GRACE observations of rapid mass variations at the core-mantle boundary during deep mantle phase transitions in interaction with core flow

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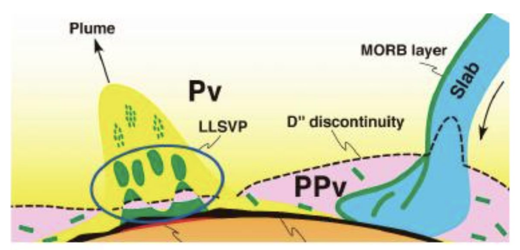
Motivations

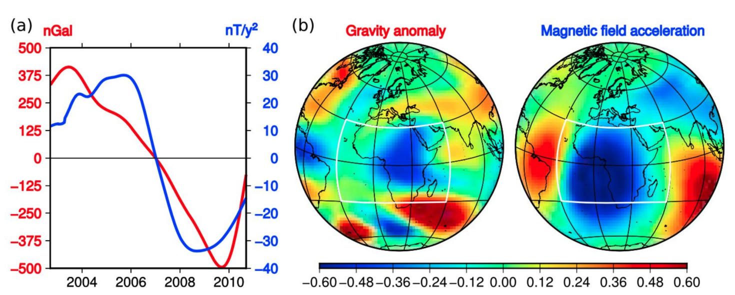
Measurements of the space-time variations of the gravity field from the GRACE & GRACE-FO missions (since 2002) → new constraints on deep mass redistributions ?

Mass redistributions due to variations of the CMB topography: coupling with sudden changes in core flows ?

This could help to better understand sudden changes in the secular variation of the geomagnetic field, the geomagnetic jerks.



(Hirose et al. 2008)



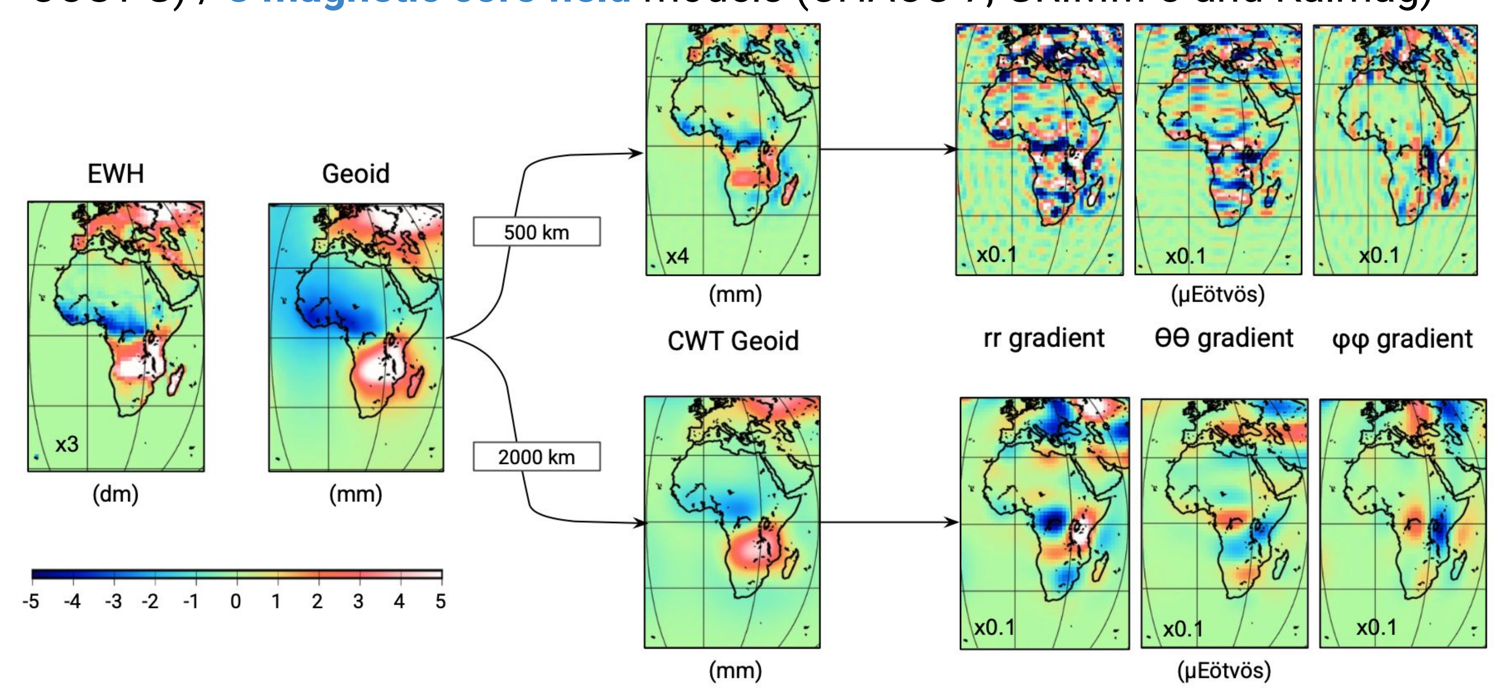
(Mandea et al. 2015)

