Study of the turbulence in the central plasma sheet during August 24-28 geomagnetic storm using the CLUSTER satellite data

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Resumen

Hemos utilizado la Técnica de medición de intermitencia local (local Intermittency Measure Technique) basada en la técnica de la transformada de wavelet para estudiar las fluctuaciones de velocidad en el plasma, medidas por experimento de espectrómetro de iones de satélite CLUSTER, durante la tormenta geomagnética de 24-28 de agosto de 2005. Los resultados obtenidos mostraron un aumento significativo de nivel de turbulencia intermitente al final de la fase principal. Esto puede estar relacionado con un aumento significativo en la actividad de las subtormentas y estiramiento de las líneas del campo geomagnético observado en la fase principal. Este hecho es importante para la comprensión de la naturaleza de las tormentas geomagnéticas.

Palabras clave: Magnetosfera terrestre, turbulencia, tormenta geomagnética, plasma sheet, coeficiente de difusión, intermitencia.

Abstract

We used the local Intermittency Measure Technique based on the wavelet transform to study plasma velocity fluctuations measured by CLUSTER II Ion Spectrometry experiment during August 24-28 geomagnetic storm. The results obtained showed a significant increase in the level of intermittent turbulence at the end of main phase. It can be related to a significant increase in the substorm activity, and stretching of the geomagnetic field lines observed during the main phase. This fact is important for understanding the nature of geomagnetic storms.

Key words: Magnetosphere of the Earth, turbulence, geomagnetic storm, plasma sheet, eddy diffusion coefficient, intermittency.

Introduction

Recent studies have shown that turbulent processes in space plasmas are very important. It is well known that turbulence in ordinary fluids significantly changes the basic properties of flow and large-scale flow patterns, therefore the turbulent processes should also play an important role in the dynamics of the Earth's magnetosphere.

The turbulence in space plasmas, and in particular, in the plasma sheet of the magnetosphere of the Earth was studied intensively during last decade (see Borovsky and Funsten, 2003, for a most complete review). Antonova (2002) assumed that the plasma sheet can be considered as a turbulent wake behind an obstacle. Presence of turbulence leads to the intense plasma mixing in the plasma sheet and to its stabilization due to a balance between the expansion due to the eddy-diffusion of the plasma and the compression by large scale down-dusk electric field (Antonova and Ovchinnikov, 1999).

The sources of turbulence in the plasma sheet are not clear till now. Angelopoulos *et al*. (1999) showed that the magnetotail is in a state of bimodal convection, where the potential flow is stagnant unless driven by localised flow bursts. It was found that both the bursty bulk flow events and the ambient flows could be described as an intermittent turbulence.

Recently, turbulence in the plasma sheet has been studied in detail using the CLUSTER magnetic field data (Vörös *et al*., 2004, Weygand *et al*., 2005). In particular it was found that the magnetic field fluctuations in the plasma sheet have multi-scale features and the turbulence present in the plasma sheet is intermittent. Intermittency is a well established property of any fluctuation that energy at a given scale is not evenly distributed in space. In other words behaviour of multiscale complex phenomena consists of periods of relative quiescence which are interrupted by short bursts of activity. Such patterns in activity are observed in systems ranging from the stock market to turbulence (Vassilicos, 1995). Burlaga (1991) studied large-scale fluctuations of the interplanetary magnetic field (IMF) and showed that the solar wind is a flow of turbulent plasma that displays a multifractal structure and an intermittent character. Non-Gaussian nature of probability distribution function (PDF) of plasma velocity and magnetic field in the MHD solar wind turbulence has been revealed also by Marsch and Tu (1994, 1997). They showed that these PDFs have strong deviations from the Gaussian form, especially at a small scale. The wings of the distribution appear to be stretched and higher than expected for a Gaussian, indicating that the strongest fluctuations are governed by deterministic rather than by stochastic dynamics. It was also found in Marsch and Tu (1994, 1997) that the radial components of both the velocity and the magnetic field look more intermittent than the two perpendicular components. Sorriso-Valvo *et al.* (1999) showed that in both fast and slow solar wind streams magnetic field intensity is more intermittent than the bulk solar wind speed. Bruno *et al.* (1999, 2001, 2003) studied how the presence of intermittency affects the radial evolution of the anisotropy in the solar wind velocity and the magnetic field fluctuations.

In this paper, we continue the study of intermittent processes in the plasma sheet for the August 24-28, 2005 geomagnetic storm using the bulk velocity measurements made by CLUSTER mission by applying the Local Intermittency Measure (LIM) technique.

