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Turbulence and plasma inhomogeneity observed by Swarm constellation

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HOW did the idea for INTENS come into being?

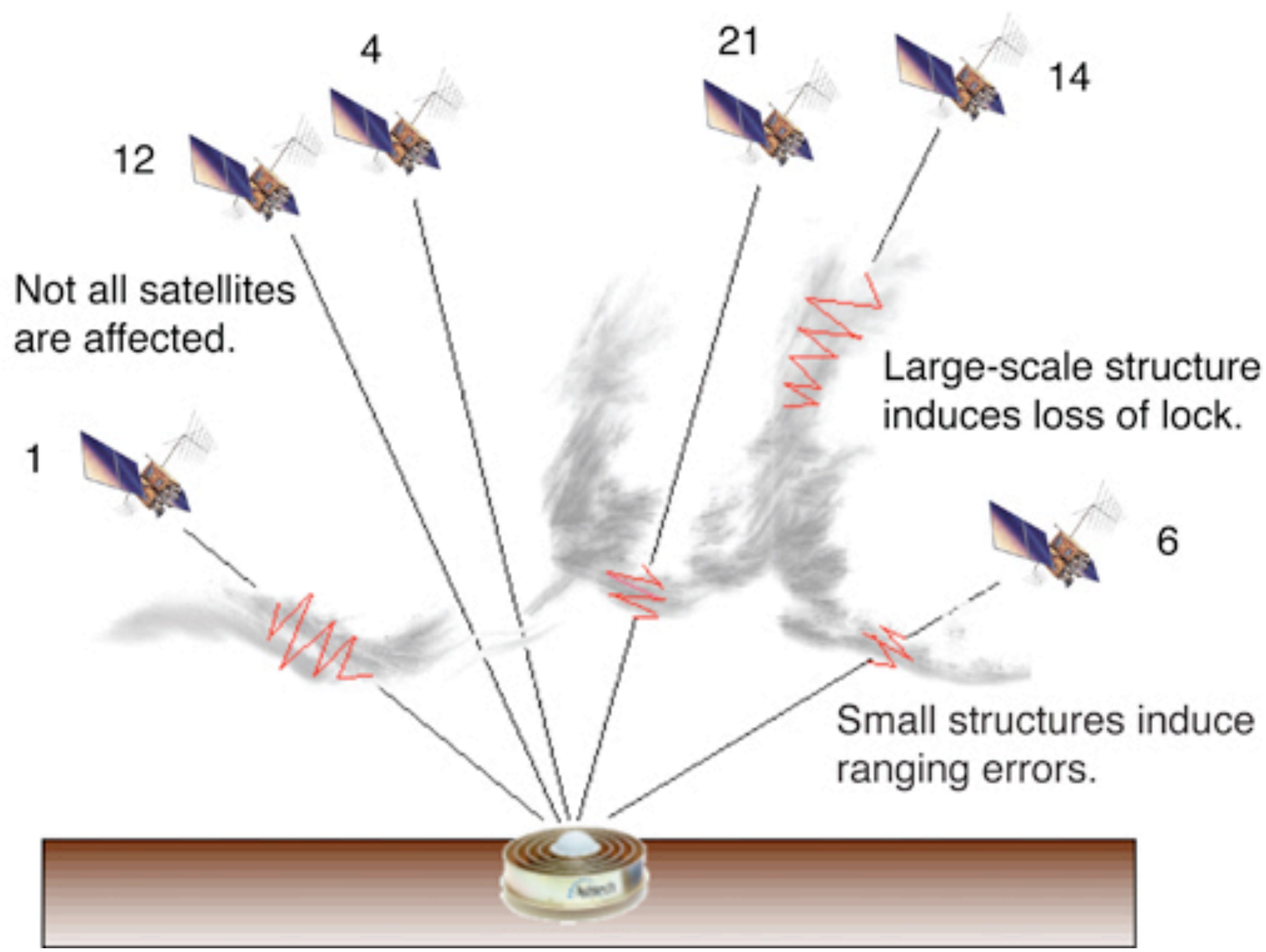
In the last years the dependence of our society on the Global Navigation Satellite System (GNSS) has increased substantially.

