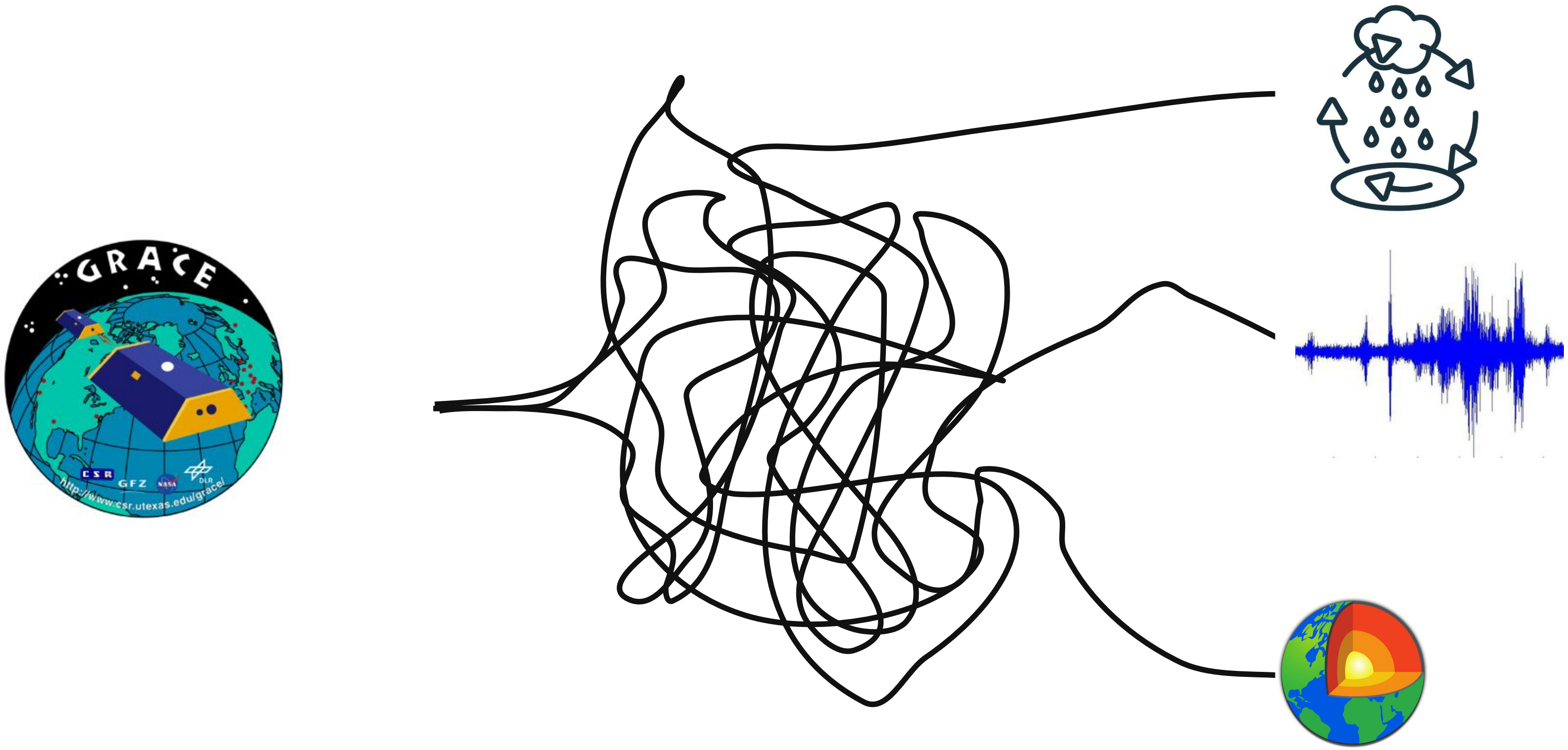
Mass redistributions at the core mantle boundary from satellite gravity

