Scaling exponents estimated from Swarm magnetic field data: a climatological view for the polar regions

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Scientific Rationale

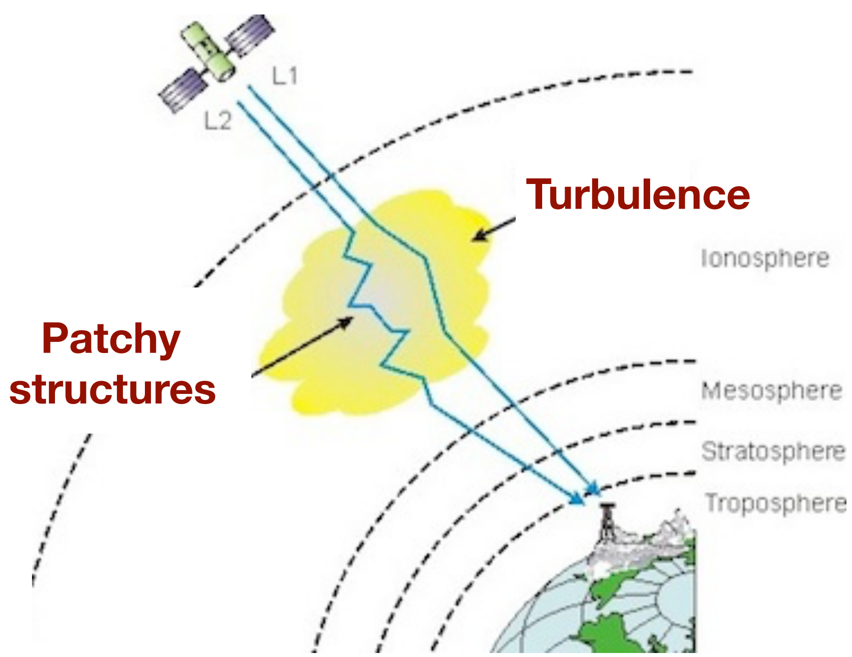
To study the *scaling features* of the magnetic field fluctuations and its dependence on the IMF orientation at scales between 10 km and 300 km in the polar regions in order to get information about the role of *turbulence in the ionosphere* and in the ionosphere-magnetosphere coupling.

The study is based on *ESA Swarm constellation measurements* in the *F region of the ionosphere* and the results are presented in terms of *climatological (statistical) maps.*

Introduction

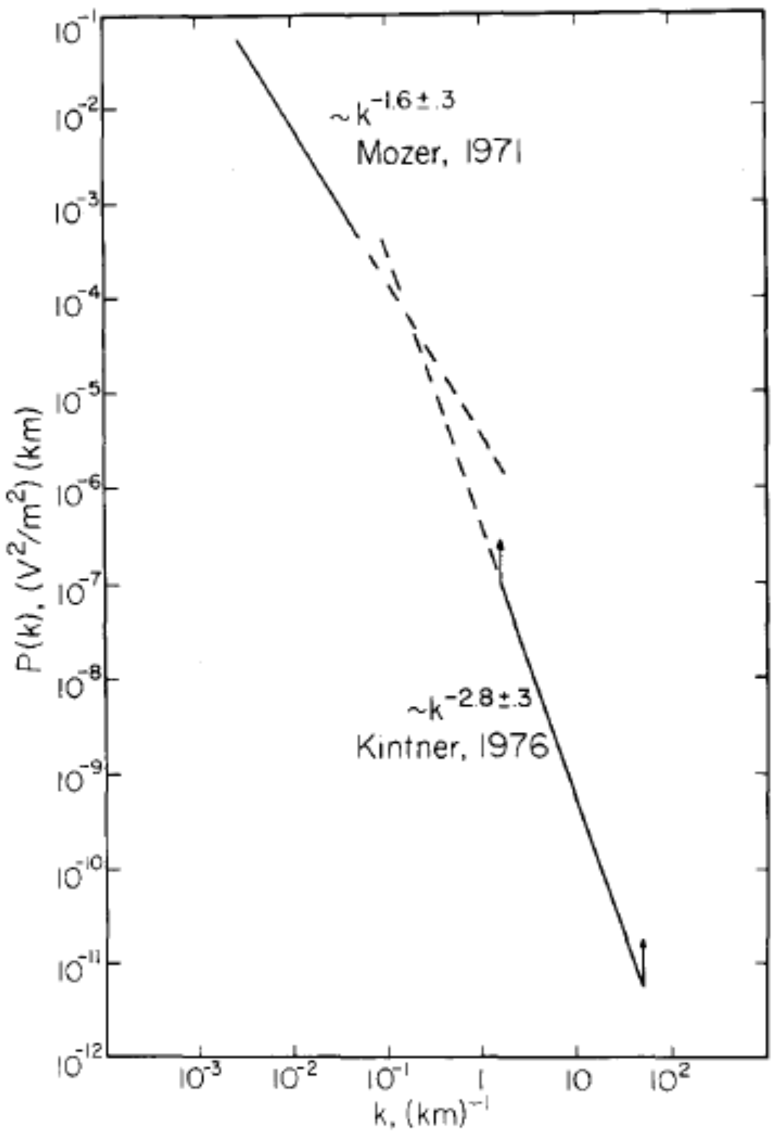
Turbulence is *ubiquitous in astrophysical and space plasma media, as well as in magnetospheric and ionospheric ones.*