Objective: Search for gravity signals of mass redistributions at the CMB at timescales of months up to a few years

Gravity signal related to the 2007 magnetic jerk in the Atlantic ocean ?

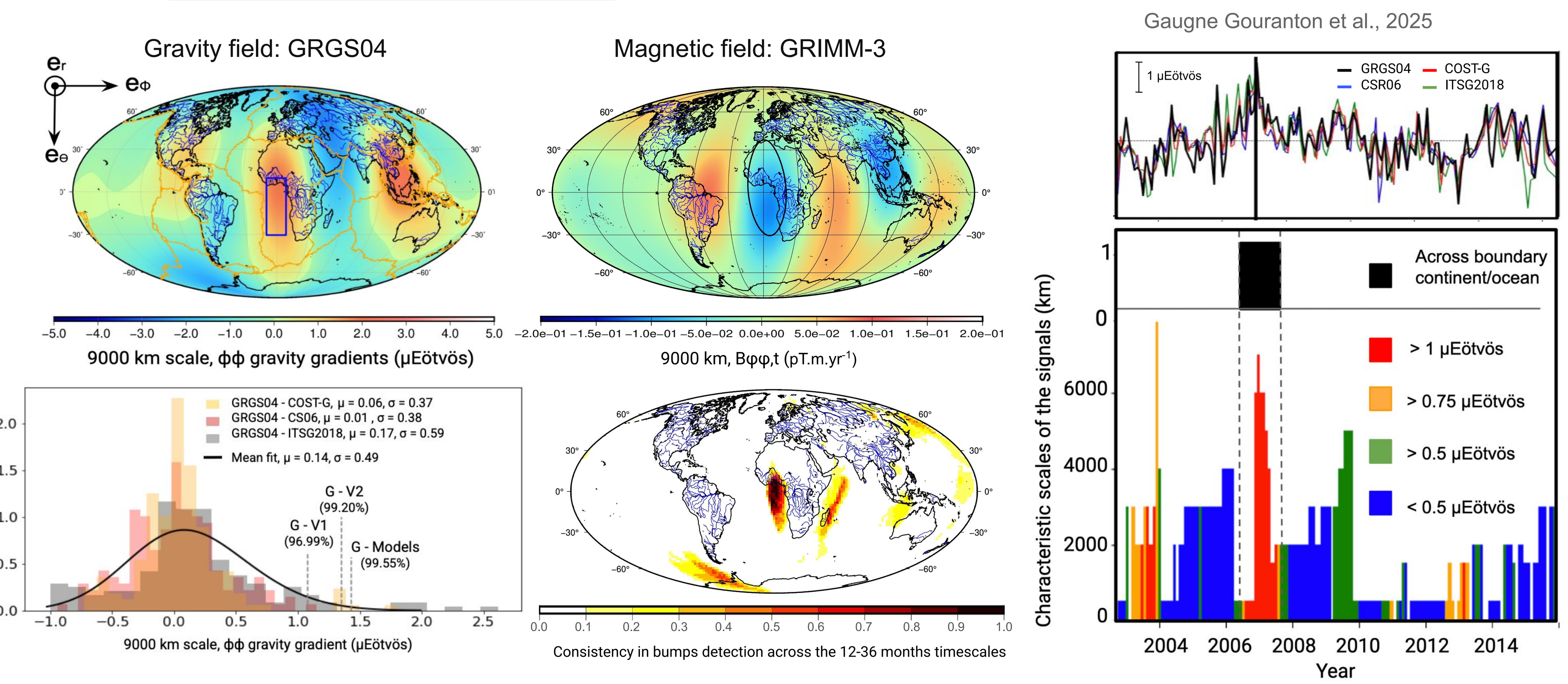
Methods

- 4 GRACE/SLR and pure SLR geoid models (GRGS04, CSR06, ITSG2018 and COST-G) / 3 magnetic core field models (CHAOS-7, GRIMM-3 and Kalmag)



