ESA/Contract No.4000125663/18/I-NB
EO Science for Society Permanently Open Call For Proposals EOEP-5 BLOCK4- (INTENS)

On the RODI and Ionospheric Electron Density Spectral Features During Geomagnetic Storms

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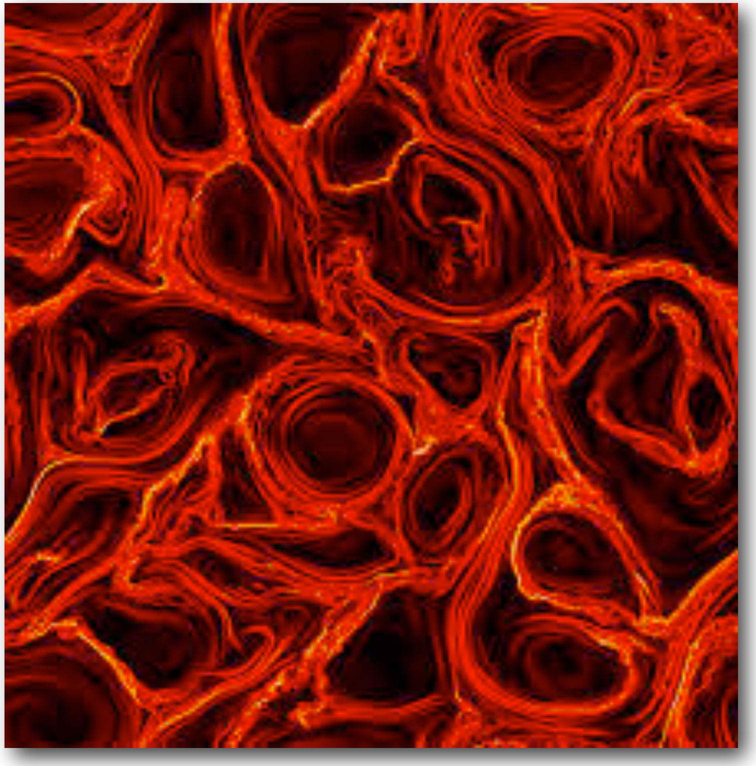
AIM

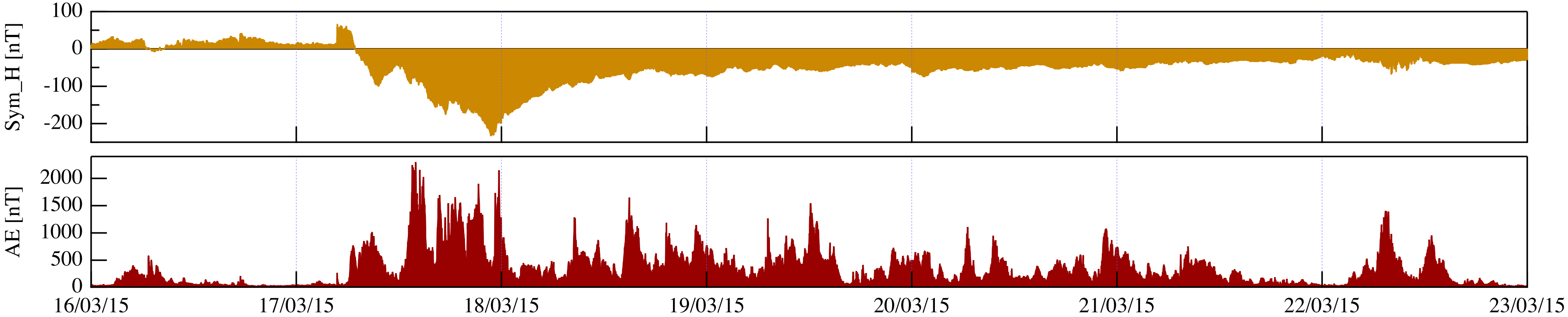
★To analyse the **scaling features of the electron density** fluctuations in order to get information about **the role of turbulence in the ionospheric plasma** during a geomagnetic storm.

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. It can play a relevant role in space weather.



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



We consider a period of 7 days during the St. Patrick's event occurred on 2015. This event is well described by the two different geomagnetic indices (Sym_H and AE) which give us information about the geomagnetic disturbances recorded on the ground at mid- and high-latitude regions during the magnetic storm.

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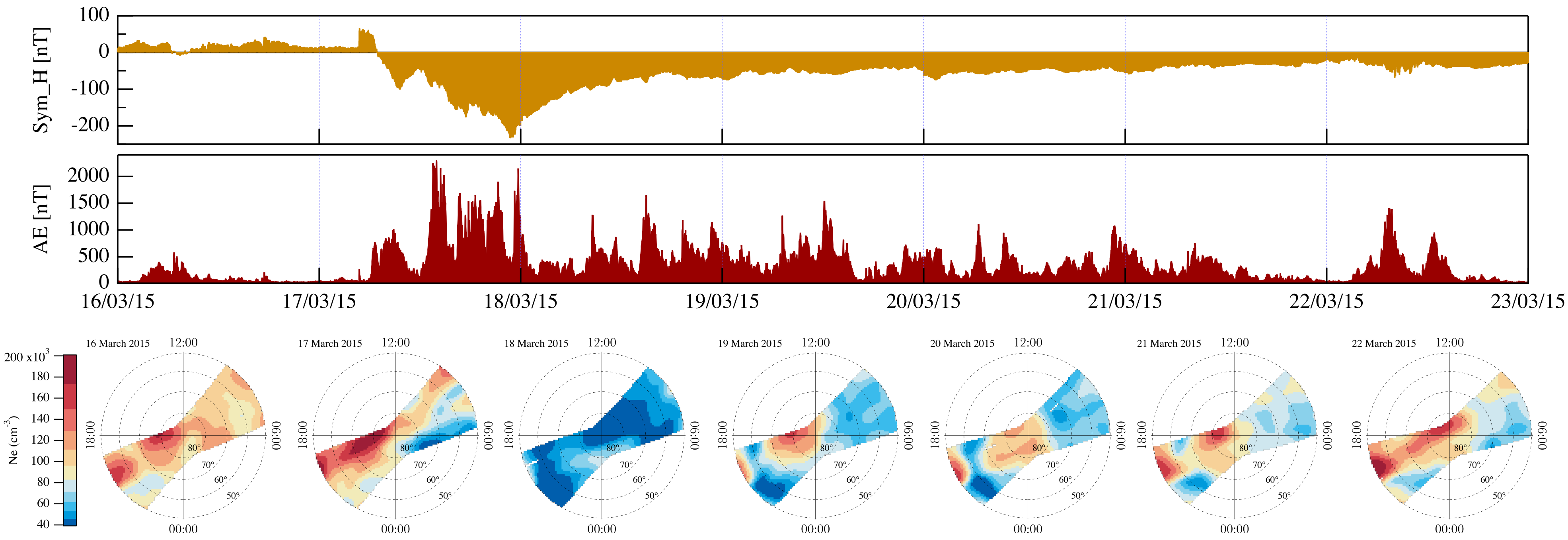

