Observability of the Earth's core signals in GRACE-based gravity field

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Context

Fluid outer core motions are known from the geomagnetic field changes. As these motions involve mass variations, they might also be observed through gravity field variations.

[1, 2] proposed different core processes that would perturb the gravity field. **[3]** pointed out a possible correlation between gravity and magnetic fields variations.

Such mechanisms involve mass variations. So the objective of **my PhD** is to propose new constraints on the core motions from the variations of the gravimetric field.

This poster verifies our capacity to detect these theoretically predicted signals into gravity field variations.

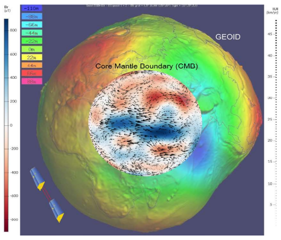


Fig. 1. Geoid, geomagnetic field and fluid motions at the CMB (icgem.gfz-potsdam.de geodyn.univ-grenoble-alpes.fr)

Difficulties

Gravity field variations contain multiple geophysical and environmental signals with amplitudes greater than the predicted core signals (Fig 3). GRACE and GRACE Follow-On (FO) missions suffer from time-gaps and problems in determining specific Stokes coefficients (Fig 2) **[4]**.

Lecomte et al. 2022 (submitted) [5] details the uncertainties of the GRACE solution and the geophysical correction models (post-glacial rebound, hydrological and oceanic loadings).

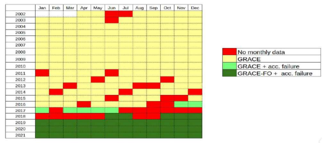


Fig. 2. GRACE & GRACE-FO calendar and problems

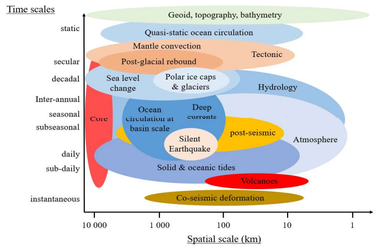


Fig. 3. Spatial and temporal scales of the physical processes causing mass variations in the Earth system

Theoretical processes

Three effects were tested with a pluri-annual sinusoidal behavior:

- **Dissolution / Crystallisation** at the CMB **[2]** (Fig 4, Fig 5a)
- **Pressure changes** at the Core Mantle Boundary (CMB) **[1, 6]** (Fig 5b)
- **Reorientation of the Inner Core** (IC) **[1]** (Fig 6, Fig 5c)

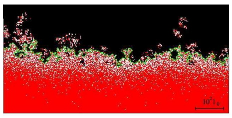


Fig. 4. Cellular automaton model corresponding to Dissolution / Crystallisation processes *(Figure from [2])*

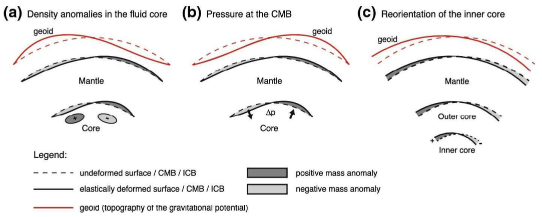


Fig. 5. Geoid and mantle variations caused by core processes *(Figure from [1])*

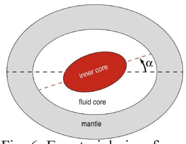


Fig. 6. Equatorial view for the reorientation of IC *(Figure from [1])*

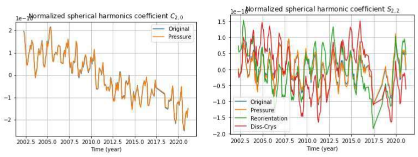


Fig. 7. GRACE gravity coefficients ($C_{2,0}$, $S_{2,2}$) containing core synthetic signals

The amplitude differs between processes (Fig 7). Pressure effects have a small amplitude while reorientation and dissolution / crystallisation effects may be observed on $S_{2,2}$ coefficient.

