UNIVERSITÀ DELLA CALABRIA
DIPARTIMENTO DI FISICA

A statistical study on the timescales involved into the solar wind-magnetosphere interaction during the March 17, 2015 storm

T. Alberti[1], G. Consolini[2], F. Lepreti[1], A. Vecchio[3], and V. Carbone[1]

[1]Dipartimento di Fisica, Università della Calabria, Rende (CS), Italy
[2]INAF-IAPS, Via del Fosso del Cavaliere 100, 00133, Roma, Italy
[3]LESIA-Observatoire de Paris, 5 place Jules Janssen, 92190 Meudon, France

1. Introduction

The magnetospheric dynamics in response to solar wind changes in the course of magnetic substorms and storms can be investigated via a set of geomagnetic indices, which monitor the changes of some of the most important current systems: the Auroral Electrojet indices (AE, AU, AL and AO) and the low latitude geomagnetic ones (Dst, Sym-H, ...). The variations of these indices are, indeed, associated with the changes of the auroral electrojets and ring current systems during geomagnetic substorms and storms. In this work, we present a case study of the relevant timescales responsible for coupling between the solar wind changes and the magnetospheric response during the St. Patrick's Day Geomagnetic Storm of 2015, by investigating the behavior of the IMF-Bz component and the AE, AL and Sym-H indices at different timescales using the Empirical Mode Decomposition (EMD). Indeed, the EMD allows us to extract the intrinsic oscillations (modes) present into the different datasets and then, by means of the Delayed Mutual Information (DMI), we investigated the relevance of the different timescales involved in the solar wind-magnetosphere coupling.

2. Data

We use solar wind data from ACE spacecraft (http://cdaweb.gsfc.nasa.gov) and geomagnetic indices from OMNIWeb (http://omniweb.gsfc.nasa.gov).

3. Empirical Mode Decomposition (EMD)

The Empirical Mode Decomposition (EMD) allows us the investigation of non-stationary and non-linear data [1] by decomponing each data set $X(t)$ in N empirical modes, called Intrinsic Mode Functions (IMF), and a residue $r(t)$:

$$X(t) = \sum_{n=1}^{N} C_n(t) + r(t) \qquad (2)$$

In Eq. (2), $C_n(t)$ represents a zero mean oscillation $C_n(t) = A_n(t)\sin(\phi_n(t))$ (being $\phi_n(t)$ and $f_n(t) = d\phi_n/dt$ the istantaneous phase and frequency respectively) characterized by a typical timescale T_n. Since the decomposition is local, complete and orthogonal, it can be used as a filter by recostructing partial sums of Eq. (2).
The time series and an example of EMD applied to AE Index are shown in Fig. 1.

