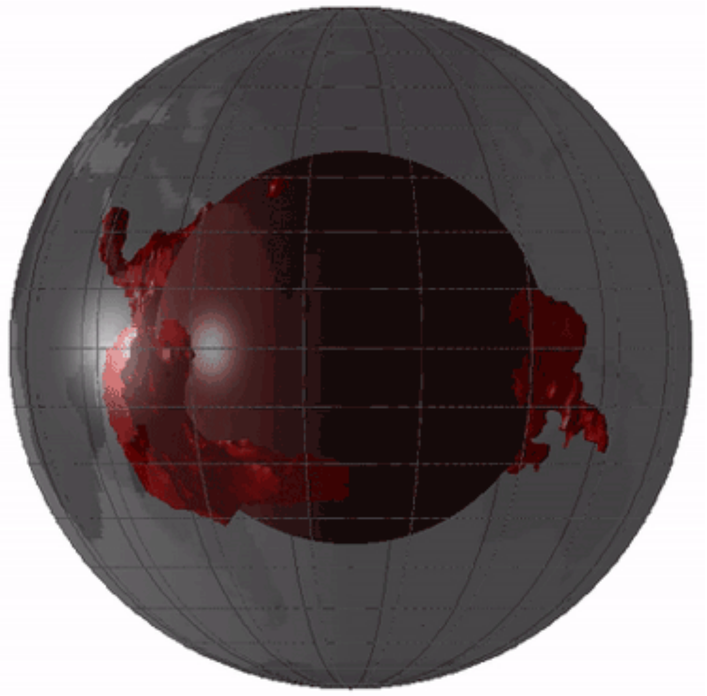
- Seismic tomography is like taking an MRI scan of the Earth
- Models consistently show seismically slow regions at the base of the mantle



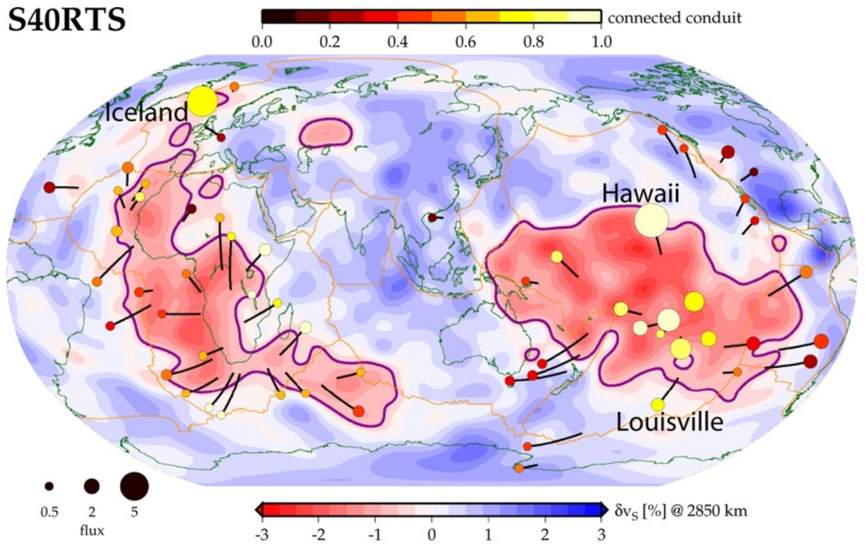
Ritsema, et al., 2011

LLVPs

Why do we care about them?



© Sanne Cottaar



Jackson, et al., 2021

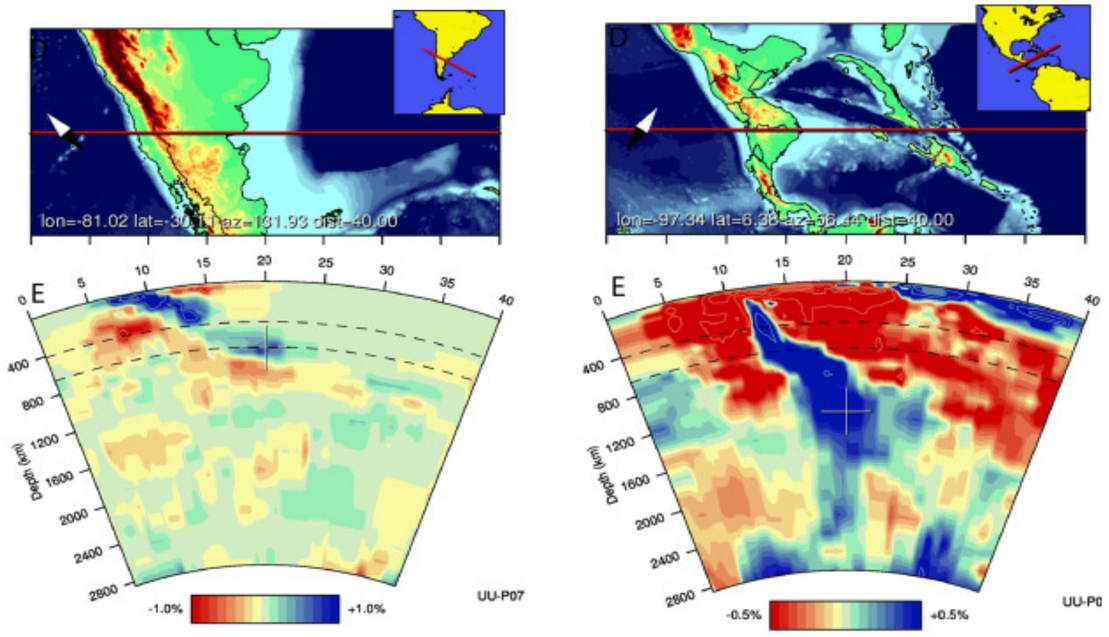
- 2% - 9% of mantle volume
- Mantle plumes project onto the low velocity regions
- May control heat flux out of the core - magnetic field

LLVPs

What are they?

1)Thermal (or effectively isochemical)
    a)Megaplumes
    b)Plume clusters
2)Thermochemical
    a)Primordial
        i)Domes and thermochemical superplumes
        ii)Primordial thermochemical piles
    b)Crustal accumulation

McNamara, 2019



Van Der Meer et al ., 2018

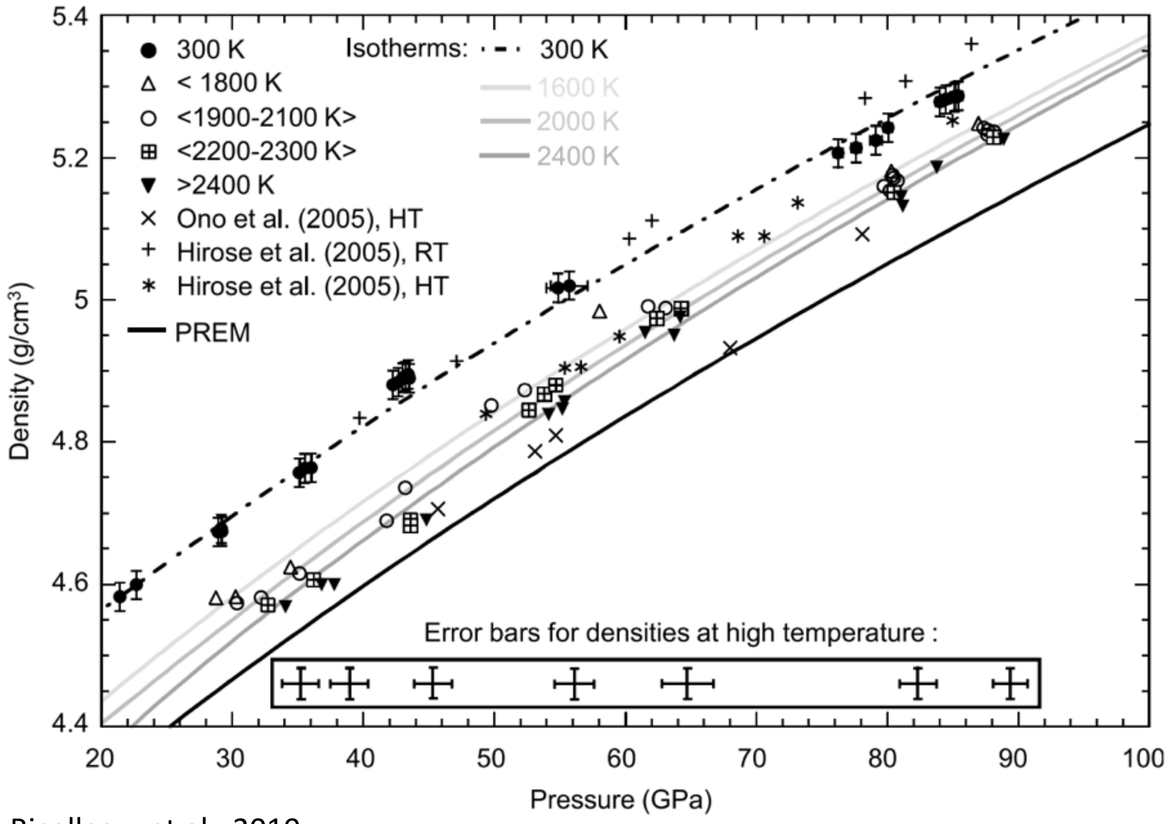
LLVPs

What are they?

1)Thermal (or effectively isochemical)
- a)Megaplumes
- b)Plume clusters

2)Thermochemical
- a)Primordial
  - i)Domes and thermochemical superplumes
  - ii)Primordial thermochemical piles
- **b)Crustal accumulation**

McNamara, 2019



Ricolleau, et al., 2010

How can we simulate LLVP evolution?

