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The Plasma turbulence in the ionosphere – statistical analysis of the Demeter's measurements

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Abstract

We report the observation of ELF plasma turbulence registered by DEMETER satellite in different regions of the ionosphere. Some of the presented registrations are associated with seismic activity which is seen at the altitude of the DEMETER's orbit as a disturbance of the plasma parameters and electromagnetic field. Other are associated with the fluxes of the energetic electrons registered in the polar cusp at the ionospheric altitude. We apply to study this turbulent processes wavelet, bispectral analysis and statistical description of the measurements of the electric field variations.

1. Introduction

What is the turbulence? This question has no clear answer, but some essential features can be mentioned: many degrees of freedom (different scales), all of them in non -linear interaction (cross-scale couplings), creating cascade of energy from bigger sizes (lower frequencies) to smaller (higher frequencies). Main characterizations of the turbulence are related to the shape of the power spectrum and high order spectral analysis [1].

In our studies we use data gathered onboard of the DEMETER satellite. Short description is given in the next section.

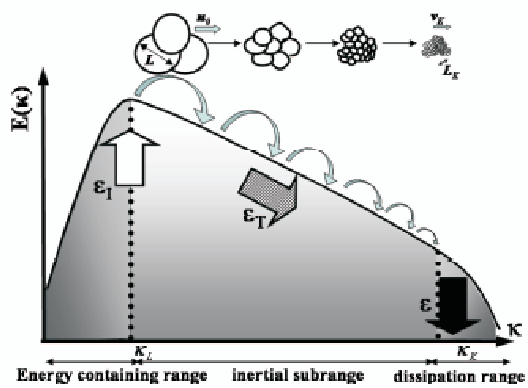


Figure 1: The schematic illustration of the energy cascade across the spectrum in the space of the wave vectors.

Theory of the turbulence predicts the different slope of the spectra for the different types of the turbulence: noncompressible turbulence (K-1941) $k^{-5/3}$ noncompressible isotropic MHD (IK-1965) $k^{-3/2}$ noncompressible anisotropic MHD (SG-2000) $k_{\perp}^{-2}$ and whistler turbulence (DB-1997) $k^{-7/3}$

2. Experiment description

DEMETER is a low-altitude satellite (710km) launched in June 2004 onto a polar and circular orbit which measures electromagnetic waves. In December 2005, the altitude of the satellite was decreased to 660km. The ELF (Extremely Low Frequency) range for the electric field is from DC up to 1250 Hz. There are two modes: a survey mode where spectra of one electric and one magnetic component are onboard computed and a burst mode where, in addition to the onboard computed spectra, waveforms of one electric and one magnetic field component are recorded. The choice of the component is done by telecommand. The burst mode allows performing a spectral analysis with higher time and frequency resolution. Details of the wave experiment can be found in [2,3,4] During the burst mode, the waveforms of the six components of the electromagnetic field are also recorded up to 1.25 kHz.

3. Methods of analysis

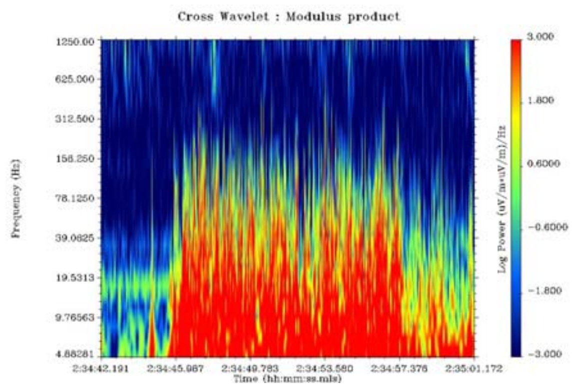
Wavelet Analysis. The traditional Fourier analysis is not relevant to study turbulence. The Fourier transform spreads information about the localized features over all scales making it impossible to study the evolution of different scale structures simultaneously. The important property of the wavelet transform is that the square of the wavelet coefficients can be interpreted as local energy and their statistics is easy to visualize and understand. The usefulness of wavelet analysis in studying the turbulence has been underlined by Farge [5] in the context of coherent structures. The main advantage of using the wavelet transform is that it preserves the information about local features (e. g. singularities) of the signal and allows reconstruction of the signal over a given range of scales. This property is of particular importance in studying turbulence, which often shows coherent structures apparently related to nonlinear processes. Applications of the wavelet analysis to study turbulence in the space plasma were discussed by [6]. Further we use the complex Morlet wavelet which is represented by the function of time t and central frequency ω_0.

