DETECTING MAGNETOSPHERIC AND IONOSPHERIC CURRENT SYSTEMS PATTERNS FROM SWARM OBSERVATIONS

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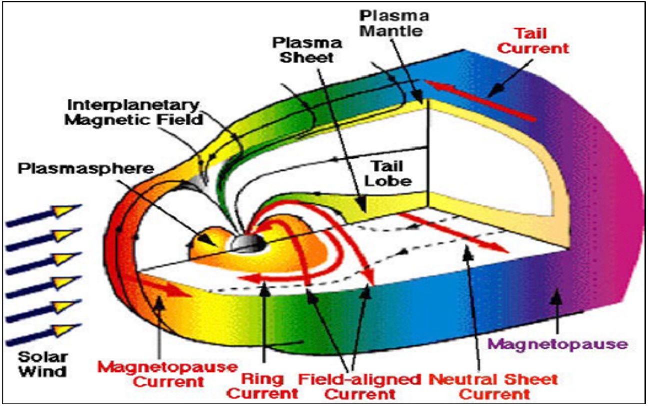
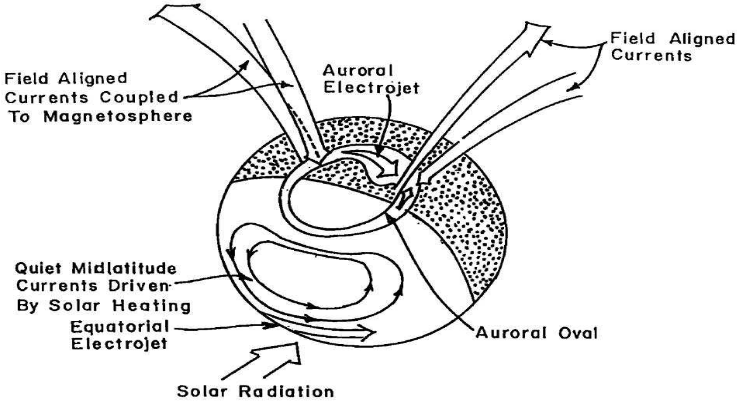
A LOOK INSIDE THE MAGNETOSPHERE

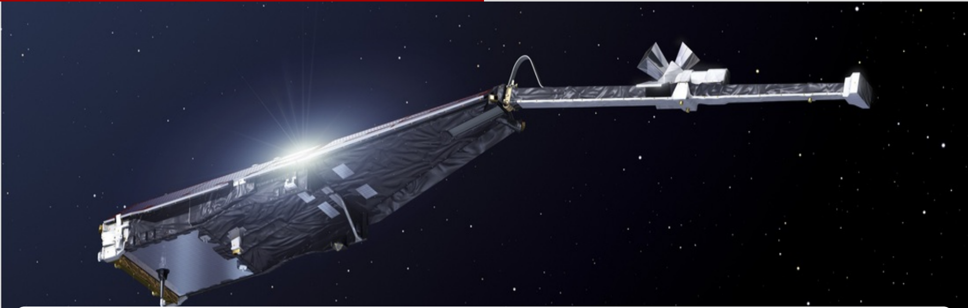


- Enhanced westward **ring current** causes a world-wide depression of the geomagnetic horizontal component $\Rightarrow$ **geomagnetic storms** $\Rightarrow$ **disturbed period**
- **Field aligned currents** are responsible for the magnetosphere-ionosphere coupling $\Rightarrow$ **geomagnetic substorms**

A LOOK INSIDE THE IONOSPHERE

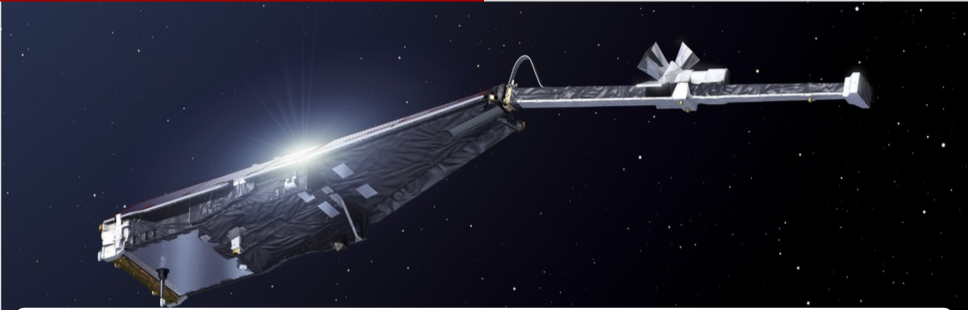


- **Auroral electrojets** enhancements lead to changes in the auroral oval region
  $\Rightarrow$ **geomagnetic substorms**
- **Solar quiet Sq current** located at mid-latitude is driven by solar radiation
  $\Rightarrow$ **quiet period**



