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Geomagnetic Field Fluctuations and Ionospheric Turbulence: a Characterization by Swarm Constellation

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AIM

To provide a **multi-parametric characterization** of the **turbulence** and **complexity** in the F-region of the ionosphere by investigating the **nature of the fluctuations** and the **scaling properties** of the magnetic field and electron density recorded by Swarm constellation.

The **Swarm mission** gives us the opportunity to analyse simultaneously the Earth's magnetic field fluctuations as well as electron density fluctuations. Using magnetic data at low resolution (1 Hz) and reducing plasma parameters to 1 Hz rate we could analyse the **scaling features of the meso-scale fluctuations** of all these parameters so providing a multi-parametric characterization of turbulence in the spatial scales between **10 and 300 km**.

WHY

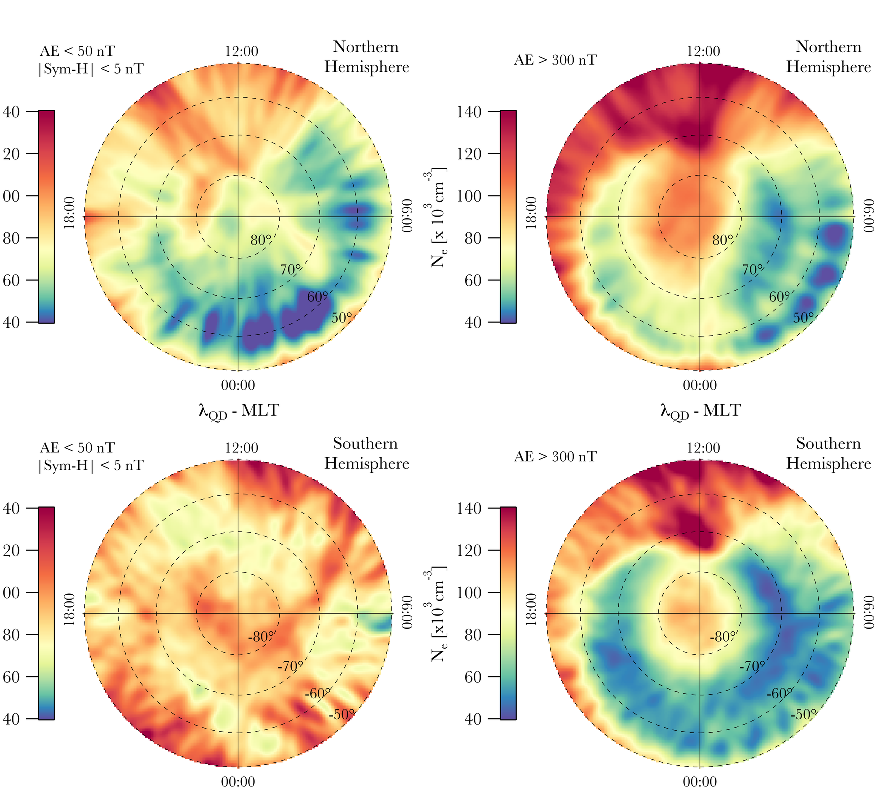
The **turbulence phenomena are at the base of several crucial ionospheric dynamical processes** that generally occur as consequence of the coupling processes between solar wind, magnetosphere and ionosphere. Turbulence is able to generate/create magnetic and plasma structures that can strongly affect the homogeneity of the plasma in the ionospheric regions. Taking into account that these plasma density structures can be responsible for the delay, distortion or total loss of electromagnetic signals while passing through the ionosphere, this means that turbulence is also capable of compromising the performance of the Global Positioning System (GPS) and the Global Navigation Satellite System (GNSS) that are vital for precision positioning, navigation, and timing applications. Thus, the **ionospheric turbulence indirectly plays a key role also in the frame work of space weather.**

DATA

1) Electron density (1 Hz)
2) Level 1b low-resolution (1 Hz) geomagnetic field data
3) AE and SYM_H geomagnetic indices for characterizing the geomagnetic activity at hight and mid latitudes: quiet AE< 50 nT and -5 nT<SYM-H<5 nT, disturbed AE>300 nT.

Data cover a period of 4 years (April 2014-March 2018) and are relative to Swarm A satellite.