Turbulence plays a crucial role in *fluids, plasmas and transport processes*, and is responsible for the generation of *multiscale coherent structures.*



In ionospheric plasmas the study of turbulence might play a special role to understand several processes, such as the *ionospheric heating* and the formation of *plasma structures* affecting the medium homogeneity and having a relevant impact on *telecommunication*, *Global Positioning System* (GPS), *Geographic Information System* (GIS), and *Global Navigation Satellite System* (GNSS) to list just a few examples of technologies.

Introduction



From Kintner and Seyler, SSR, 41, 91, 1985

from Tam et al., GRL, 2005

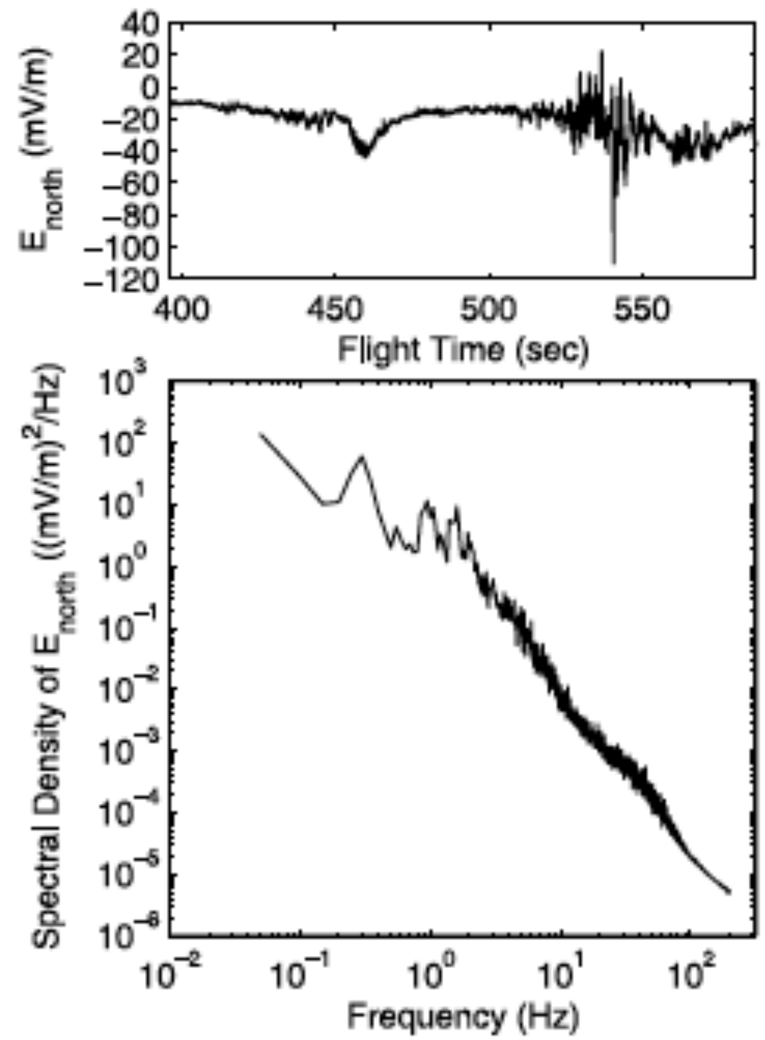
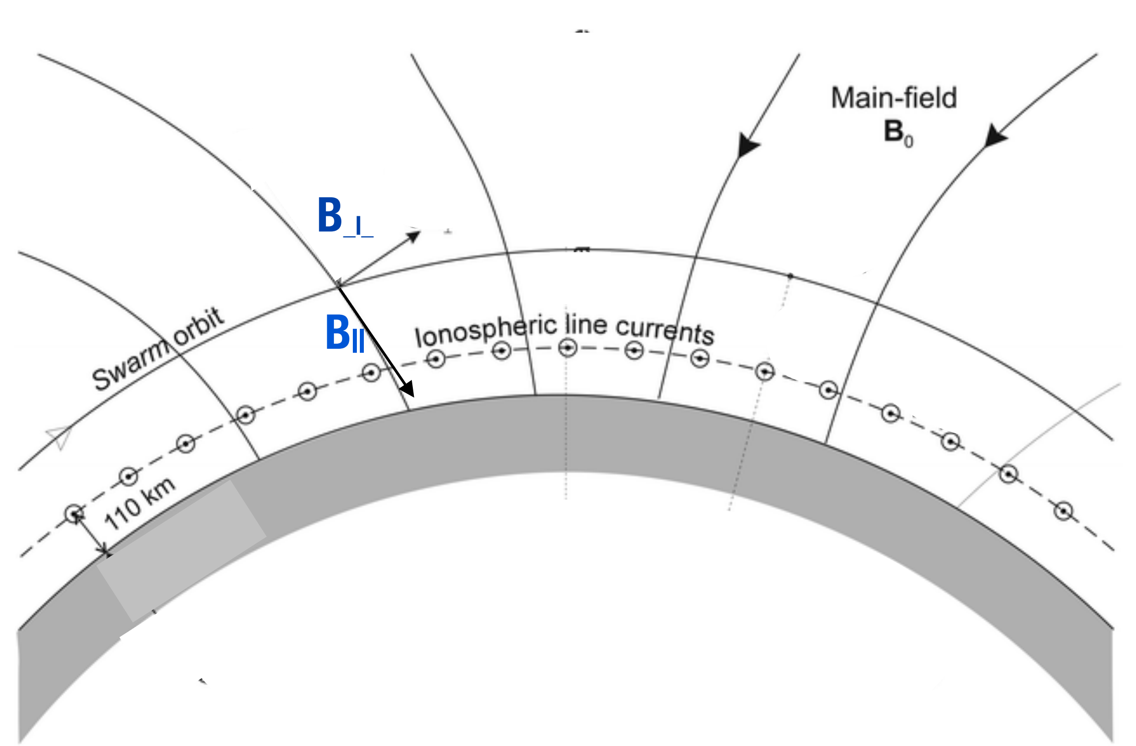


Figure 1. Top: Plot of electric field component E_{north} versus the flight time of SIERRA for the duration when the rocket was above 700 km altitude. Bottom: Average spectral density of E_{north} over the duration.

Data Description

This study is based on 1Hz *in-situ* measurements of magnetic field by *ESA-Swarm constellation*, *Swarm A* and *C*, over a period of 4 years from 04/2014 to 03/2018.

We consider in our analysis only the magnetic field of external origin by removing the geomagnetic field using CHAOS 6 model (Finlay et al, 2016) up to 110° order of the spherical harmonics expansion.



adapted from Drost Aakjær et al., EPS, 2016

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

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

Methods

One of the peculiar features of turbulence is to display *scale invariance, i.e., an intrinsic (statistical) self-similarity (and self-affinity of signals)*, which manifests in the time series of associated physical quantities (velocity, magnetic field, plasma parameters, etc.).