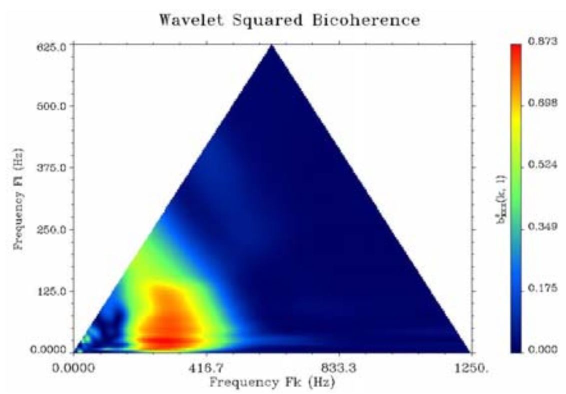
Bispectral analysis When we discuss the development of the plasma turbulence and cascade of the energy in the spectrum, the first step in this cascade and the fundamental process which is involved is the 3- wave interaction. The resonance conditions for these processes are: $\omega_1+\omega_2 = \omega_3$, $\mathbf{k_1}+\mathbf{k_2} = \mathbf{k_3}$, where ω_1, ω_2 and ω_3 are the wave frequencies and $\mathbf{k_1}$, $\mathbf{k_2}$ and $\mathbf{k_3}$ are the wave vectors of the interacting waves. Verification of these conditions is possible using the so called bispectral analysis. This method for the studies of the plasma processes was first proposed by Kim and Powers [7]. It allows finding the nonlinearly interacting wave modes by computing the bispectrum of the signal which gives the information about phase coherence of these waves. A quantitative measure of the phase coherency may be obtained using the bicoherence spectrum The computer procedures for applications of the methods of wavelet and bispectral analysis have been developed in the package SWAN [8]. These methods of analysis have been applied by authors of this paper earlier to study the nonlinear processes in the magnetospheric cusp [9]. Statistical methods of the turbulence description use the probability distribution function (PDF) and its parameters, skewness and kurtosis, as well as, structural function determining the intermittency of the turbulent processes.

4. Measurements

Fig. 2 shows the example of the turbulent process over the seismic regions. It was registered over the seismic region in Chile 9 days before earthquake on February 2010.

Figure 3 presents the turbulence registered in the polar cusp registered when the strong flux of the energetic electrons appears there.





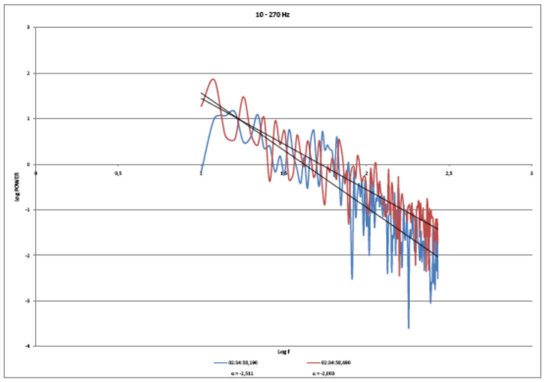


Figure 2: The example of the ionospheric turbulence registered by DEMETER satellite. Upper panel shows the wavelet spectra of the electric field, middle panel represents the bispectrum of the variations of the electric field, 3 waves interaction is clearly seen in the lowest part of the frequency band, middle panel gives the shape of the power spectra with slope index typical for the mhd turbulence .

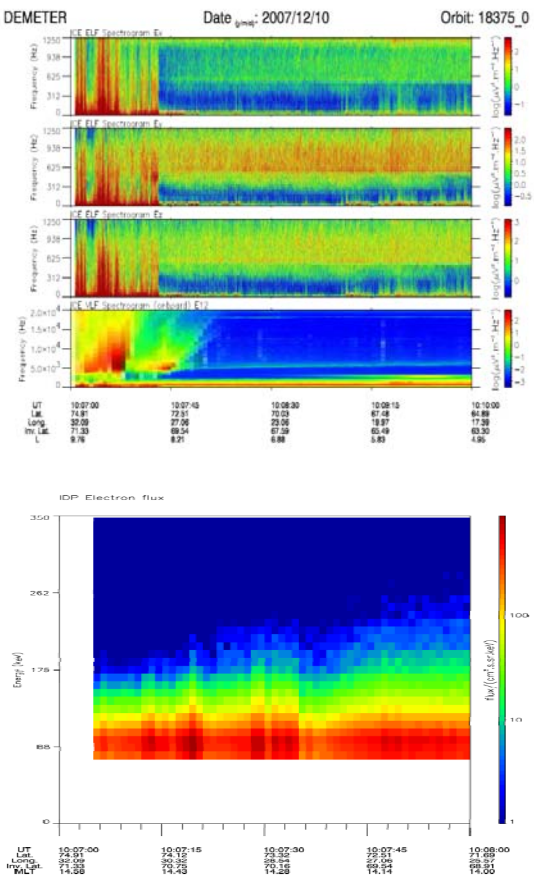


Fig.3. Wave spectra (upper panel) of 3 components of electric field in ELF range and 1 component in VLF and energetic electrons spectra (lower panel) taken by DEMETER in the polar cusp at the ionospheric altitude.

4. Summary and Conclusions

The measurements of the DEMETER satellite performed during its operation time in the different regions of the ionosphere shown that ionosphere is the excellent laboratory to study of the nonlinear plasma processes. More examples and more detail discussion will be given in our presentation.

Acknowledgements

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