For dissolution / crystallisation, vertical displacement and mass redistribution effects represented by loading Love numbers k'^{1}_{n} are none negligeable.

Results by analysis techniques

Wavelet analysis

The wavelet analysis of the Stokes coefficients shows the spectral content as a function of time.

This analysis is compared between the original GRACE time series ***(left)*** and the time series containing the synthetic core signals ***(right)***.

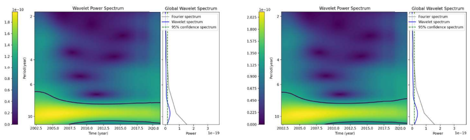


Fig. 8. Wavelet analysis of $C_{2,1}$ of GRACE time-series (left) and GRACE time-series + signal due to a pressure change of 100 Pa at CMB (right)

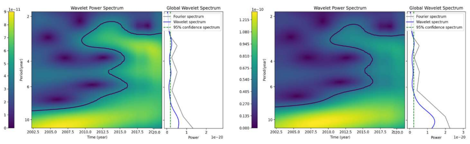


Fig. 9. Wavelet analysis of $C_{2,2}$ of GRACE time-series (left) and GRACE time-series + signal due to a pressure change of 100 Pa at CMB (right)

The effects of pressure changes at the CMB are not large enough to appear in the wavelet analysis (Fig. 8, Fig. 9).

The effect of a reorientation of the IC clearly appears in the analysis for the largest parameter assumptions : $\alpha = 1.5°$, $h_{2,2} = 36$ m (Fig. 10).

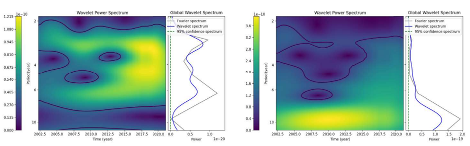


Fig. 10. Wavelet analysis of $S_{2,2}$ of GRACE time-series (left) and GRACE time-series + signal due to a reorientation of IC (right)

EOF analysis

The Empirical Orthogonal Function (EOF) analysis separates the signal into subfunctions. One particular EOF is associated with a map and a time series.

Fig. 11 shows EOF of the GRACE time-series after temporal and spatial filters. Reorientation of the IC process appears in the 2nd EOF. It is also the case for Dissolution / Crystallisation but only without Earth elasticity. ($k'^{1}_{6} = 0$)

Fig. 11a. 2nd EOF of GRACE gravity field with temporal and spatial filters

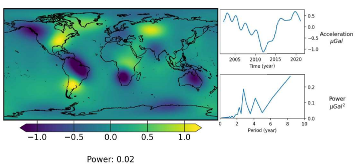


Fig. 11b. 2nd EOF of GRACE + reorientation of IC ($\alpha = 1.5°$, $h_{2,2} = 36$ m)

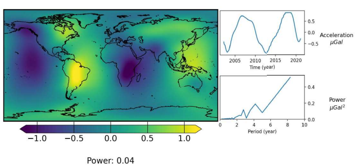
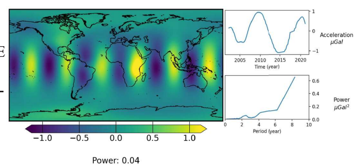


Fig. 11c. 2nd EOF of GRACE + dissolution / crystallization at CMB ($h_{6,6} = 30$ cm, $k'^{1}_{6} = 0$)



Correlation analysis

A correlation between gravity and magnetic fields highlights possible common signal from core processes **[3]**. We used CHAOS 7.9 model **[8]** to retrieve the secular acceleration $\partial^2_t B$ up to $l = 8$.

