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EO Science for Society Permanently Open Call For
Proposals EOEP-5 BLOCK4- (INTENS)

Ionospheric Turbulence Development During St. PatricK's Day Storm

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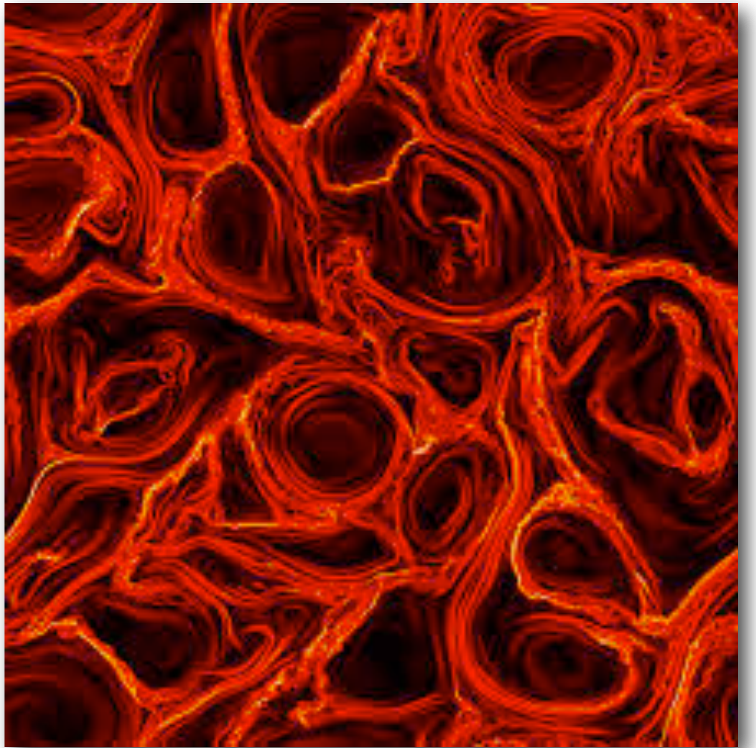
AIM

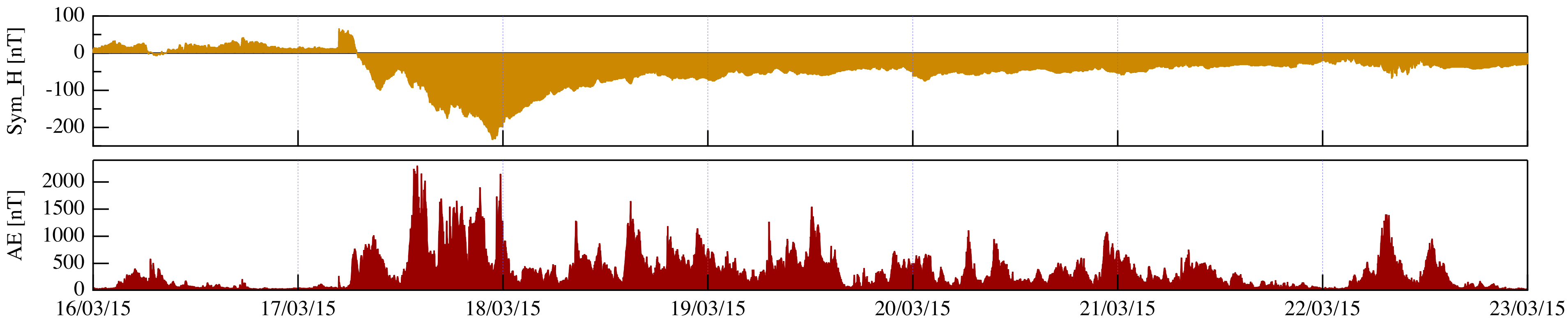
★To analyse the dynamical changes of the scaling features of the electron density and geomagnetic field fluctuations in order to obtain information about **the turbulent nature of the ionospheric plasma** during the St. Patrick's storm.

WHY

Turbulence plays a central role in several processes involving the plasma and particle transport. In the Earth's ionosphere, it plays a fundamental role in the overall dynamics. It is able to generate/create magnetic and plasma structures that can strongly affect the homogeneity of the plasma in the ionospheric regions.



DATA: Magnetic Field and Electron Density Measurements Recorded by Swarm constellation during St. Patrick's day storm