We focus on the analysis of the fluctuations of in-situ electron density provided by the Langmuir probe on board Swarm satellites (data at 1 Hz coming from SwarmA and SwarmB). Data are presented in terms of Quasi-Dipole latitude and MLT coordinates and reported in polar view daily maps.

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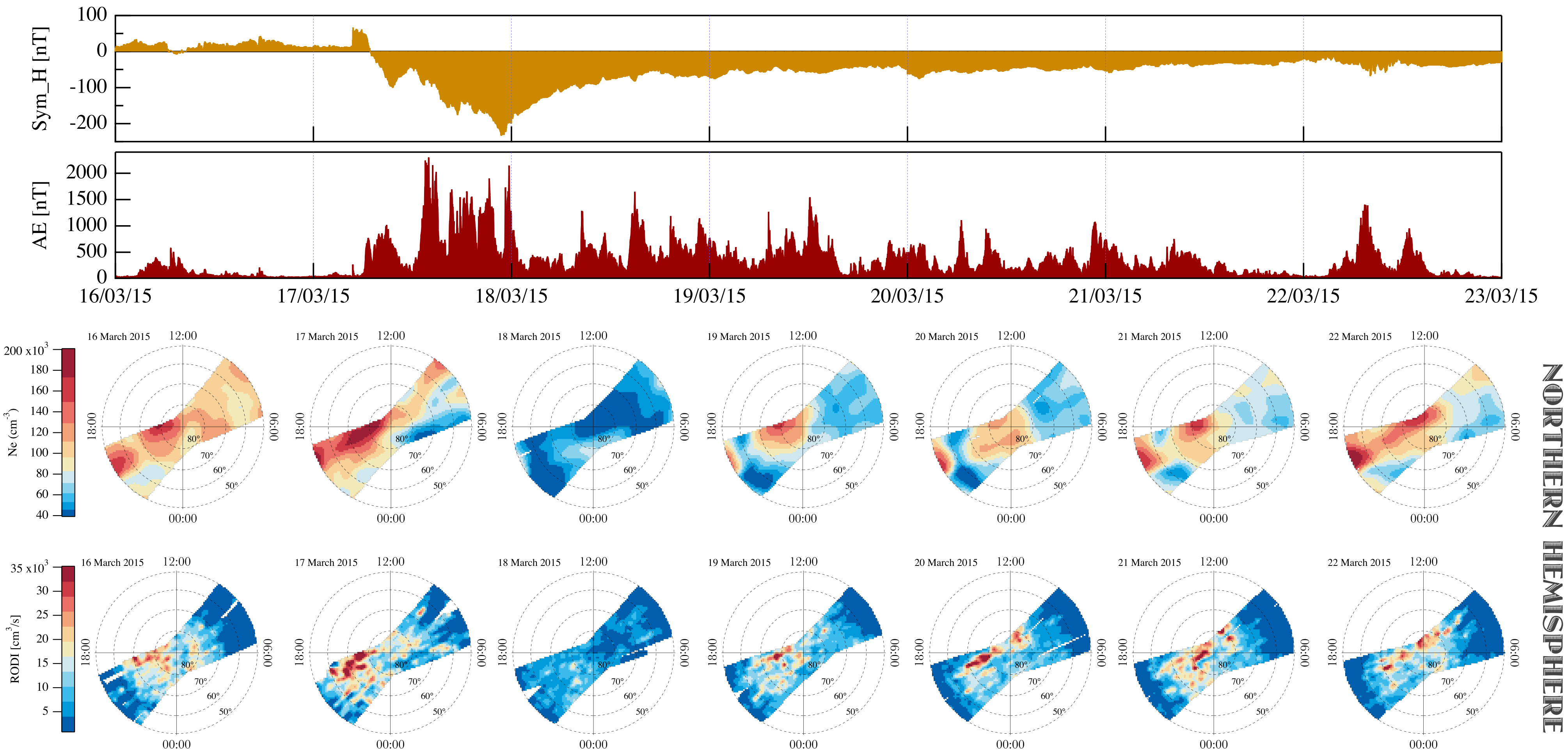

Using Ne we evaluate the Rate Of change of Density Index (RODI). RODI is commonly used to quantify the structuring of ionospheric plasma and as a proxy of ionospheric plasma irregularities.

Is there a relation between the occurrence of plasma density irregularities as described by the **Rate Of change of electron Density Index** and the **scaling properties of electron density fluctuations** during the development of the geomagnetic storm ?

If the **origin of plasma density irregularities is due to a turbulence process** the plasma density fluctuations are expected to show **scale invariance**.

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The study of the scaling properties of electron density fluctuations can be, indeed, important to understand if the **turbulence is the main source of the irregularities and to understand the type of turbulence**.

How to investigate scale-invariance ?

