Mapping CMB heat flux from seismic tomography

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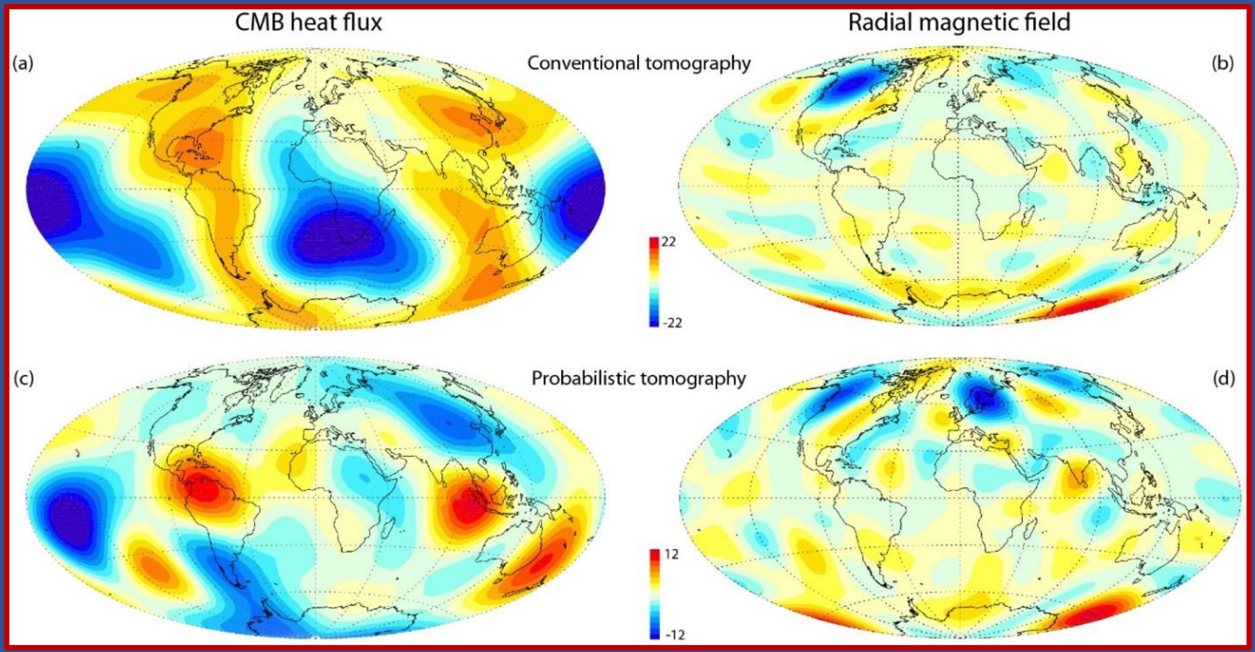


ANR DYRE-COMB kick-off meeting, July 7th 2023

Motivations

- Heat flux at CMB (mantle-side), Φ_{CMB} = kdT/dr, and its variations (spatial and temporal) impact core dynamics.

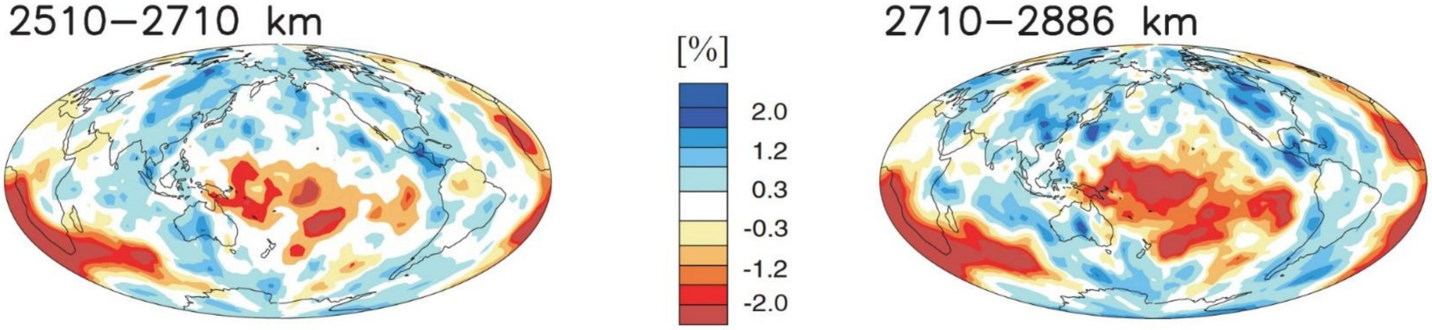
- No direct measurements of CMB heat flux. Need to access temperature gradient and its spatial variations.

- Temperature changes : may be inferred from seismic tomography and appropriate modelling.