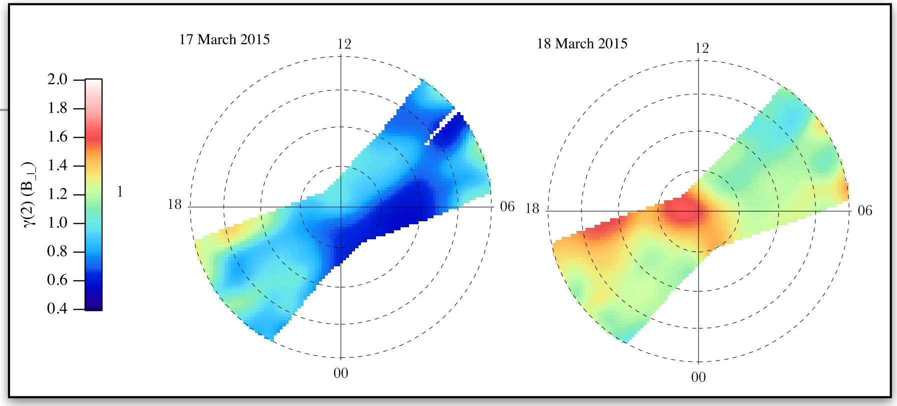


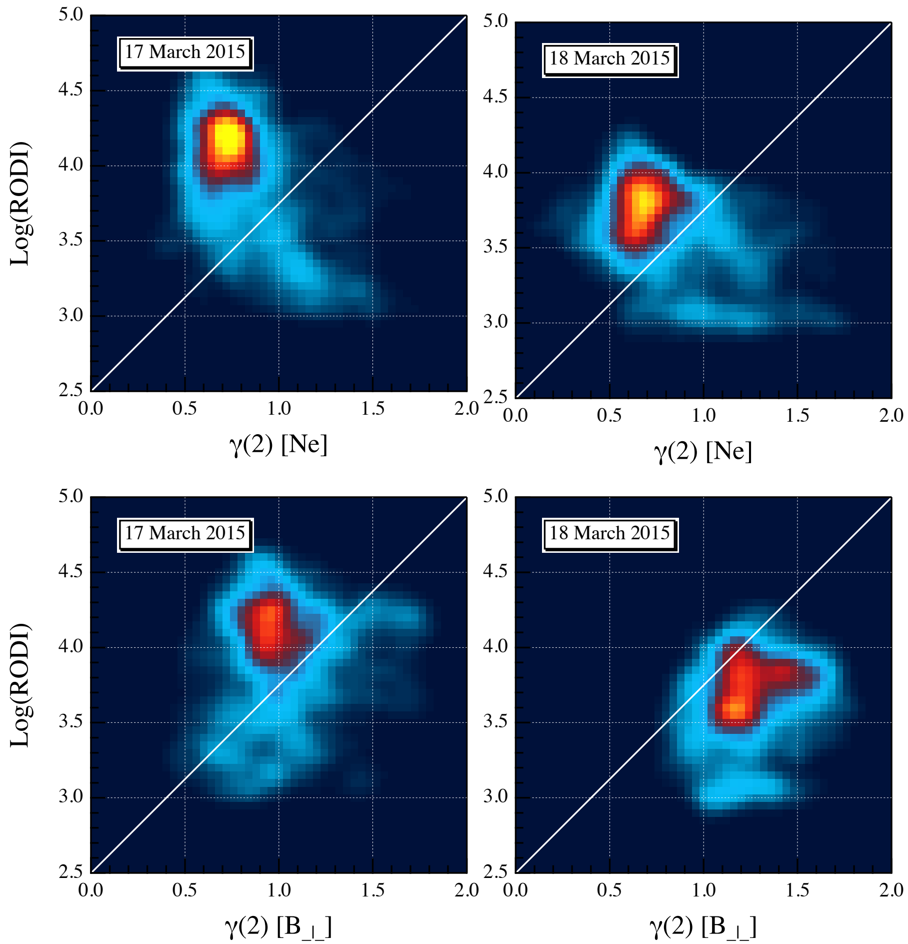
MAIN RESULTS

- Electron density and magnetic field fluctuations are characterized by scaling properties which change during the development of the analysed geomagnetic storm, that is clearly evident in the case of the magnetic field fluctuations.

- We correlate the scaling properties of the magnetic and electron density fluctuations with the RODI, which is a measure of plasma structuring. RODI is strongly correlated with an anti-persistent character of the electron density fluctuations, characterized by a spectral exponent near 1.6-1.7. This could be a signature of the role that turbulence might play in generating multi scale plasma structures.

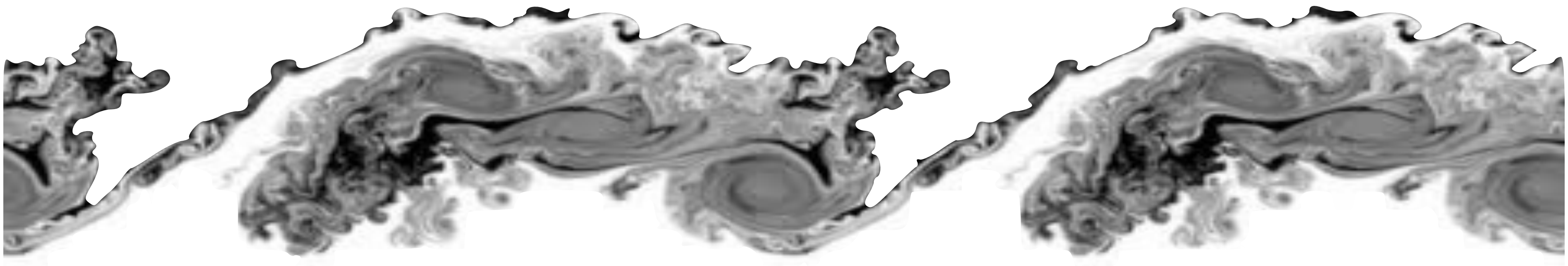
- The correlation of the scaling properties of the magnetic field fluctuations in the direction perpendicular to the main field with RODI exhibits a decrease of RODI in correspondence of an increase of the scaling exponents.





Are You Interested?

Go On



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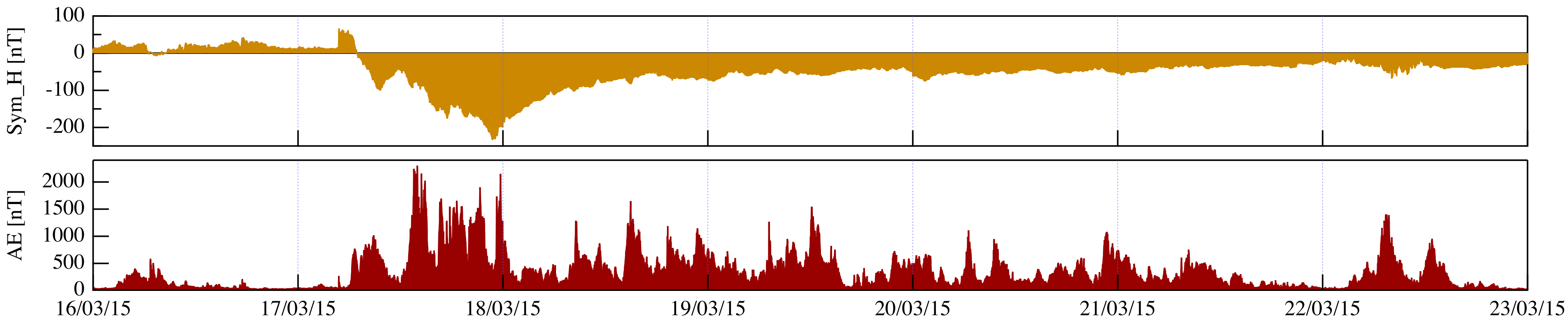
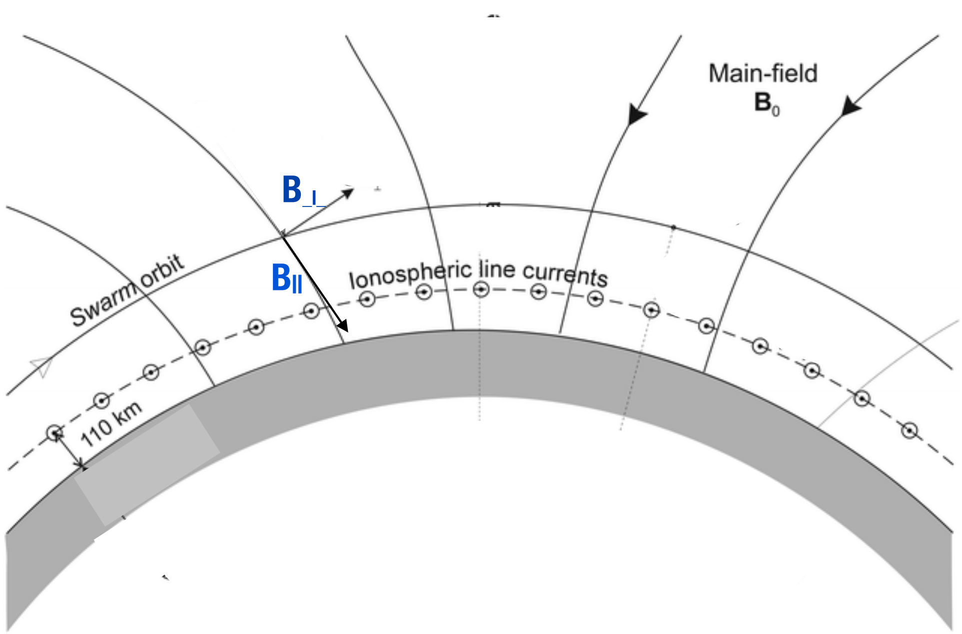


