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Auroral oval layers detection by using CSES plasma and electric field data

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Summary. — Ionospheric medium fluctuations are detected at various spatial and temporal scales. Plasma irregularities encountered crossing high latitude current systems can be extremely thin and, therefore, unlikely to identify with standard detectors. This work aims to show plasma layer features obtained by electric field instrument on-board the Chinese Seismo Electromagnetic Satellite while crossing the equatorward boundary of the auroral oval allowing the characterization of its various layer. In addition, we made the multi-scale statistical analysis in order to describe the fluctuations of the ionospheric medium.

1. – Introduction

The region located in both northern and southern high latitude ionosphere characterized by particle precipitating from the magnetosphere is defined Auroral Ovals (AOs). Such particle precipitation gives rise to luminosity in both visible and ultraviolet wavelength through direct interaction with the atmospheric atoms. In general, the dynamics of the AO strictly depends on the geomagnetic activity. In fact, its equatorward boundary (EWB) position depends either on the energy of the particle precipitations or on the magnetospheric electromagnetic fields (*e.g.*, [1] and references therein). Its poleward boundary is defined as the separation between the closed field lines and the polar cap. Since the AO is highly variable and rich on many space and time scales [2], it must be assumed as a time- and space-multiscale complex dynamical system. This makes the plasma motion definitely non-laminar and instabilities give rise to irregularities at many different time and space scales (*e.g.*, [3]). In the present paper, an interval of local data collected by the CSES (China Seismo Electromagnetic Satellite) satellite is analyzed, corresponding to an orbit in which the satellite went inside the region of tailward-stretched geomagnetic lines, meeting the EWB plasma. The physical quantity examined is the electric field ($\mathbf{E}(t)$) from the electric field detector (EFD) [4] experiment on board of CSES. $\mathbf{E}(t)$ is expected to be related to the local plasma quantities in terms of both its trend behaviour and fluctuations. In addition, the high rate sampling of $\mathbf{E}(t)$ allows to highlight how the transition from the topside-plasmaspheric environment to the EWB plasma (and vice versa) is neither a sudden jump nor a smooth transition, but rather a layer in which it is possible to meet those plasma structures characterizing the new region [2].

2. – Data and methods

2·1. *CSES satellite data.* – CSES-01 is a Sun synchronous satellite which orbits at ~ 507 km altitude [5]. In this study we used EFD data in the frequency band from DC to 2 kHz with a sampling frequency of 2.5 kHz. The electric field components were analyzed under the geographical coordinate (GEO) system. Finally, following the approach of [4], we removed the spurious electric field due to the spacecraft motion inside the geomagnetic field ($\mathbf{v}_s \times \mathbf{B}$, where $\mathbf{v}_s$ is the satellite speed and $\mathbf{B}$ is the magnetic field) from each $\mathbf{E}(t)$ components.

2·2. *Non-stationary signals decomposition and their multiscale statistical analysis. The Fast Iterative Filtering algorithm.* – When a signal under analysis is non-stationary, like in most real-life applications, standard methods, like (Short Time) Fourier Transform and Wavelet Transform, prove to be inadequate to provide detailed time-frequency information, due to their inherent linearity. In recent years, Lin *et al.* [6], following the idea of Huang *et al.* [7] (EMD decomposition), have proposed the so-called Iterative Filtering (IF) algorithm, *i.e.*, an alternative method which is an iterative, local and adaptive data-driven method. They first divide the signal $s(t)$ into several simple components, called Intrinsic Mode Components (IMCs), plus a trend $r(t)$; then each IMC is analyzed separately in the time-frequency domain via what is called the computation of the instantaneous frequency of each component. The mathematical *a priori* convergence and stability of IF has been proven in [8, 9] works. In the last years IF has been speeded up in what is called Fast Iterative Filtering (FIF) [9].

In order to evaluate the multiscale properties of a signal $s(t)$, following the approach in [10], we first use FIF to decompose $s(t)$ into $IMC_\ell(t)$, characterized by a peculiar scale of variability ℓ, so that $s(t) = \Sigma_{\ell=1}^{m} IMC_\ell(t) + r(t)$, where $r(t)$ is the residue of the decomposition. The connection between each $IMC(\ell)(t)$ and the scale of variability ℓ of $s(t)$ has been analyzed by the use of a multiscale statistical analysis (MSSA). This technique calculates and analyses, for each IMC, the 4th moment of the probability distribution $p(IMC_\ell(t))$ (the kurtosis excess $K_{ex} = K(\ell) - 3$), and the relative energy $\epsilon_{rel} = E(\ell)/E_{Tot}$ (*e.g.*, [2]).