Numerical mantle modelling

$$\nabla \cdot \boldsymbol{u} = 0$$ Mass

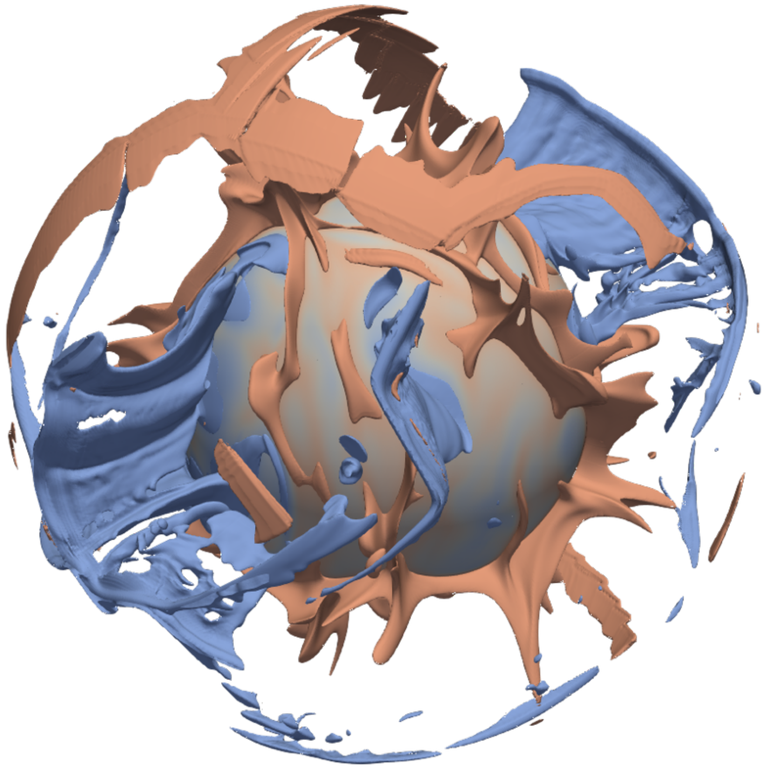
$$\nabla \cdot \left(\eta \left\{\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T\right\}\right) - \nabla p = \boldsymbol{g}\,\alpha\,\rho_0\,(\delta T - C\,B\,\Delta T)$$ Momentum

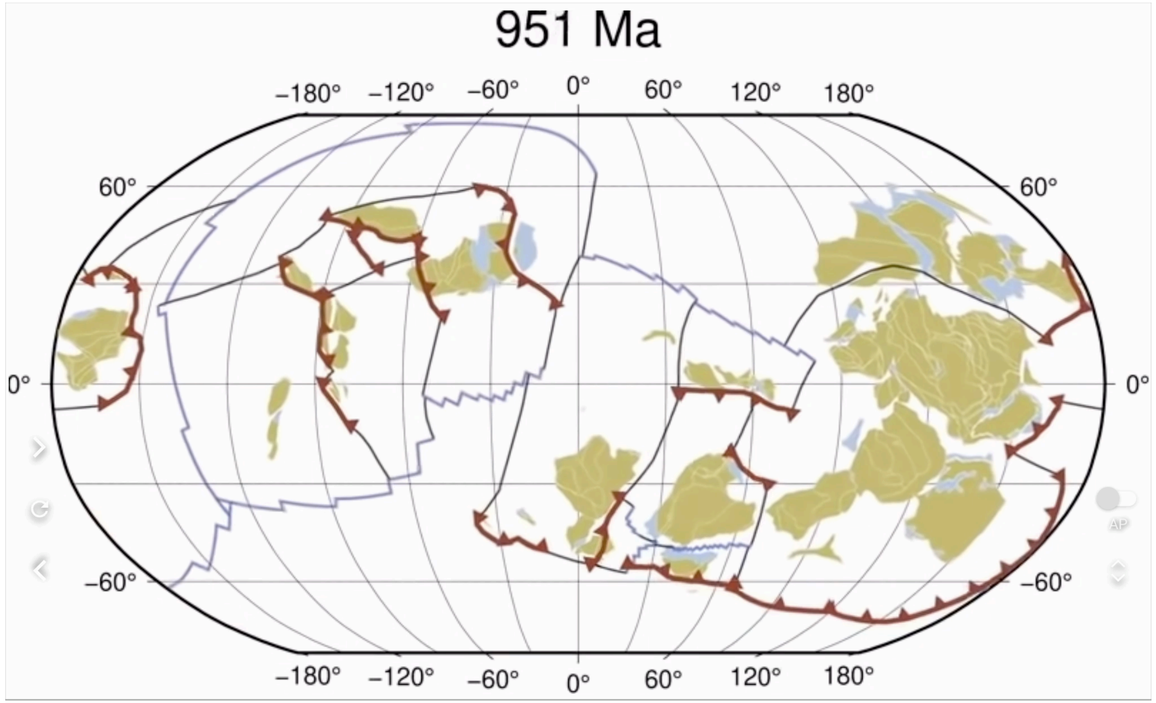
$$\rho_0\,C_p\left(\frac{\partial T}{\partial t} + \mathrm{u}\cdot\nabla T\right) - k\,\nabla^2 T - H = 0$$ Energy

- Boussinesq approximation
- C = bulk compostion
- B = buoyancy number
- H = Heating rate (including from radioactive decay)

How can we simulate their evolution?

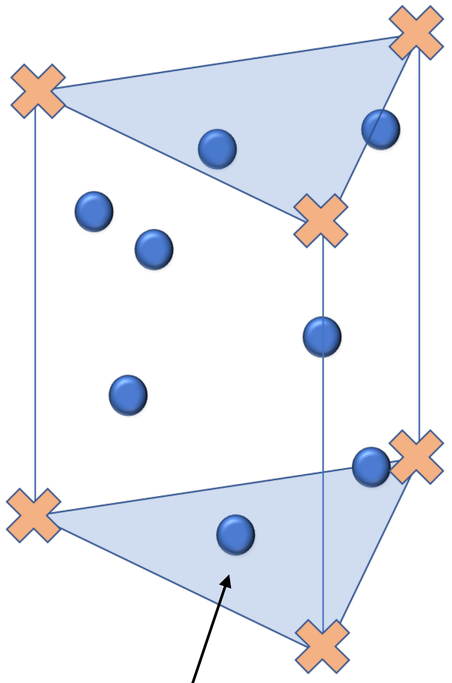
- Circulation – assimilate plate velocities
- Buoyancy drives mantle flow
  - **Thermal**
  - Chemical

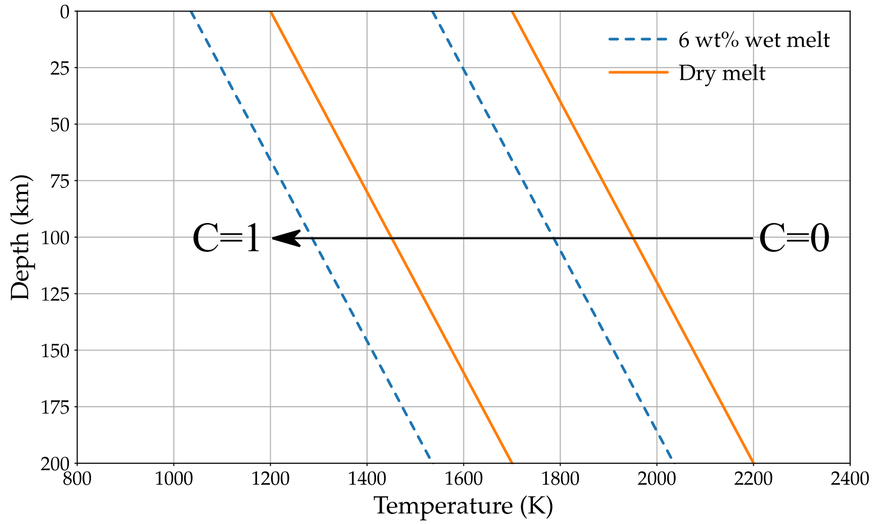




How can we simulate their evolution?

- Circulation – assimilate plate velocities
- Buoyancy drives mantle flow
  - **Thermal**
  - **Chemical**