DATA: Swarm 1 Hz magnetic field measurements



adapted from Drost Aakjær et al., EPS, 2016

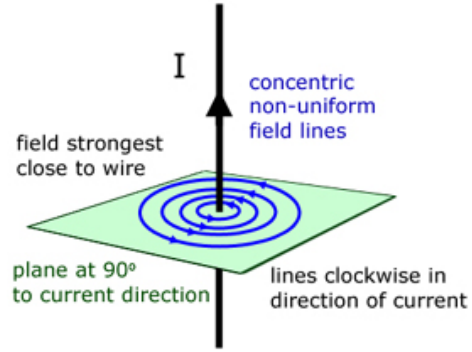
$$B_{||} = \frac{1}{B_0}\mathbf{B}_{ext} \cdot \mathbf{B}_0 \qquad \mathbf{B}_\perp = \mathbf{B}_{ext} - B_{||}\frac{\mathbf{B}_0}{B_0}$$

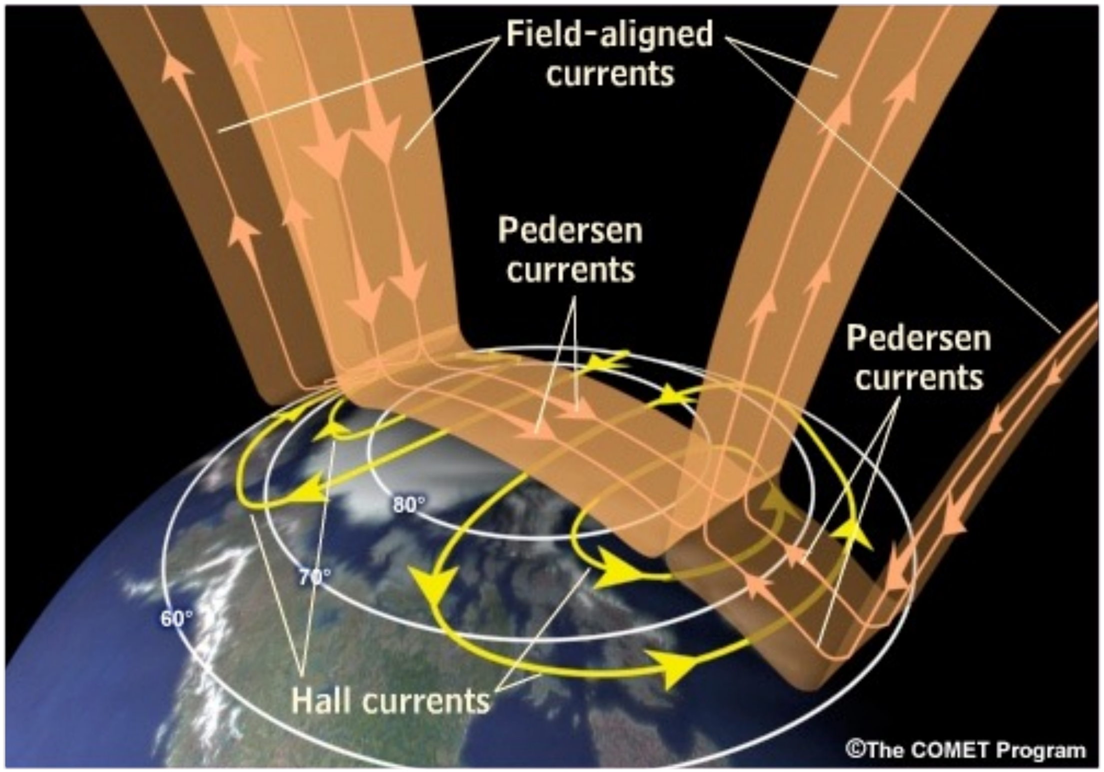
1. **Remove magnetic field of internal origin** from the original data to extract the external one. We use CHAOS 6 model (Finlay et al., 2016). This allows to better quantify the fluctuations.

2. **Modify the reference system** in which the magnetic field is represented defining the external magnetic field in terms of parallel and perpendicular components to the main field.

DATA: Swarm 1 Hz magnetic field measurements

The magnetic field produced by an electric current is, at least in the vicinity of the current, always perpendicular to the current direction.