First order approximation : convert lower mantle tomography ($d\ln V_S$) assuming that seismic velocity are purely thermal in origin. Then :

$$d\ln V_S \sim dT_{CMB} \sim \Phi_{CMB}$$

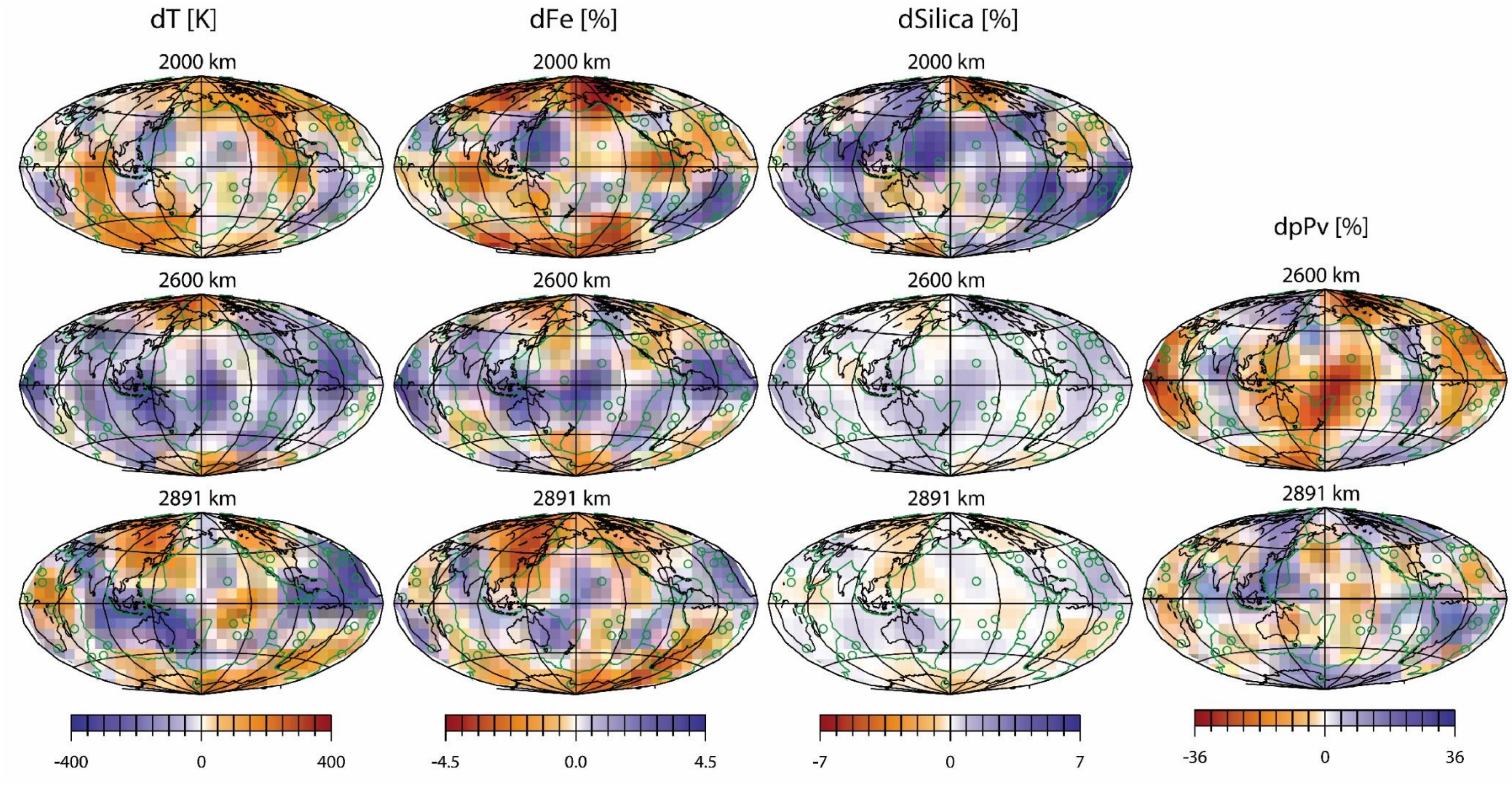
- But : seismic velocity anomalies are unlikely purely thermal in origin ; chemical source is needed to explain them (in particular large low shear wave velocity provinces.



HMSL-S, *Houser et al. (2008)*

Probabilistic tomography

- V_S, V_P and density from normal modes : resolve thermal and compositional contributions to seismic anomalies.



Mosca et al. (2012)