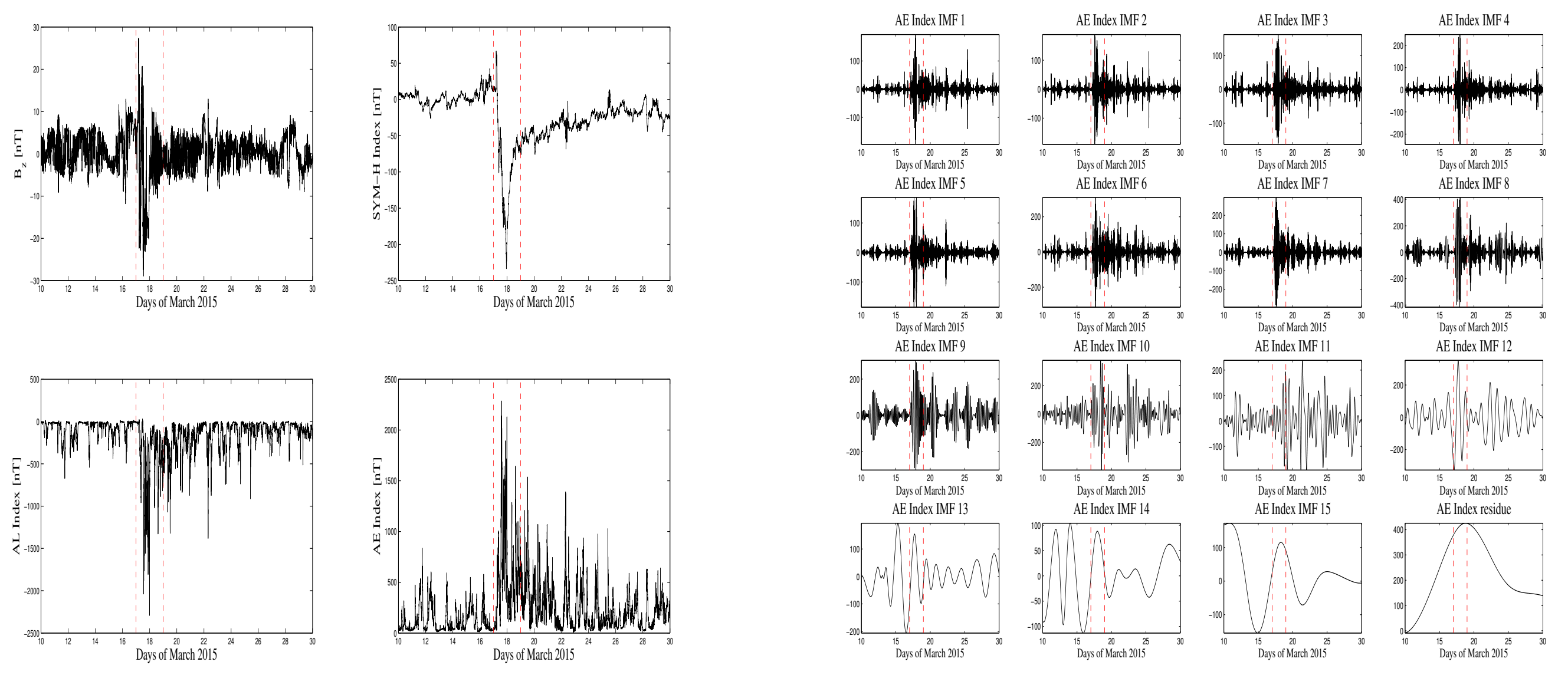

FIG. 1: Original time series (left panels) and intrinsic modes of AE Index obtained via EMD (right panels).

4. Timescale separation: internal and external dynamics?

We investigate the behaviour of the different modes involved into the solar wind-magnetosphere coupling by evaluating the characteristic mean frequency of each mode and by observing their distributions with respect to the mode index n.