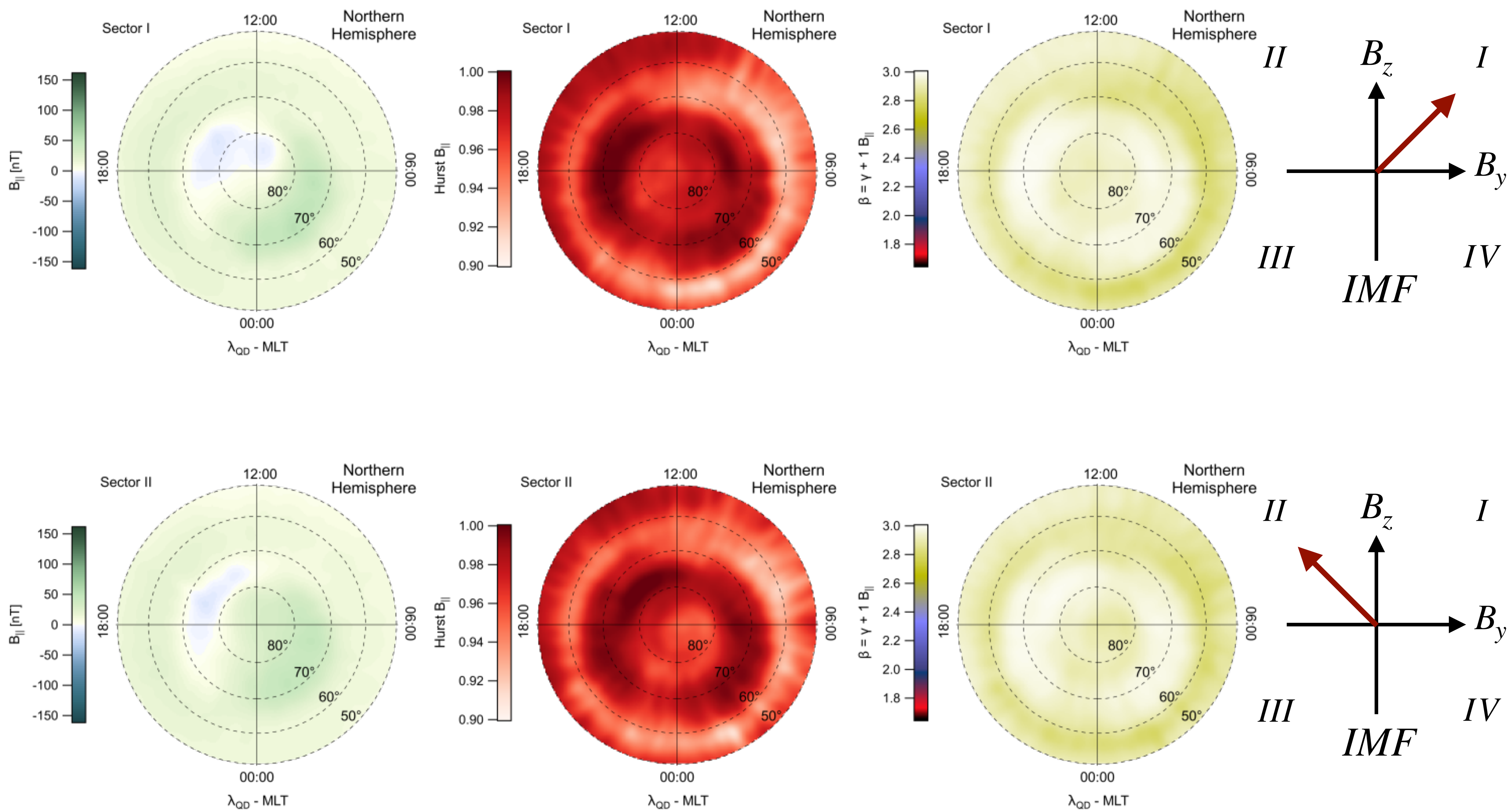
This property implies that *several quantities*, such as for instance the structure functions, *scale according to a power law:*

$$S_q(\delta) = \langle | \, x(\vec{r} + \delta \cdot \hat{n}) - x(\vec{r}) \, |^q \rangle \sim \delta^{\gamma(q)}$$

Here, we investigate both the *first-order scaling exponent* ($\gamma(1) \equiv H$) and the *second-order one* ($\gamma(2) \rightarrow \beta = \gamma(2) + 1$), which provide information on the *persistence of fluctuations (increments)* and its spectral features.