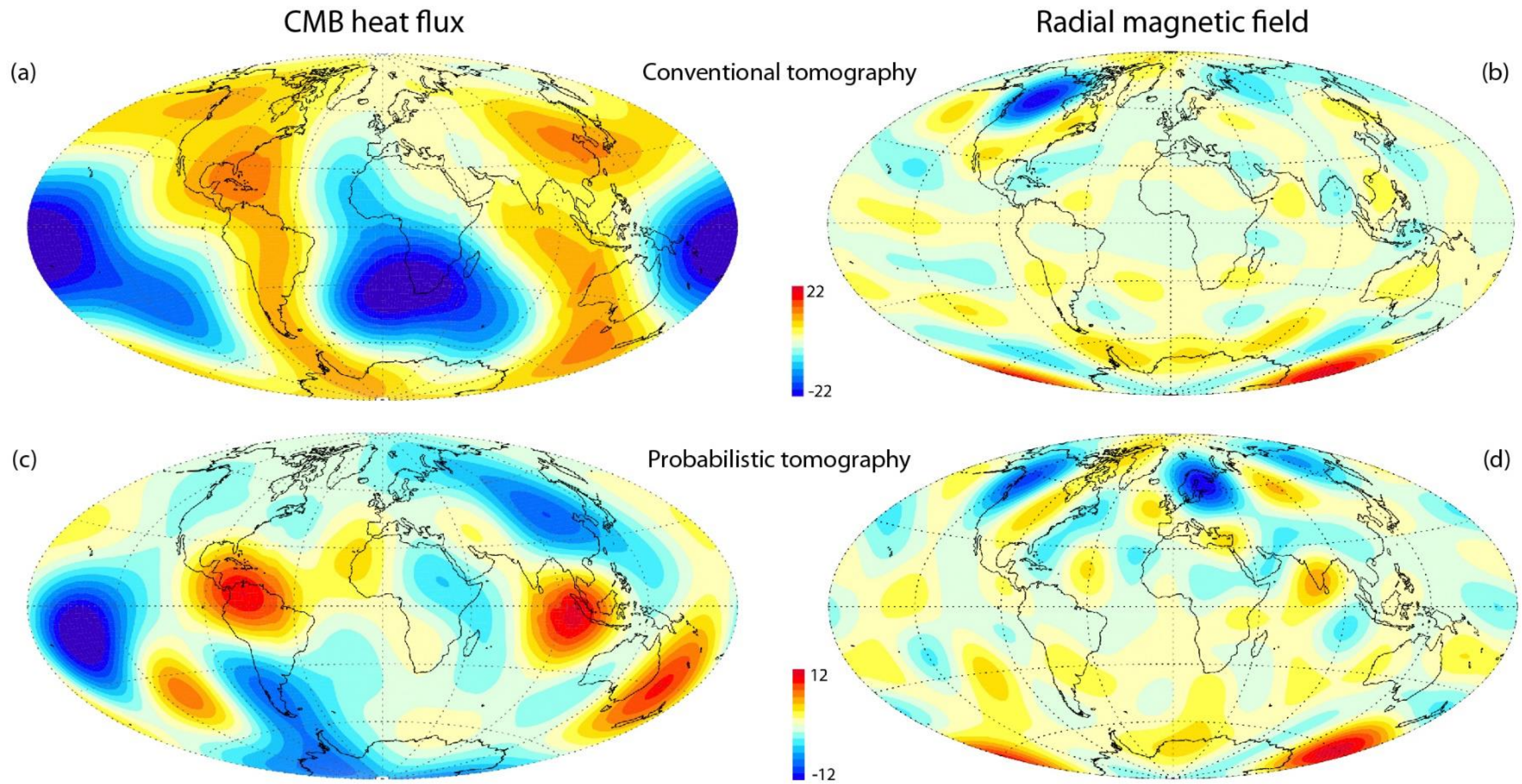
CMB heat flux from probabilistic tomography

- CMB heat flux from probabilistic tomography.

- Impact on core dynamics :

- Larger time averaged convective and magnetic activity at low latitude.

- Low latitude magnetic flux and kinetic energy are more time-dependent.



Amit et al., GJI (2015)

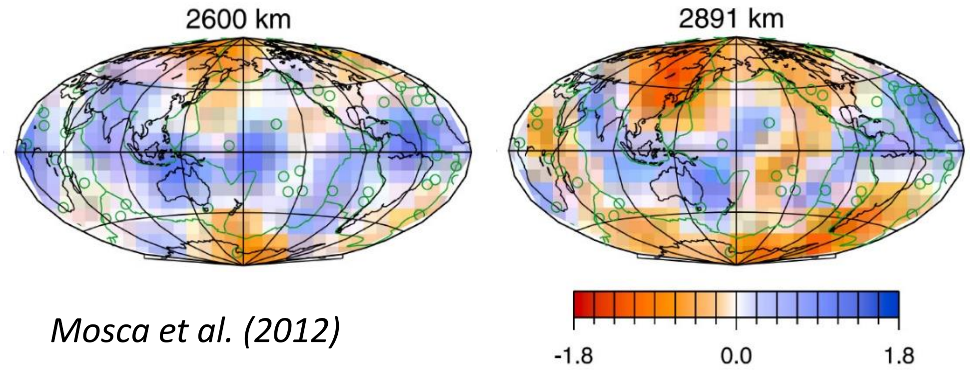
CMB heat flux from probabilistic tomography

▸ Some limitations of probabilistic tomography :

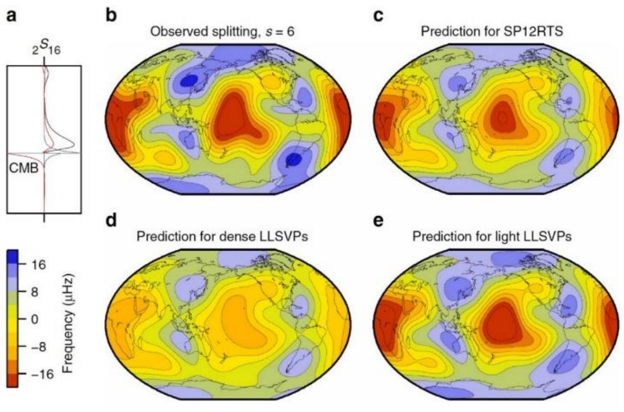
- Low resolution : limited to spherical harmonic degree 2, 4 and 6.