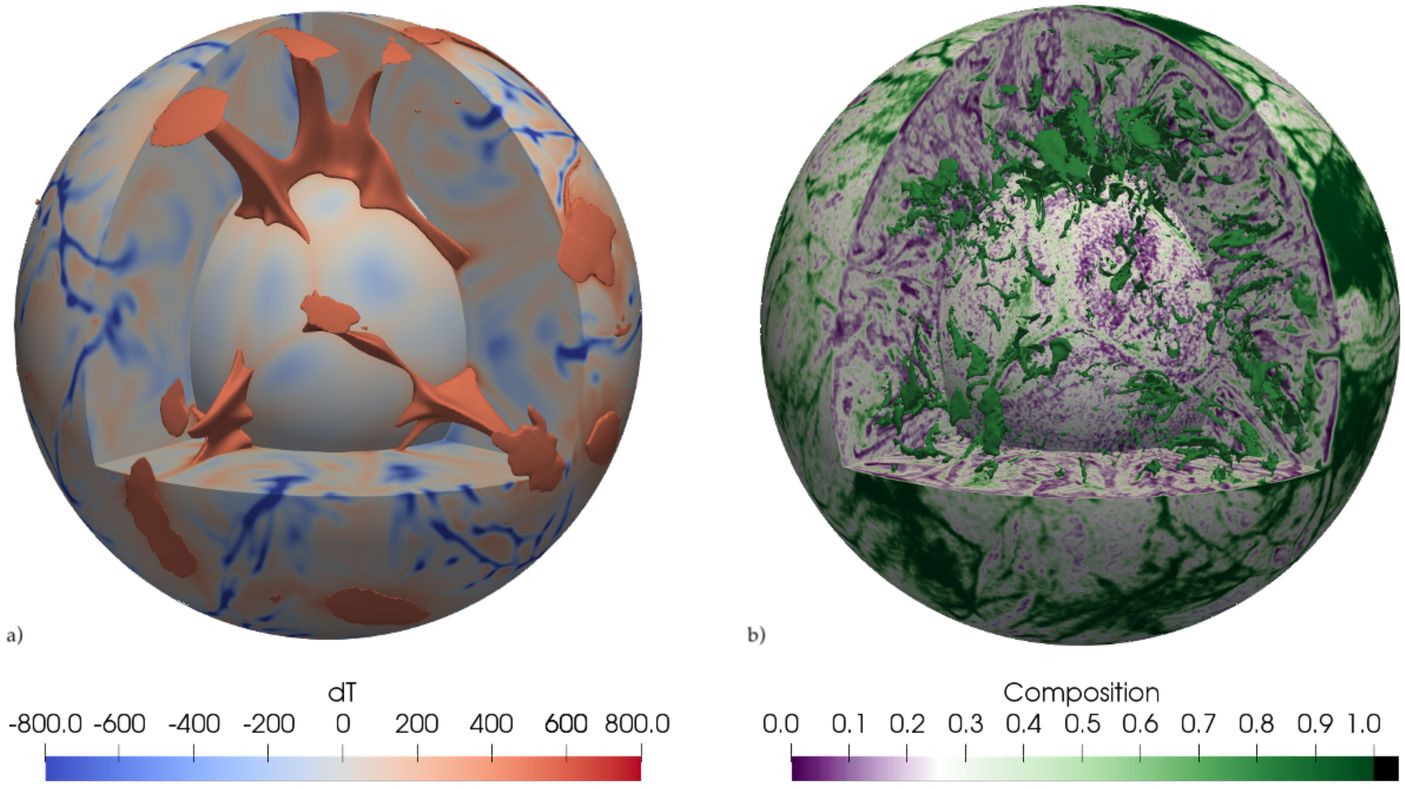




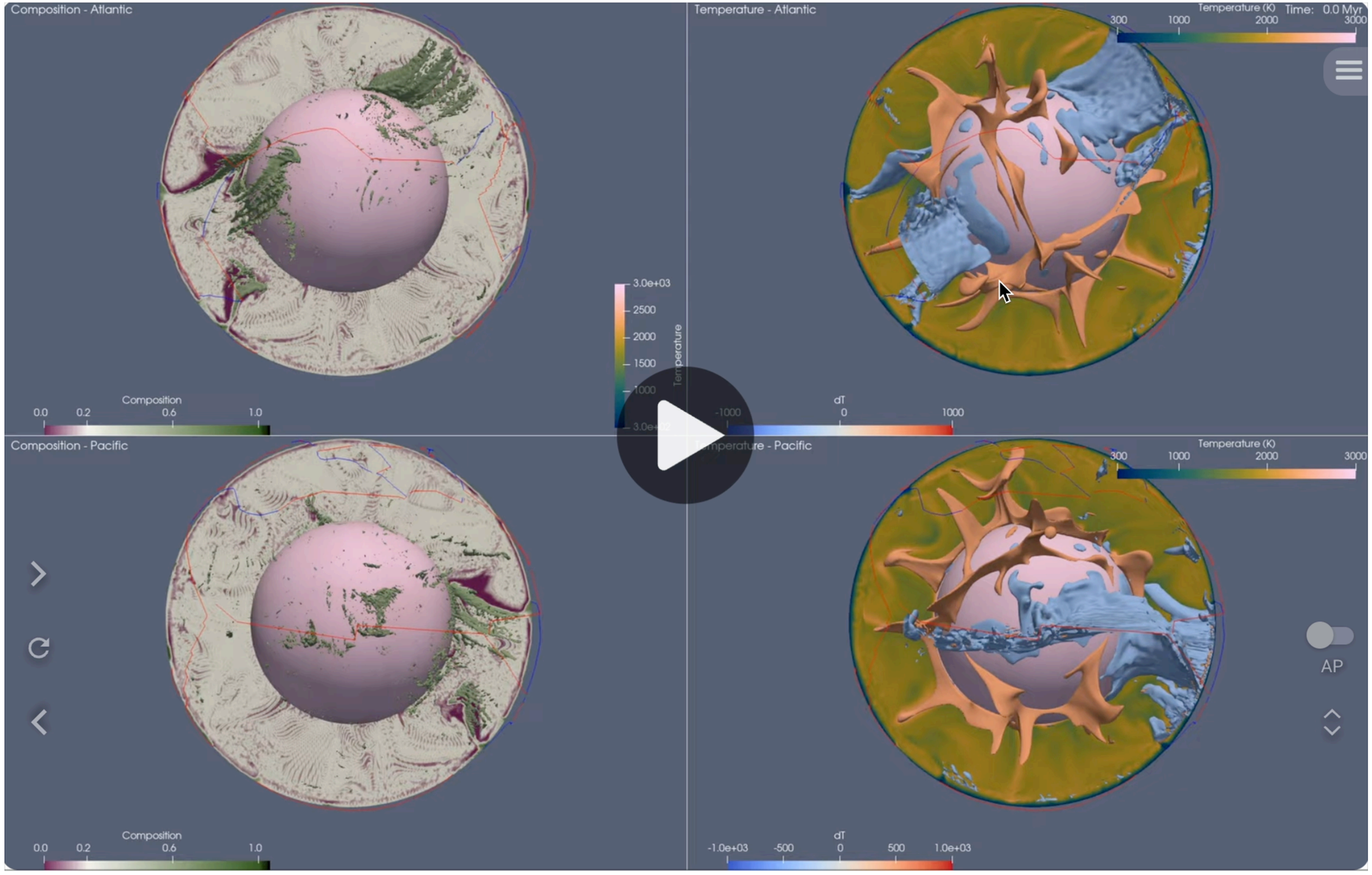
Tracer particle stores bulk (C=0-1)
and isotopic composition

How can we simulate their evolution?

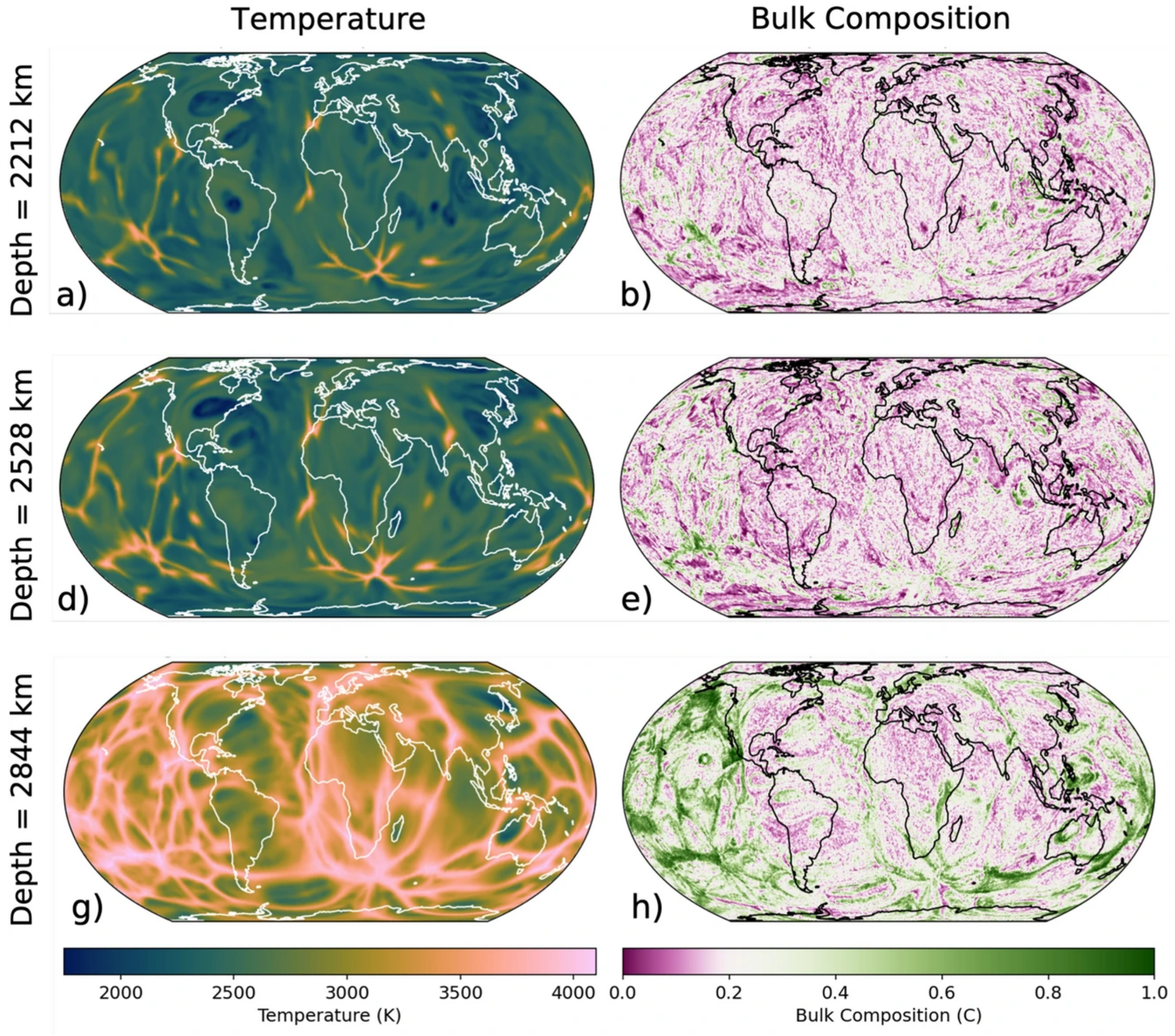
- Circulation – assimilate plate velocities
- Buoyancy drives mantle flow
  - **Thermal**
  - **Chemical**