Critical applications (railway control, highway traffic management, precision agriculture, commercial aviation, and marine navigation) require and depend on GNSS services.

This means that our critical infrastructures and economy are dependent on positioning, navigation, and timing services.
Our society is vulnerable to damages due to the malfunction of these systems.

HOW did the idea for this project come about?

The quality of GNSS depends on the state of the ionosphere, on the **plasma density irregularities** in the ionosphere that can affect communication between ground facilities and satellites. Signals can be delayed, distorted or lost while passing through the ionosphere.

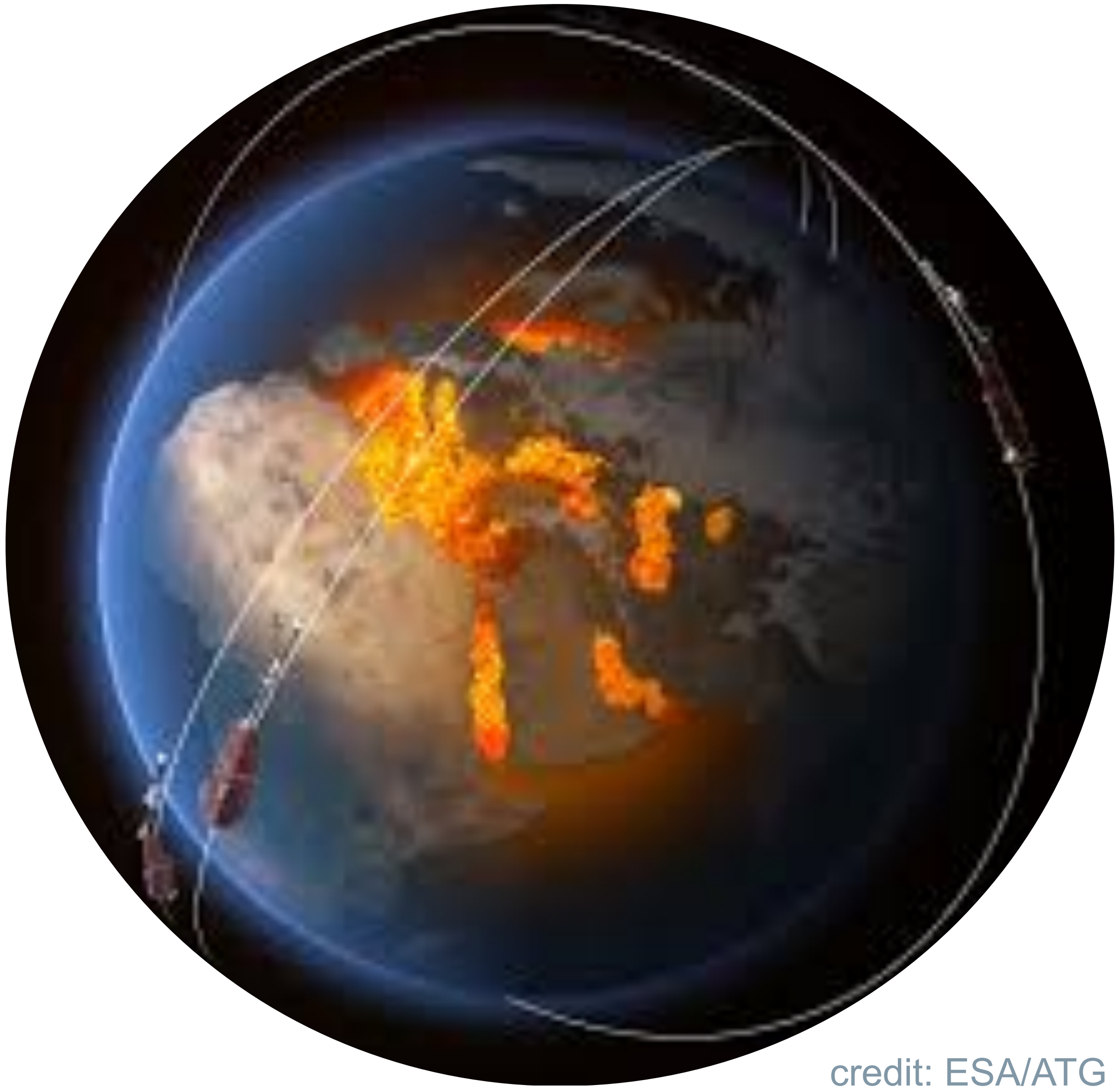


From Wasiu et al., 2017 https://doi.org/10.1117/12.2278224

Several studies have pointed out that **ionospheric turbulence** is of central importance in driving these irregularities. Instability mechanisms and **turbulence** phenomena characterize the electron density but also the **electric and magnetic fields** present in the ionosphere.

HOW did the idea for this project come about?