- Filter the geoid at different spatial scales using a wavelet analysis to focus on large scales which are those of deep signals
- For each scale, the geometry of the signals is described by calculating the gravity gradients in the local spherical frame (no degree 0 or 1 terms)
  → Rotations of the spherical frame to align with the orientation of the signals
- Temporal wavelet transform: search for transient signals maximum over the period September 2006 - April 2007, at monthly to inter-annual timescales

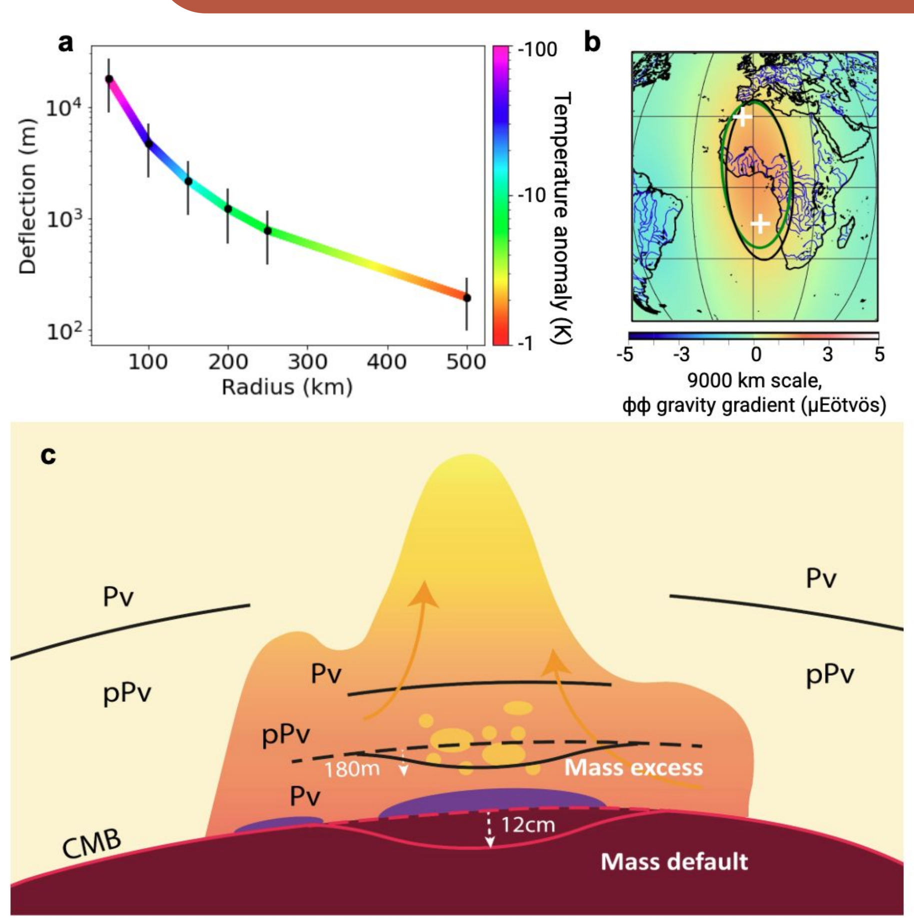
Detection of signal



Anomalous North-South oriented signal across the boundary between the Atlantic ocean and the African continent, with a high intensity at the largest 9000-km spatial scales of the analysis in January 2007 in both magnetic and gravity fields.

- Source in the fluid envelope ? No, different location, characteristic scales, temporal variations
- CMB deflection due to core flow ? The gravity-based CMB topography changes (60cmx5000kmx2000 km) presented here are too large to be explained by the dynamic pressure of core flows.