3. – Results and discussion

Figure 1 shows the EFD observations over the southern AO on August 11, 2018. Upper panel in (a) shows the trace of CSES orbit with respect to the map of AO emission (in kilorayleigh) [2] at 21:35 UT. Lower panel in (a) shows the E_x component behaviour. On the basis of E_x behavior, the observations can be divided into two time series: 1) before $-49°$ of latitude ($\mathbf{E}_{out}(t)$, outside the AO); 2) between 50° and 65° in latitude ($\mathbf{E}_{in}(t)$, inside the AO). The black dashed line represents the EWB as determined by DMSP

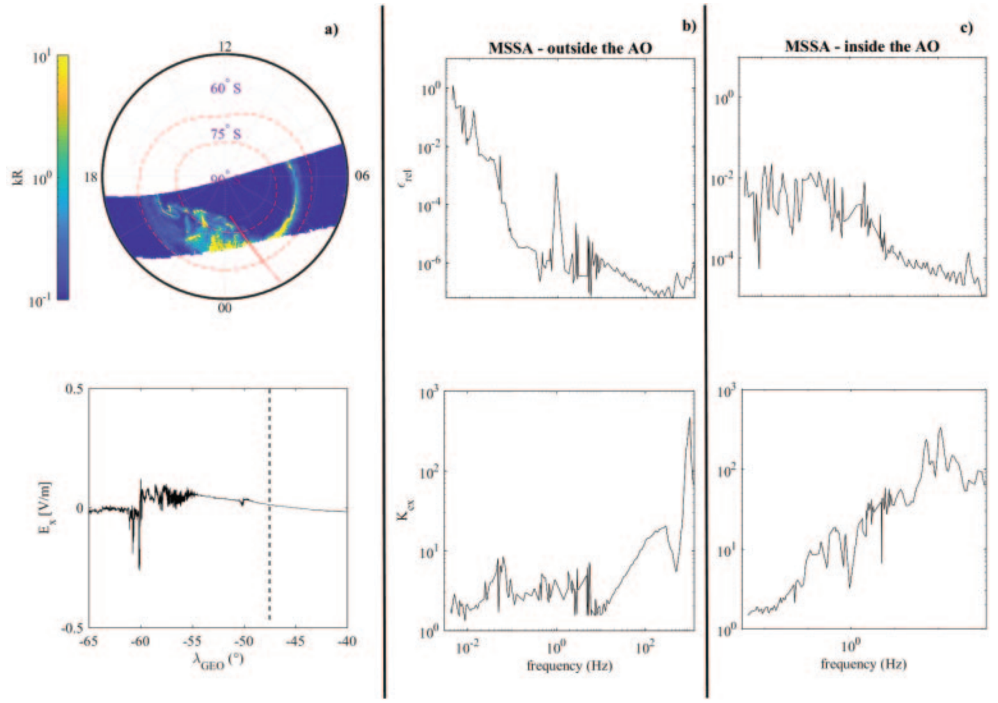

Fig. 1. – EFD observations over the southern AO on August 11, 2018. (a) Trace of the CSES orbit with respect to the map of AO emission taken (in kilorayleigh) by the DMSP satellite (upper panel) and the E_x behaviour measured by CSES in geographycal reference frame as a function of latitude (lower panel). The black dashed line represents the EWB layer of the AO. (b), (c) MSSA in terms of relative energy (upper panel) and excess of kurtosis (lower panel) as a function of the average frequency of each IMC outside and inside the AO, respectively.

observations ([2] and references therein). The E_x behaviour indicates at a glance how an irregular structure follows the smoother part of the series. In fact, when entering the EWB, E_x becomes more spiky.

The proper analysis of multi-scale statistics of E_x is performed by analyzing both $E_{x_{out}}(t)$ and $E_{x_{in}}(t)$, assuming that each segment is quasi-homogeneous in fluctuation field. Such hypothesis, which is true in the first approximation, allows their FIF decomposition and MSSA analysis in a time-independent way. The statistical parameters $\epsilon_{rel}(f)$ and $K_{ex}(f)$ are reported as functions of the mean frequency of each time-scale (IMC) evaluated via FIF decomposition in (b) (outside the AO) and (c) (inside the AO). It can be easily seen that the energy becomes differently distributed along the scales (f), so that smaller structures appear in the irregular portion of the crossed medium. Moreover, while in panel (b) $K_{ex}(f)$ is almost flat, with increasing trend only for frequency greater than 40 Hz, panel (c) shows $K_{ex}(f)$ growing monotonically. This indicates that the smaller the structures considered, the less Gaussian distribution they show. In the presence of fully developed turbulence, which is not ascertained to be the case here, this would be an indication of the occurrence of a non-homogeneous multiscale fluctuation field, which is reminiscent of an intermittency phenomena [11].

4. – Conclusions

In this work we have presented the results of applying MSSA to the high latitude fluctuations observed by EFD experiment on-board of CSES, while crossing the EWB of the southern AO. According to the previous results by [2], fluctuations observed in the electric field observations, produced by the particles precipitating from the magnetotail along the geomagnetic lines, are characterized by features pointing towards spatio-temporal inhomogeneous fluctuations. In other words, we found that in the external part of the auroral electrojet, *i.e.*, in the EQW boundary of the AO, fluctuations are sparsely and strongly inhomogeneous, which could be the counterpart of the occurrence of turbulence generated by local kinematic instabilities in regions characterized by strong shear flows. Their presence produces variations in $\mathbf{E}(t)$ that are characterized by kurtosis distributions decreasing with increasing space details, suggesting that the EWB of the AO is a plasma medium in a turbulent state showing patchy multi-scale structures.

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