The Swarm mission gives us the opportunity to analyse simultaneously the Earth's magnetic field fluctuations as well as electron density and temperature fluctuations.



credit: ESA/ATG Medialab

Using magnetic data at low resolution (1 Hz) and reducing plasma parameters to 1 Hz rate we can analyse the scaling features of the fluctuations of all these parameters so providing a multi-parametric characterization of turbulence in the spatial scales between 10 and 400 km.

Scientific Objectives

- **Dynamical description of the scaling features** of magnetic field and plasma parameters during the development of selected geomagnetic storms.
- **Multi-parametric characterization of the ionospheric turbulence from a statistical point** of view according to different geomagnetic activity levels and IMF orientations.
- Application of **information theory approaches** to Swarm data during extreme Space Weather events to provide new and more descriptive parameters of these events.

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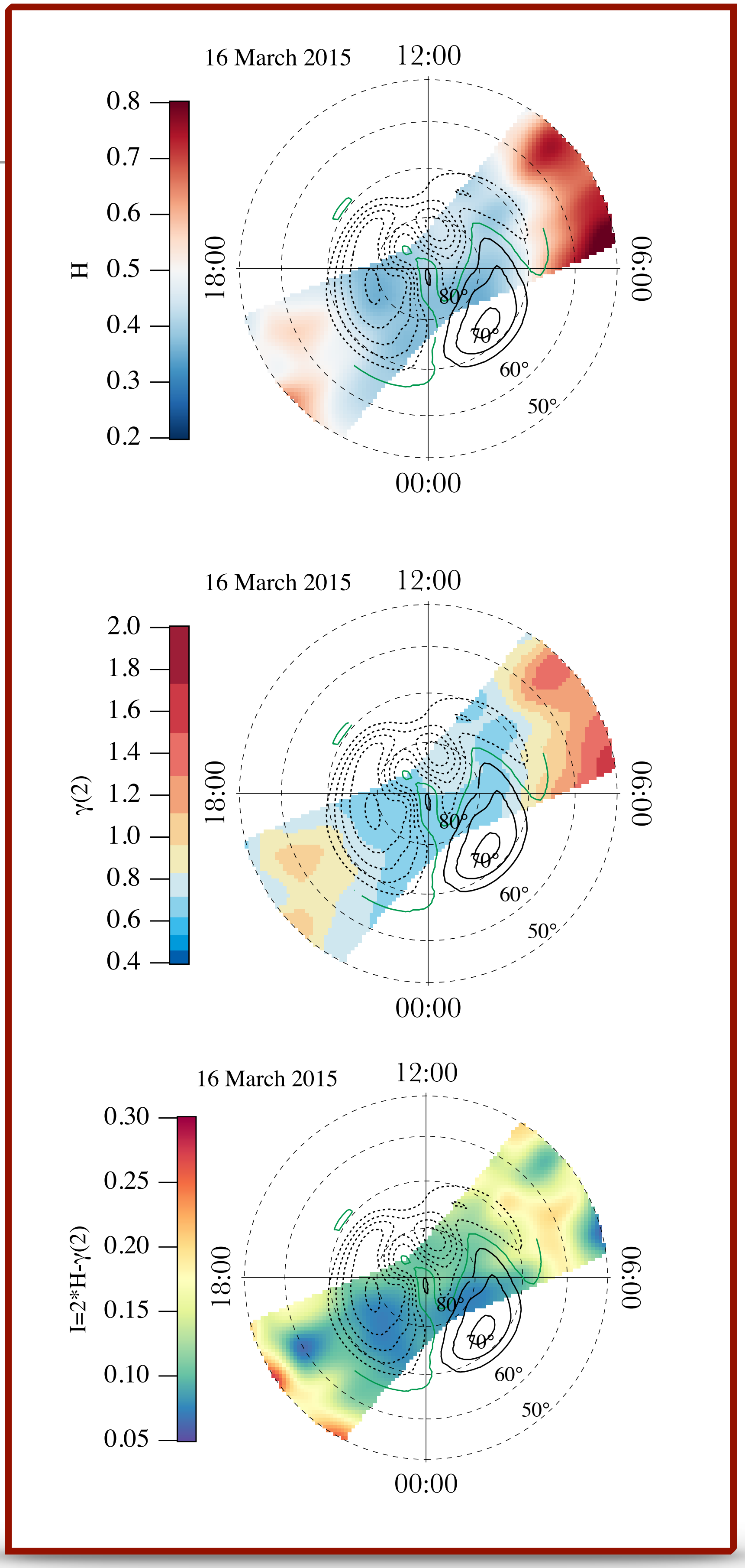
An INTENS result

