The signature of external drivers from Swarm satellite data

D. Saturnino[1,*], M. A. Pais[2,3], J. Domingos[2], F. Pinheiro[2,3]

[1] *Laboratoire de Planétologie et Géodynamique, UMR6112-CNRS, University of Nantes, France*
[2] *CITEUC, Geophysical and Astronomical Observatory, University of Coimbra, Portugal*
[3] *Department of Physics, University of Coimbra, Portugal*
[*] *diana.saturnino@univ-nantes.fr*

Introduction

Separation of the different contributions of the measured magnetic field is still an issue. To deal with this problem, one can either use parameterized functions (e.g. comprehensive models) or non-parametric statistical methods.
Principal Component Analysis (PCA) has been used to decompose Virtual Observatories (VO) geomagnetic field series built from Swarm data, with as a main goal to separate internal field modes [1]. A decorrelated quadrupolar structure, oscillating in time with a quasi-annual periodicity, has also been identified.

We follow a similar approach here, but compute the VO series differently:
- no selection criteria is used to eliminate data that have important external contributions and
- an Equivalent Source Dipole (ESD) approach is used to reduce a cloud of satellite data points to one VO observation [2].

We expect that external contributions are well represented in our VO series, during the Swarm satellite mission duration, to allow a more clean separation and precise characterisation of principal modes from external current systems.
Results may provide proxies to monitor the dynamics of specific external sources and, ultimately, they can be used in alert systems for the space weather effects.

VO dataset

The analysis is made on ESA's Swarm vector satellite data (XYZ), with 1 Hz sampling, from Jan-2014 to Aug-2019.

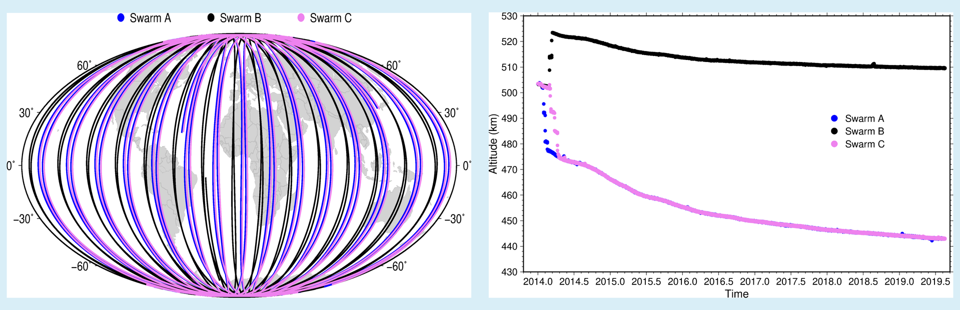

Fig. 1: The 3 Swarm satellites daily (left) orbits and (right) mean altitude.

Satellite data is acquired globally but at different altitudes. The VO approach aims to extract satellite magnetic time series as is done at ground stations, i.e, at a fixed altitude.
To build each VO value at a certain epoch, **all measurements** acquired inside a 2° radius cylinder during 30 days are considered. Then, ESD is used to reduce them to a single observation at a fixed altitude (500 km). Each VO is 3° away from its neighbours. The set of VO coordinates is fixed in time:

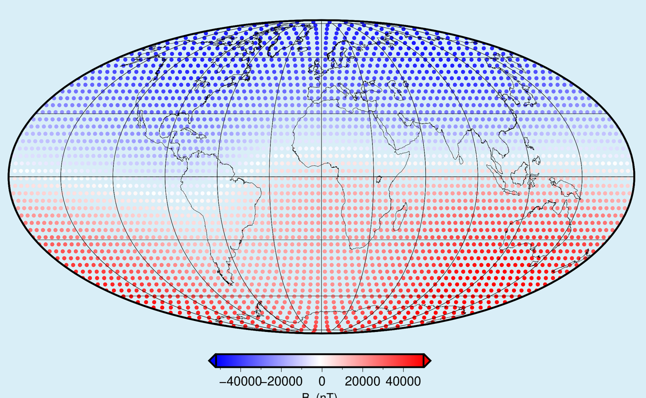

Fig. 2: Radial field at VO locations at epoch 2015.62

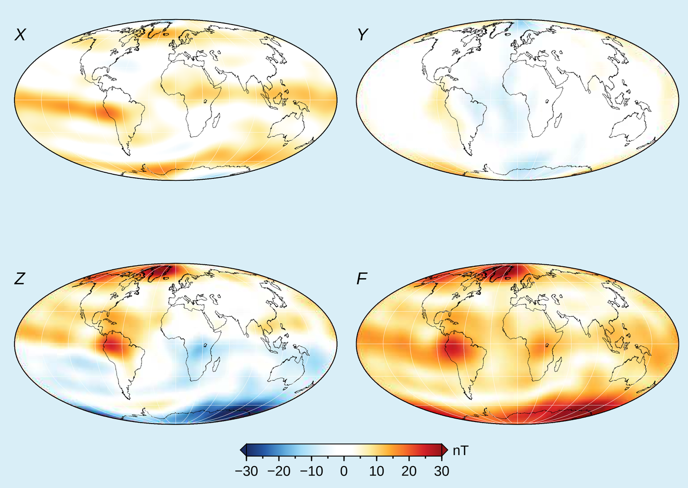

Fig. 3: External contributions present in VO data; difference between IGRF-12 and a magnetic field model computed from VO data, truncated at $n = 13$, and epoch 2015.04. (from [2])

PCA approach

We use PCA analysis to separate highly correlated spatio-temporal geomagnetic variations from less correlated structures. The dataset matrix $\mathbf{X}$ is decomposed into principal components [3]:

$$\mathbf{X} = \sum_{i=1}^{M} \alpha^i \, PC^i(t) \, EOF^i(x, y, z)$$

with α^i the weight of each component in the expansion, PC^i it's time variation and EOF^i it's spatial structure.
The variance in the data explained by mode-i is given by $\lambda^i = (\alpha^i)^2/(M-1)$ where M is the number of epochs. As an estimate of the sampling errors on λ^i, we compute $\sigma_{\lambda^i} = \sqrt{\frac{2}{M}}\lambda^i$.

PCA on VO series

The main PCA mode has the spatial structure of the geomagnetic field secular variation, at present, and changes linearly in time, as also found in [1] (Figure 6).
We checked that, for datasets spanning time periods > 2 years, PCA components from internal sources gain increasing importance.
For time intervals $\lessapprox 2$ years, it is possible to resolve PCA modes with a short timescale variability that are probably due to external sources (Figures 5 and 7).

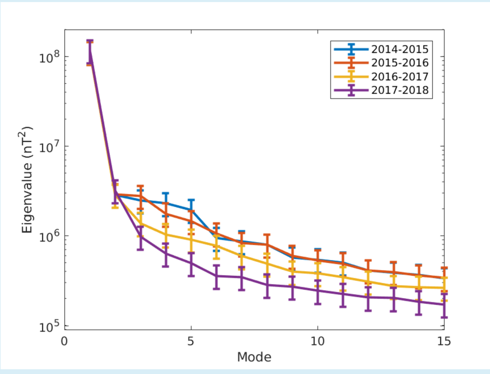

Fig. 4: Variability explained by each mode (λ^i), and error estimates (σ_{λ^i}).