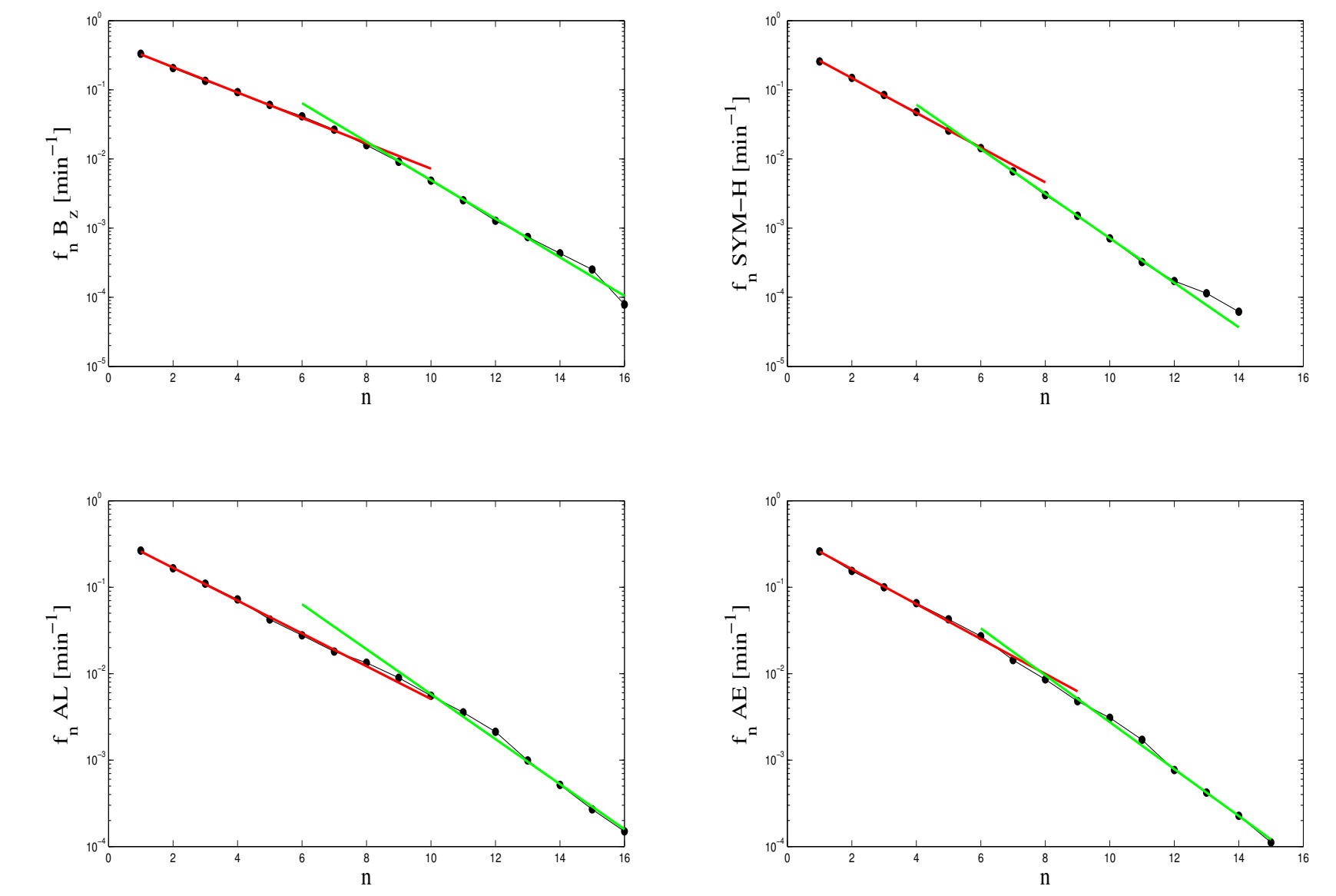

FIG. 2: Characteristic mean frequencies f_n versus n.

Analyzing Fig. 2 it can be seen that a clear timescale separation is evident, allowing us to split each set of modes into two subsets:

1. a short-timescale reconstruction which contains modes with a characteristic timescale $\tau \lesssim 200$ min
2. a long-timescale reconstruction involving modes with $\tau > 200$ min

This feature is observed into each decomposition suggesting that a relation between the input (solar wind) and the output (magnetospheric response) could be associated with processes characterized by τ lower/greater than 200 min.

5. Delayed Mutual Information (DMI) Theory

In order to detect an association between solar wind and magnetospheric processes we use the Delayed Mutual Information (DMI) Theory which provides us an estimation of the total (linear and nonlinear) correlation between two signals [2].
Considering a time delay Δ, it is possible to introduce a quantity capable of quantifying the information shared by two sequences

$$MI(\Delta) = \sum_{i,j=1}^{N} p_{ij}(X(t), Y(t+\Delta)) \log \frac{p_{ij}(X(t), Y(t+\Delta))}{p_i(X) p_j(Y)} \qquad (1)$$

where $p_{ij}(X(t), Y(t+\Delta))$ is the joint probability of observing the couple of values (X, Y), while $p_i(X)$ and $p_j(Y)$ are the probabilities of observing X and Y as independent variables. The quantity MI measures how much knowing one of these variables reduces the uncertainty about the other. This means that high mutual information indicates a large reduction of uncertainty and suggests possible correlations.

6. DMI results: IMF-Bz component

In Fig. 3 we report the DMI results between the IMF-Bz component and the geomagnetic indices on different timescales.