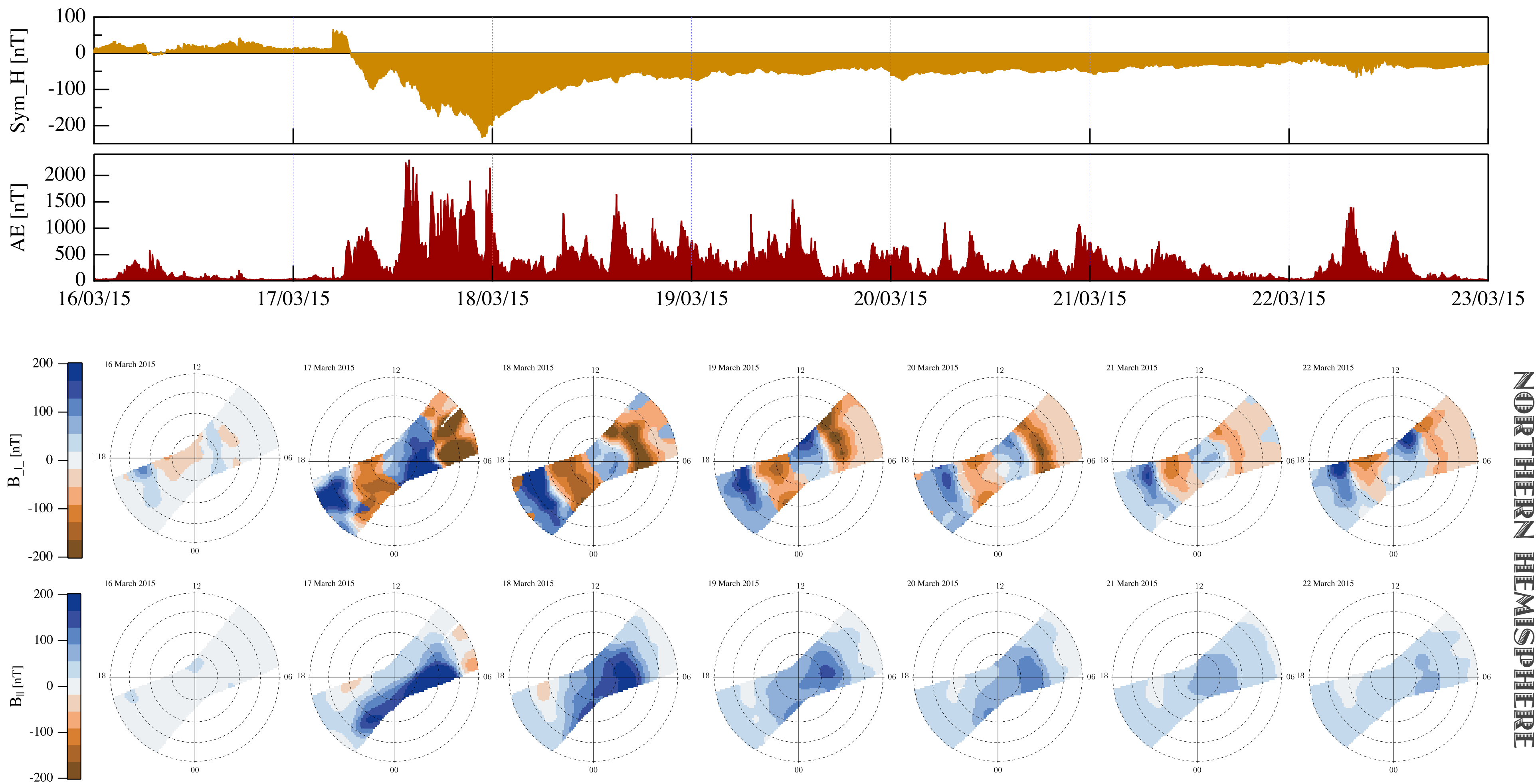




The magnetic field caused by FACs is **perpendicular** to the field line (and hence not observable in the magnetic component parallel to the field line).

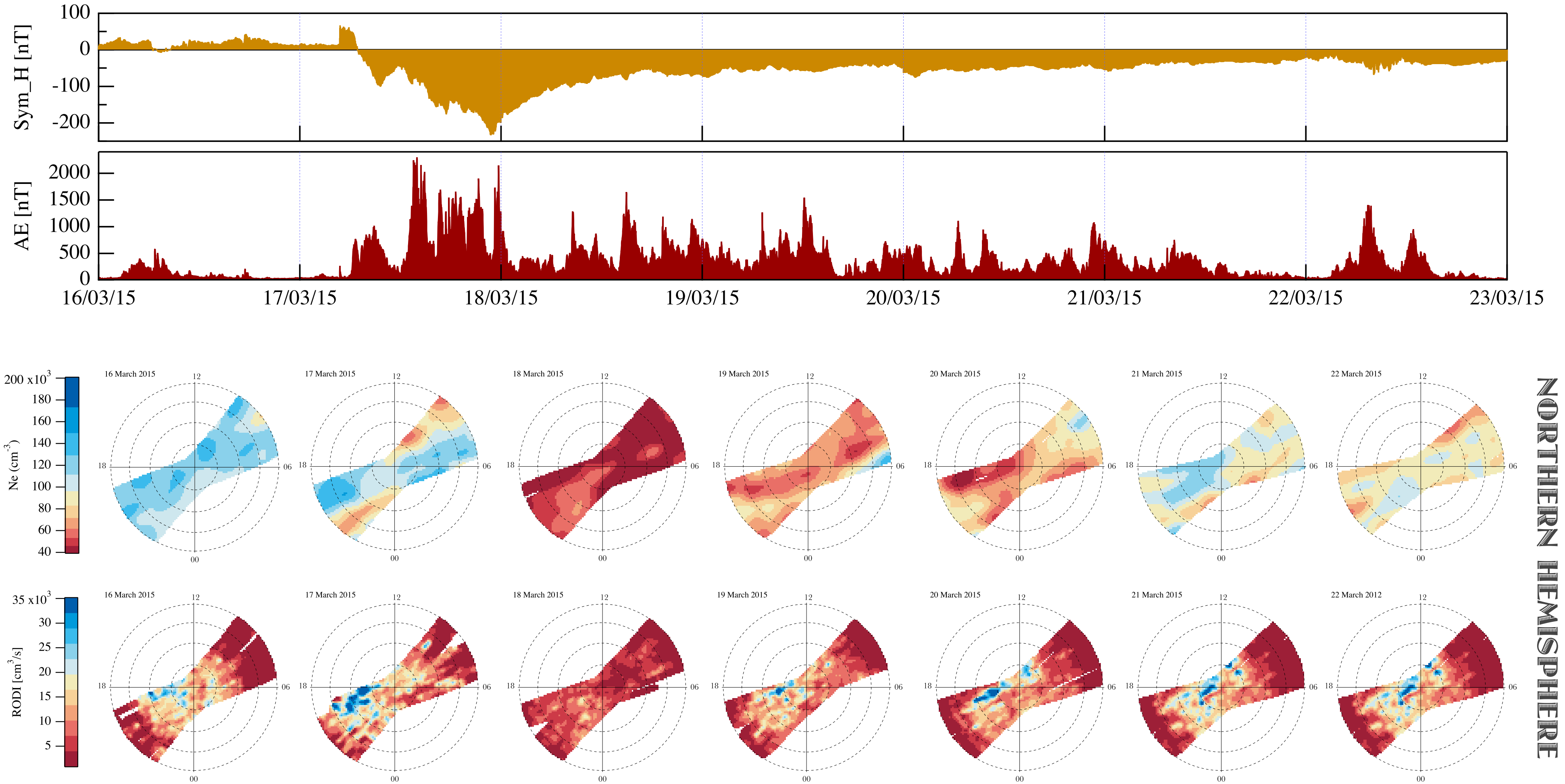
The field component **parallel** to the magnetic field, is only marginally affected by FACs. It is, however, sensitive to contributions from the horizontal currents.