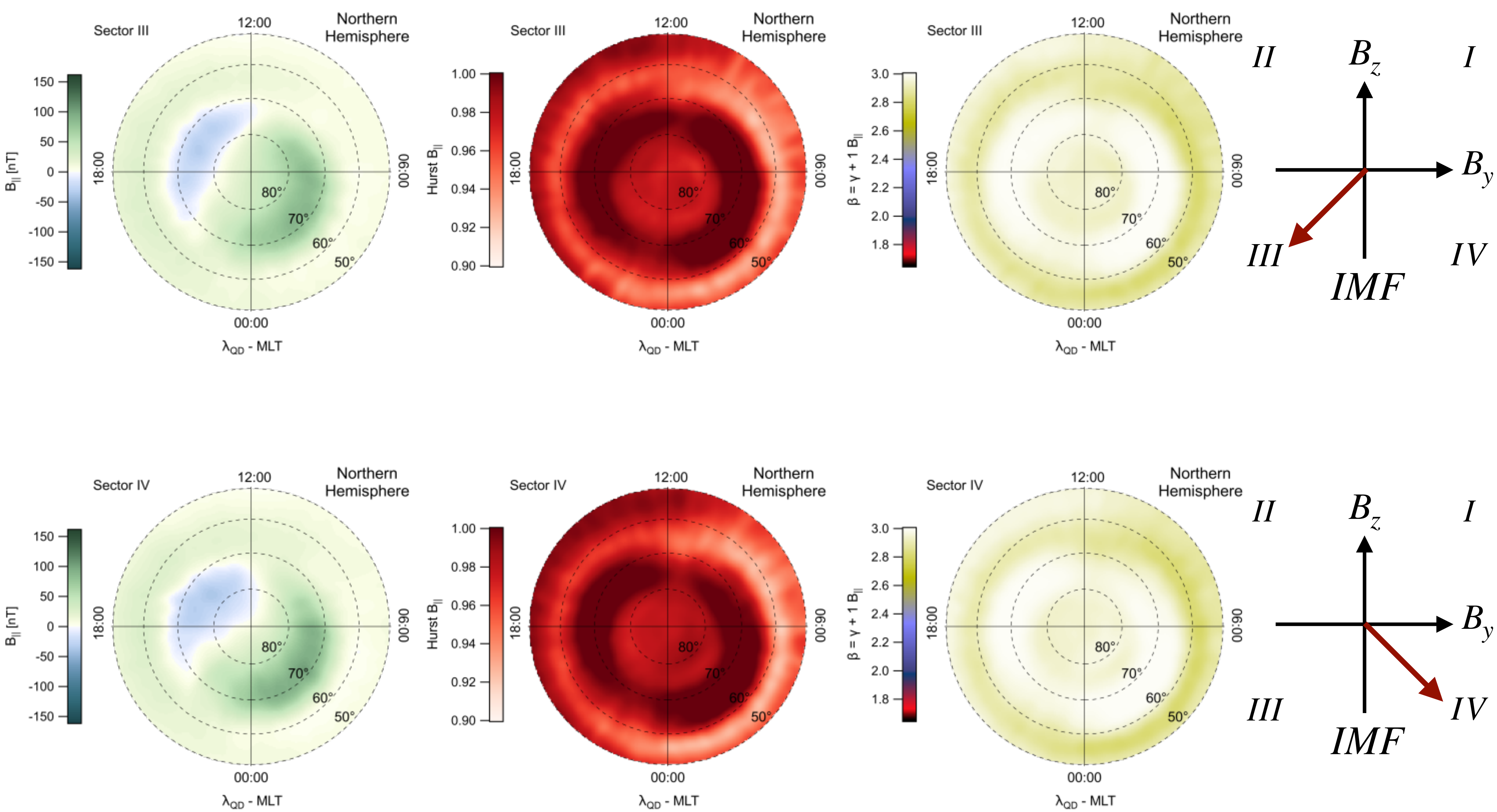
We used the DSFA (Detrended Structure Function Analysis) [*De Michelis et al.*, GRL 2015] which is a suitable method for evaluating local scaling exponents.