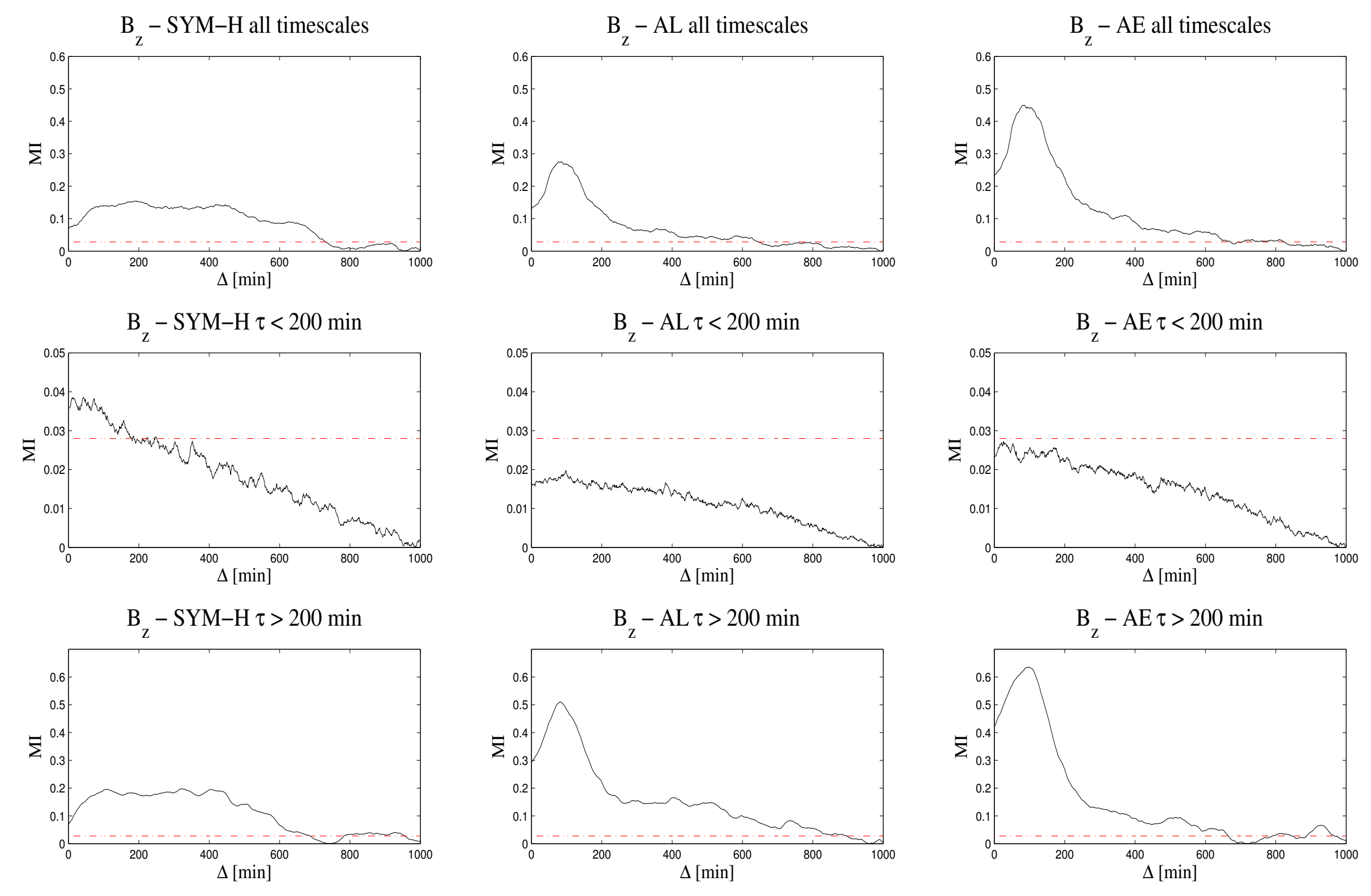

FIG. 3: DMI results. (The dashed line refers to the 5% null hypothesis level via surrogate data test).

7. DMI results: Perrault-Akasofu Parameter

The same analysis is carried out for the Perreault-Akasofu ϵ parameter as shown in Fig. 4.