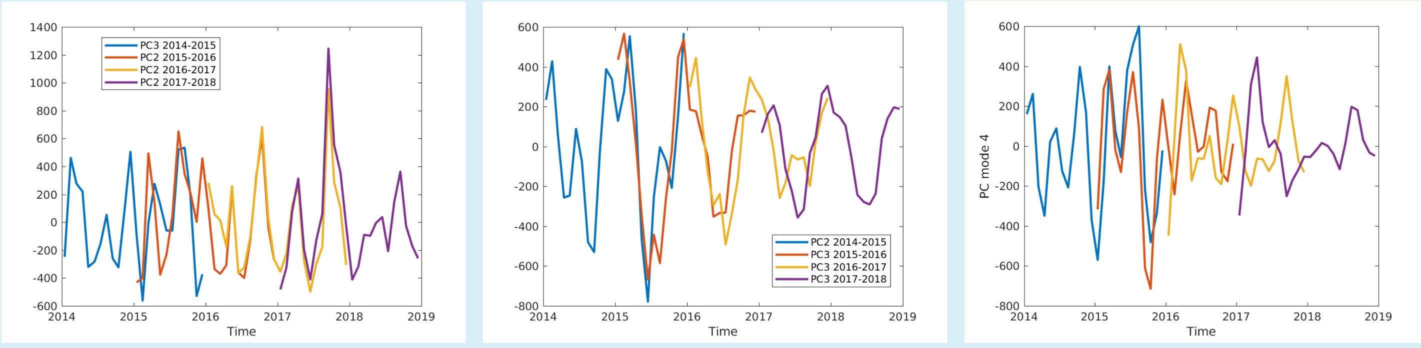

Fig. 5: PCs for modes 2, 3 and 4, for all periods.

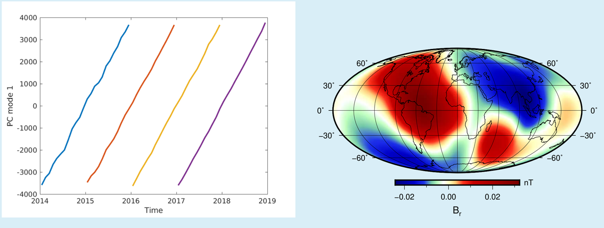

Fig. 6: PC 1 for all periods, and EOF 1 (B_r), for period 2014-2015.

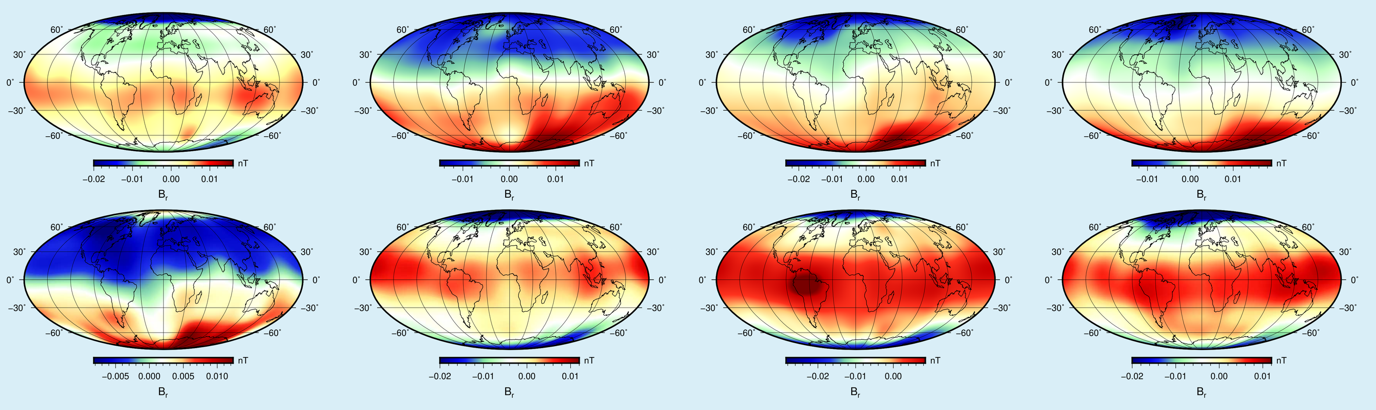

Fig. 7: EOF maps (columns) and periods (rows) for modes 2 and 3.

PCA after core field model subtraction

PCA applied to VO data, after subtraction of the CHAOS-6 [4] core field model truncated at degree 13.