Mass redistributions at the CMB / in the D" layer



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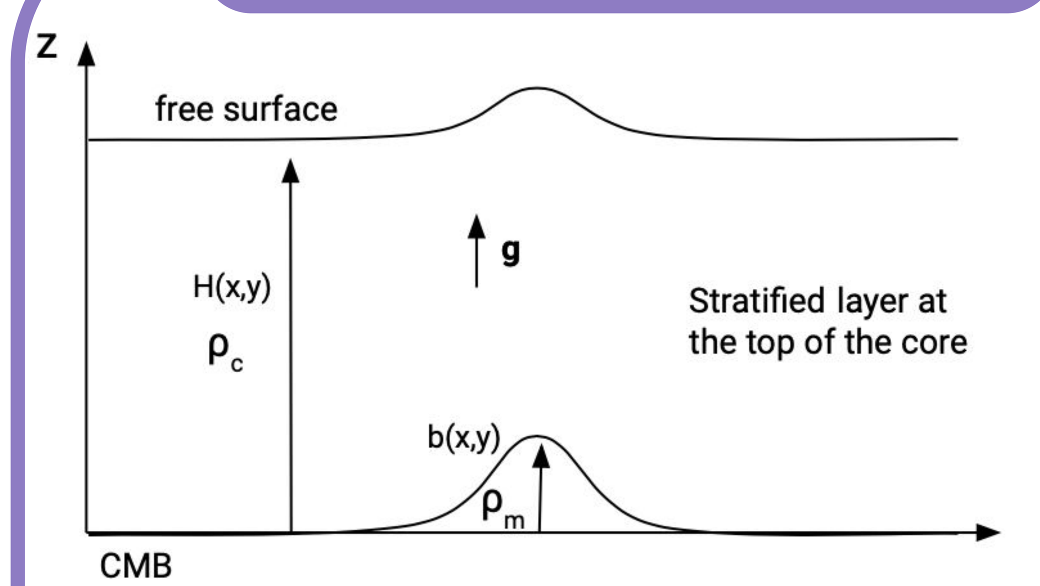
Source in the mantle above the CMB, related to the perovskite (Pv) to post-perovskite (pPv) phase transition:

- Characteristics of the transition: fast (Langrand et al 2019), density contrast (100 kg/m³), location in the D" region
- The depth of the Pv to pPv transition depends on temperature
- **Proposed scenario**: we consider a pPv lens at the base of plumes of the African LLSVP. A slightly colder, rising material transforms from Pv to pPv at greater depth → mass anomaly.
- **Model parameters**: 350 km thick D" layer, phase transition at 50 km above the CMB. Mass source represented by two surfacic caps at locations (4°W,29°N and 5°E,15°S), with radius between 50 and 500 km.

With a -1K thermal anomaly, we can reproduce the characteristics of the 2007 signal. Induced dynamic CMB topography: 12 cm.

In interaction with core flow



$$\begin{cases}
\dfrac{\partial Hu}{\partial t}+\dfrac{\partial}{\partial x}(Hu^2+gH^2/2)+\dfrac{\partial}{\partial y}(Huv)=Hfv-\dfrac{\rho_m}{\rho_c}gH\dfrac{\partial b}{\partial x}\\
\dfrac{\partial Hv}{\partial t}+\dfrac{\partial}{\partial x}(Huv)+\dfrac{\partial}{\partial y}(v^2+gH^2/2)=-Hfu-\dfrac{\rho_m}{\rho_c}gH\dfrac{\partial b}{\partial y}\\
\dfrac{\partial H}{\partial t}+\dfrac{\partial Hu}{\partial x}+\dfrac{\partial Hv}{\partial y}=0\\
\dfrac{\partial B_r'}{\partial t}=-\nabla_H(\mathbf{u_h}B_r)
\end{cases}$$

We show that 10 cm high, 1000km wide CMB topography can leads to 5.10^{-5} m/s for the flow in a 80 km thick stratified layer.

With the induction equation, we find:

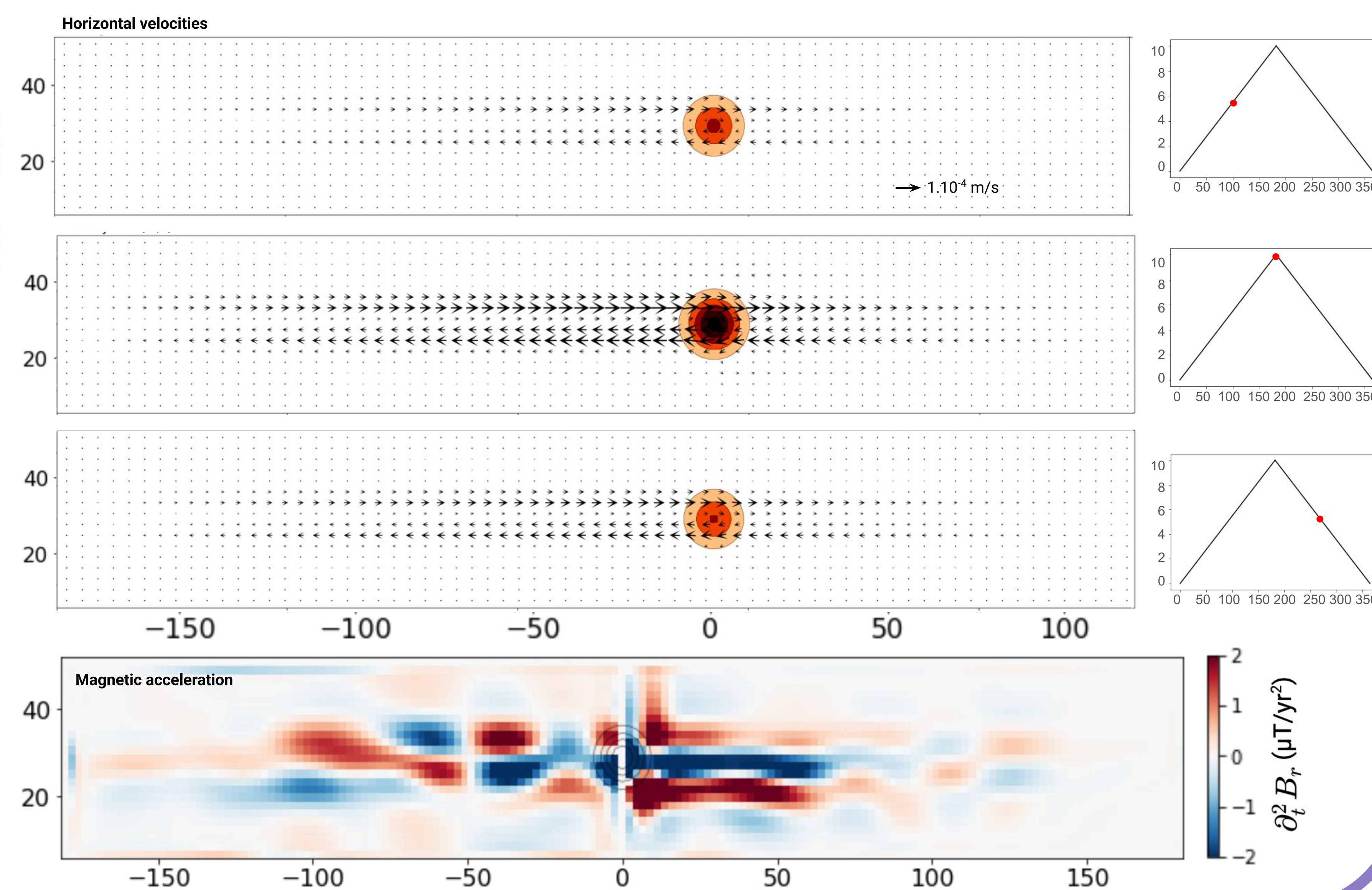
$\dfrac{\partial B_r'}{\partial t}\sim 4\mu T/yr^2$

This is consistent with results on the 2007 geomagnetic jerk (e.g. Lesur 2022).

We solve the shallow water equations (SWE) in the β-plane approximation (Rossby 1937), to represent flow in a stratified layer at the top of the core.
Time variations of the CMB topography: 6-months increase/ 6-months decrease

Parameters:

thickness of the stratified layer	variation of CMB topography	radial magnetic field (GRIMM3)	radial magnetic field anomaly	density of the core and of the mantle	velocity anomalies
H	b	B_r	B_r'	ρ_c, ρ_m	u, v
80 km	10 cm			10000/5500 kg/m³	



Conclusion

An anomalous GRACE gravity signal is detected in the Eastern Atlantic, with maximum intensity in January 2007. We suggest a scenario of **deep mass redistributions** from the **Pv-pPv** phase transition, generating ~ **10cm** of dynamic **CMB topography**. Solving the SWE in a **stratified layer** of 80 km thick at the top of the core gives an right of magnitude ~ **4µT/yr²** compatible with the 2007 geomagnetic jerk. Next, we will include the Lorentz force in the shallow water equations.

References

- I, Panet JGR, 123 (12):11–062, 2018
- M. Mandea, et al., JGR, 120:5983–6000, 2015
- Langrand et al, Nature communications,10(1), 5680, 2019
- Rossby, C. G.I, J. Mar. Res, 1, 15–27, 1937. a
- V. Lesur, et al, SG, 2022, 10.1007/s10712-021-09662-4
- C. Gaugne Gouranton et al., GRL, 52, e2025GL116408, 2025

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