- Assumed mode coupling (e.g., self-coupling, narrow band, …) affects structure coefficients, and thus density maps (Yang and Tromp, 2015).

- No consensus : Stoneley modes suggest lighter LLSVPs (Koelemeijer et al., 2017), while other modes suggest heavier LLSVPs (Trampert et al., 2004, Mosca et al., 2012).



Mosca et al. (2012)



Koelemeijer et al. (2017)

▸ Alternative approach : mapping CMB heat flux from thermo-chemical structure deduced from simulations of mantle convection.

- Simulations of convection predict temperature, phase (post-perovskite), and compositional fields.

- Calculate synthetic velocity anomalies ($d\ln V_S$) and heat flux (Q_{CMB}) from these fields.

- Infer relationship between synthetic $d\ln V_S$ and Q_{CMB}.

Simulations of thermo-chemical convection

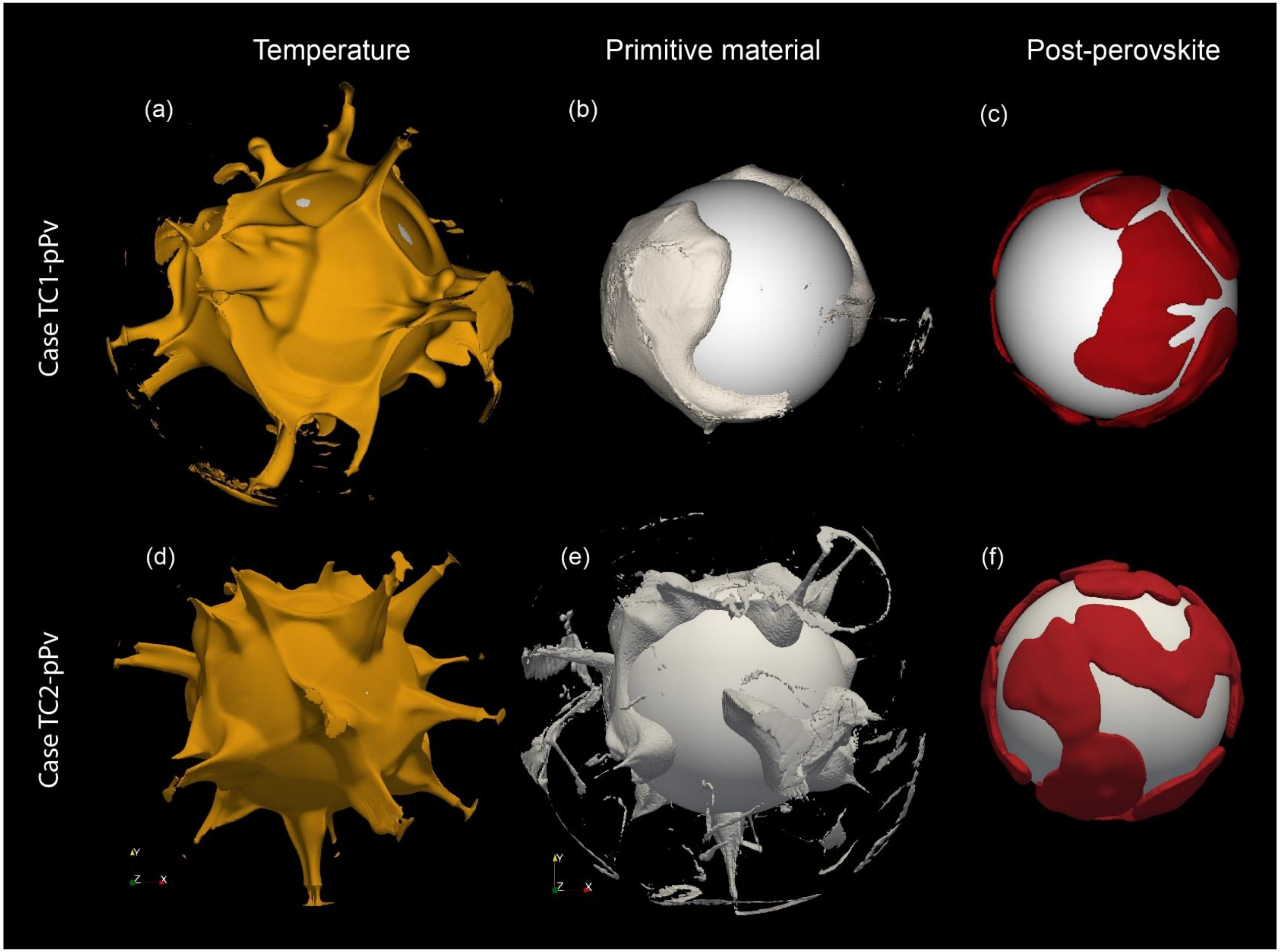
- 3D-spherical simulations using StagYY, with initial layer of dense material (3.5 % in volume) at the bottom of the shell.