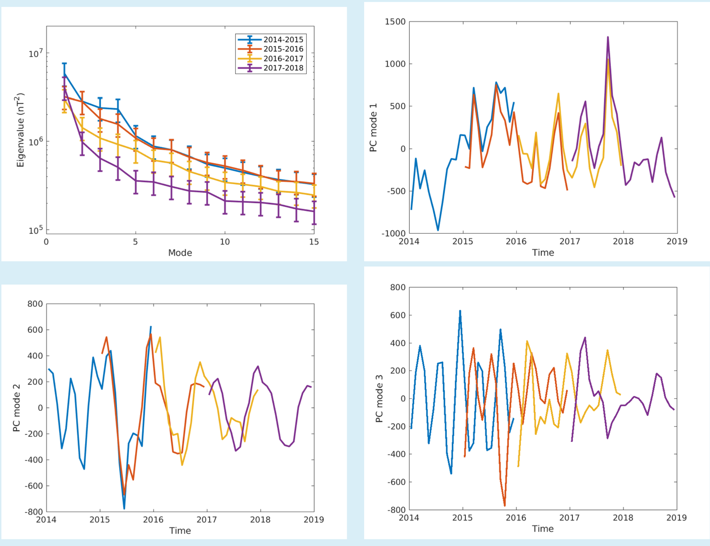

Fig. 8: (Top left) Variability due to each mode; (other) PCs for modes 1, 2 and 3 for all periods.

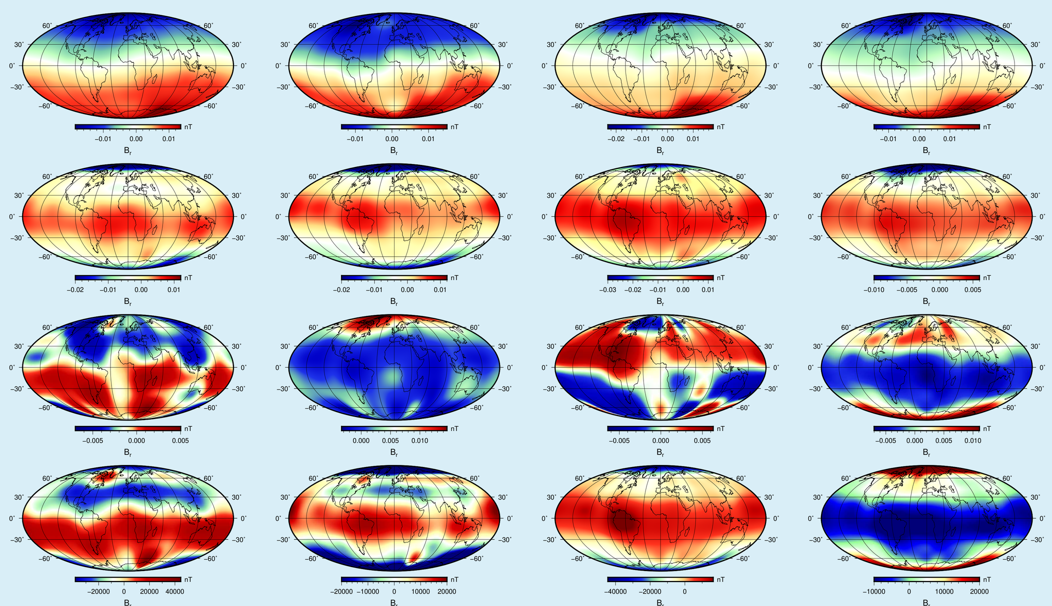

Fig. 9: EOF maps (columns) and periods (rows) for modes 1, 2, 3 and combination of degenerate modes, 2, 3 and 4, for all periods.

Discussion

- For datasets spanning 2-yr periods, two main short timescale series and corresponding spatial structures come out, probably from external origin.
- A new mode comes out from this analysis, dipolar and with 4 to 6 months characteristic time, that was not resolved in [1].
- Using the raw VO series, the main mode is the (linear) secular variation of the internal field.
- Removing a main field model contribution from VO series, the previous first PCA mode disappears. First modes are now seemingly due to external sources. 'External' modes are slightly better separated.
- The PCs derived from consecutive time intervals agree in phase and amplitude over the superposition period.

References

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