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



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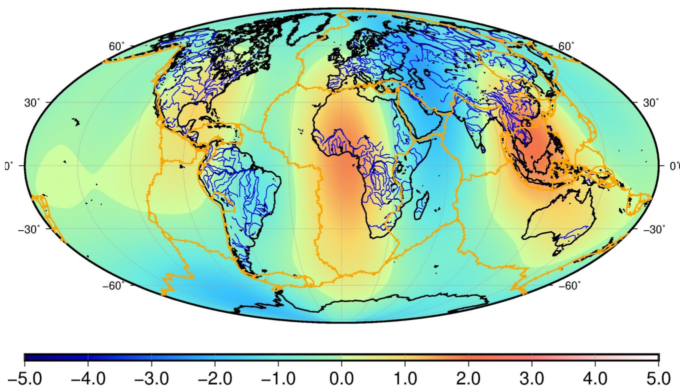
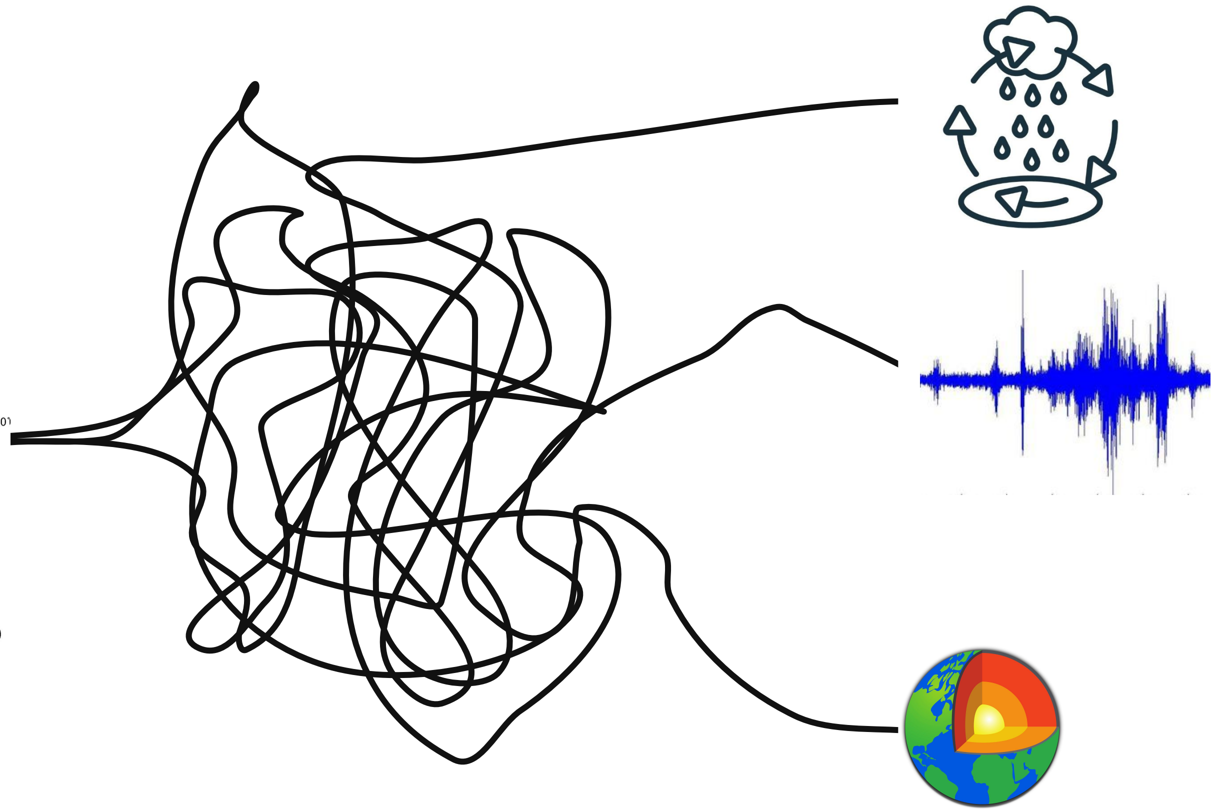
January 2007



9000 km scale, φφ gravity gradients (μEötvös)



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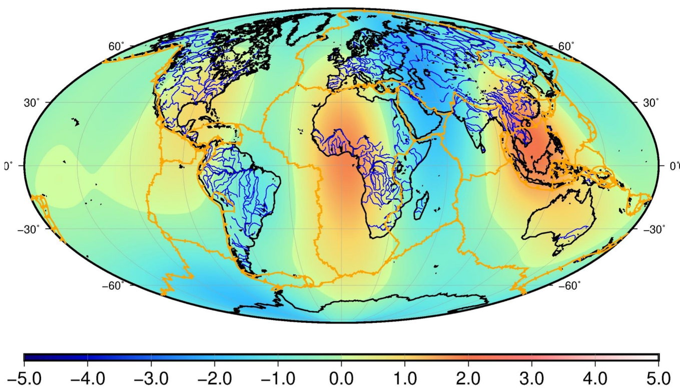