- Post-perovskite phase is included in 4 simulations, with Clapeyron in the range 8-16 MPa/K. Controls the height and thickness of pPv-lens above CMB.

- Viscosity depends on temperature (E_a, modelling activation energy) : influence thermo-chemical structure (low temperature-dependence leads to less stable piles).

Case	E_a	pPv	Γ_{pPv} (MPa/K)	<T> (K)	$\langle \Phi_b \rangle$ (mW/m²)
A	20.7	no pPv	-	1830	54.8
B	13.8	no pPv	-	1410	67.2
C	20.7	Single crossing	8	1960	90.7
D	13.8	Double crossing	13	1820	127.8
E	20.7	Double crossing	13	2090	114.6
F	20.7	Double crossing	16	2120	119.6

Simulations of thermo-chemical convection

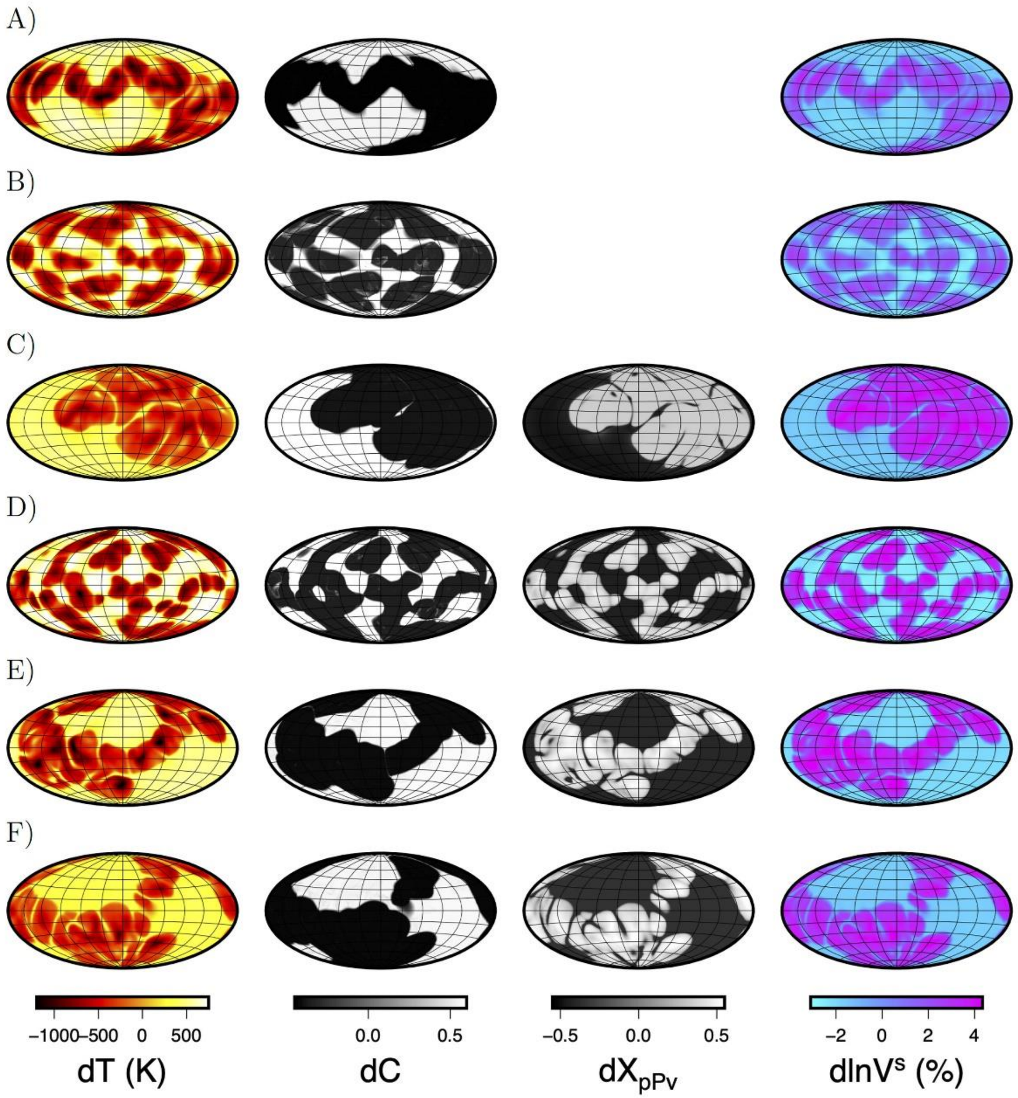


Mapping CMB heat flux from seismic velocities

- Simulations of thermo-chemical convection : temperature, phase (post-perovskite) and compositional fields.