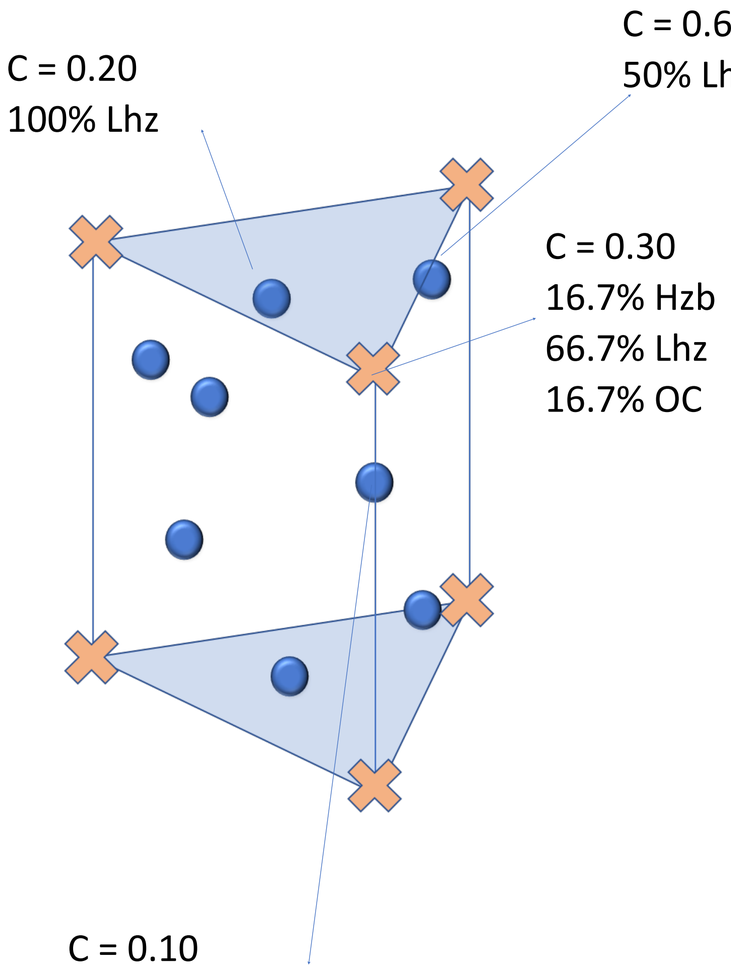
How can we simulate their evolution?

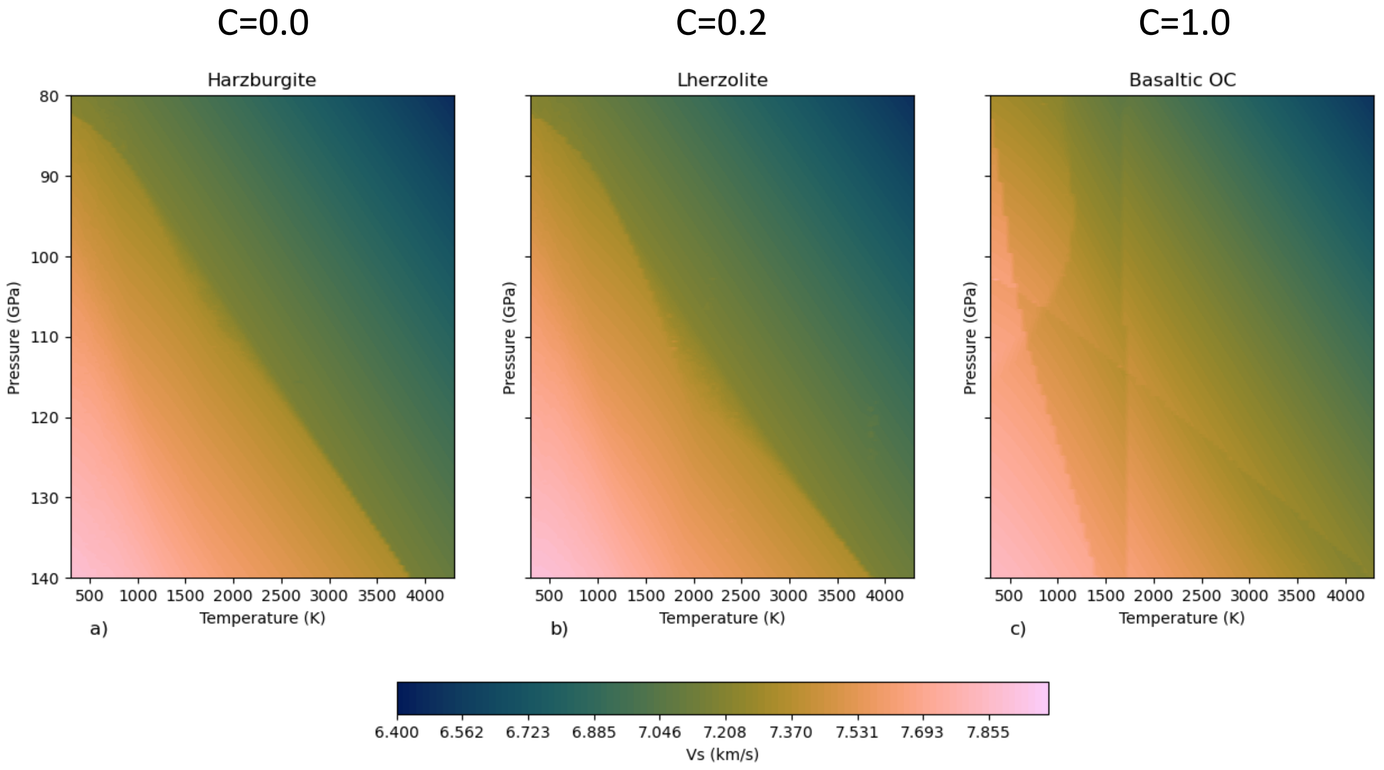


How can we simulate their evolution?

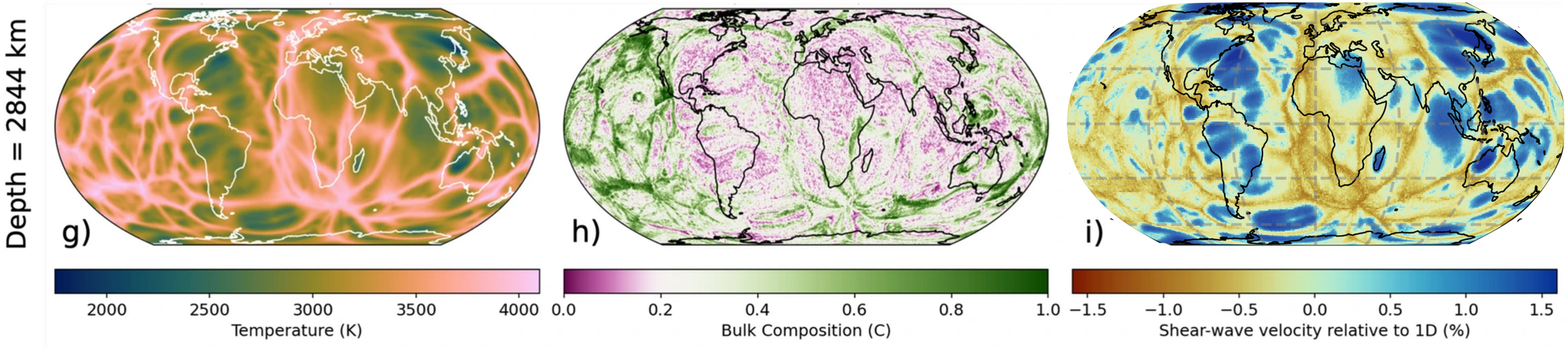


Predicting seismic velocities



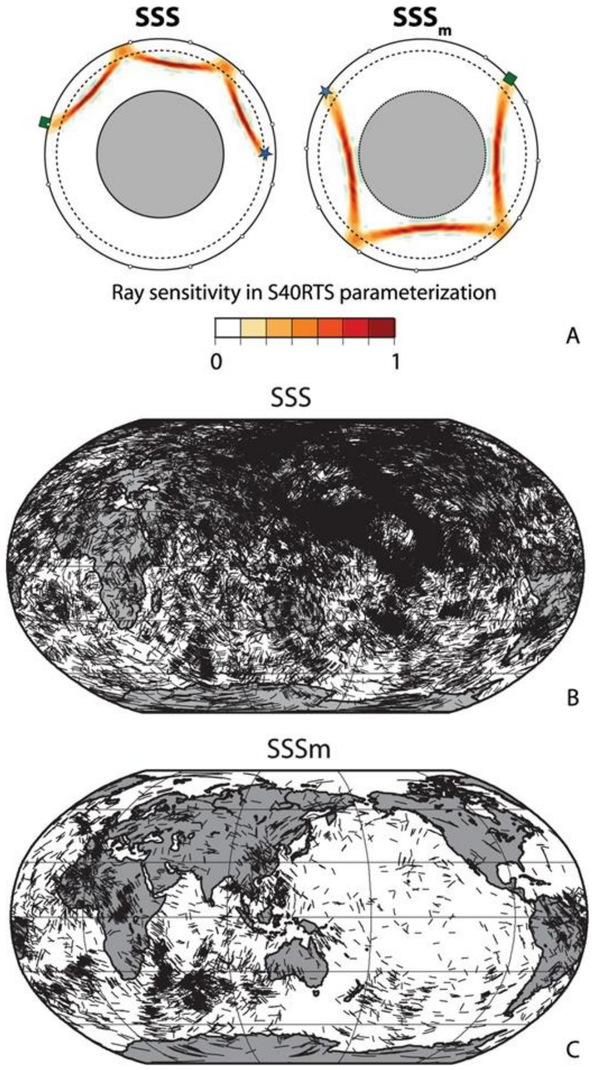


How can we simulate their evolution?