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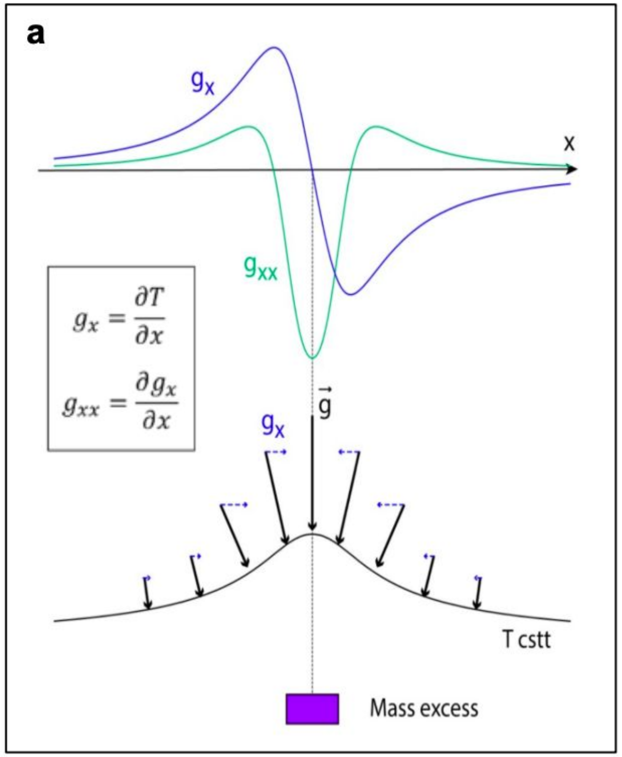
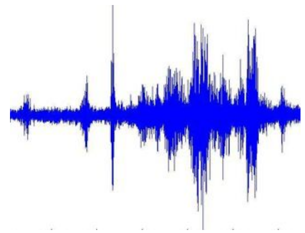


Multi-scale gravity gradients



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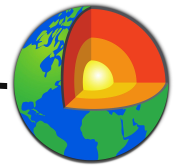

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Come to see the result of our investigation !

Motivations

The GRACE & GRACE-FO missions (since 2002) can provide new constraints on deep mass redistributions by measuring the space-time variations of the gravity field.

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, called geomagnetic jerks.

(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 signal (2004-2017) and apply a moving average of 1 year to 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 $=10^{-9}$μGal/cm) at the largest 9000-km spatial scales of the analysis in January 2007.

Figure 2 - Characterization of the signal detected in 2007. (a) Map of the 9000 km scale gravity gradients in January 2007 (GRGS04). (b) Local spectrum of the φφ gravity gradients pointing to the characteristic scale... (c) Map showing the location (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 now compare its spatio-temporal fingerprint with those of hydrological, oceanic and atmospheric sources based on global circulation models, GRACE-based reconstructions (V1 & V2) and the geographic distribution of land and ocean..

Hypothesis: observed gravity variations are solely due to water.

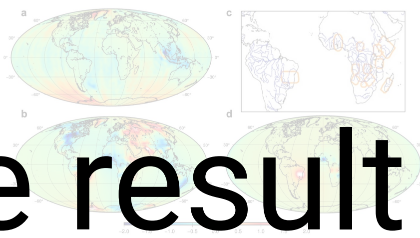

Figure 4 - Geoid of ocean (a) and hydrology (b) by method V1, in January 2007. Geoid of hydrology by method V2 (d), in January 2007. Orange rectangles represent the areas where we put a hydrological water load in method V2 (c).

Figure 4 - Spatio-temporal multiscale gravity gradient 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 gradients due to hydrology, compared to GRACE.

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

- Their local spectra in the Atlantic box indeed show a peak between 2000 and 4000-km scales which is consistent with a first maximum in the GRACE-observed spectrum.
- The 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) Deflection of the phase transition as a function of radius of the anomaly and its temperature. (c) Time series of the 9000 km scale modelled φφ gravity gradients for 2 different viscosities in the D" layer. (d) Map of the 9000 km scale modelled φφ gravity gradients (also including hydrology reconstructed by method V2).

Sources from the fluid core are expected to generate too small gravity signals, we focus on a mantle side source.

Source at the CMB: large topographies are required to explain gravimetric anomaly (at least 60cm over a continental-size zone).

Source in the mantle above CMB:

- Characteristics of perovskite (Pv) to post-perovskite (pPv) phase change in the D" region: fast (Langrand et al 2019), density contrast (100 kg/m^3), large Clapeyron slope (7-14 MPa/K)
- African LLSVP : Pv-pPv phase transition deeper
- **Scenario proposed:** deflection of the Pv/pPv interface in the presence of a moving thermal heterogeneity in the deep upwellings of the African LLSVP. This creates 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, areas undergoing the phase transition: two caps (4°W,29°N and 5°E,15°S) of different size (radius from 50 km to 500 km)
- Able to explain the characteristics of the 2007 anomalous gravity signal (spatio-temporal fingerprints)
- Generate a dynamic CMB topography of at least 5 cm.

Conclusion

We evidence an anomalous large-scale gravity gradient signal in 2007 in a broad zone of the Atlantic ocean. This signal is not **well explained by surface water sources**. We propose that at least part of this gravity signal could **reflect deep mass redistributions** from the **Pv-pPv** phase transition and generate a pluri-centimetric **dynamic CMB topography**.
Next step: analysis of the magnetic field.

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