- Calculate seismic shear velocity anomalies averaged in the bottom 200 km …

- ... and CMB heat flux (~ dT).



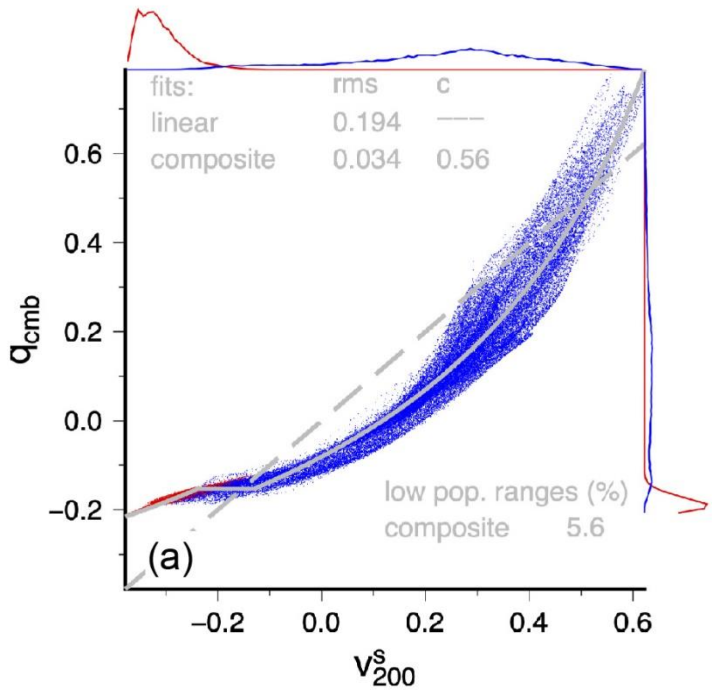
Choblet et al., submitted to PEPI

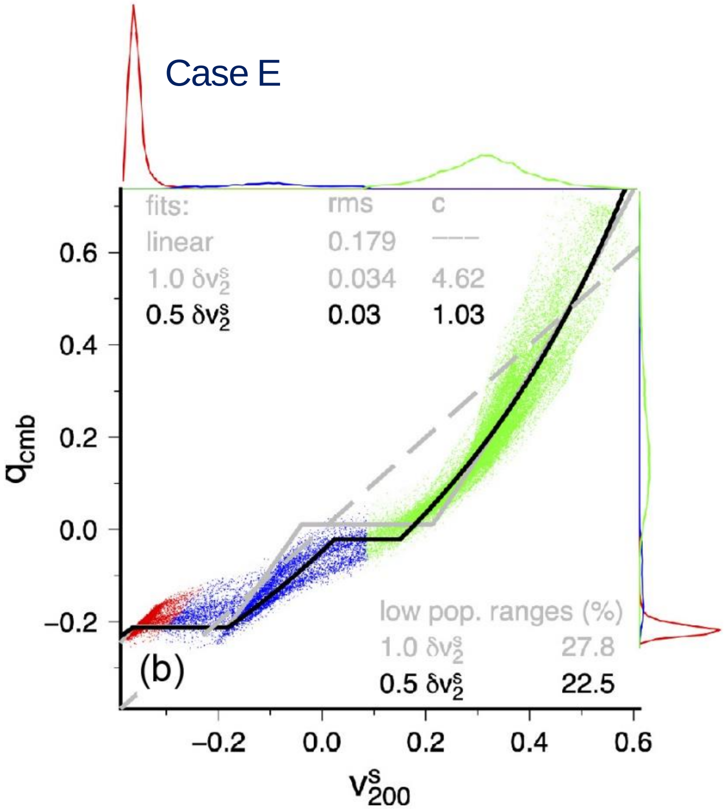
Mapping CMB heat flux from seismic velocities

- Determine synthetic relationships (mappings) between seismic velocities and heat flux.

