Mass redistributions at the core mantle boundary from satellite gravity

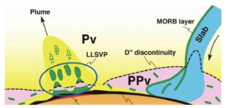
Charlotte Gaugne[1], Isabelle Panet[1,2], Marianne Greff[1], Mioara Mandea[3], Séverine Rosat[4]

[1] Université Paris Cité, Institut de physique du globe de Paris, CNRS, IGN, F-75005 Paris, France,
[2] ENSG - Géomatique, IGN, F-77455 Marne-la-Vallée, France,
[3] Centre National d'Etudes Spatiales, Paris, France,
[4] Université de Strasbourg, CNRS, EOST, ITES UMR7063, Strasbourg France

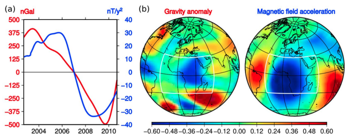
Motivations

The GRACE mission (since 2002) can provide new constraints on deep mass redistributions by measuring the space-time variations of the gravity field. This could help to better understand sudden changes in the secular variation of the geomagnetic field, called geomagnetic jerks.

Characterize the origin of sudden changes in core flows: link to variations of the topography in the CMB ?



(Hirose et al. 2008)



(Mandea et al. 2015)

Objective: Search for gravity signatures of mass redistributions at the CMB at timescales of months up to 2-3 years

Methods

- GRACE/SLR and pure SLR geoid models: GRGS04 compared with CSR06, ITSG2018, COST-G, SLR-AIUB
- We subtract a mean, annual and semi-annual signals (2003-2015) and apply a moving average of 1 year on the residual time series

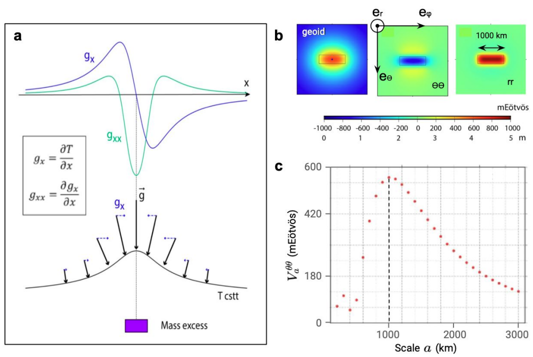


Figure 1 - Multi-scale gravity gradients

(Panet et al. 2022)

- Gravity gradients in the local spherical frame, at different spatial scales (no terms of degree 0 nor 1)
- Rotations of the spherical frame to align with the orientation of the signals → separate signals with different characteristic scales and orientations
- Wavelet transform of the gravity gradients time series at scales 28-32 months : search for peaks in the period June 2006 - December 2007
- Bump in the time series ↔ peak in the wavelet-transformed coefficients

Detection of signal

Anomalous North-South oriented signal across the boundary between the Atlantic ocean and the African continent, with a high intensity (≥1µEötvös) at the largest 9000-km spatial scales of the analysis in January 2007.

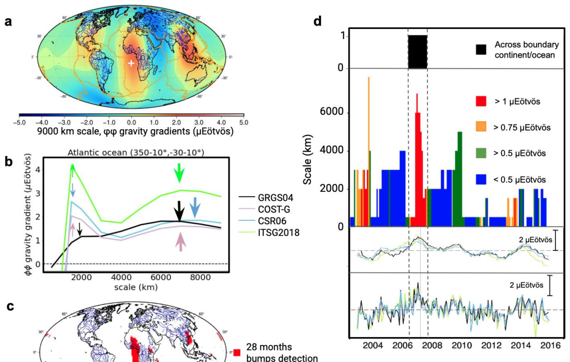


Figure 2 - Characterisation of the extracted signal in January 2007. **(a)** Map of the 9000 km scale gravity gradient in January 2007 in GRGS04. **(b)** local spectrum of the φφ gravity gradients pointing to the characteristic scale. **(c)** Map showing the locations (in red) where an anomalous bump-like transient is detected between June 2006 and December 2007 in the time series of the 7000-km scale φφ gravity gradients. **(d)** Unicity of the signal detected

Water cycle

To investigate a potential origin of the 2007 Atlantic signal within the fluid envelopes of the Earth, we compare its spatio-temporal fingerprint with those of hydrological, oceanic and atmospheric sources based on global circulation models, GRACE-based reconstructions (V1) and the geographic distribution of land and ocean (V2).

Hypothesis: observed gravity variations are solely due to water.