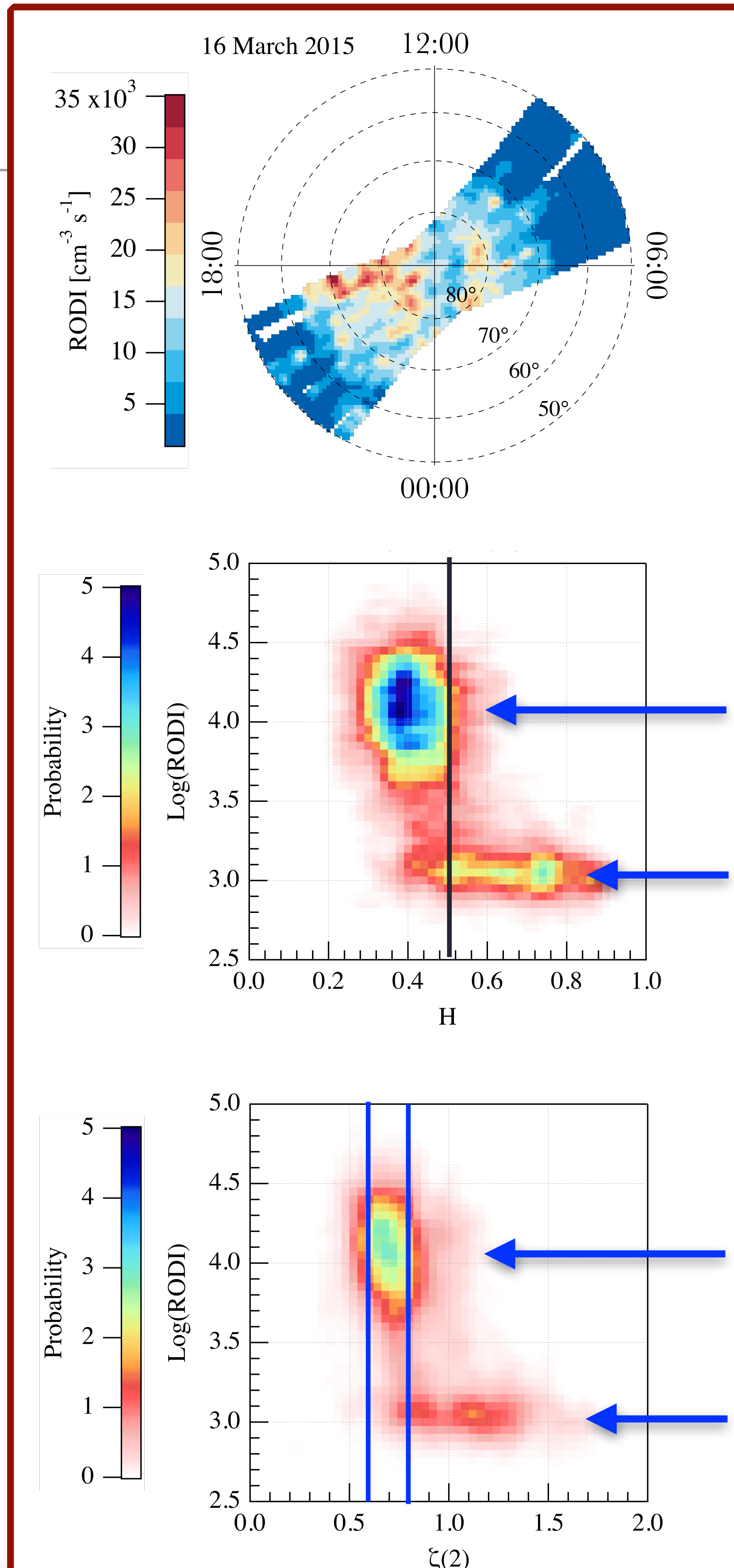
- We have considered 6 different geomagnetic storms.
- We analysed the scaling properties of the Ne and B fluctuations during the development of each geomagnetic storm.
- For Ne fluctuations we have found:
    - At high-latitude, inside the auroral oval, the Ne fluctuations are characterized by a turbulent behavior with values around **5/3 of the power spectral density** scaling exponent.