Instrumentation and data analysis

For this study we used the Cluster Ion Spectrometry experiment (CIS) data. The CIS1 instrument measures the 3-dimensional distribution functions of H^+, He^{++}, He^+, and O^+ ions over the energy per charge range 20-40000 eV/e, and the high-resolution CIS2 instrument measures 3D distributions without mass selection in the energy range 5 eV-32 keV (Rème *et al.*, 2001). Moments (density N, bulk flow velocity vector V, pressure tensor P, and heat flux Q) of the distribution functions are calculated on-board every 4s.

Bulk velocity fluctuations were analysed using the Local Intermittency Measure technique. This method makes it possible to single out intermittent events from the time series by applying the wavelet transform (Farge *et al.*, 1990). This method has been used for the first time in space plasma context by Veltri and Mangeney (1999) and Bruno *et al.* (1999). In particular, Bruno *et al.* (2001), using the LIM method, located and studied in detail physical properties of intermittent events which resulted to be a sort of tangential discontinuities. The wavelet coefficients $w\ (\tau,\ t)$ are obtained through a convolution between the analysed function $f\ (t)$ and a shifted and scaled version of a given wavelet basis (ψ) as:

$$w\ (\tau, t) = \int f(t')\frac{1}{\sqrt{\tau}}\,\psi\left[\frac{t' - t}{\tau}\right] dt' \qquad (1)$$

According to Parceval's theorem, $|w\,(\tau, t)|^2$ represents the energy content of fluctuations at the scale τ and the time t. The Local Intermittency Measure is defined as (Farge, 1990):

$$LIM\ (\tau, t) = \frac{|w\ (\tau, t)|^2}{\left\langle |w\ (\tau, t)|^2 \right\rangle_t} \qquad (2)$$

When the *LIM* is equal to one for any time and scale, the time series does not exhibit an intermittent behaviour. On contrary, when it is greater than one, this means that a given time t and scale τ contribute more than the average over t to the Fourier energy spectrum at scale τ, and the series is intermittent.

Meneveau and Sreenivasan (1991) introduced the Flatness Factor of the wavelet coefficients distribution as:

$$FF\ (\tau) = \left\langle LIM^2\ (\tau, t)\right\rangle_t \qquad (3)$$

Meneveau (1991) showed that the flatness of the distribution of the wavelet coefficients at a given scale is equivalent to the flatness of the data at the same scale that is why we can interpret the $\langle LIM^2 \rangle$ at a given scale as the flatness of the data at that scale.

Values of $FF(\tau)>3$ allow localisation of events which lie outside the Gaussian statistics and cause intermittency.

In the following paragraphs we illustrate the application of *LIM* procedure to a bulk velocity fluctuation event measured in the plasma sheet August 24, 2005 (see Fig. 1).

Fig. 2 shows the $LIM\ (\tau, t)$, obtained from this velocity time series using equation (2). The Mexican Hat basis was used (see Daubechies, 1992 for a review):

$$\psi\ (t) = \left[\frac{2}{\sqrt{3}}\pi^{-1/4}\right](1 - t^2)\ e^{-t^2/2} \qquad (4)$$

After that we calculated the flatness factor using the equation (3) (see Fig. 3) and fitted them by a power law $FF(\tau) = \mu\tau^{-\alpha}$. As can be seen from Figs. 2 and 3, the values of flatness factor generally exceed 3, and the bulk velocity series analysed show an intermittent behaviour.