Filtering against seismic tomography

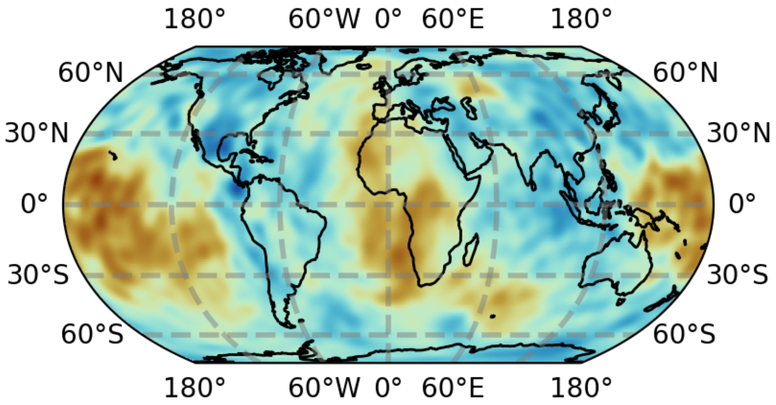
- Filter account for the sparse resolution of tomography model (S40RTS)



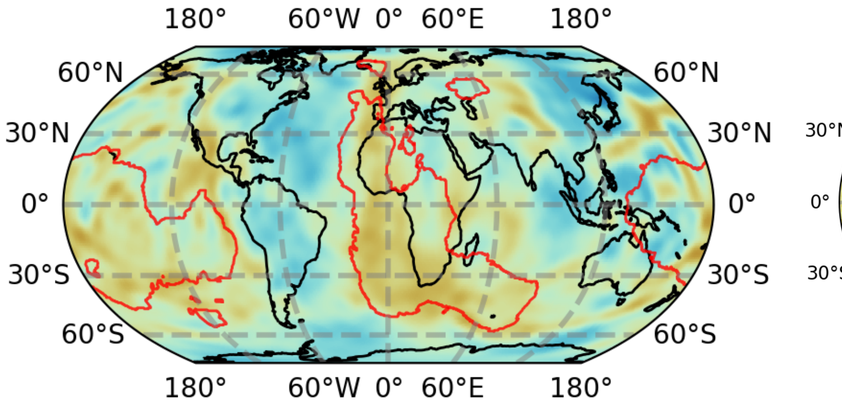
Ritsema et al.,2011

Filtering against seismic tomography

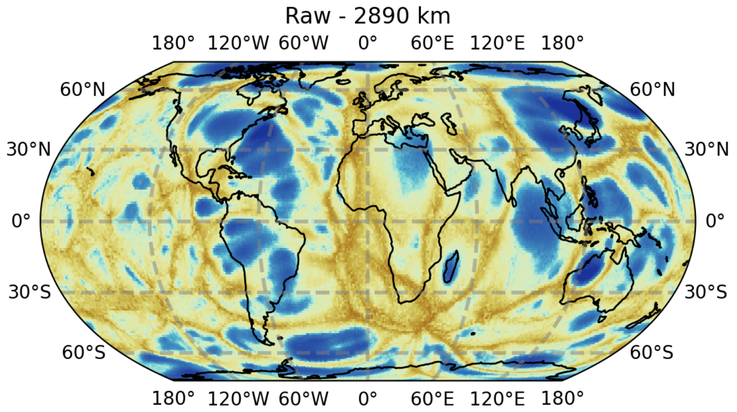
Seismic tomography

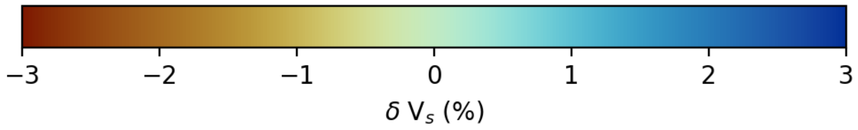


Filtered Model Velocities



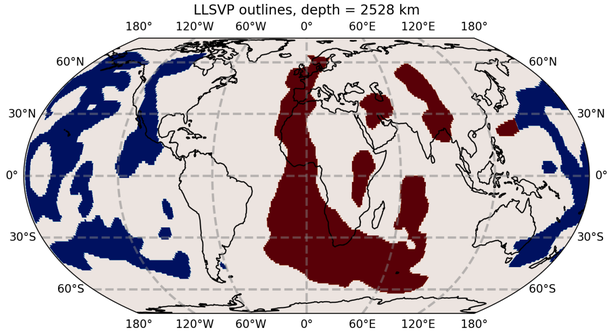
Raw Model Velocities

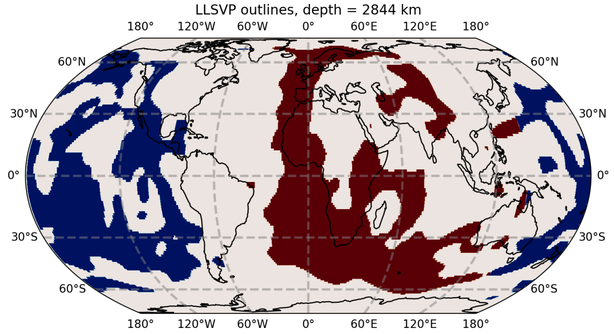


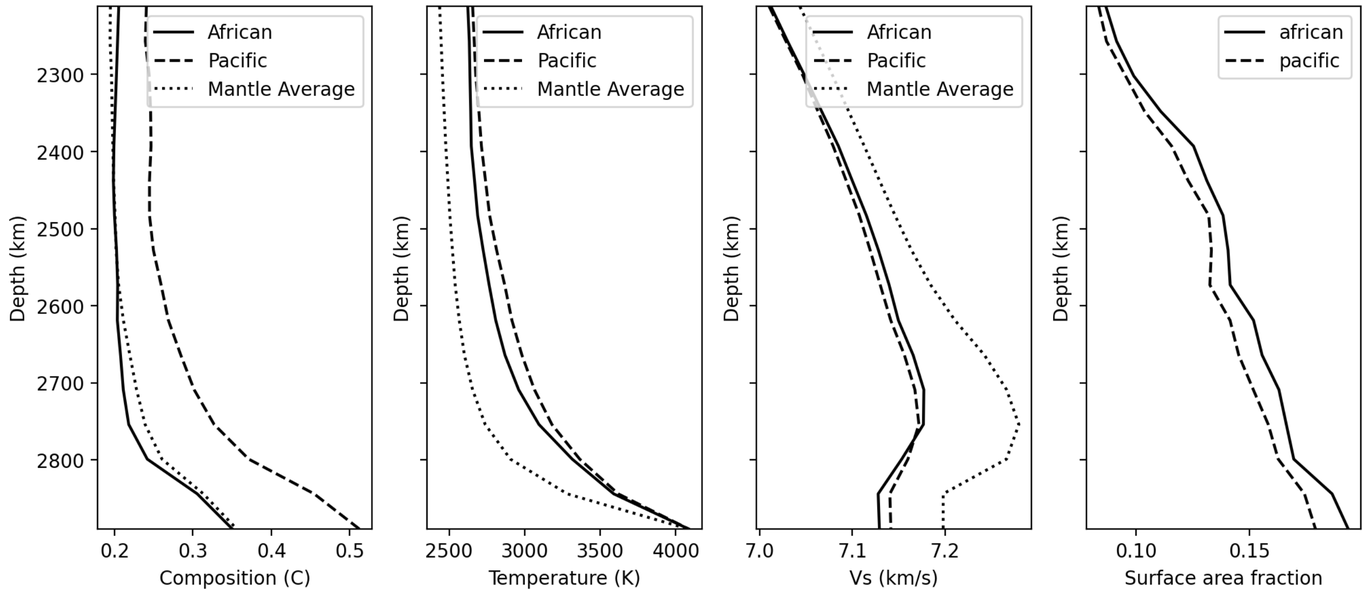


How can we simulate their evolution?