These results support the idea of a turbulence as the main responsible of the observed electron density fluctuations.



An INTENS result

- **RODI** is used as measure of the plasma density variations. They may be due to different processes not necessarily linked to turbulence phenomena.
- We evaluate the the **joint probability distributions** between RODI and first and second-order scaling exponents. We find that the plasma density variations describe by RODI can be splitted into two families 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 turbulence as a source of these perturbations**.



Manuscript submitted to JGR Space Physics:
“On the 2015 St. Patrick storm turbulent state of the ionosphere: hints from the Swarm mission” by De Michelis et al.

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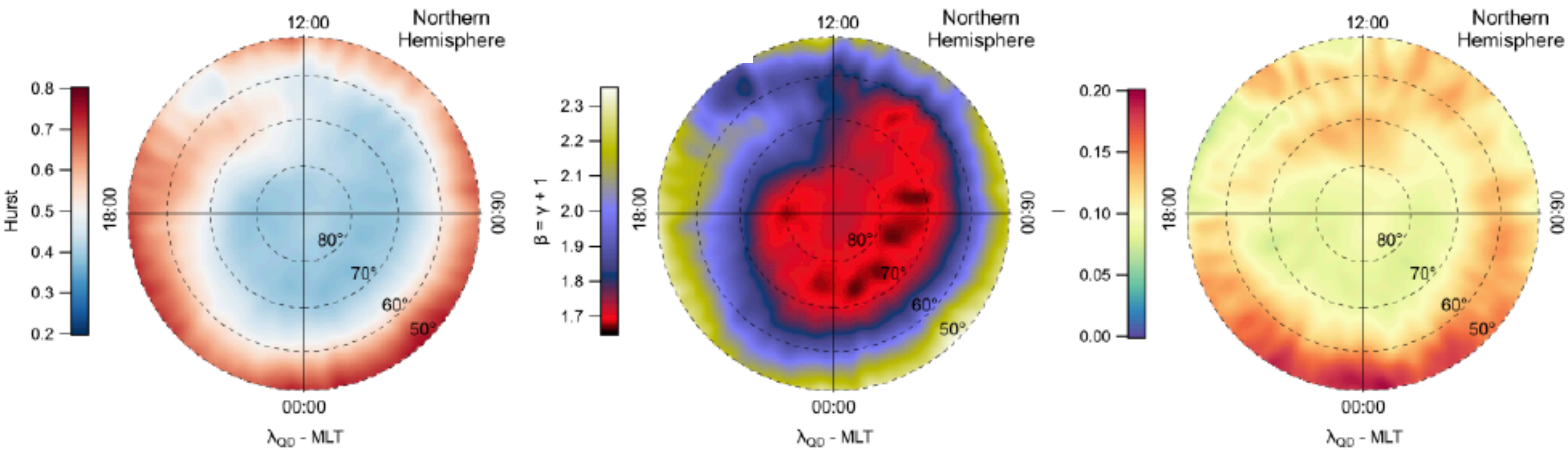
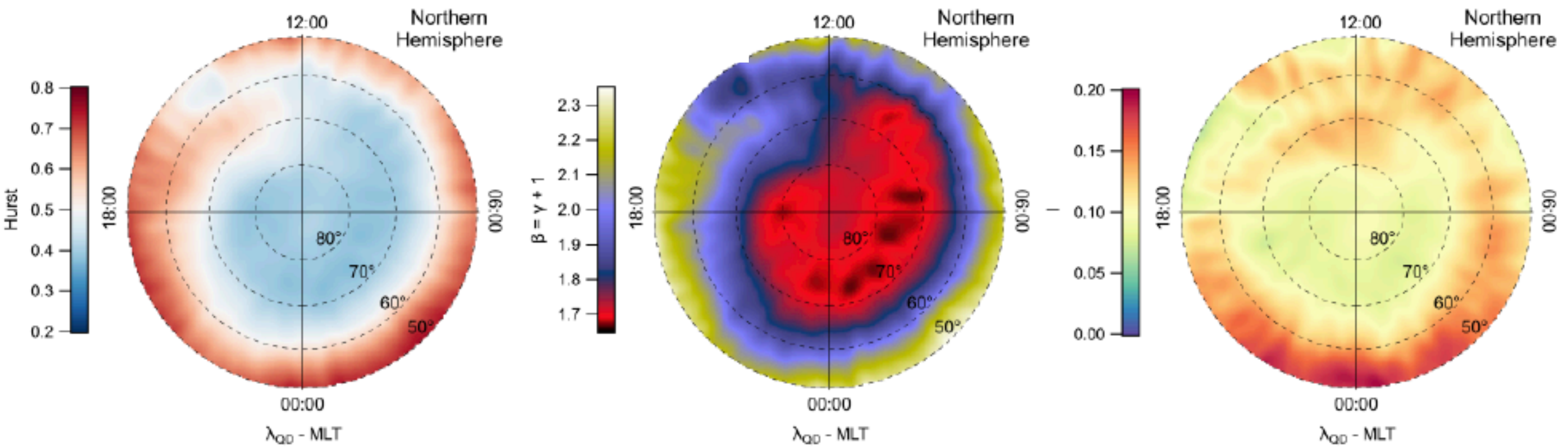
An INTENS result



We used 4 years of data (1 April 2014 to 31 March 2018) and analyzed the scaling exponents of the Ne fluctuations according to different IMF orientations. The values of the Hurst exponent, power spectral density exponent and intermittency give us information on the occurrence of turbulence. Figure reports polar view of the average spatial distribution of these three quantities, in the Northern Hemisphere, in QD latitude coordinates (50°N-90°N) and MLT for Bz<0 and By=0.