Fig. 12a. Correlation between GRACE (μGal) and CHAOS 7.9 (nT.y⁻²) models

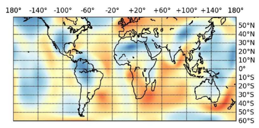


Fig. 12b. Correlation between GRACE + reorientation of IC (μGal) and CHAOS 7.9 (nT.y⁻²) models ($\alpha = 1.5°$, $h_{2,2} = 18$ m)

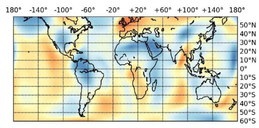
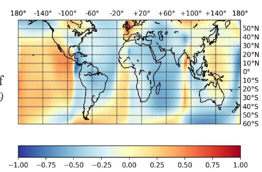


Fig. 12c. Correlation between GRACE + reorientation of IC (μGal) and CHAOS 7.9 (nT.y⁻²) models ($\alpha = 4.5°$, $h_{2,2} = 54$ m)



Correlation maps for other signals than those induced by a reorientation of IC are not significant.

Parameters for reorientation of IC

With the wavelet analysis method, we assess the possible values for the two parameters of the reorientation of IC (α and $h_{2,2}$).

They have to be large enough to be detectable but not too large else they would have already been detected.

With the hypothesis that $T_1 = 10$ yr, the possible values for the angle α of axial rotation and the topography $h_{2,2}$ are displayed on Fig.13.

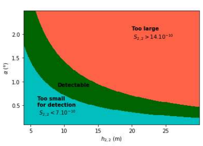


Fig. 13. Space of parameters for the reorientation of IC

Conclusions

Dissolution / crystallization at CMB produce a surface gravity effect that might be observed at degree 2 with topography effects larger than 100 m. Earth gravito-elasticity effect is non-negligeable on the amplitude of the associated signals.

Pressure changes at the CMB do not have an amplitude large enough to be detected with the different analysis techniques. An amplitude 10 times larger than the predicted is needed for a possible detection with the current GRACE observations.

A reorientation of IC might be detectable depending on the values of the parameters involved in the model. According to the litterature, with the current estimate of the average range of each parameter and associated assumptions such as hydrostatic equilibrium of the IC Boundary, the effect might be detectable.

These results will be detailed in **Lecomte et al. 2023 (in preparation)**.

Bibliography

[1] M. Dumberry and M. Mandea, "Gravity Variations and Ground Deformations Resulting from Core Dynamics", Surveys in Geophysics, pp. 1–35, 2021..

[2] M. Mandea, C. Narteau, I. Panet, and J.-L. Le Mouël, "Gravimetric and magnetic anomalies produced by dissolution-crystallization at the core-mantle boundary", Journal of Geophysical Research: Solid Earth, vol. 120, no. 9, pp. 5983–6000, 2015, doi: 10.1002/2015JB012048.

[3] M. Mandea, I. Panet, V. Lesur, O. de Viron, M. Diament, and J.-L. L. Mouël, "Recent changes of the Earth's core derived from satellite observations of magnetic and gravity fields", Proceedings of the National Academy of Sciences, vol. 109, no. 47, pp. 19129–19133, Nov. 2012, doi: 10.1073/pnas.1207346109.

[4] U. Meyer et al., "International Combination Service for Time-variable Gravity Fields (COST-G) Monthly Series 2020". doi: 10.5880/ICGEM.COST-G.001.

[5] H. Lecomte, S. Rosat, M. Mandea, J-P. Boy, J. Pfeffer, "Uncertainty of low-degree space gravimetry observations: surface processes versus internal signal" , Journal of Geophysical Research: Solid Earth, 2022 **(submitted)**

[6] N. Gillet, M. Dumberry and S. Rosat, "The limited contribution from outer core dynamics to global deformations at the Earth's surface", Geophysical Journal International, vol. 224, no. 1, Jan. 2021, pp. 216–229, doi: 10.1093/gji/ggaa448

[7] J. Hinderer, H. Legros, "Elasto-gravitational deformation, relative gravity changes and earth dynamics", Geophysical Journal International, vol. 97, no. 3, Jun. 1989, pp. 481–495,doi: 10.1111/j.1365-246X.1989.tb00518.x

[8] C. C. Finlay et al., "The CHAOS-7 geomagnetic field model and observed changes in the South Atlantic Anomaly", Earth, Planets and Space, vol. 72, 2020.