- Similar seismic signature, temperature
- Different compositions

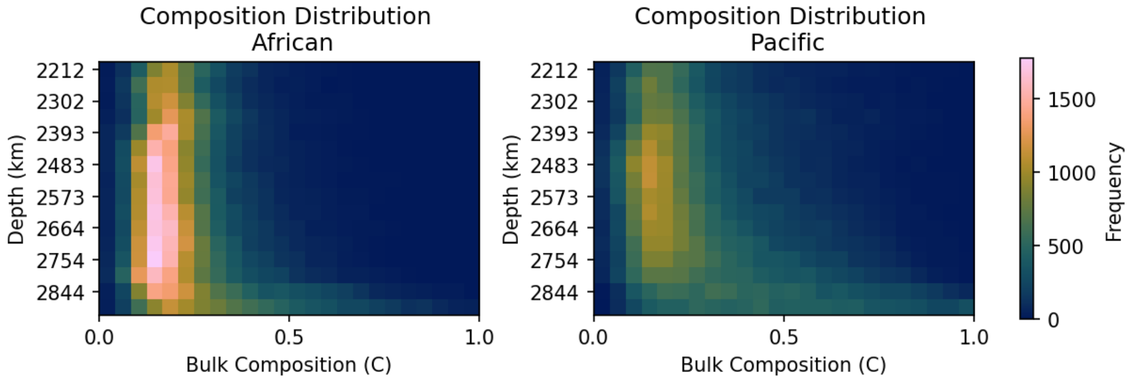


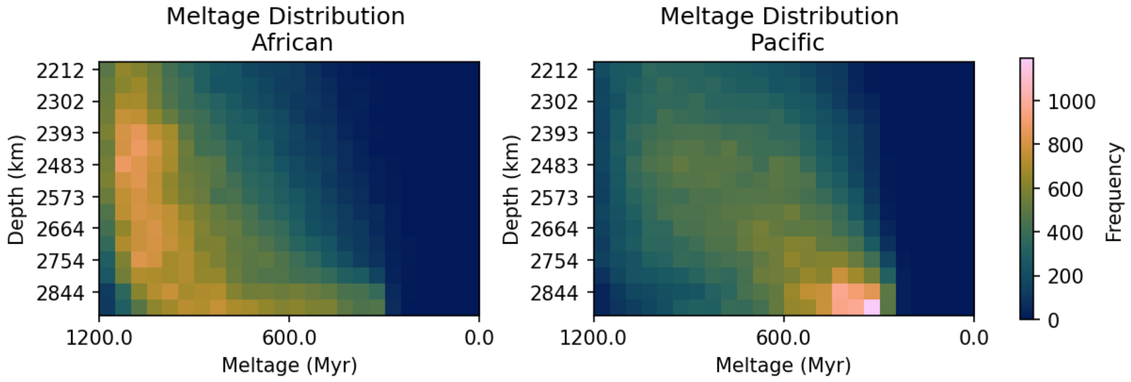


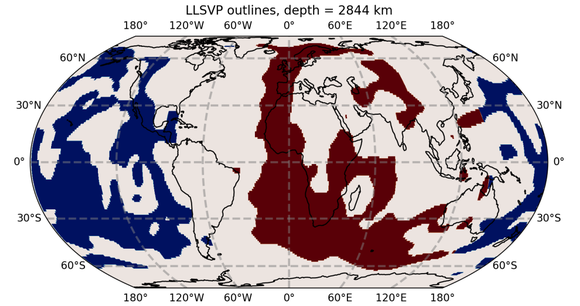


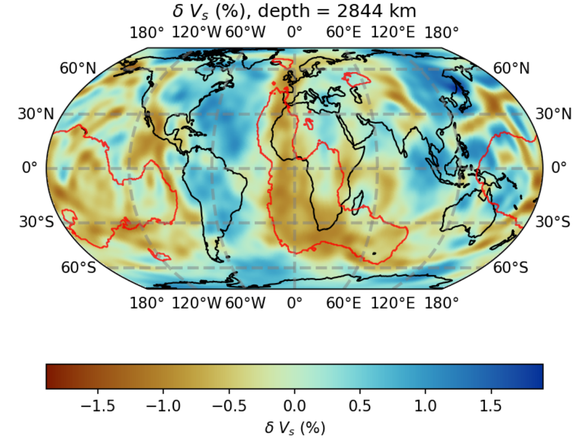
How can we simulate their evolution?

- Similar seismic signature, temperature
- Different compositions
- Different ages



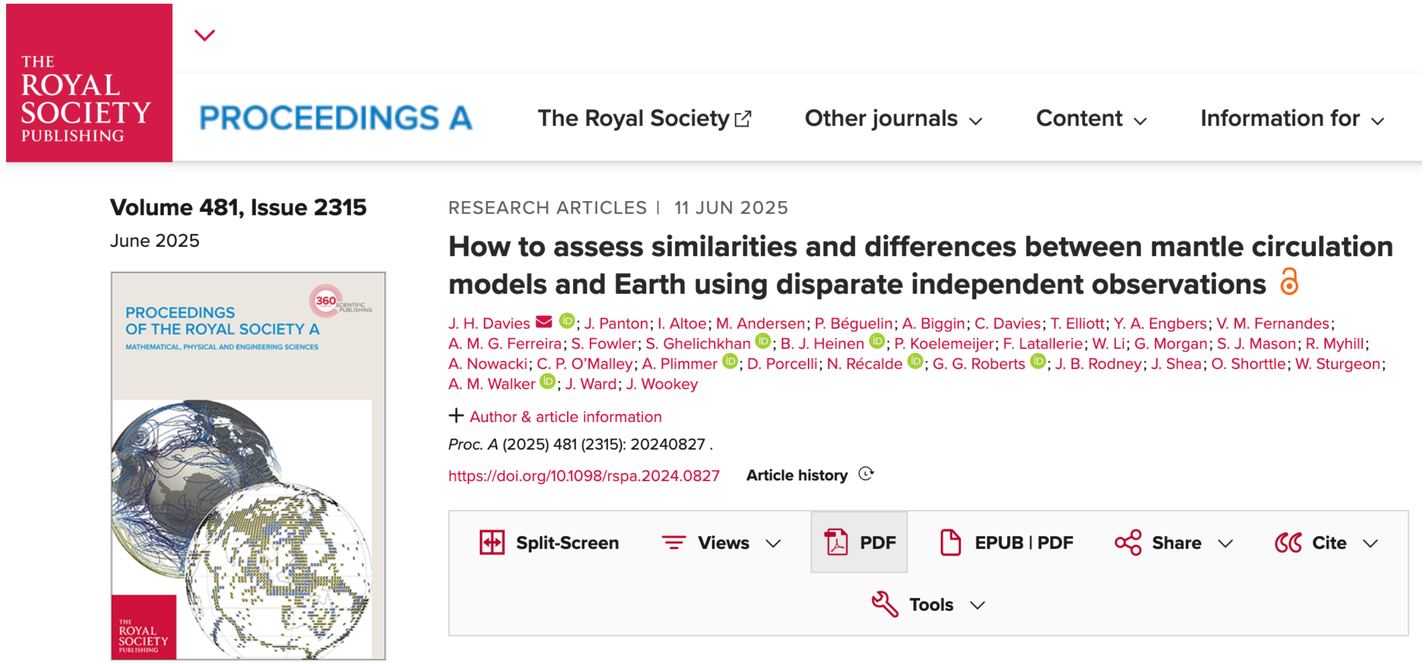






MC2 Project

- Library of 3D mantle circulation simulations
- Exploring a wide range of parameter spaces
- Developed metrics by which MCMs can be assessed against disparate observations
- Thanks to **ARCHER2**!



THE ROYAL SOCIETY PUBLISHING

PROCEEDINGS A | The Royal Society | Other journals | Content | Information for

Volume 481, Issue 2315

June 2025

RESEARCH ARTICLES | 11 JUN 2025

How to assess similarities and differences between mantle circulation models and Earth using disparate independent observations

J. H. Davies; J. Panton; I. Altoe; M. Andersen; P. Béguelin; A. Biggin; C. Davies; T. Elliott; Y. A. Engbers; V. M. Fernandes; A. M. G. Ferreira; S. Fowler; S. Ghelichkhan; B. J. Heinen; P. Koelemeijer; F. Latallerie; W. Li; G. Morgan; S. J. Mason; R. Myhill; A. Nowacki; C. P. O'Malley; A. Plimmer; D. Porcelli; N. Récalde; G. G. Roberts; J. B. Rodney; J. Shea; O. Shorttle; W. Sturgeon; A. M. Walker; J. Ward; J. Wookey

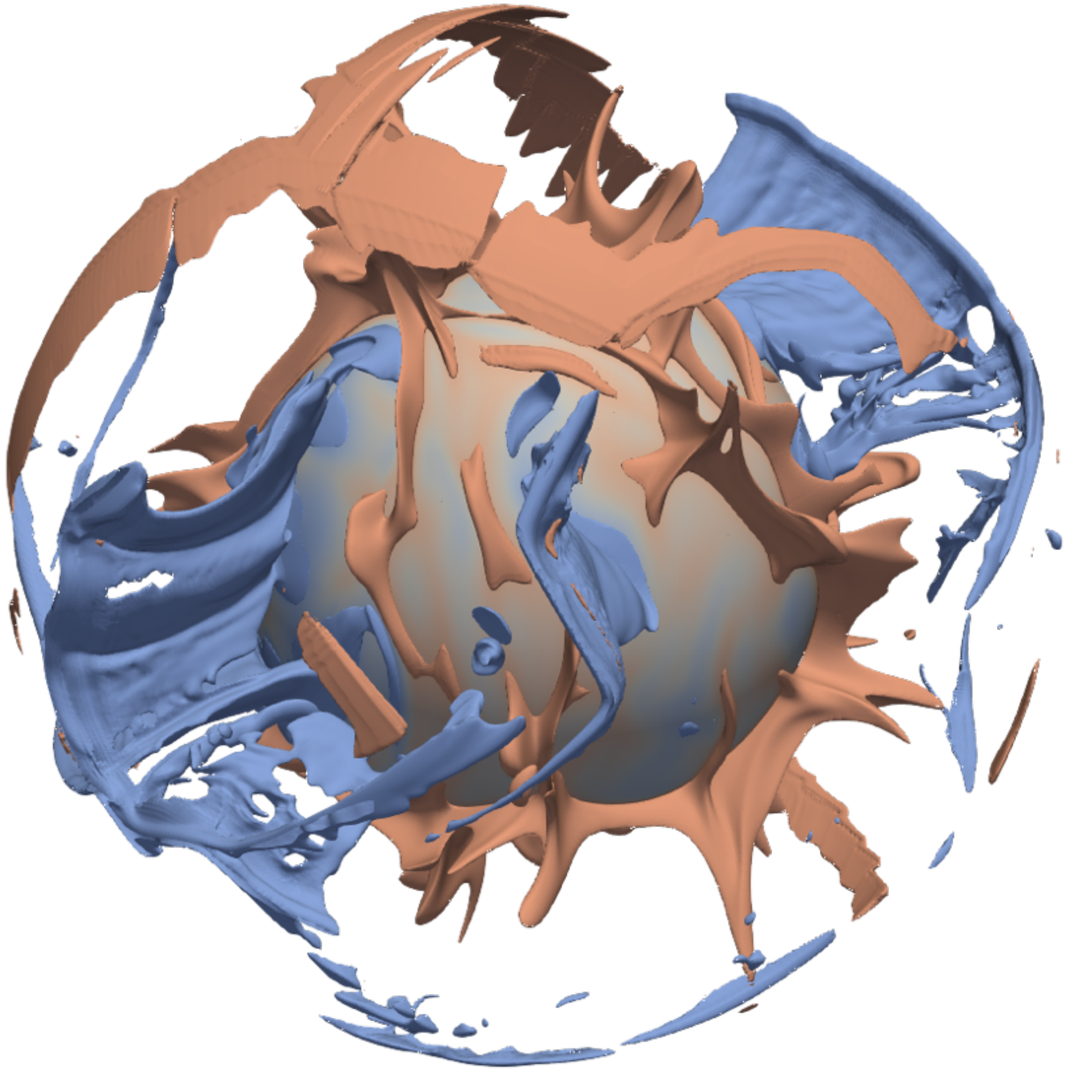
+ Author & article information

Proc. A (2025) 481 (2315): 20240827 .