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

$$S_q(\tau) = < |N_e(t+\tau) - N_e(t)|^q >_T$$

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

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To study the **nature of the scaling properties** of electron density fluctuations means to study the **scaling exponents**

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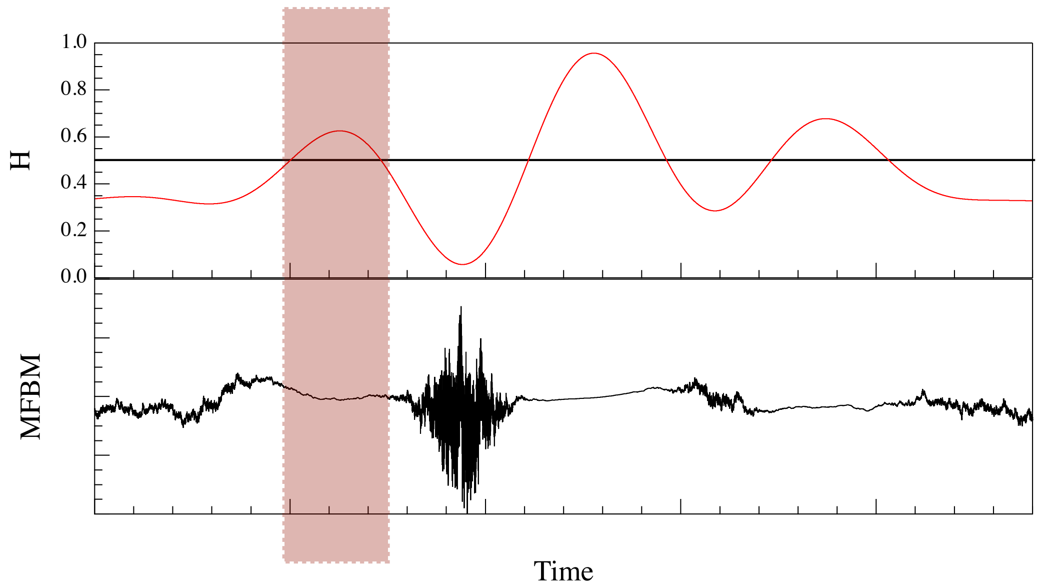
We can suppose that the results obtained in the time domain are also valid in the spatial one (Doppler effect equivalent to Taylor's hypothesis).

Results:
1st-order Structure Function

$$S_1(\tau) =< |N_e(t+\tau) - N_e(t)| >_T \sim \tau^{\gamma(1)}$$

The **Hurst exponent** quantifies the relative tendency of a time series:

- to cluster in a direction (H>0.5). It has a **persistent** behavior. Long-range correlated signals are characterized by a sign-persistence of their increments.
- to regress strongly to the mean (H<0.5). It has a anti persistent behavior. That happens in short correlated signals.



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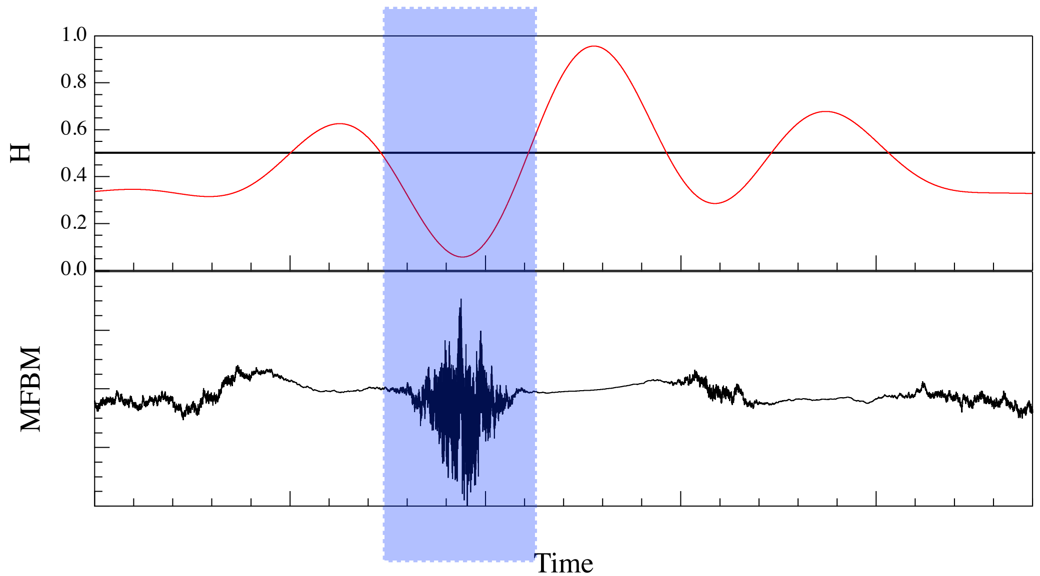
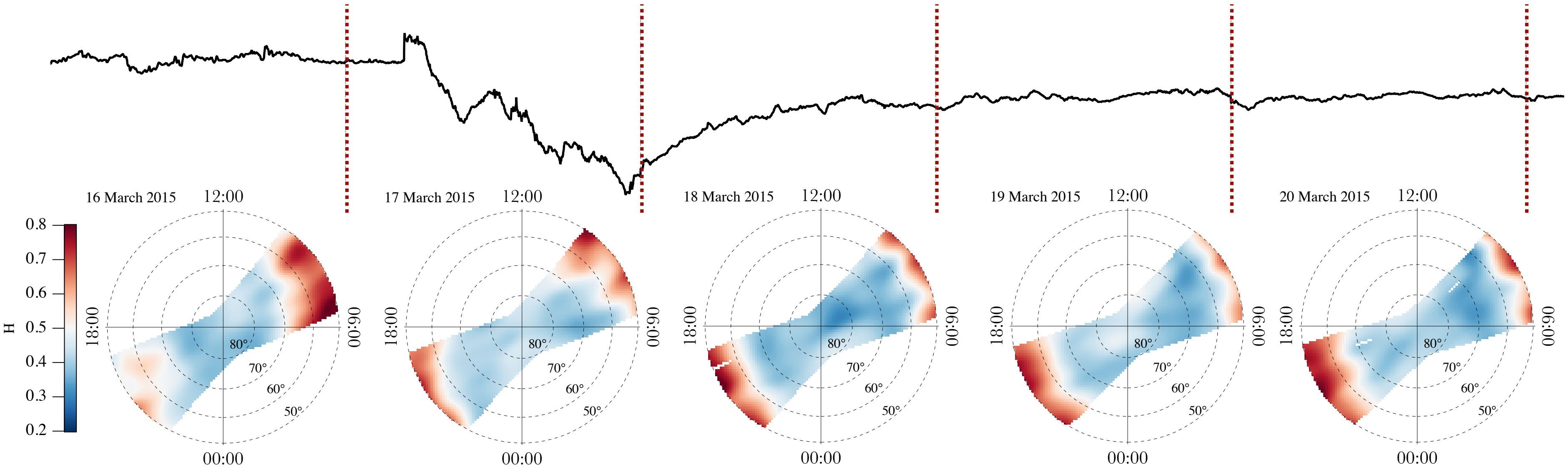