Case A

Case E



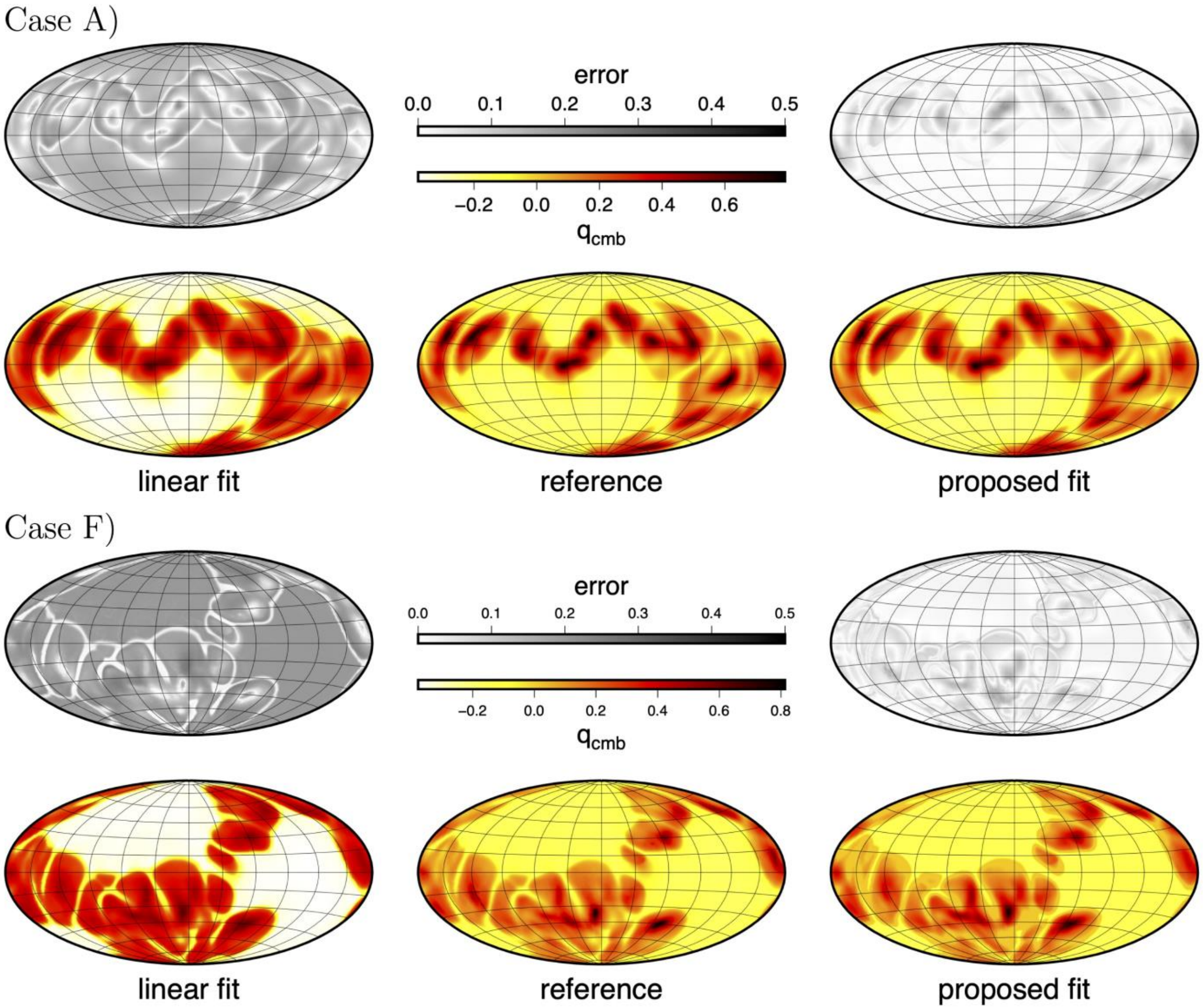


Choblet et al., submitted to PEPI

$$q = \frac{c v_T}{1 - v_T + c}$$

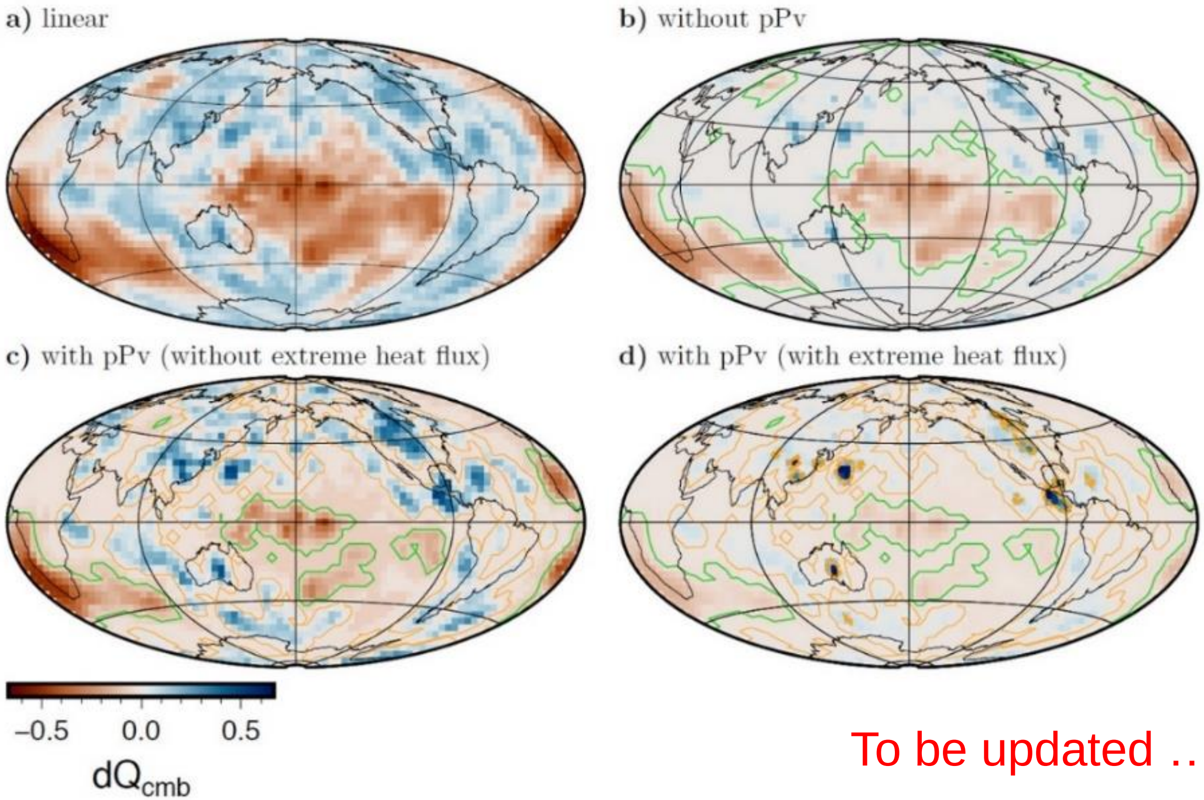
v_T : normalized thermal component of velocity anomaly.