DATASET:
External components of the geomagnetic field from Swarm constellation



Day by day evolution of external magnetic field in terms of perpendicular and parallel components to the main field during the St. Patrick's day storm.

DATASET:
Electron Density and RODI (Rate Of change of Density Index) from Swarm constellation



Electron density reported day by day during the St. Patrick's day storm together with the RODI index evaluated using method described by Jin et al. (JGR 2019).

How to investigate scale-invariance ?

We consider **qth-order structure function** $S_q(\tau)$, which for a signal $x(t)$ defined over an interval T is given by

$$S_q(\tau) = \langle| \; x(t+\tau) - x(t) \; |^q \rangle_T$$

when we deal with a scale-invariant signal the $S_q(\tau)$ exhibits a power law behavior as a function of the time separation

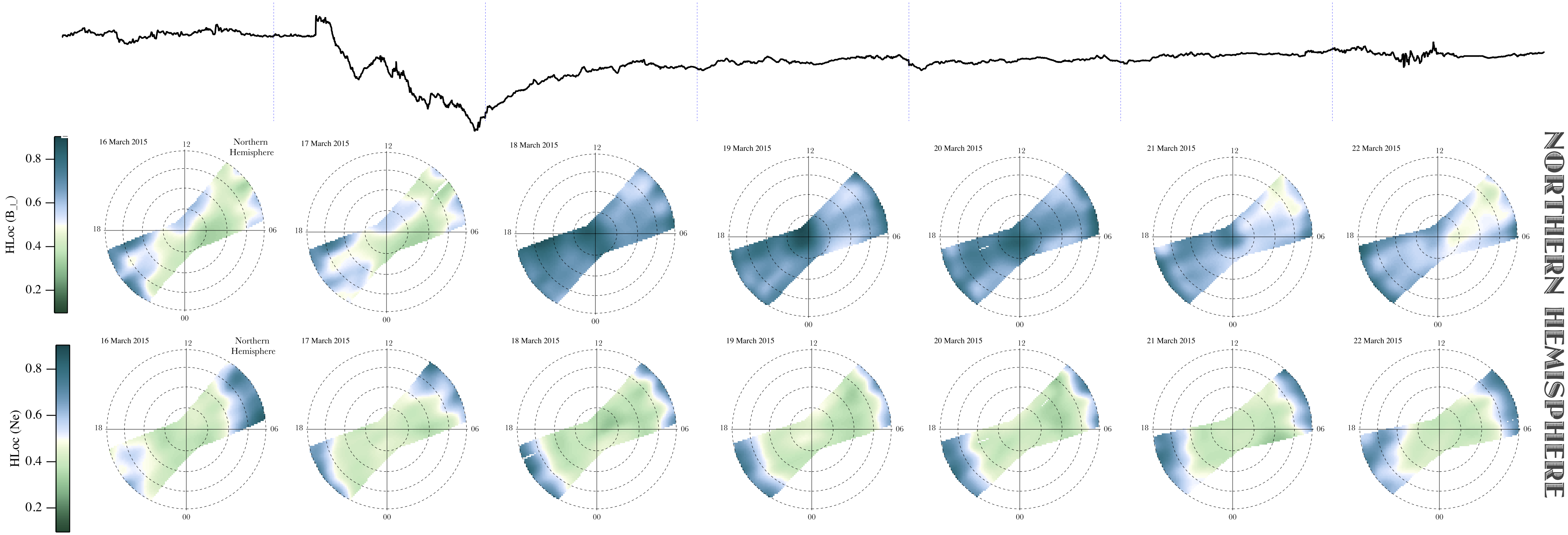
$$S_q(\tau) \sim \tau^{\gamma(q)}$$

In the case of the 1^{st}-order structure function $S_1(\tau)$ the scaling exponent is called *Hurst exponent H.*

The *Hurst exponent* quantifies the relative tendency of a time series either to regress strongly to the mean (H<0.5) or to cluster in a direction (H>0.5).

Results:
Local Hurst Exponent

The **Hurst exponent** quantifies the relative tendency of a time series either to regress strongly to the mean (H<0.5), that means to be characterized by an **anti-persistent** behavior (Green color in the figure), or to cluster in a direction (H>0.5), that means to be characterized by a **persistent** behavior (Blue color in the figure).



The scaling properties of the magnetic field and electron density fluctuations change during the development of the geomagnetic storm. These changes are clearly evident in the magnetic field fluctuations.