Electron Density DATA

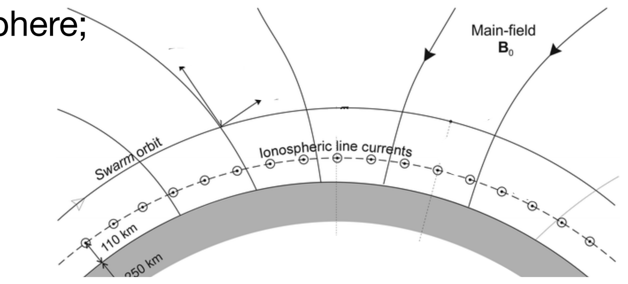


Several characteristic features of the polar ionosphere can be recognized looking at these maps:

1) **Ne** density is almost double on the dayside with respect to the nightside;
2) When AE>300 nT, the region characterized by a high level of **Ne** expands into the polar cap from the dayside, thus producing the well known tongue of ionization (TOI);
3) During disturbed periods, there is an enhancement of the **Ne** around dusk (Storm time Enhanced Density -SED)
4) In the subauroral ionospheric region, primarily in the night side, **Ne** shows a depletion which identifies the Main Ionospheric Trough (MIT).

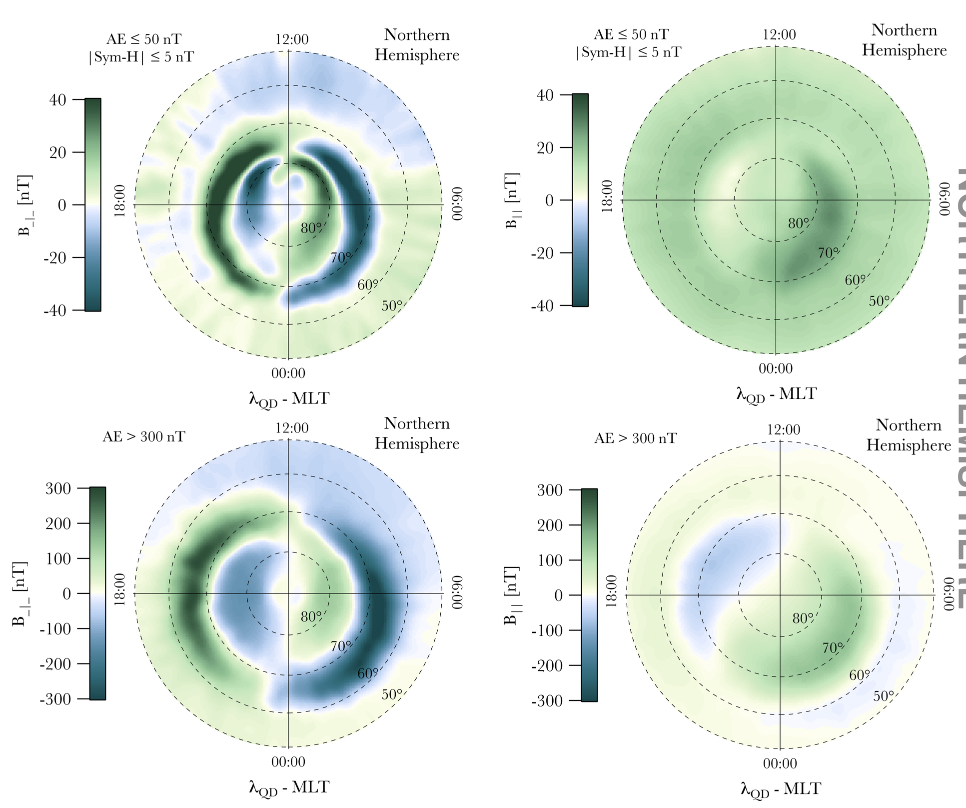
Magnetic Field DATA

We remove from the original data the geomagnetic field of internal origin (core and crust) by using the CHAOS-6 model. The difference between the observed magnetic field and that modeled using CHAOS-6 describes the magnetic field due to sources located in the ionosphere and magnetosphere;