Radial gravity gradient

V1

$$v^{rr}_{\ell,m} = \frac{(\ell+1)(\ell+2)}{a^2}\left(\frac{a}{r}\right)^{\ell+3}\frac{4\pi G a}{2\ell+1}\,\sigma_{\ell,m}$$

$$\sigma_{\ell,m} = \frac{a^2}{(\ell+1)(\ell+2)}\,\frac{2\ell+1}{4\pi G a}$$

V2

Rectangular water sources: reproduce the amplitude and the characteristic scales as reflected by local spectra in various **drainage basins** of Africa and South America

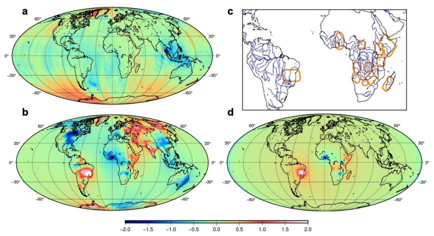


Figure 4 - Geoid of ocean **(a)** and hydrology **(b)** from V1 in January 2007, and of hydrology from V2 **(d)**. Orange rectangles represents the zone where we put a hydrological signal for V2 **(c)**.

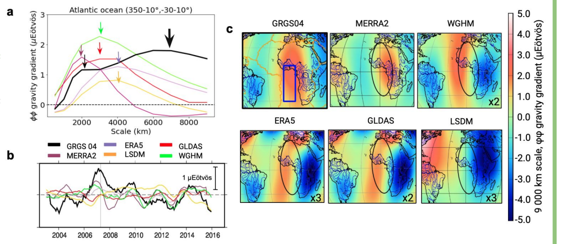


Figure 4 - Multiscale gravity gradient spatio-temporal fingerprint of water sources in hydrological models. **(a)** local spectrum of the φφ gravity gradients pointing to the characteristic scale of these signals. Time series **(b)** and map in January 2007 **(c)** of the 9000 km scale gravity gradient.

For continental hydrology and oceanic sources (modelled or reconstructed from GRACE), and their combinations, the characteristic scale and location different from those of the 2007 GRACE anomaly.

- Their local spectra in the Atlantic box indeed all peak between 2000 and 4000-km scales which is consistent with a first maximum in the GRACE-observed spectrum.
- Location across the ocean/continent boundary is also not well explained by any of the considered hydrological models.

The 2007 Atlantic signal is not well explained by surface water sources, these conclusions support the possibility of a deeper origin within the solid Earth.

Mass redistributions at the CMB / in the D" layer

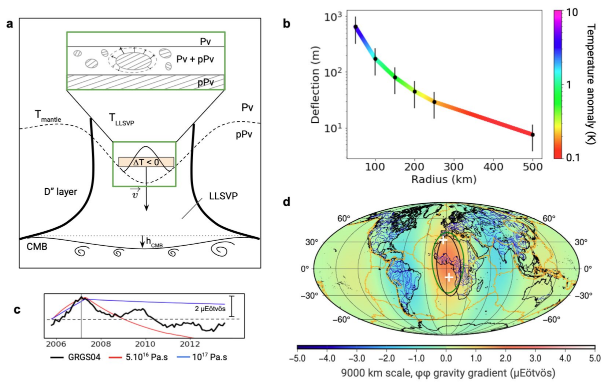


Figure 5 - **(a)** Negative temperature anomaly passing through the Pv-pPv phase transition. **(b)** Deflexion of the phase transition as a function of radius of the anomaly and its temperature. **(c)** Time series of the 9000 km scale φφ gravity gradients for the model for 2 different viscosity in the D" layer. **(d)** Map of the 9000 km scale φφ gravity gradients for the model adding hydrology V2.

Source from the core is expected to be to small to generate dynamic CMB topography, we focus on a mantle side source.

Source at the top of the CMB can not explain both geomagnetic jerk and gravimetric magnitude anomaly.

Source in the mantle above CMB:

- Characteristics of Pv-pPv : fast (Langrand et al 2019), density contrast (100 kg/m³), occur in the D" region
- African LLSVP : Pv-pPv phase transition deeper (7-14 K/m)
- **Scenario proposed:** Pv cold anomaly (T') passing through the phase transition and transform to pPv before other material at temperature T creating a mass anomaly.
- **Model parameters:** visco-elastic D" layer of 350 km and viscosity of 5.10^{16} Pa.s, phase transition at 50 km above CMB, 2 calottes (4°W,29°N and 5°E,15°S) modelling the transformed pPv of different size (radius from 50 km to 500 km)
- Reproduce characteristic of the 2007 anomalous signal (spatio-temporal fingerprints)
- Generate a dynamic CMB topography of at least 12.5 cm.

Conclusion

The 2007 Atlantic signal is **not well explained by surface water sources**. This leads us to propose that part of this gravity signal could **reflect deep mass redistributions** from the **Pv-pPv** phase transition and generate a **dynamic CMB topography** notable. We next propose to do the same study on the magnetic field.

References

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