Spectral Features: Spectral Density Exponent

To better characterize the scaling properties of the geomagnetic field fluctuations we evaluate the **2th-order structure function:**

$$S_2(\tau) = < |x(t+\tau) - x(t)|^2 >_T$$

$$S_2(\tau) \sim \tau^{\gamma(2)}$$

The values of $\gamma(2)$ permit us to describe the spectral properties of the analyzed signal. According to Wiener-Khinchin theorem, the Fourier power spectral density (PSD) exponent β of a signal is related to $\gamma(2)$ according to the following relation:

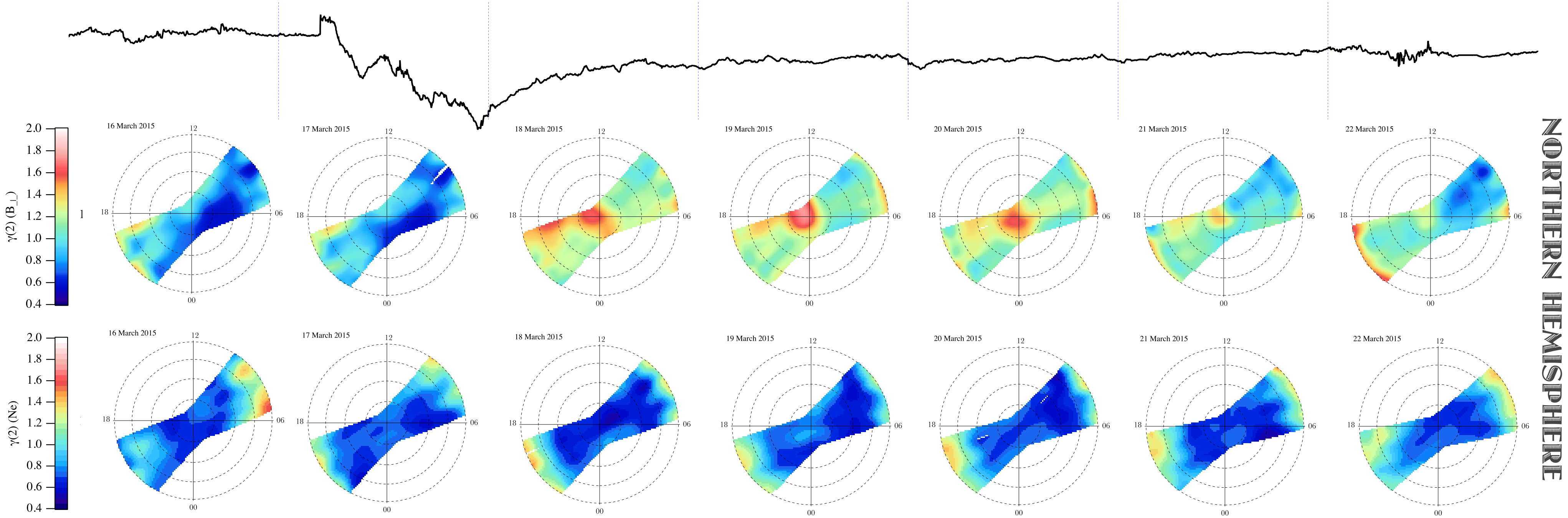
$$PSD(f) \sim f^{-\beta} \quad \rightarrow \quad \beta = \gamma(2) + 1$$

Thus, from $\gamma(2)$ it is possible to infer the scaling exponents β of the power spectrum of the original signal, which **provides information on the different turbulence regime and processes.**

Results
Spectral Features: Spectral Density Exponent

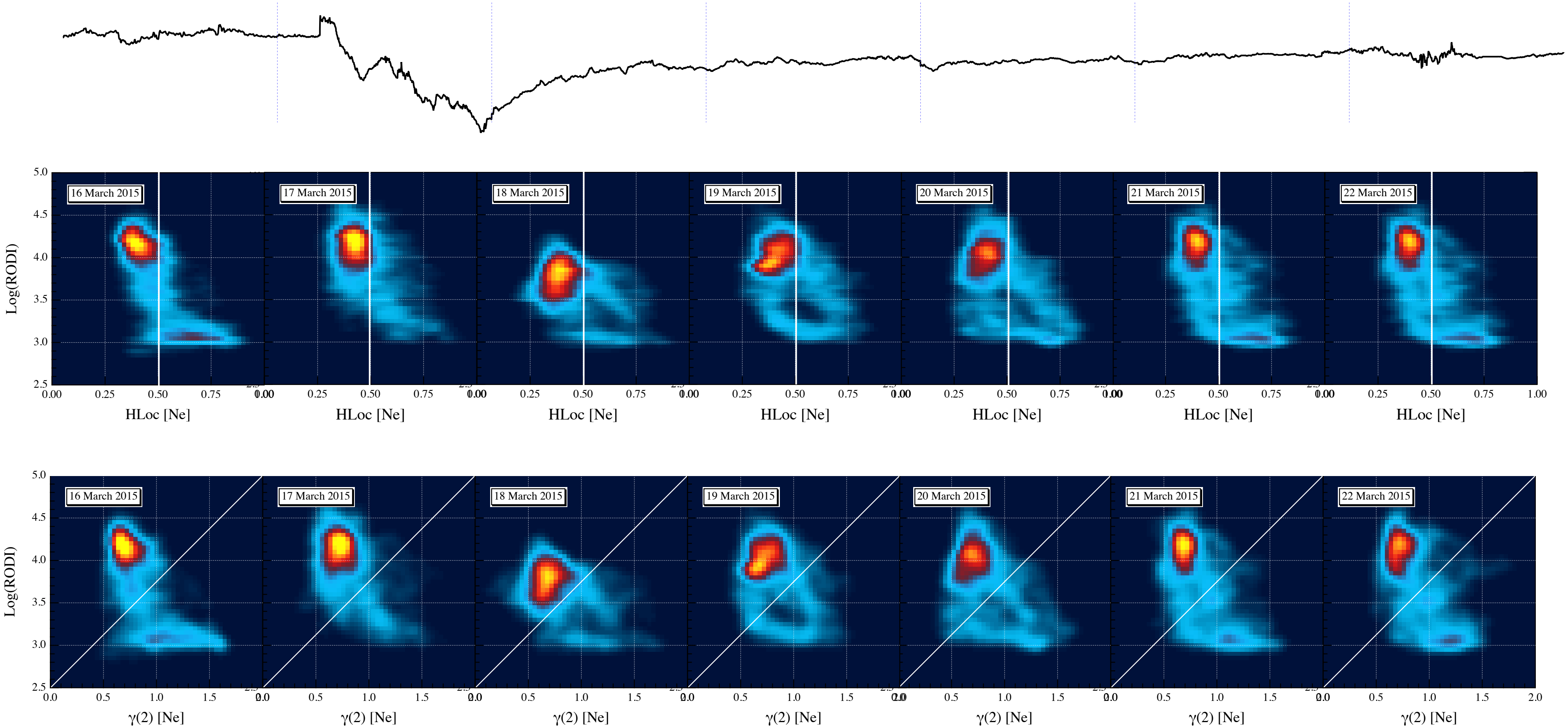
$$S_2(\tau) = < |x(t+\tau) - x(t)|^2 >_T$$

$$S_2(\tau) \sim \tau^{\gamma(2)}$$



The spectral scaling exponents of the magnetic field and electron density fluctuations change during the development of the geomagnetic storm and depend on the latitude and MLT. The electron density is characterized by values of the spectral density exponents lower than those associated with the magnetic field fluctuations.