Results:
1st-order Structure Function

$$S_1(\tau) =< |N_e(t+\tau) - N_e(t)| >_T \sim \tau^{\gamma(1)}$$

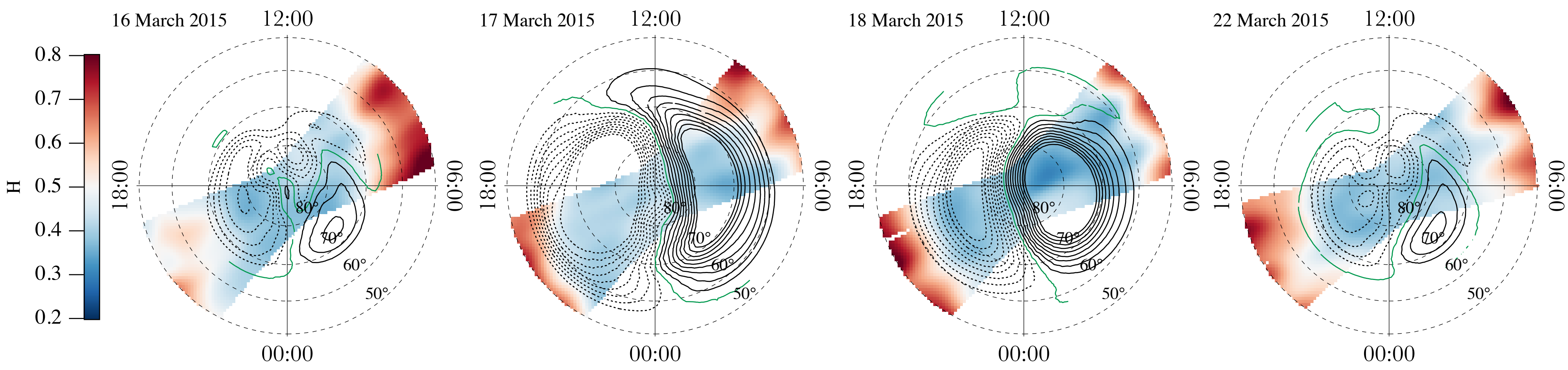
- The **anti persistent character** seems to be a typical features of high-latitudes.
- The **persistent character** appears to be a typical features of mid-latitudes.

- The position of the profile of the local Hurst values with respect to H = 0.5 seems to follow the spatial and temporal evolution of the auroral zone during the selected period.



Results:
Local Hurst Exponent

Here we have superposed to our results the statistical convection patterns derived from SuperDARN plasma drift measurements and obtained using the “CS10 Statistical Convection Model”.



A good agreement is found between the regions characterized by a anti-persistent behavior of the electron density fluctuations and both the position and the extension of the statistical convection patterns obtained in the same period.

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 **can provide information on the different turbulence regime and processes.**