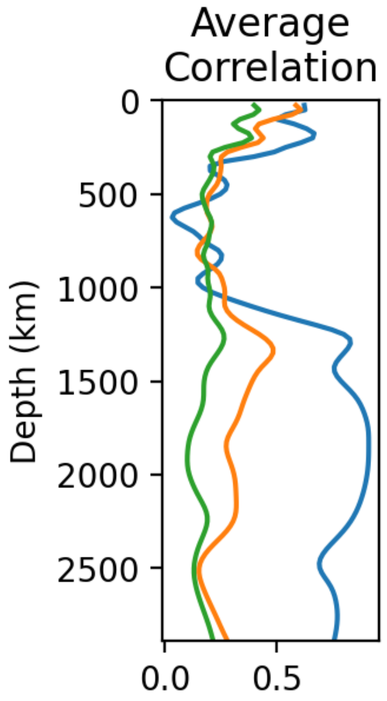
https://doi.org/10.1098/rspa.2024.0827 **Article history**

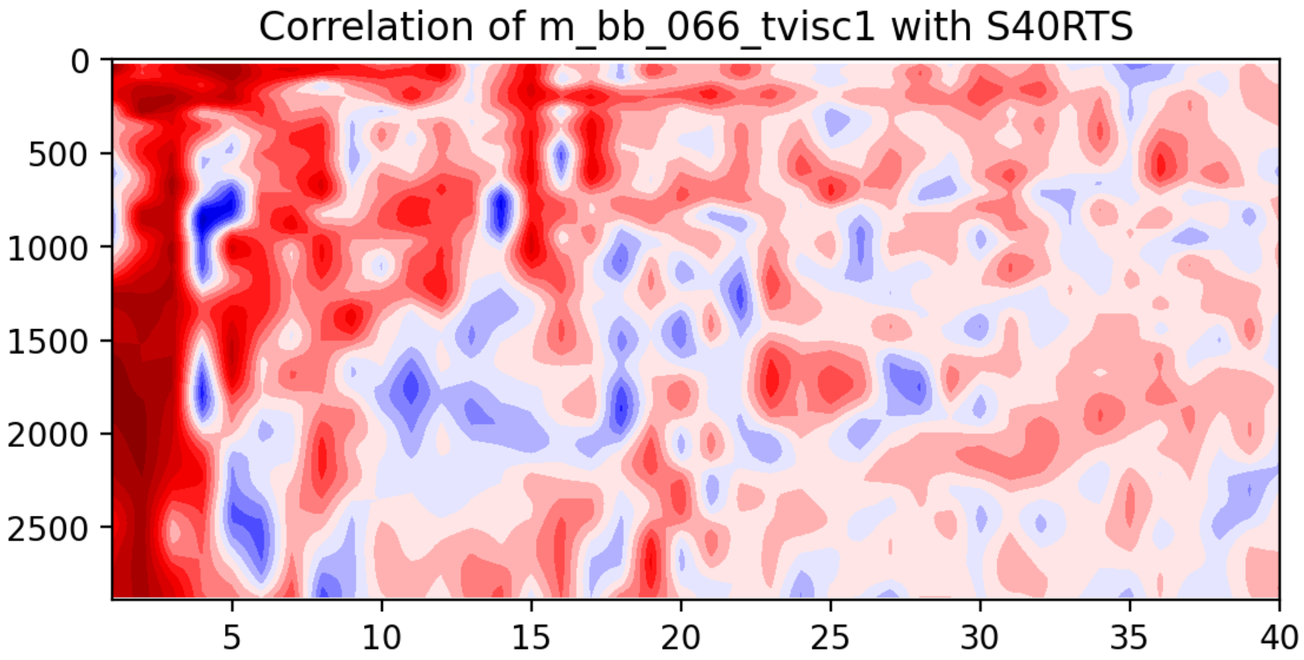
Split-Screen | Views | PDF | EPUB | PDF | Share | Cite | Tools

Thanks!