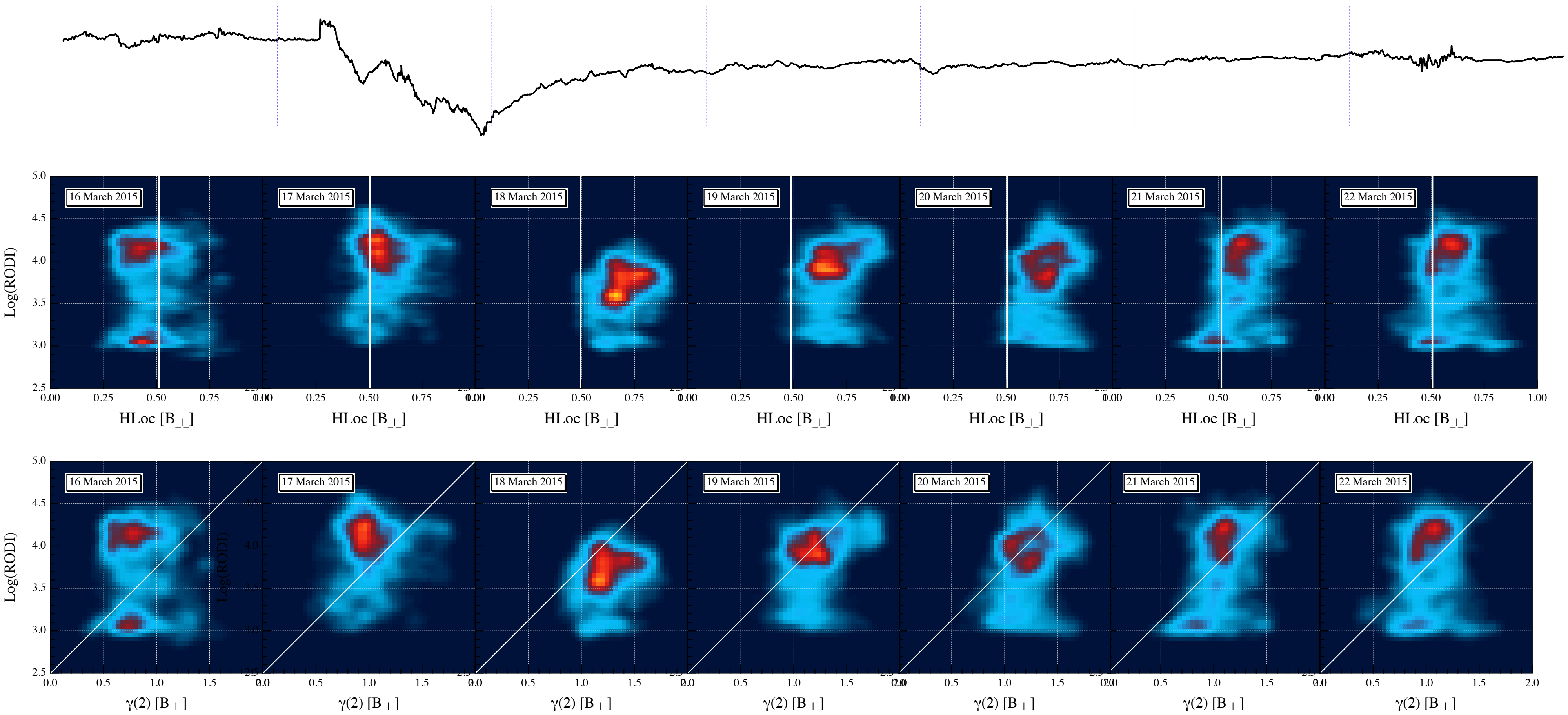
Results:
RODI vs Structure Function Exponents of Electron Density



High values of the RODI index, which is the variance of electron density fluctuations and indicates structuring of the plasma within a fixed time interval (in our case 10 s), are correlated to an anti-persistent character of the electron density fluctuations and values of the spectral exponent around 0.66.

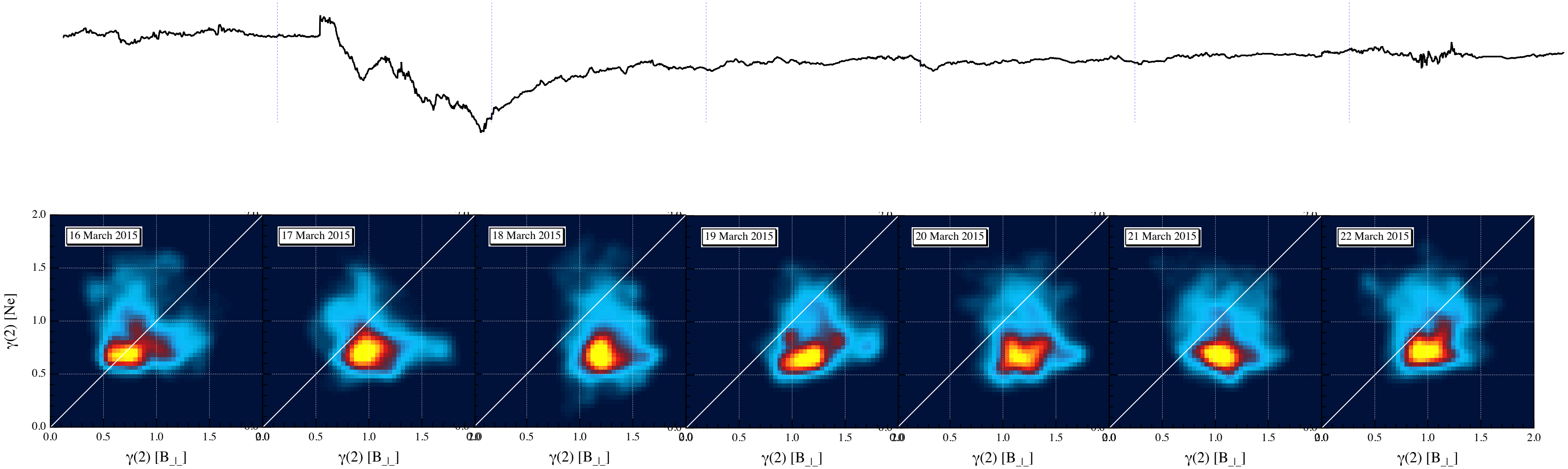
These features remain throughout the storm.