Mapped CMB heat flux



Mapped CMB heat flux

- Mappings can be applied to available seismic tomography (e.g., Houser et al., 2008) to recover Earth's CMB heat flux.



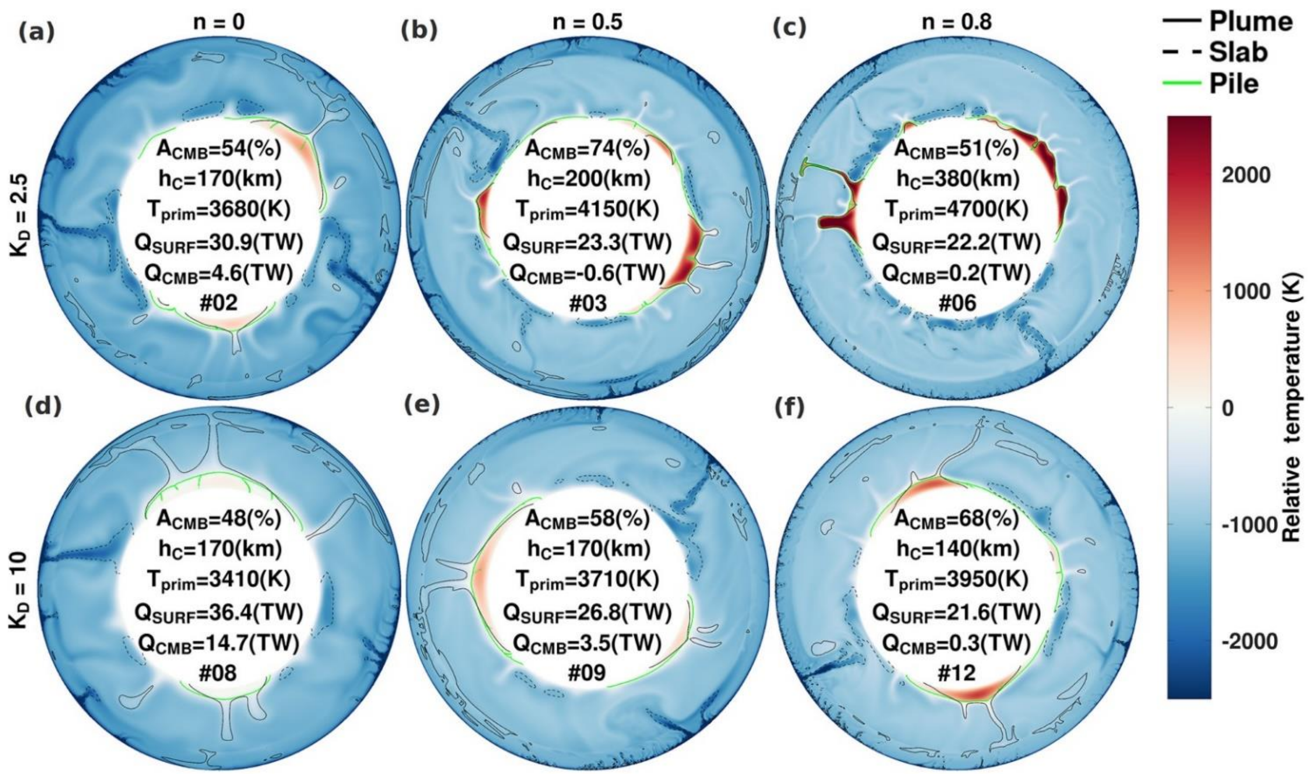
To be updated …

- Low heat flux anomalies beneath LLSVPs are attenuated, while large heat flux patches are enhanced.
- The presence of pPv further attenuates the low heat flux anomalies within LLSVPs

Perspectives

▸ Account for changes in thermal conductivity :

- In heat flux calculations : conductivity decreases with increasing temperature and increasing iron content.
- In numerical simulations : thermo-chemical structure affected by variations in conductivity.



Guerrero et al., Solid Earth (2023)

▸ Apply 'tomographic filter' to shear velocity maps deduced from simulations of convection.

Core-mantle interactions : perspectives

▸ Impact of locally negative CMB heat flux on core dynamics and structure.