Results: magnetic field parallel component

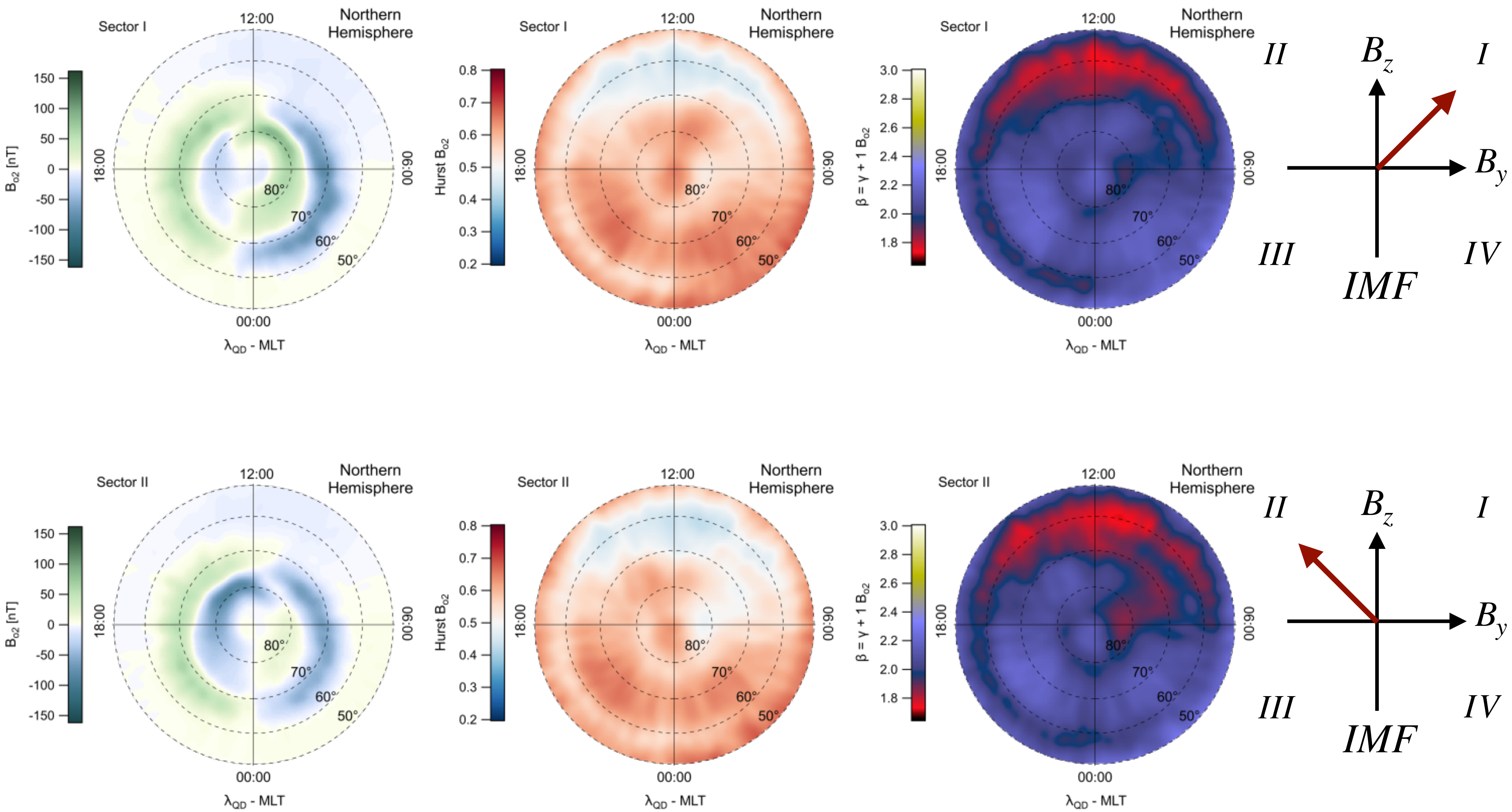


Consolini et al.