Results:
RODI vs Structure Function Exponents of Magnetic Field



The comparison with the changes in the scaling features of the magnetic field external fluctuations is less clear and requires a more detailed analysis, although a decrease of RODI seems to be associated with an increase of the scaling exponents. This is particularly evident in the early recovery phase.

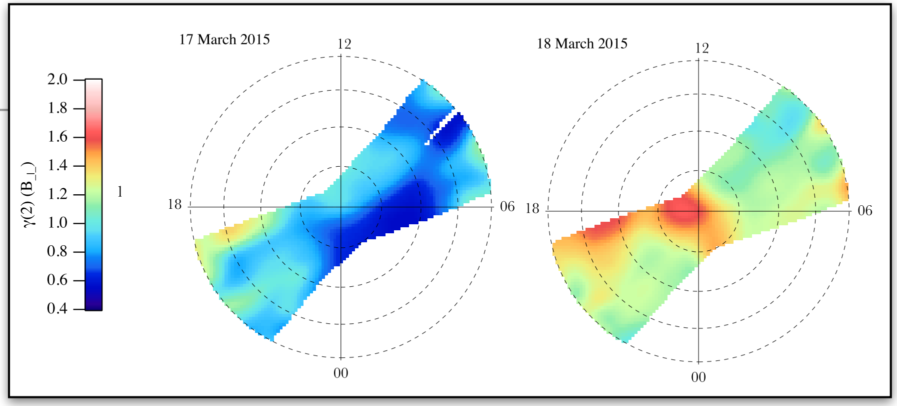
Results:
Ne vs B_|_ 2nd-order Structure Function Exponents



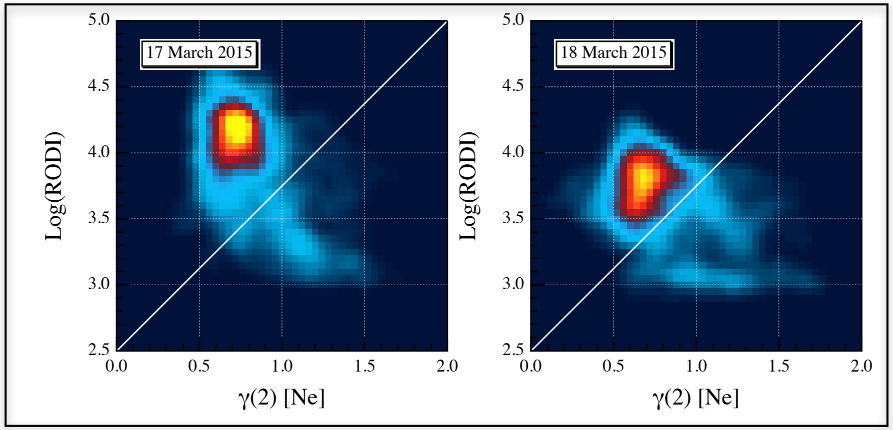
Comparison between the 2nd-order exponents of electron density fluctuations and magnetic field perpendicular component. The 2nd-order exponents of electron density are always smaller than those of the magnetic field perpendicular component during storm time (main and recovery phases). That could be the consequence of a more intermittent character of the electron density, which could be related to a passive scalar nature of this quantity. This point, which might be extremely relevant for modeling the dynamics of ionospheric plasma, requires a more detailed analysis involving also a study of the compressive nature of the observed magnetic field fluctuations.

Conclusions

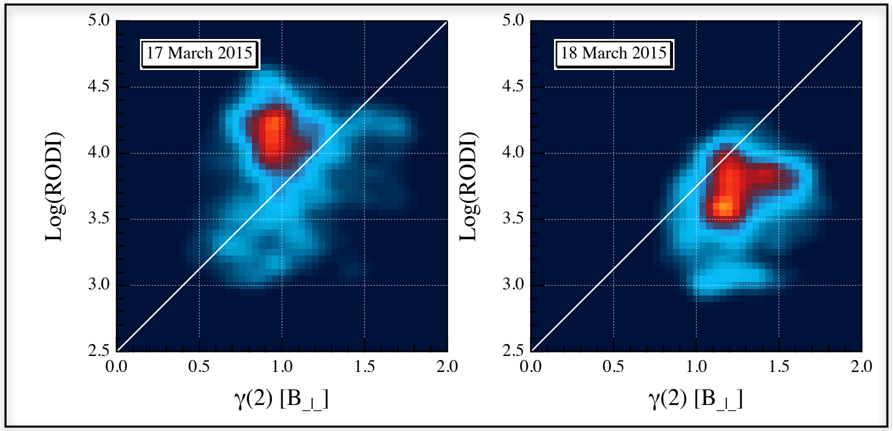
- Electron density and magnetic field fluctuations are characterized by scaling properties which change during the development of the analysed geomagnetic storm, that is clearly evident in the case of the magnetic field fluctuations.



- We correlate the scaling properties of the magnetic and electron density fluctuations with the RODI, which is a measure of plasma structuring. RODI is strongly correlated with an anti-persistent character of the electron density fluctuations, characterized by a spectral exponent near 1.6-1.7. This could be a signature of the role that turbulence might play in generating multi scale plasma structures.



- The correlation of the scaling properties of the magnetic field fluctuations in the direction perpendicular to the main field with RODI exhibits a decrease of RODI in correspondence of an increase of the scaling exponents.



thank you!