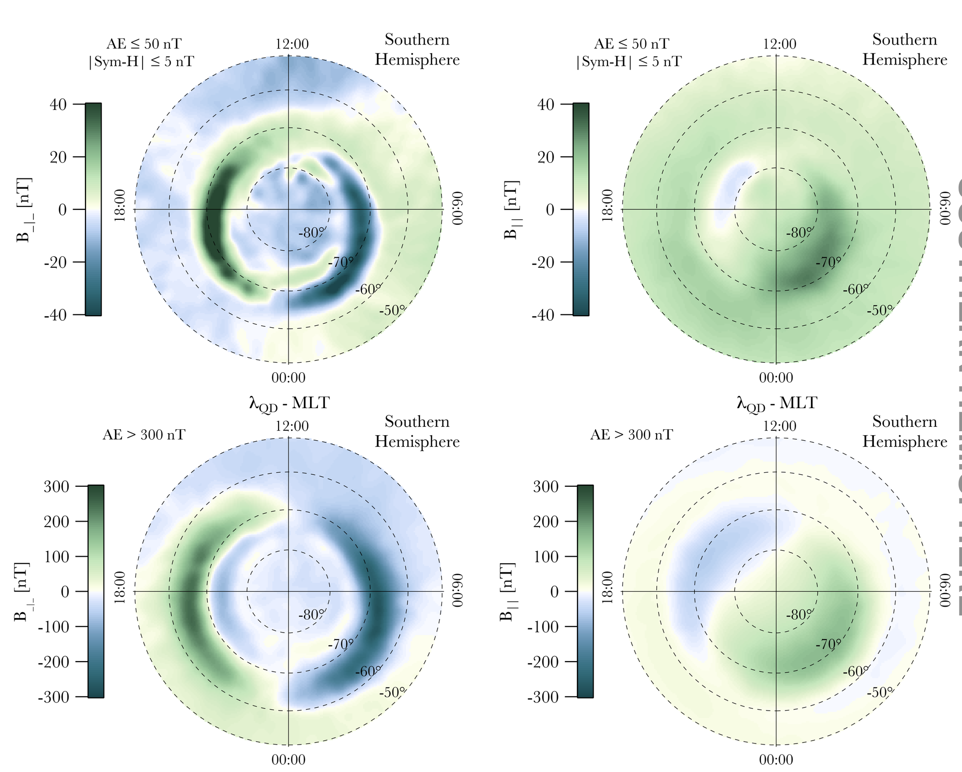


The residual field is decomposed into:

1) a component parallel to the direction of the main field, which mainly describes the effects on magnetic field due to the horizontal currents.
2) a component perpendicular to the direction of the main field which takes into account of the field-aligned currents.



NORTHERN HEMISPHERE



SOUTHERN HEMISPHERE

METHOD of ANALYSIS

A fundamental feature of the turbulence is the occurrence of scale invariance. It means that turbulent fluctuations do not occur on a characteristic scale, but they are intrinsically multiscale.

To investigate the scaling features of the magnetic field fluctuations and electron density fluctuations, we apply the standard structure function analysis. We employ this method based on local analysis (moving window), which for a signal *x*(t) defined over an interval T consists in evaluating:

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

where τ is a time separation. When we deal with a scale-invariant signal

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

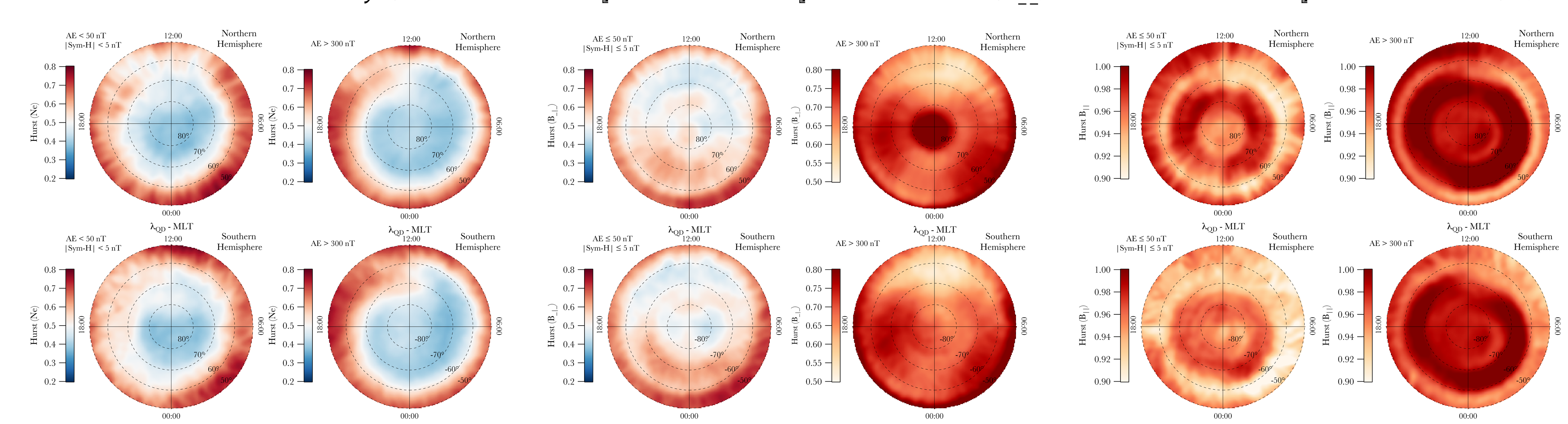
In the case of Swarm's data, the first and second order scaling exponents are calculated for fluctuations in the range from 1 s to 40 s (T = 300s). These temporal scales correspond to investigate spatial fluctuations from 8 km up to 300 km, under the assumption of Taylor's hypothesis.