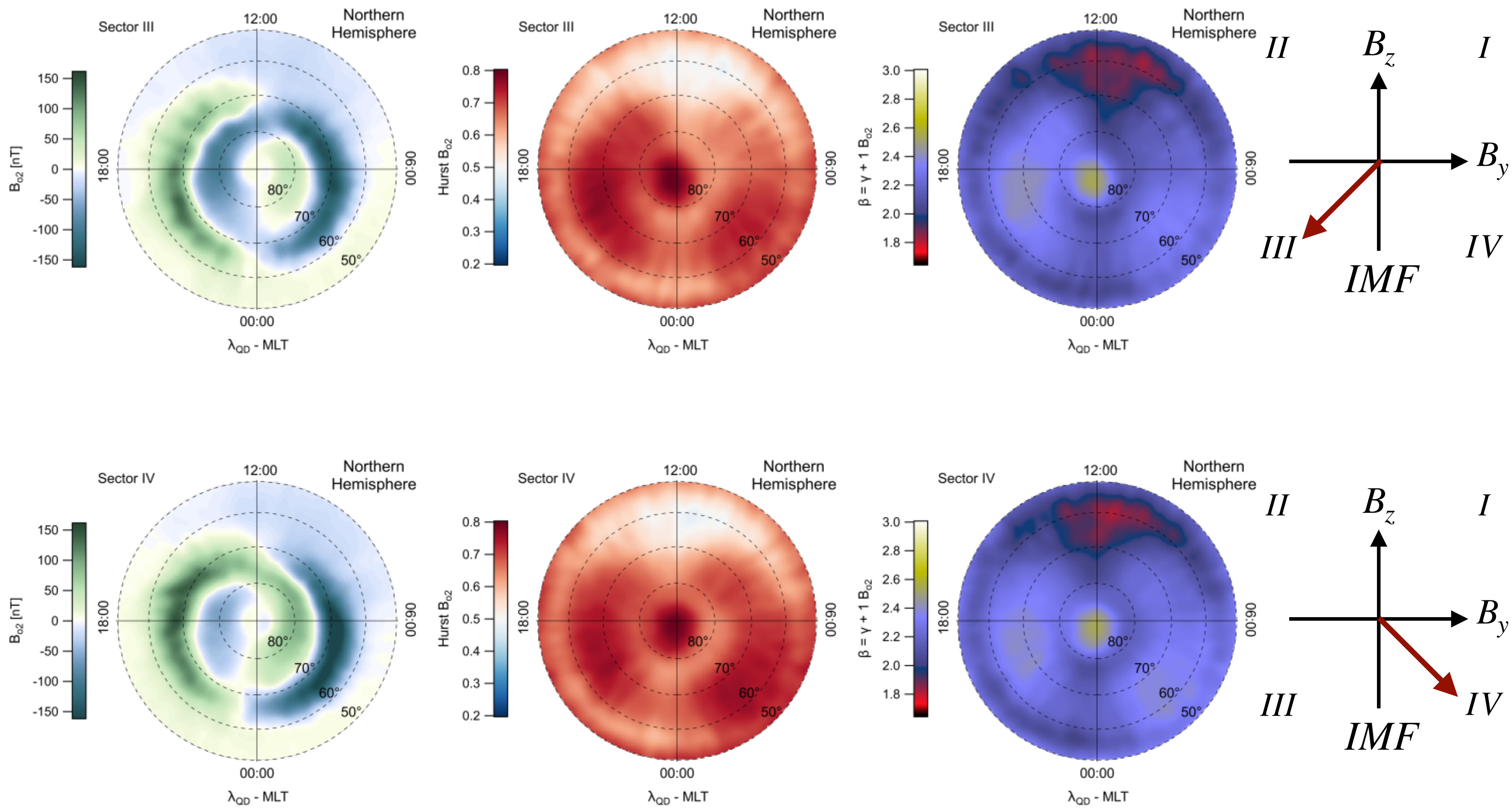
Results: magnetic field parallel component



Results: magnetic field perpendicular component



Results: magnetic field perpendicular component



Summary

Summarizing our results we can observe

1) The *fluctuations are strongly anisotropic* (2D) and the scaling features are consistently anisotropic too.