Results
Spectral Features: Spectral Density Exponent

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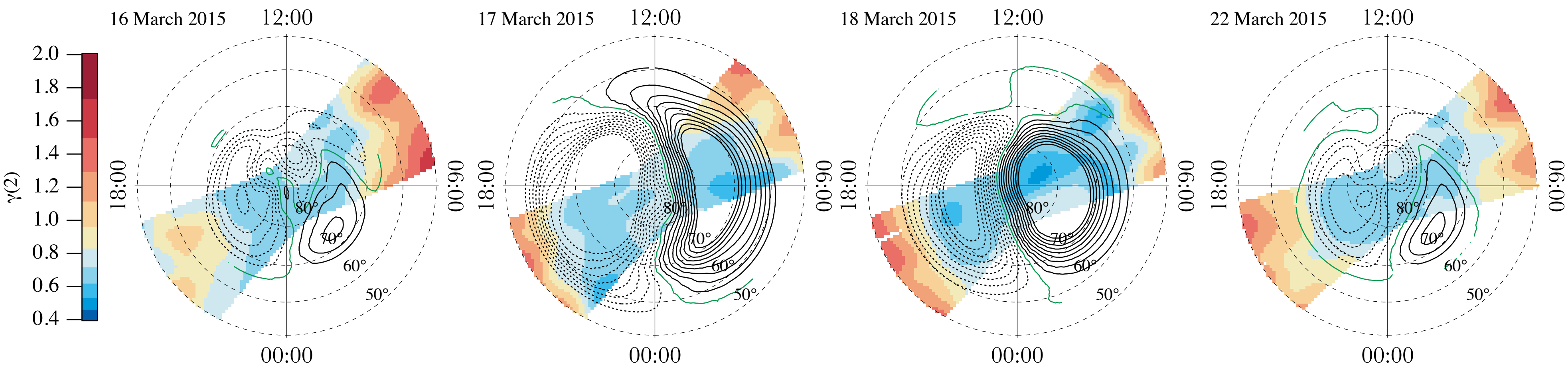
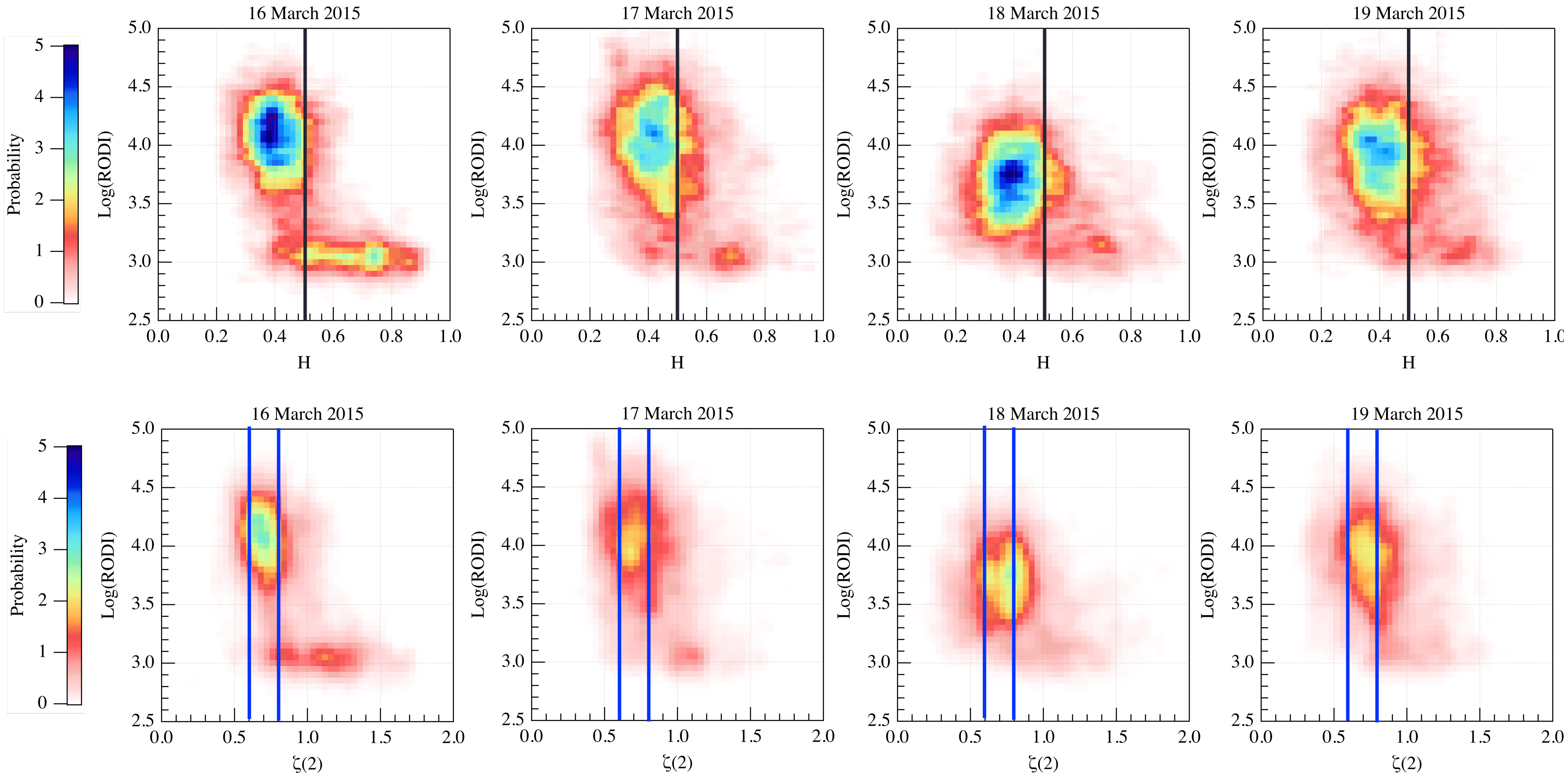
Also in this case, we have superposed to our results the statistical convection patterns derived from SuperDARN plasma drift measurements and obtained using the “CS10 Statistical Convection Model”.



Different scaling (turbulence) regimes and processes may characterize the regions where the convection patterns are localized. The values in the range 0.6 to 0.8 support the idea of a fluid and/or MHD turbulence as a source of these perturbations.