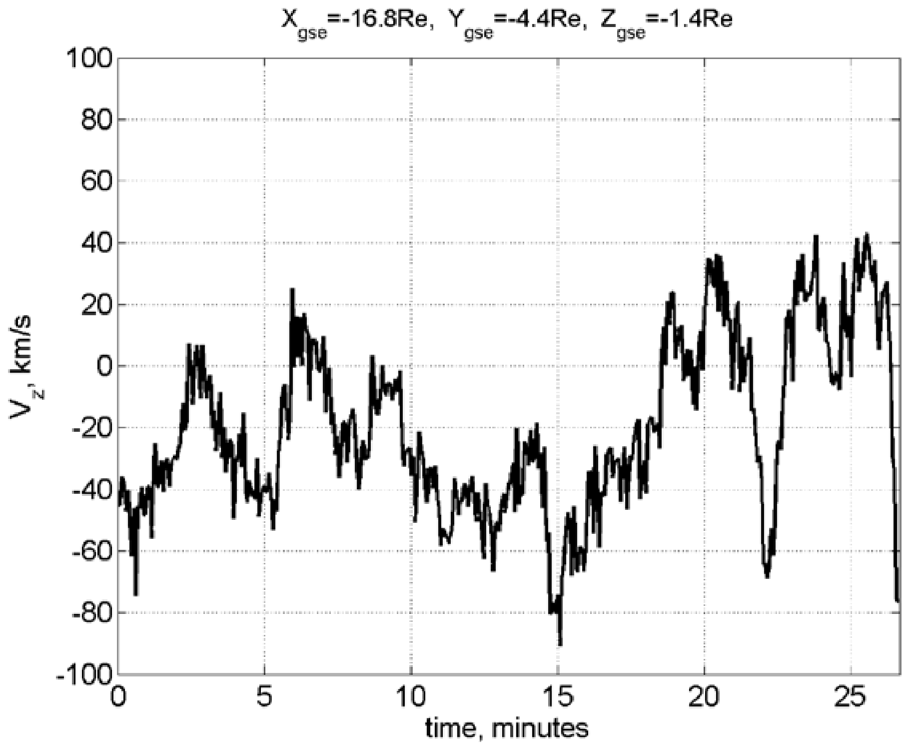

Fig. 1. Typical example of bulk velocity fluctuations (Z- component), obtained by CLUSTER 1 August 24, 2005 starting at 6:50 aproximately (400 points, 1600 s of measurements).

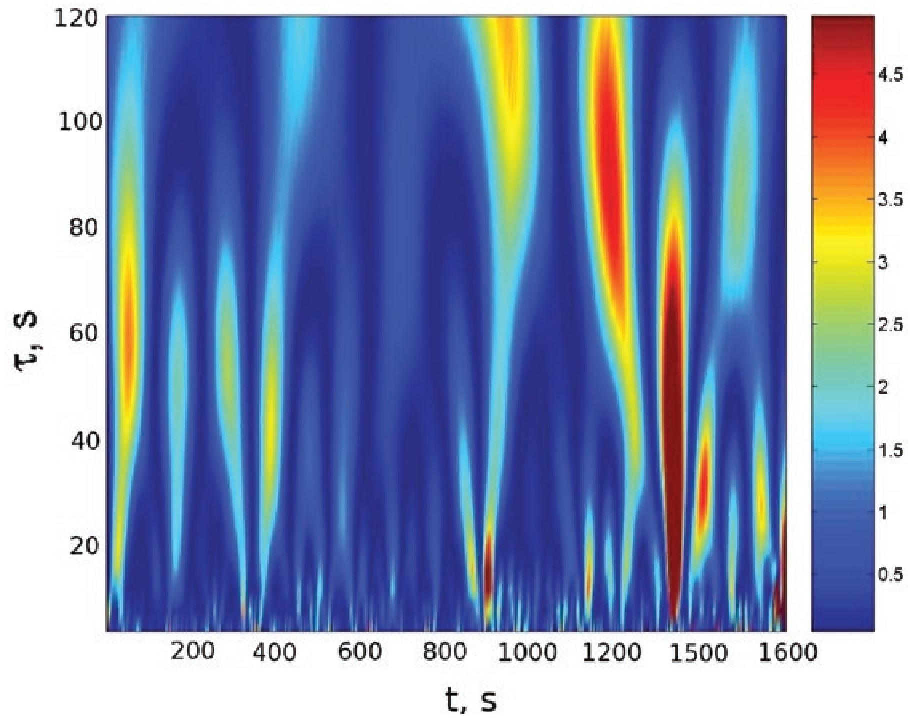

Fig. 2. Example of the Local Intermittency Measure *LIM* (τ, t), obtained from the bulk velocity fluctuations, shown in Fig. 1.