2) Magnetic field component *parallel* to the main field shows *persistent fluctuations*, whose persistency character increases in the FAC regions under negative B_z conditions. The *spectral features* are characterized by a spectral exponent $\beta \sim 3$.

3) The fluctuations *perpendicular* to the main field, although mainly persistent, $\gamma(1) > 0.5$, are *characterized by spectral exponents* $\beta \sim 2.0 - 2.4$, i.e., less steeper than the parallel one. Furthermore, on the *dayside noon sector* an *anti-persistent character* and *spectral features* more similar to those expected for a *2D HD/MHD turbulence* are observed.

Summary

The observed features could be due to the occurrence of *electrostatic turbulence* in a low-β plasma (*Kintner and Seyler*, 1985)

$$\mathbf{v} = \frac{\mathbf{E} \times \mathbf{B}}{B^2}$$

or due to *multiscale coherent turbulent structures in the form of flux tubes* in the region of FACs, which are expected to be *filamentary structures*. (*Chang et al.*, 2005)

$$\mathbf{B} = \mathbf{e}_z \times \nabla\psi + B_0 \mathbf{e}_z \;\; \rightarrow \;\; \mathbf{B} = (\delta B_x, \delta B_y, B_0)$$

$$\mathbf{J} \times \mathbf{B} \sim 0$$

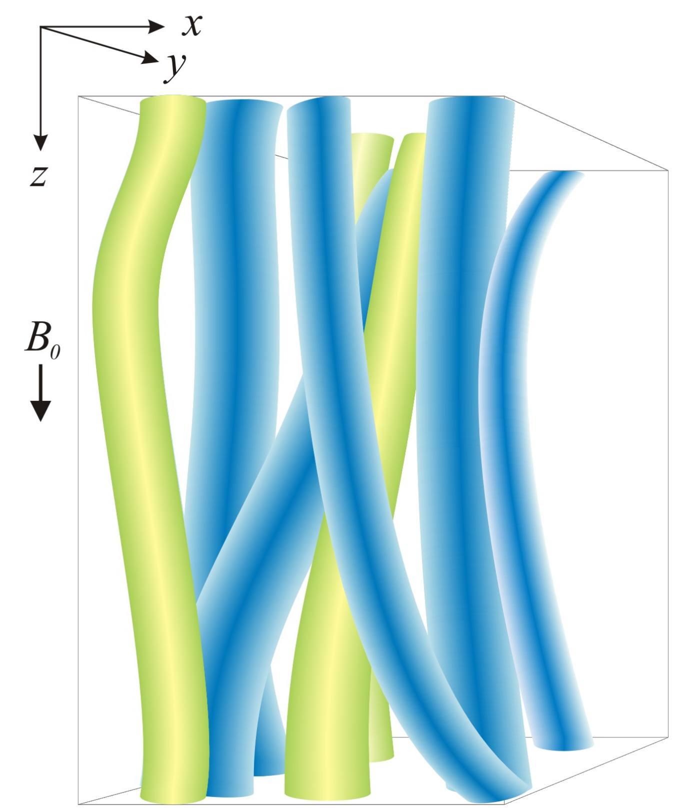
$$\nabla \cdot \mathbf{J} \sim 0$$

$$\mathbf{B} \cdot \nabla J_z \simeq 0$$

$$\nabla \cdot \mathbf{B} = 0$$

$$B_0 \frac{\partial J_z}{\partial z} = -\left(\delta B_x \frac{\partial}{\partial x} + \delta B_y \frac{\partial}{\partial y} \right) J_z + \ldots.$$

$$(\delta B_x, \delta B_y) = \left(\frac{\partial \psi}{\partial y}, -\frac{\partial \psi}{\partial x} \right)$$



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