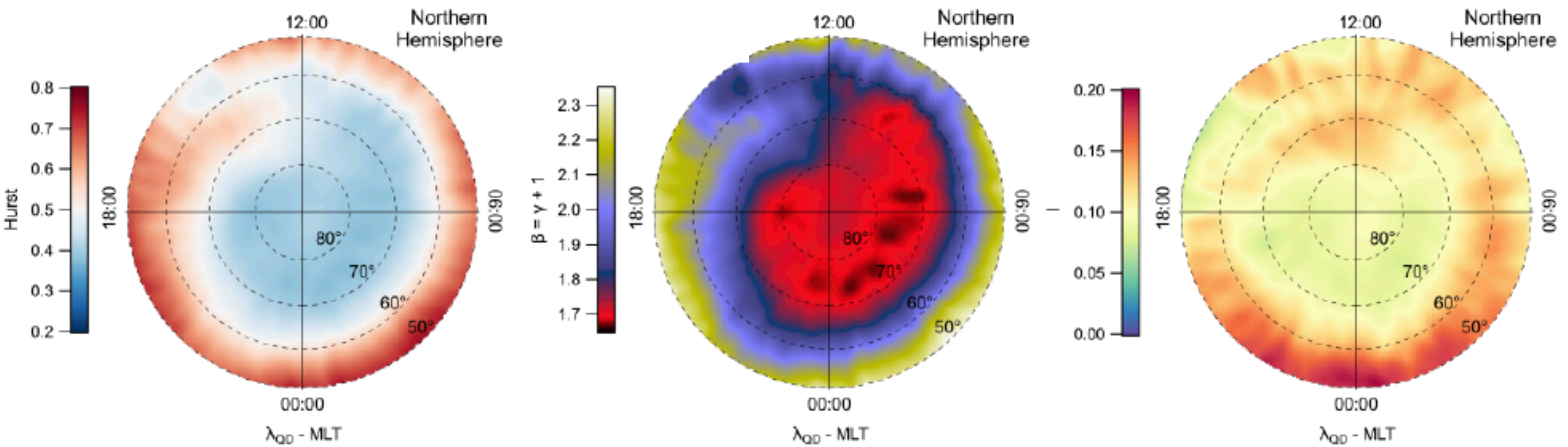
An INTENS result



We notice that:

- the area characterized by anti-persistent behavior (H<0.5) of Ne fluctuations is at high latitude in the auroral oval
- in the same region, the power spectral density exponent (β) of Ne fluctuations tends to 5/3
- the highest values of intermittency ($I = 2H - \beta + 1$) can be found at mid latitude and they seem to draw the shape of the plasmasphere boundary at high-latitude ionosphere

An INTENS result



It is possible to obtain information on the spatial distribution of ionospheric turbulence according to fixed IMF orientations. This means that we can obtain information on the areas where there is a high probability that signals can be delayed, distorted or lost while passing through the ionosphere due to the occurrence of turbulence phenomena.

Manuscript in preparation for the JASTP special issue "The Plasma Physics of the Magnetosphere"