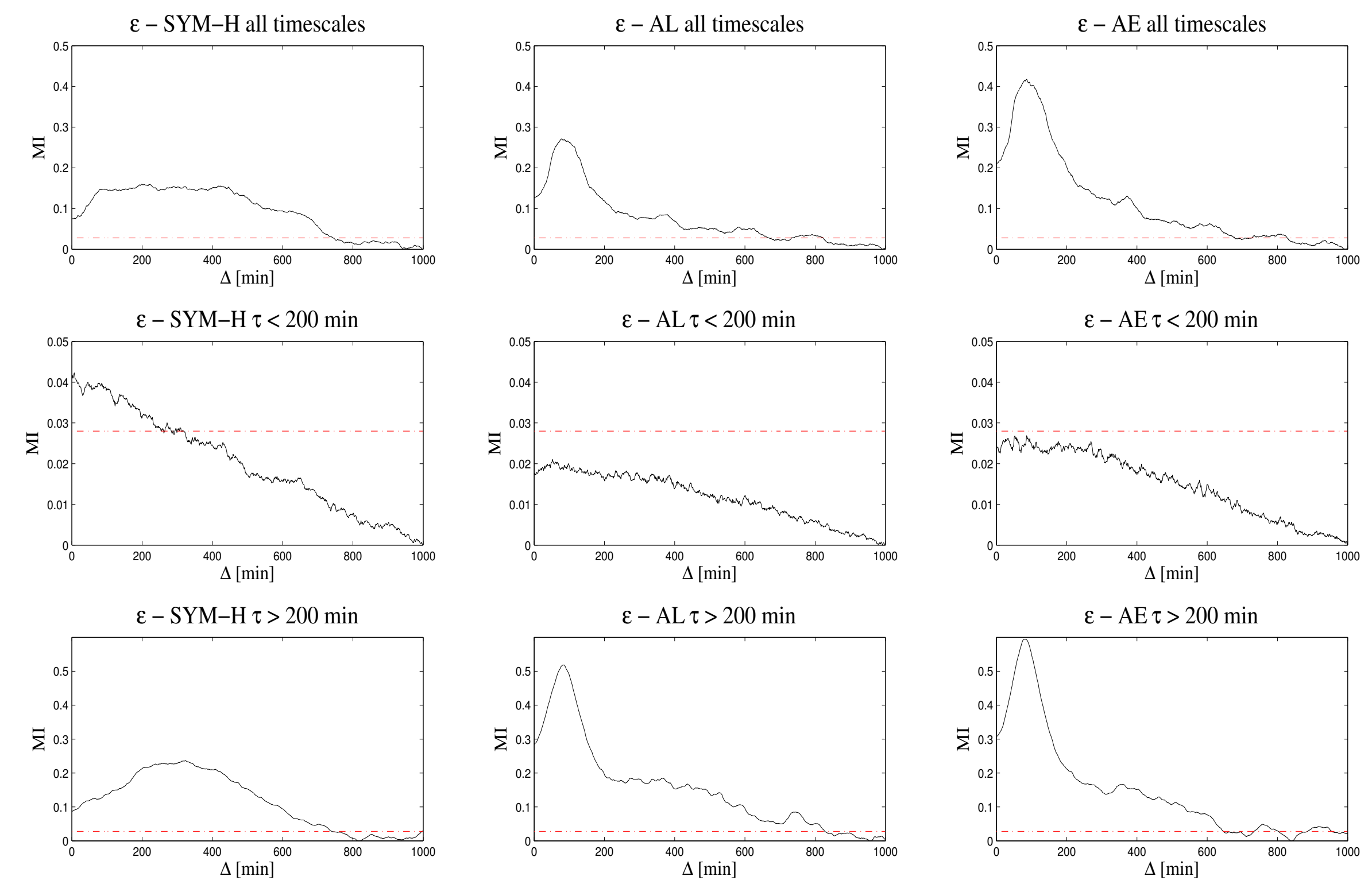

FIG. 4: DMI results (as for Fig. 3) obtained by considering the Perreault-Akasofu ϵ parameter.

8. Discussion

By comparing, on different timescales through the EMD, the IMF-Bz component and ϵ parameter with geomagnetic indices SYM-H, AL, AE, we show the existence of a timescale separation (see Fig. 2) which allows us to detect two contributions: (i) short-timescale ($\tau \lesssim 200$ min), (ii) long-timescale ($\tau > 200$ min).
In order to find a connection between external and internal timescales, the DMI is applied (see Fig. 3) showing that:

1. the magnetospheric short-timescale reconstructions seem to be not related to that in the solar wind because the MI is under the null hypothesis threshold. This is a relevant result indicating an internal origin of timescales lower than 200 min;
2. on the contrary, the solar wind long-timescale reconstruction plays a primary role into the generation and transmission of timescales greater than 200 min in the magnetosphere.

Moreover, a time delay of ~ 100 min is found between input and output according to the travel time of the perturbation from the ACE spacecraft position to the Magnetopause and to the internal magnetosphere. Finally, a great information transfer can be observed between IMF-Bz component (ϵ parameter) and AE/AL indices, while a lower transfer is found when IMF-Bz (ϵ) and SYM-H are considered.
These results can be very useful for Space Weather prediction models of storms and substorms.

References

1. Huang, N.E. et al., Proc. R. Soc. Lond. Ser. A 454, 903, 1998
2. De Michelis, P., G. Consolini, M. Materassi, and R. Tozzi, J. Geophys. Res., 116, A08225, 2011

Acknowledgements: This research work is partly supported by the Italian MIUR-PRIN grant 2012P2HRCR on *The active Sun and its effects on Space and Earth climate* and by Space Weather Italian COmmunity (SWICO). The authors acknowledge J.H. King and N. Papatashvilli at NASA and CDA Web for solar wind data.

E-mail contact: tommaso.alberti@unical.it