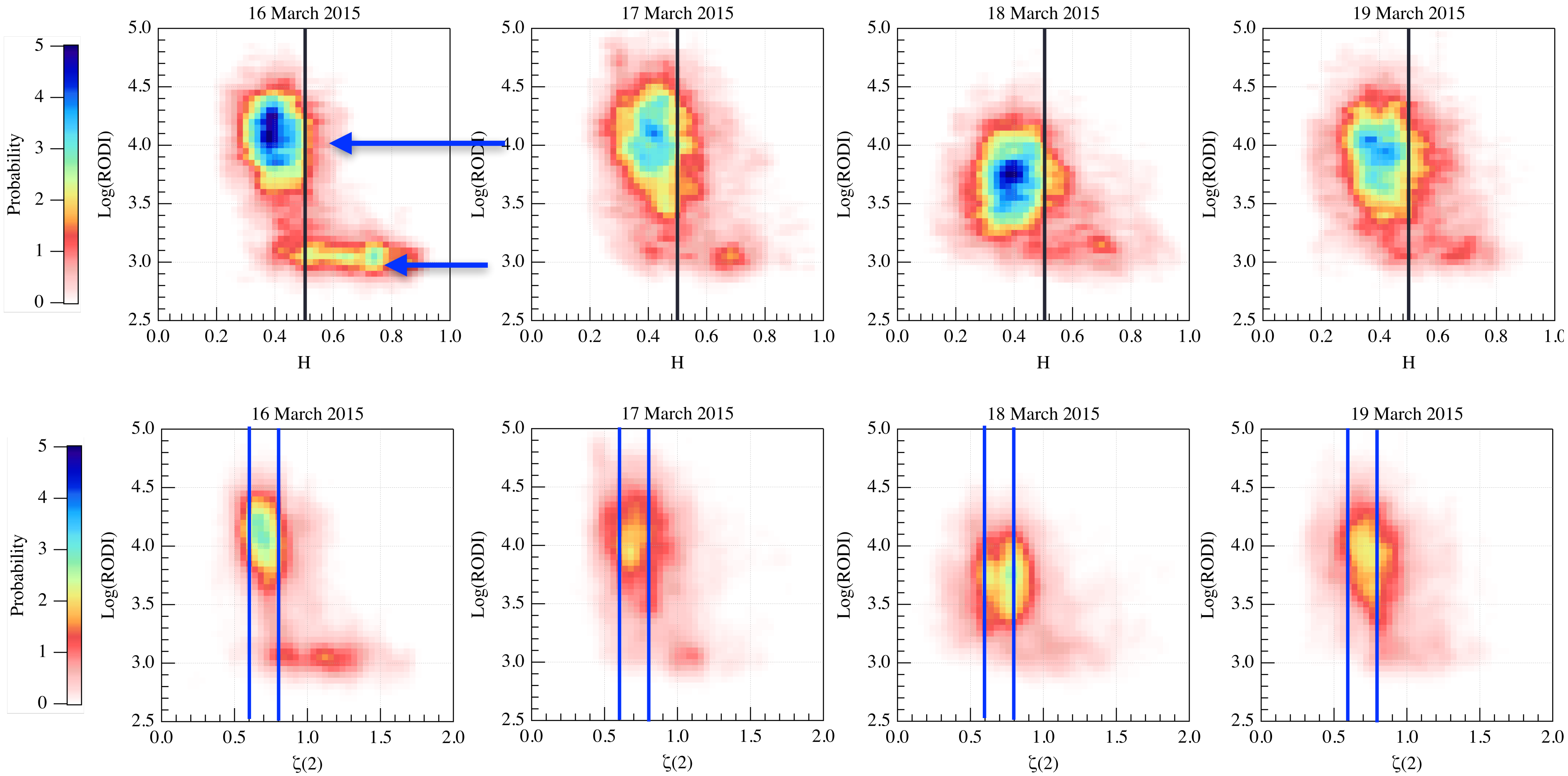
Results:
RODI vs Structure Function Exponents of Electron Density

To investigate the possible relationship between RODI parameter and the scaling features of the Ne fluctuations we evaluate the the **joint probability distributions** between RODI and first and second-order scaling exponents.



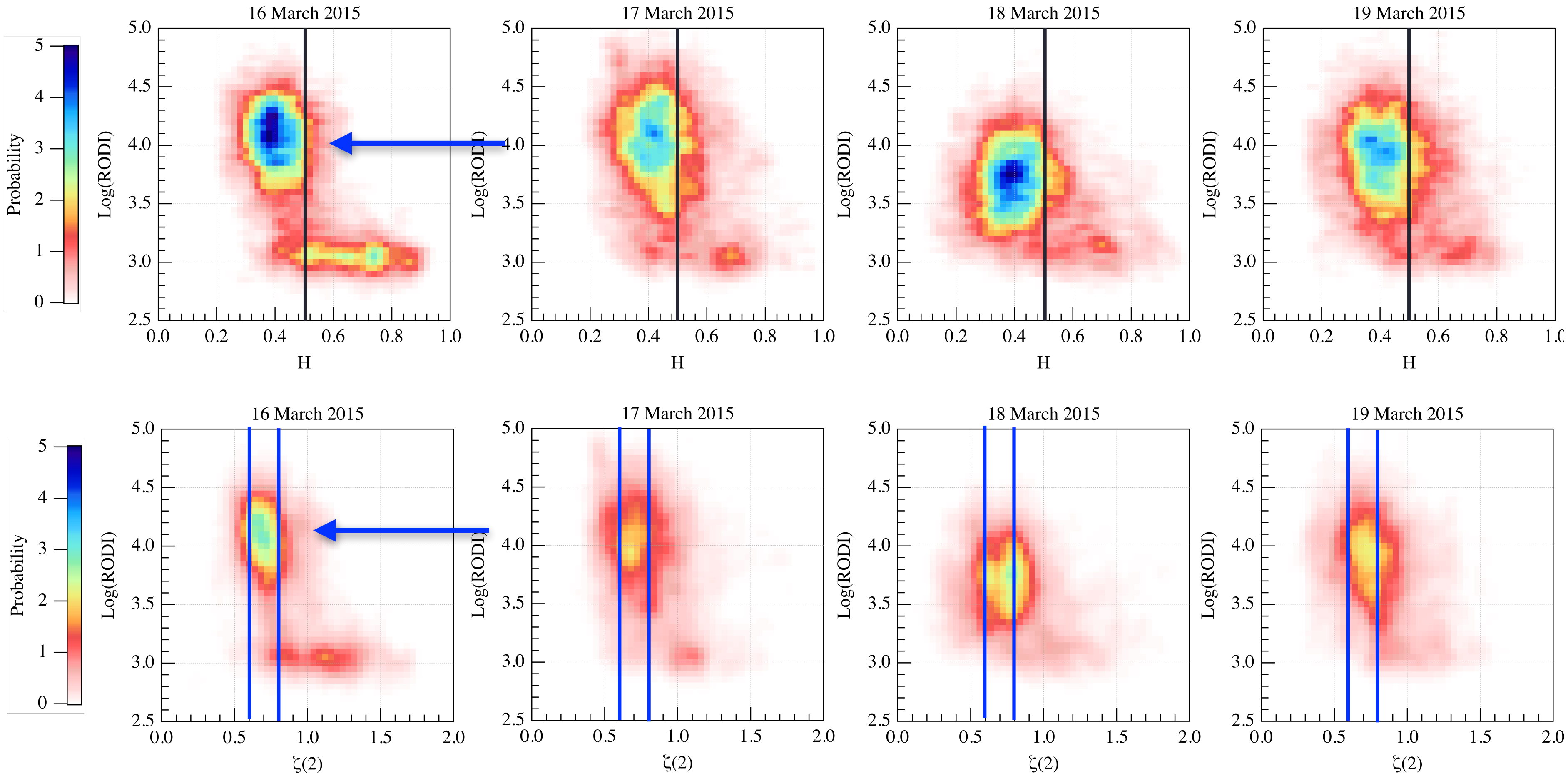
Results:
RODI vs Structure Function Exponents of Electron Density

The scaling features of electron density fluctuations permit us to find **two families** of plasma irregularities which seem to be associated with different physical properties.