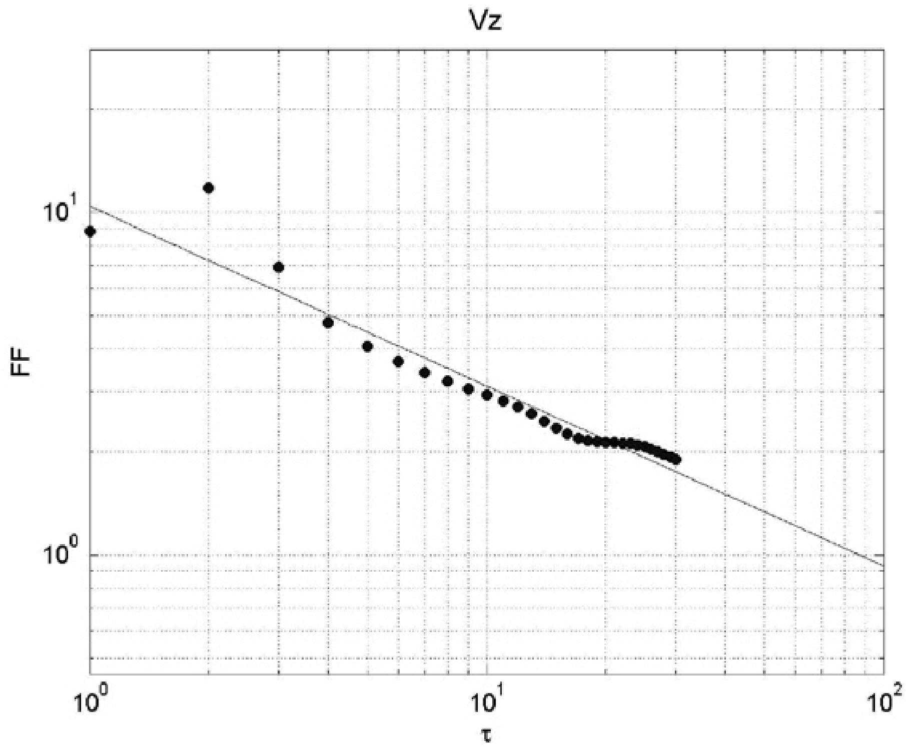

Fig. 3. Example of Flatness Factor, obtained from *LIM* (τ, t), shown in Fig. 2.

August 24-28, 2005 geomagnetic storm

The evolution of turbulence during a great geomagnetic storm was studied using the CLUSTER data when the satellites crossed the plasma sheet at the downtail distances of 15-19 Earth's radii (Re).

Fig. 4 shows the solar wind parameters and Dst value for the August 24-28, 2005 geomagnetic storm (minimum Dst=-216 nT (provisional)). The satellite crossed the plasma sheet three days before the storm analysed August 21, 2005 between 13-23 UT, when the values of Dst were nearly 0. The first plasma sheet crossing during the storm occurred August, 24 between 4-18 UT during the main phase and beginning of recovery phase. The second crossing occurred August 26 between 6-20 UT at the end of recovery phase. Analysis of provisional auroral electrojet indices showed that the substorm activity was low (AL>-200 nT) during August 21, very high during August 24 (AL=-2500 nT, at 11 UT, approximately), and ceased gradually during August 25 and 26, and stopped August 26 at 9 UT.

Fig. 5 shows variations of the fit parameters for Flatness Factor for Vz component of the bulk velocity across the plasma sheet, obtained August 24, 2005, using the CLUSTER 1 data (end of the main phase). As it can be seen, the level of intermittency increases in the central part of plasma sheet (according to the magnetic field data, CLUSTER 1 crossed the neutral sheet in 10 UT, approximately, not shown). Results, obtained for other two components of the bulk velocity were similar.

Nevertheless, the results, obtained during quiet time (August 21, 2005) and at the end of recovery phase (August 26, 2005) were different: the level of intermittency (μ) was two times lower, and the maximum close to the region of neutral sheet was not so pronounced.

Conclusions

Local Intermittence Measure Technique is a powerful tool for analysis of the time series for the presence of intermittency. The intermittency can be treated as a localised in time intervals of time series for which a correlation exists. These structures dominate the statistics of small scales fluctuations and have a typical lifetime greater than that of stochastic fluctuations surrounding them. In other words intermittency can be considered as the result of the occurrence of coherent (non–gaussian) structures emerging from the sea of stochastic Gaussian fluctuations. LIM technique has an advantage, to make