The **first order scaling exponent** (known also as Hurst exponent) provides information on the persistent in sign of subsequent signal increments (non-Markovian character), while the **second order scaling exponent** provides information on the spectral features of the fluctuations field.

The occurrence of anomalous scaling features $\zeta(2) \neq 2\zeta(1)$ is an indication of a more complex nature of the fluctuation field which cannot be represented in terms of a single scale and one exponent. This phenomenon, known as intermittency, is responsible of in-homogeneity in the energy dissipation field.

$$S_1(\tau) = < |x(t+\tau) - x(t)| >_T$$

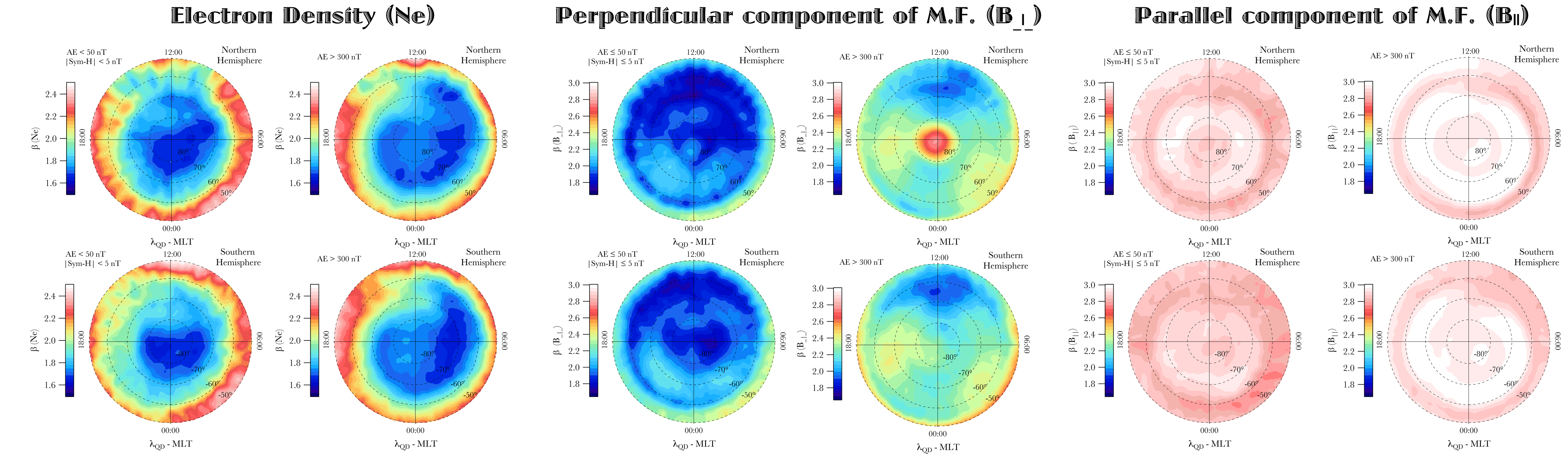
$$S_1(\tau) \sim \tau^{\zeta(1)} \quad \zeta(1)\text{=Hurst exponent}$$



Hurst exponent is used as benchmark for persistency, anti-persistency or randomness in time series analysis. It quantifies the relative tendency of a time series either to regress strongly to the mean **(H<0.5 antipersistent behaviour)** or to cluster in a direction **(H>0.5 persistent behaviour)**. There is a clear dependence on the latitude, geomagnetic activity level and the analyzed physical quantity.

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

$$S_2(\tau) \sim \tau^{\zeta(2)} \quad \beta = \zeta(2) + 1$$



Power Spectral Density (PSD) scaling exponent provides information on different turbulence regimes.The occurrence of a non linear relationship between PSD scaling exponent and Hurst exponent in some regions and/or as a function of the geomagnetic activity level is a signature for an intermittency phenomenon.