Results:
RODI vs Structure Function Exponents of Electron Density

High values of the RODI, which is the variance of electron density fluctuations and is a proxy of ionospheric plasma irregularities, are correlated to an **anti-persistent character** of the electron density fluctuations and values of the spectral exponent around 0.6-0.8



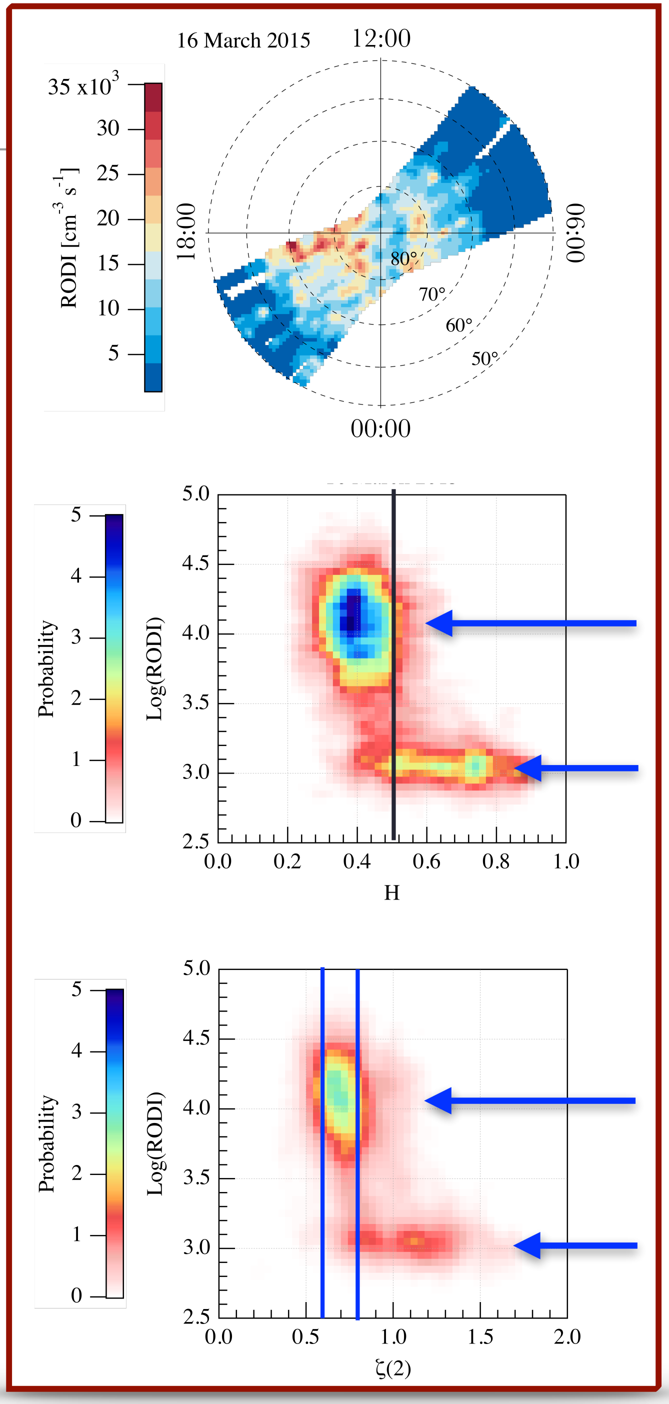
Summarizing …

- The plasma density variations may be due to different processes not necessarily linked to turbulence phenomena.