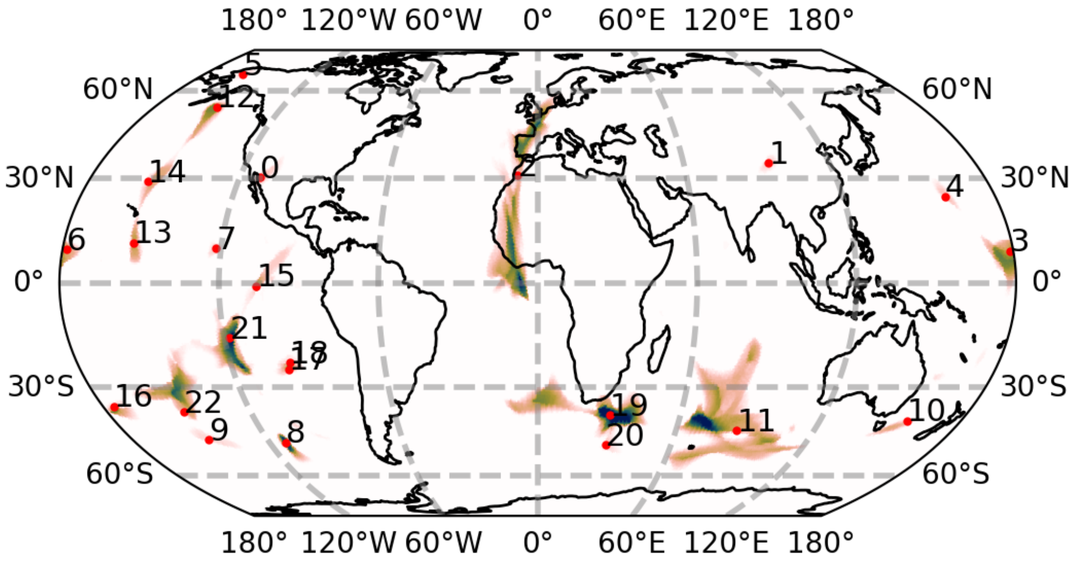


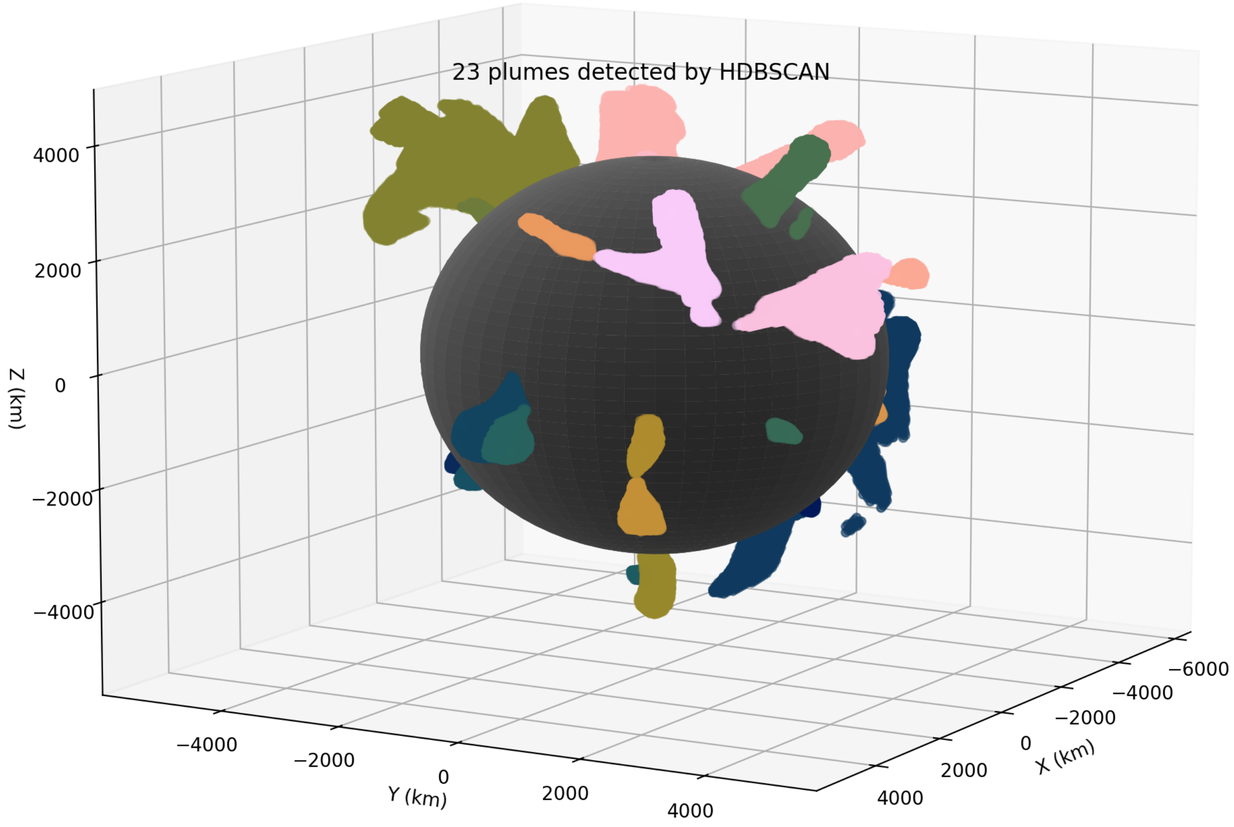
Extra bits


Average
Correlation
0
500
1000
1500
2000
2500
Depth (km)
0.0
0.5

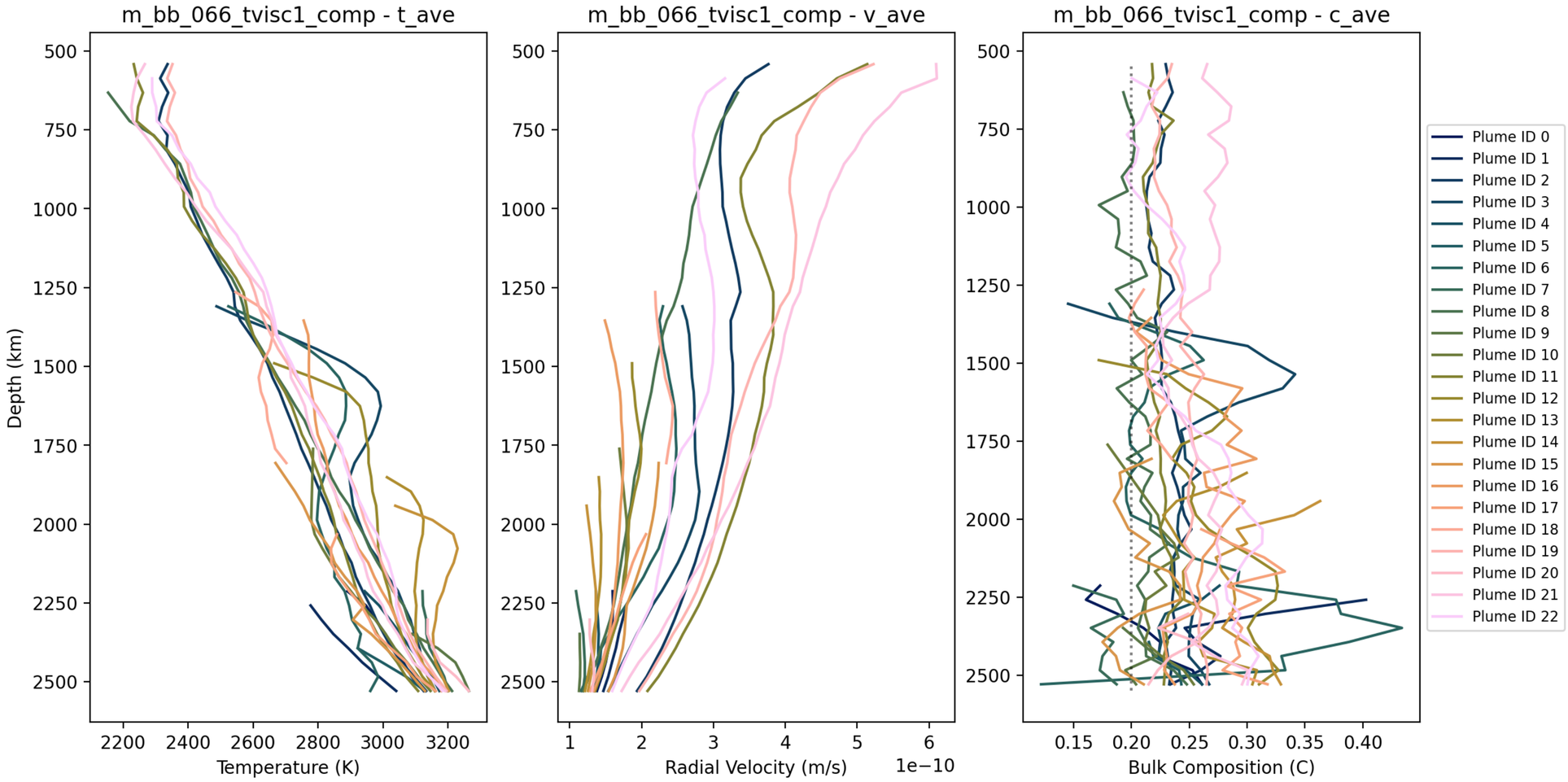

Correlation of m_bb_066_tvisc1 with S40RTS
0
500
1000
1500
2000
2500
5
10
15
20
25
30
35
40

Extra bits

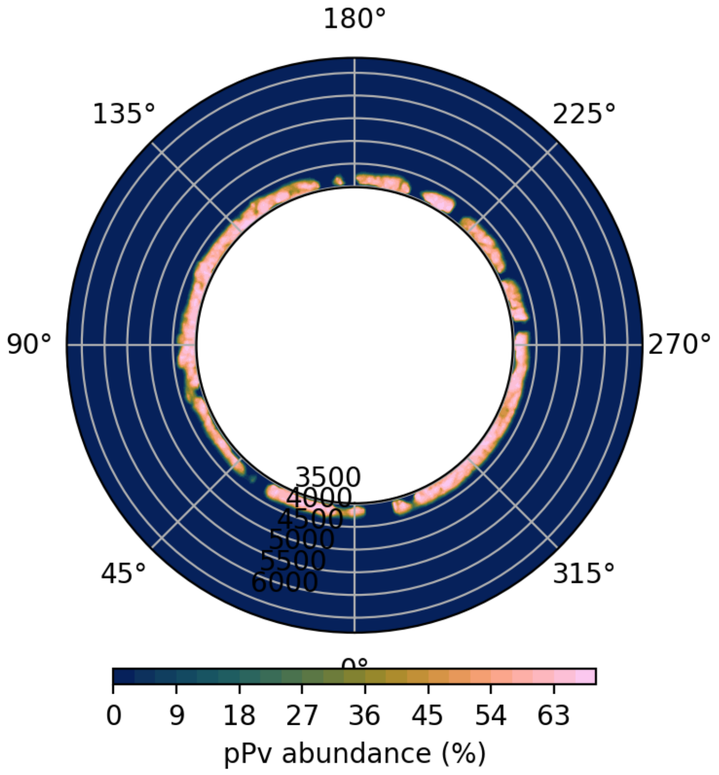

180° 120°W 60°W 0° 60°E 120°E 180°
60°N
30°N
0°
30°S
60°S
0
1
2
3
4
6
7
9
8
10
11
12
13
14
15
16
17
18
19
20
21
22

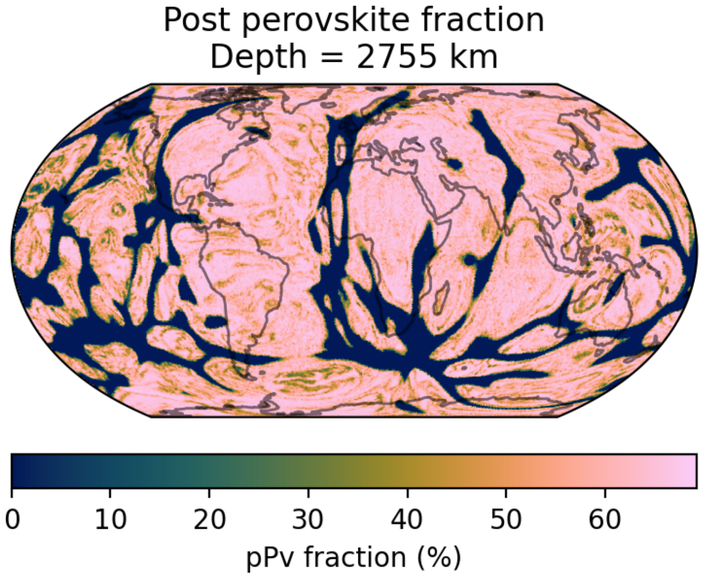

23 plumes detected by HDBSCAN
Z (km)
4000
2000
0
−2000
−4000
Y (km)
−4000
−2000
0
2000
4000
X (km)
−6000
−4000
−2000
0
2000
4000

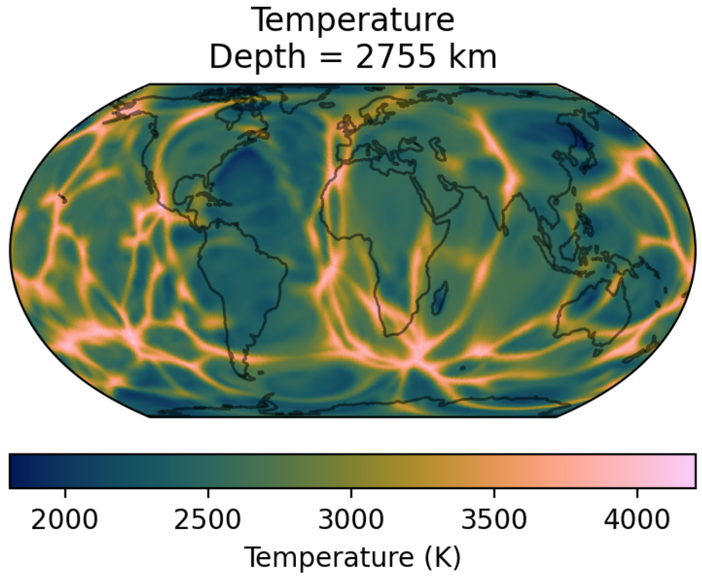
Extra bits


m_bb_066_tvisc1_comp - t_ave
m_bb_066_tvisc1_comp - v_ave
m_bb_066_tvisc1_comp - c_ave
Depth (km)
Temperature (K)
Radial Velocity (m/s)
1e−10
Bulk Composition (C)
Plume ID 0
Plume ID 1
Plume ID 2
Plume ID 3
Plume ID 4
Plume ID 5
Plume ID 6
Plume ID 7
Plume ID 8
Plume ID 9
Plume ID 10
Plume ID 11
Plume ID 12
Plume ID 13
Plume ID 14
Plume ID 15
Plume ID 16
Plume ID 17
Plume ID 18
Plume ID 19
Plume ID 20
Plume ID 21
Plume ID 22

Extra bits


180°
135°
225°
90°
270°
45°
315°
0°
3500
4000
4500
5000
5500
6000
0
9
18
27
36
45
54
63
pPv abundance (%)


Post perovskite fraction
Depth = 2755 km
0
10
20
30
40
50
60
pPv fraction (%)


Temperature
Depth = 2755 km
2000
2500
3000
3500
4000
Temperature (K)