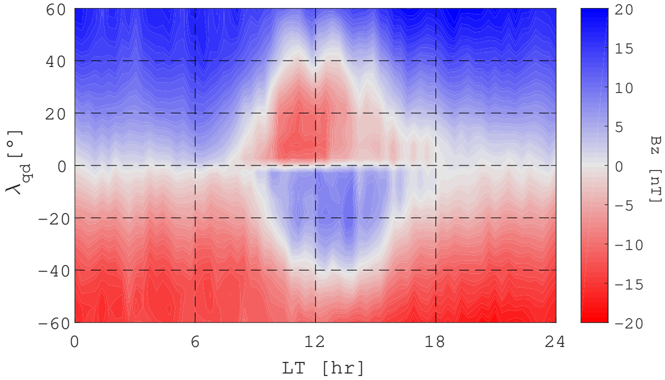
SWARM SATELLITES

- Three satellites (Alpha, Bravo and Charlie) placed in two different polar orbits: A and C fly side by side at an altitude of 460/470 km, B at an altitude of 520/530 km
- Main objectives of the mission: geomagnetic field studies, Earth core dynamics, geodynamo processes, currents flowing in the magnetosphere and ionosphere
- We used Level 1b low resolution (1 Hz) vector magnetic field data recorded onboard Swarm A from 1 April 2014 to 31 March 2016 [Friis-Christensen et al., 2008]



GEOMAGNETIC FIELD COMPONENTS

- Level-1b low resolution (1 Hz) vector magnetic field data recorded on Swarm A satellite during a period of two years from 1 April 2014 to 31 March 2016
- vertical component of the geomagnetic field (B_z) at low- and mid-latitudes during periods characterized by very low geomagnetic activity levels with $AE < 80$ nT and -10 nT $<$SYM-H$<$ 5 nT
- we removed the internal geomagnetic field from the original data by using CHAOS-6 model



- ranges between −20 and 20 nT and a two-lobe structure is clearly visible
- consistent with the solar quiet (S_q) daily variation of the geomagnetic field due to electric currents flowing in the ionosphere
- it generates an induced magnetic field directed outward (inward) in the Northern (Southern) Hemisphere
- thus it is revealed by Swarm observations as a decrease (increase) of the geomagnetic field in the Northern (Southern) Hemisphere

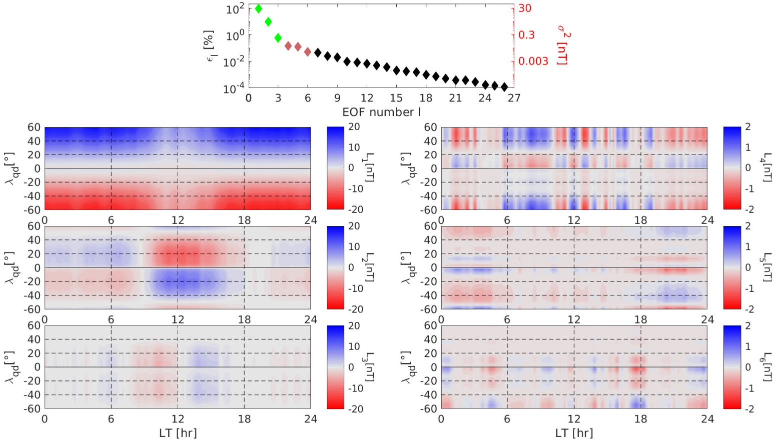
Empirical Orthogonal Function (EOF) analysis