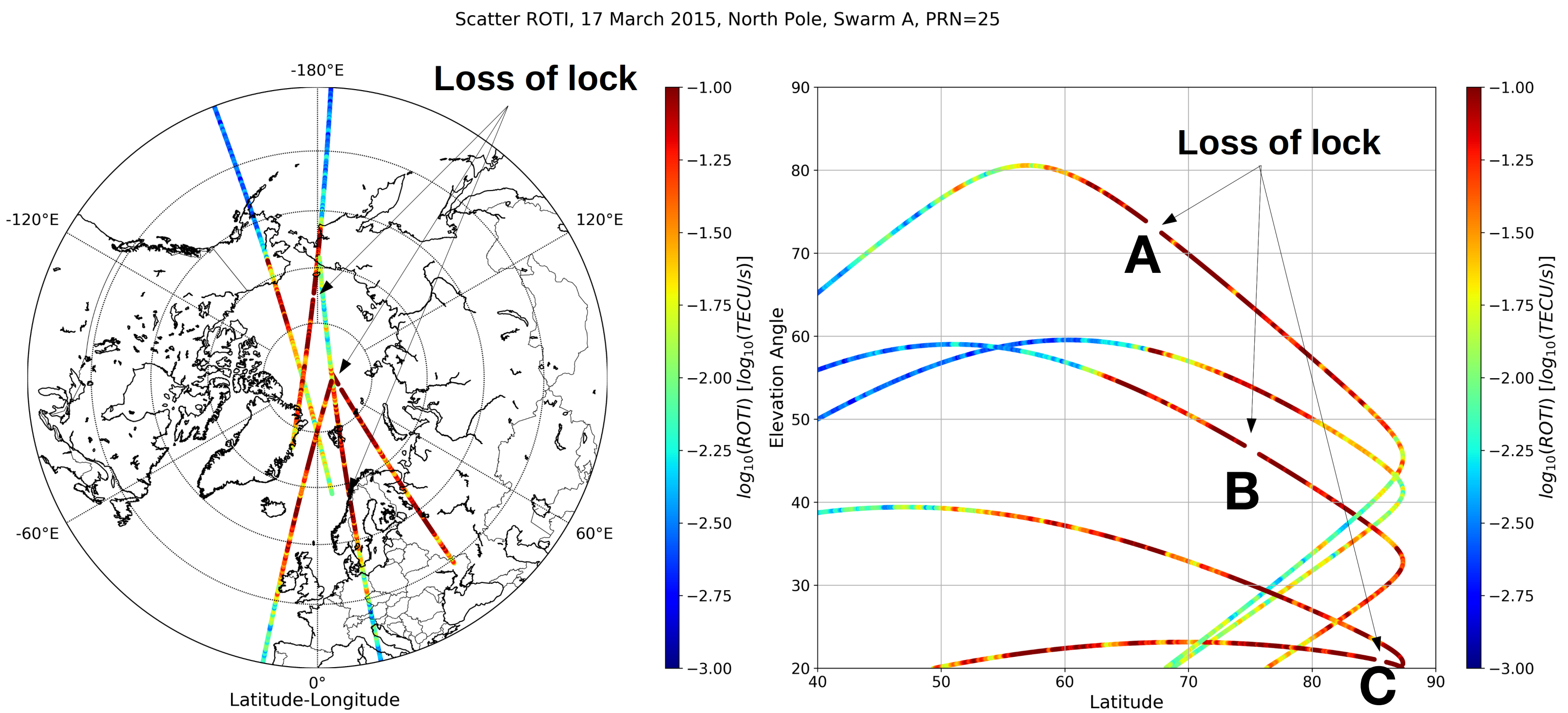
- The RODI parameter cannot be generically considered as a proxy of the occurrence of ionospheric turbulence

- The scaling features of electron density fluctuations permitted us to find two families of plasma irregularities which seem to be associated with different physical properties.

- Only **plasma density variations associated with high values of RODI are characterized by scaling properties which support the idea of a fluid and/or MHD turbulence as a source of these perturbations**.



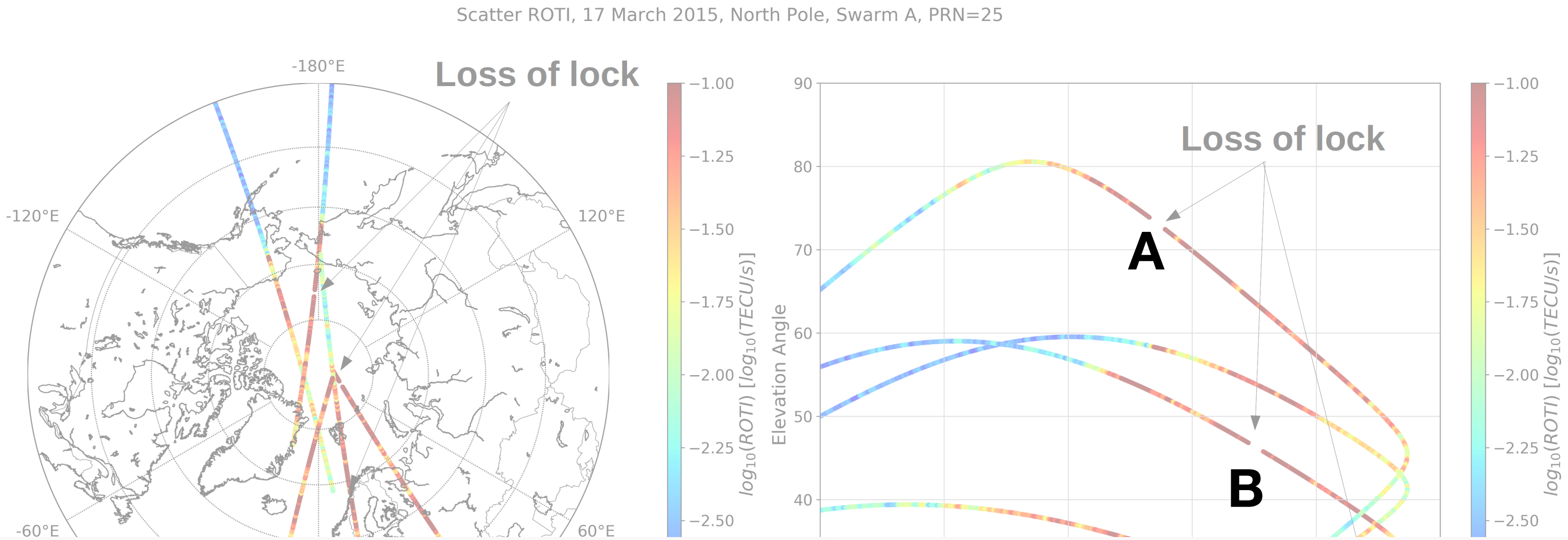
Work goes on …



	Case A	Case B	Case C
1st scaling exponent	0.39 ± 0.04	0.28 ± 0.03	0.49 ± 0.05
2st scaling exponent	0.67 ± 0.07	0.43 ± 0.04	0.82 ± 0.08

Electron density variations associated with loss of lock are characterized by scaling properties which support the idea of a fluid and/or MHD turbulence as a source of these phenomena.

Work goes on …



These results pave the way for the elaboration of a future product capable of providing information on the possible development of those turbulent phenomena which can have repercussions in the space weather framework

Electron density variations associated with loss of lock are characterized by scaling properties which support the idea of a fluid and/or MHD turbulence as a source of these phenomena.

Thank you!