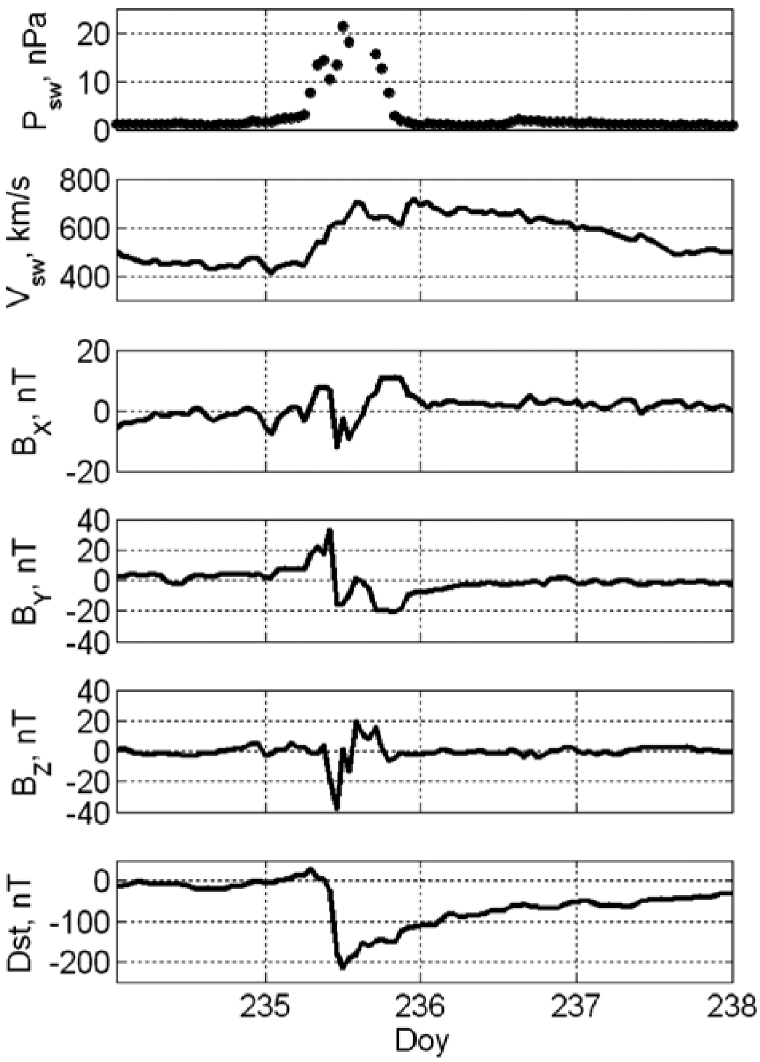

Fig. 4. The solar wind parameters and Dst variation during August 24-28 geomagnetic storm (days of year (Doy) 234-238). OMNI2 NSSDC.

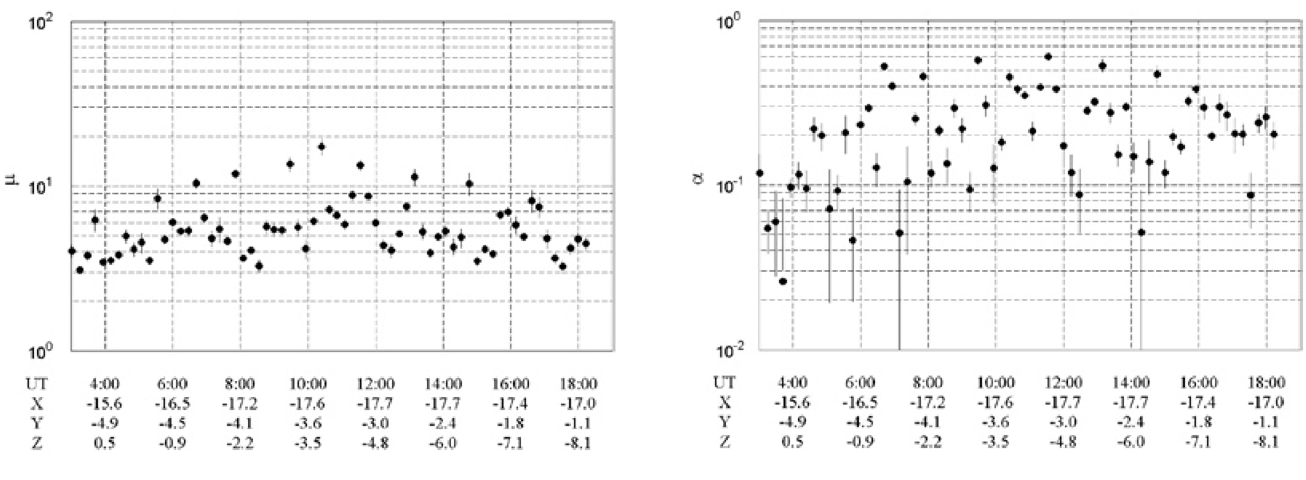

Fig. 5. Variations of the fit parameters for Flatness Factor $FF(\tau) = \mu\tau^{-\alpha}$, obtained inside the plasma sheet August 24, 2005. The results are given in GSE system of reference.

it possible to work with relatively short series. In this study it was applied to the 4 s resolution data of the bulk velocity, measured by the CLUSTER 1 satellite. Each 400 points (1600 s) time series was processed and flatness factor coefficients were obtained. It was found that the level of intermittency has a maximum close to the neutral sheet. It also was found that the level of intermittency has increased significantly at the end of the main phase of the August 24-26, 2005 geomagnetic storm. This increase can be also related to the strong substorm activity observed during August 24, 2005, that reached the values of the auroral electrojet index AL<-2500 nT.

Nevertheless, it is necessary to continue this work to be able to make definite conclusions about a relationship between turbulent processes in the plasma sheet and geomagnetic stroms.

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