Scientific Objectives

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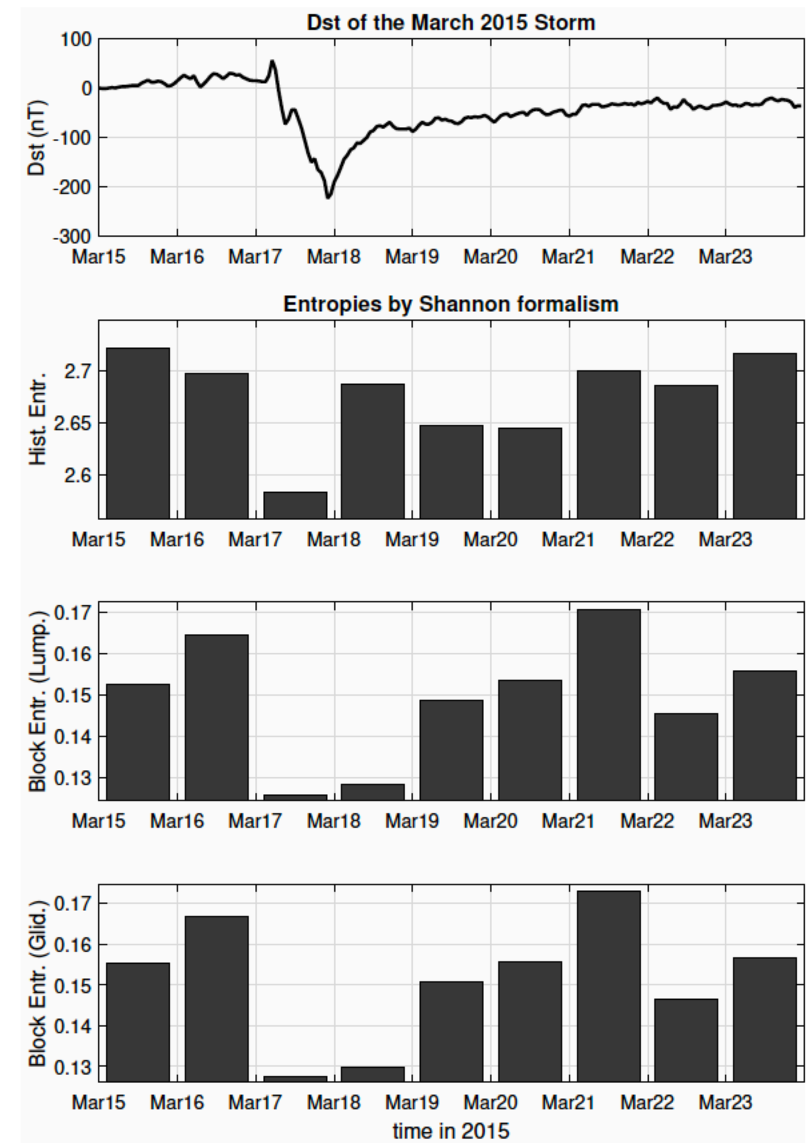
An INTENS result

We applied a series of entropy measures (e.g. Shannon, Tsallis, approximate entropy, sample entropy and fruzzy entropy) to the time series of the Earth's magnetic field intensity of external origin measured by the Swarm constellation. We focused on the St. Patrick's Day storm, which occurred on March 2015, to capture the changes of the various dynamics states of the system during the evolution of the geomagnetic storm. The application of such methods permits us to quantify the changes in the complexity of the magnetosphere-ionosphere coupling system and to understand how it responds to the onset and evolution of an intense magnetic storm.



Manuscript submitted to Entropy:
"Dynamical complexity of the 2015 St. Patrick's day magnetic storm at Swarm altitudes using entropy measures" by Papadimitriou et al.
See also abstract D1136 IEGU2020-4981 in the same session

Summary

The **ESA-INTENS** project was devoted to the **investigation of turbulence and complexity** in the **ionospheric F2 region** using data coming from the ESA Swarm constellation. The project allowed producing interesting outcomes in terms of climatological maps of the scaling features of both magnetic field and electron density fluctuations as a function of the geomagnetic activity level and interplanetary conditions, as well as in terms of dynamical changes of the ionospheric conditions by means of entropic and information theory approaches/measures.

Starting from such results, we have identified three topics which we deem promising and worth to be studied in detail:

a) the possible existence of a link between the formation of electron density inhomogeneities and the nature of the observed turbulent fluctuations;
b) the clear dependence of the scaling features of electron density fluctuations on the interplanetary magnetic field (IMF) orientation;
c) the possibility to quantify the changes in the complexity of the magnetosphere-ionosphere coupling system and to understand how it responds to the onset and evolution of intense magnetic storms using entropy measures