- a decomposition technique for both univariate and multivariate data
- the set of observations $\{\mathbf{s}(t)\}|_{t\in T} = \{s_1(t), s_2(t), \ldots, s_n(t)\}$ is converted into a set of values of linearly uncorrelated variables, i.e., the PCs $\Phi_l(t)$, as

$$\{\mathbf{s}(t)\}|_{t\in T} = \sum_{l=1}^{n} \Phi_l(t)\mathbf{L}_l^{\mathrm{T}}$$

- $\mathbf{L}_l^{\mathrm{T}}$ the transpose of the $l-$th eigenvector of the covariance matrix of $\{\mathbf{s}(t)\}|_{t\in T}$ obtained as $\mathbf{C} = \{\mathbf{s}\}^{\mathrm{T}}\{\mathbf{s}\}$
- the decomposition is complete and orthogonal (by construction)
- the normalized eigenvalue ϵ_l captures the partial variance (i.e., the energy content) of the $l-$th principal component
- summaryzing, the main steps of the EOF method are:

1. to organize data as a matrix (by using the embedding theorem for univariate data);
2. to evaluate the covariance matrix of data (embedded data for univariate data);
3. to diagonalize the covariance matrix to find eigenvectors and eigenvalues;
4. to project data on eigenvector directions to find the uncorrelated variables, i.e., the principal components.



- L_1 does not reproduce the S_q daily variation
- L_2 is characterized by a two-vortex like structure, in agreement with the S_q
- L_3 is characterized by a symmetric pattern in λ_{qd}, with no LT symmetry
- $L_4 - L_6$ show striped patterns, the remaining components (not shown) can be attributed to the noise

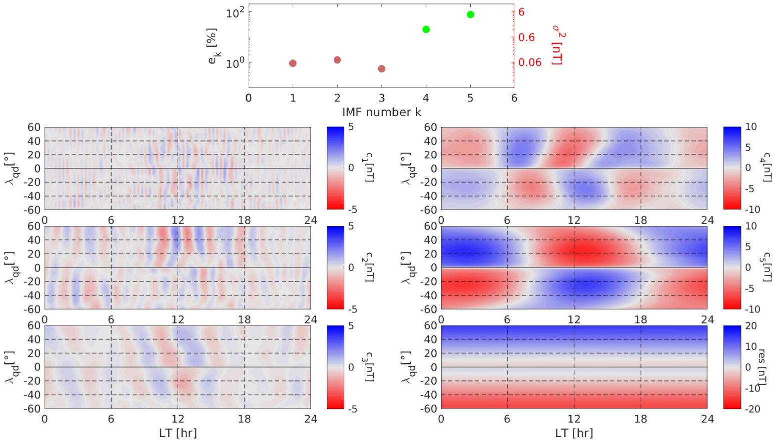
Multivariate Empirical Mode Decomposition (MEMD)

- it works directly in the data domain rather than in an associate one
- the set of observations $\{\mathbf{s}(t)\}|_{t \in T} = \{s_1(t), s_2(t), \ldots, s_n(t)\}$ is decomposed into a set of nonlinear multivariate empirical modes $\{\mathbf{c}_k(t)\}|_{t \in T}$ as

$$\{\mathbf{s}(t)\}|_{t \in T} = \sum_{k=1}^{N} \{\mathbf{c}_k(t)\}|_{t \in T} + \{\mathbf{r}(t)\}|_{t \in T}$$

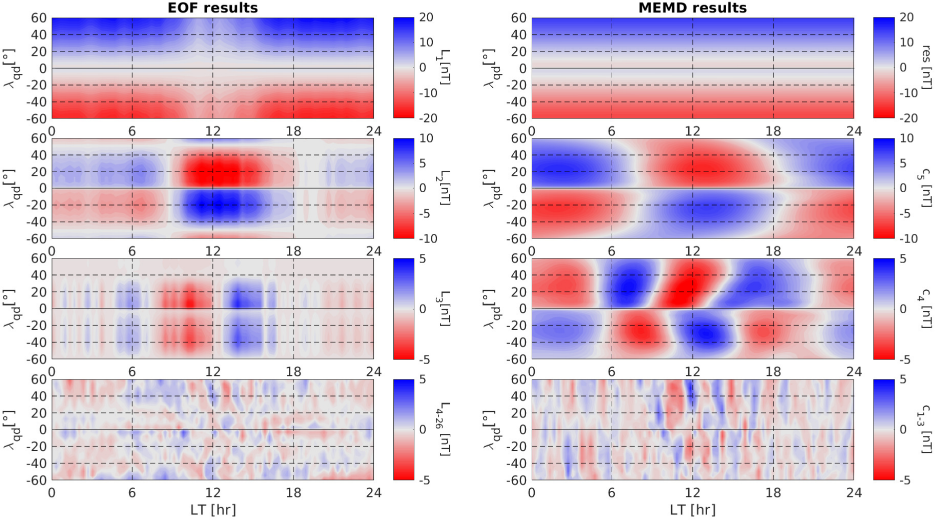
- the set of n-dimensional embedded patterns $\{\mathbf{c}_k(t)\}|_{t \in T}^{i=1,\ldots,N}$ empirically forms decomposition basis and $\{\mathbf{r}(t)\}|_{t \in T}$ is the decomposition residue
- MEMD modes empirically and locally satisfy orthogonal and completeness properties
- the energy content e_k of each MEMD mode can be evaluated as $\langle \{\mathbf{c}_k(t)\}|_{t \in T}, \{\mathbf{c}_k(t)\}|_{t \in T} \rangle$ and capture the partial variance
- summaryzing, the main steps of the MEMD method are:

1. to identify the local extrema;
2. to separately interpolate both local maxima and minima by using a cubic spline;
3. to obtain the mean envelope e_m from maxima and minima interpolations;
4. to evaluate an Intrinsic Mode Function.



- no fixed number and spatial scales of detected IMFs
- c_1, c_2 and c_3: range ± 2 nT, spatial structures similar to latitudinal ribbons
- c_4 and c_5: range from $\sim \pm 10$ nT, spatial structures of the main S_q current
- the residual: range $\sim \pm 20$ nT, inward (outward) in the Northern (Southern) Hemisphere $\Rightarrow$ magnetospheric ring current

Comparison between EOF and MEMD results for detecting the S_q variability



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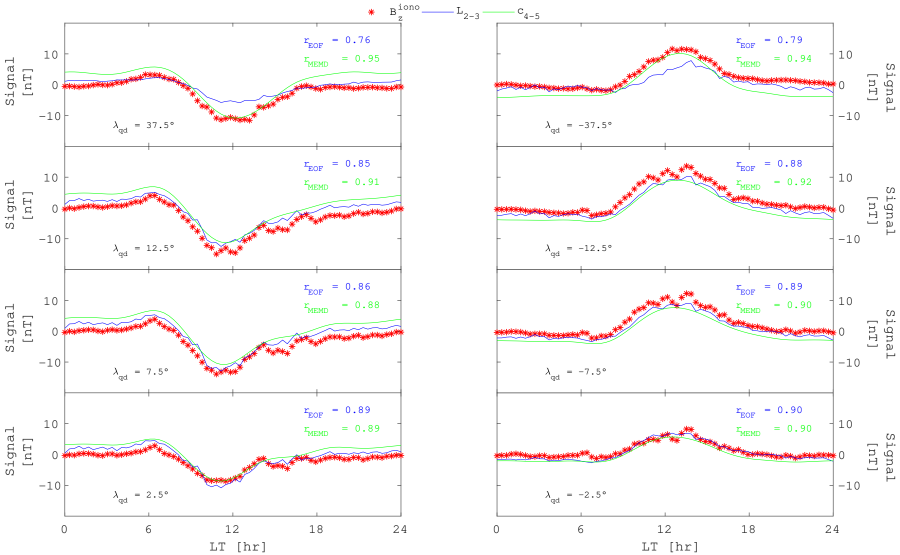

Conclusions

- MEMD method can help in the interpretation of the external magnetic field signals better than EOF method
- the first three modes appear in form of spurious North-South patterns
- c_4 and c_5 describe the effects on the geomagnetic field of the electric currents flowing in the ionosphere
- the residual is due to the electric currents flowing in the magnetosphere and describes the effect of the magnetospheric ring current

Perspectives

- MEMD method can help with the interpretation of the external magnetic field signals coming from the Swarm magnetic measurements
- It gives new insights into the analysis of the different sources responsible for the geomagnetic field of external origin
- It can be used as a good filter permitting to separate the ionospheric signal from both the magnetospheric one and the artefacts introduced by unmodeled internal contributions