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Examining the role of turbulence in the solar wind - magnetosphere interaction processes

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Abstract. In this paper we compare the intermittence properties of magnetic fluctuations (non-Gaussian shape of probability density functions) observed in the solar wind (ACE) with the simultaneous occurrence of intermittence in the Earth's plasma sheet (GEOTAIL). Intervals with different level of magnetic turbulence are investigated separately.

1. Introduction

Recent progress illuminates the key role of nonlinear couplings and turbulence in the study of solar wind - magnetosphere interaction processes. Both the solar wind and the magnetosphere represent high Reynolds number plasmas (Borovsky & Funsten 2003a) exhibiting typical properties of turbulence known from laboratory experiments and theoretical works (Borovsky & Funsten 2003b).

In a recent paper Vörös et al. (2002) have shown that the scaling and singularity properties of the solar wind turbulence unequivocally influence the associated geomagnetic response. The examination of the correlations between the basic characteristics of turbulence in the upstream solar wind and various geomagnetic indices has also shown that geomagnetic activity increases with an increase in the amplitude of the turbulence in the solar wind. The effect is remarkable and present for both northward and southward oriented interplanetary magnetic field (IMF) intervals (Borovsky & Funsten 2003a). Also, input-output modeling studies of solar wind - magnetosphere interaction processes have shown that superior predictor performance was achieved when the information on multi-scale and singularity properties of the solar wind turbulence were incorporated into nonlinear filter (Ukhorskiy et al. 2002) or neural network (Vörös & Jankovičová 2002) prediction schemes. Possible theoretical interpretations of these findings include turbulence triggered or fostered magnetic reconnection at the magnetopause (Greco et al. 2003) and/or an enhanced viscous coupling of the solar wind flow to the Earth's magnetosphere (Borovsky & Funsten 2003a).

Because of the non-homogeneous and intermittent distribution of energy in magnetohydrodynamic flows probability density functions (PDFs) are non-Gaussian. In this preliminary study we investigate the non-Gaussian characteristics of intermittent magnetic field fluctuations available from simultaneous observations in the solar wind and in the Earth's plasma sheet.

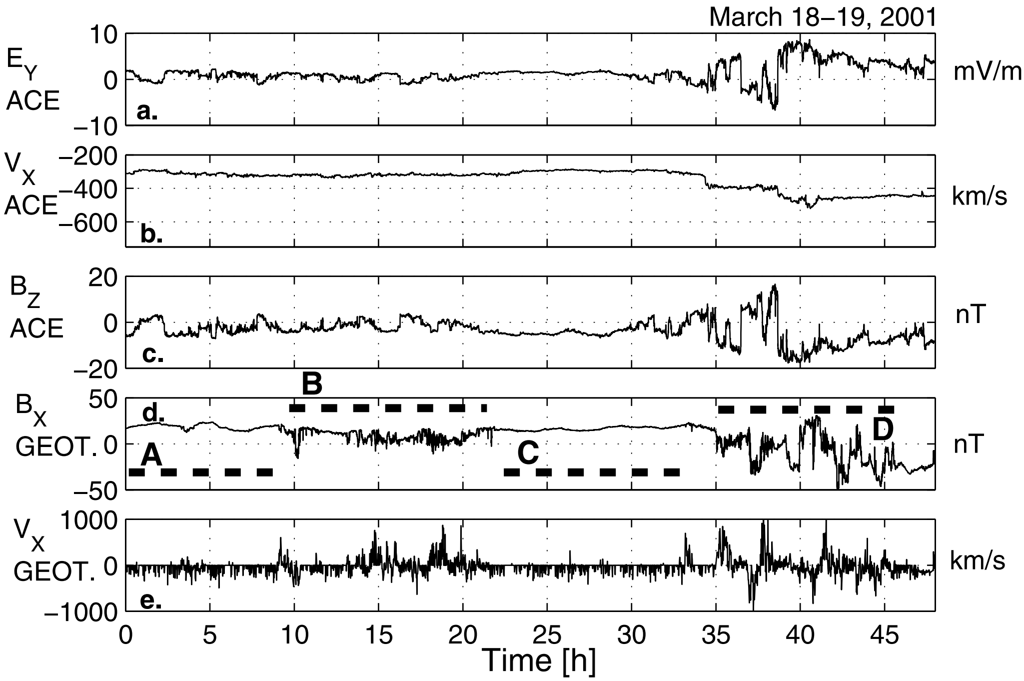

Figure 1. Solar wind (ACE) and plasma sheet (GEOTAIL) measurements

2. Non-Gaussian intermittent fluctuations

In order to investigate the non-Gaussian features of magnetic fluctuations we study the shape of PDFs during an interval, characterized by different levels of fluctuation acitivity. To be able to evaluate the statistics of magnetic fluctuations at different time scales, we consider two-point differences defined by

$$\delta B = B(t + \tau) - B(t) \tag{2.1}$$

Supposing 'frozen field' conditions, when spatial patterns in turbulence past the spacecraft with a constant bulk speed V, the spatial scales can be estimated through $V.\tau$, for different time delays τ.

2.1. *Event on March 18-19, 2001*

Velocity (V_X) and magnetic field (B_Z) measurements available from ACE spacecraft (solar wind) in the GSM coordinate system with time resolution of 64 s and 16 s respectively, are shown in Figures 1 b,c. The electric field E_Y in Figure 1a is computed as $V_X.B_Z$ with time resolution of 64 s. We note that long duration negative IMF B_Z events, associated with duskward electric fields $> 5mV/m$, occur together with intense magnetic storms. The solar wind measurements are compared with simultaneous measurements of the X components of magnetic and velocity fields in Figures 1 d,e, available with time resolution of 4s and 64 s, respectively, from the GEOTAIL mission. GEOTAIL was in GSM position $X \in (-22 \div -31)R_E$, $Y \in (-10 \div 10)R_E$ and $Z \in (-2 \div 7)R_E$. In order to have approximately simultaneous measurements form ACE and GEOTAIL the corresponding solar wind intervals are shifted by 1.5 h in statistical comparative analysis.

According to the level of magnetic fluctuations in the plasma sheet, the 2 day interval is subdivided into ~ 10 h long intervals (marked by A, B, C, D in Figure 1d). The intervals

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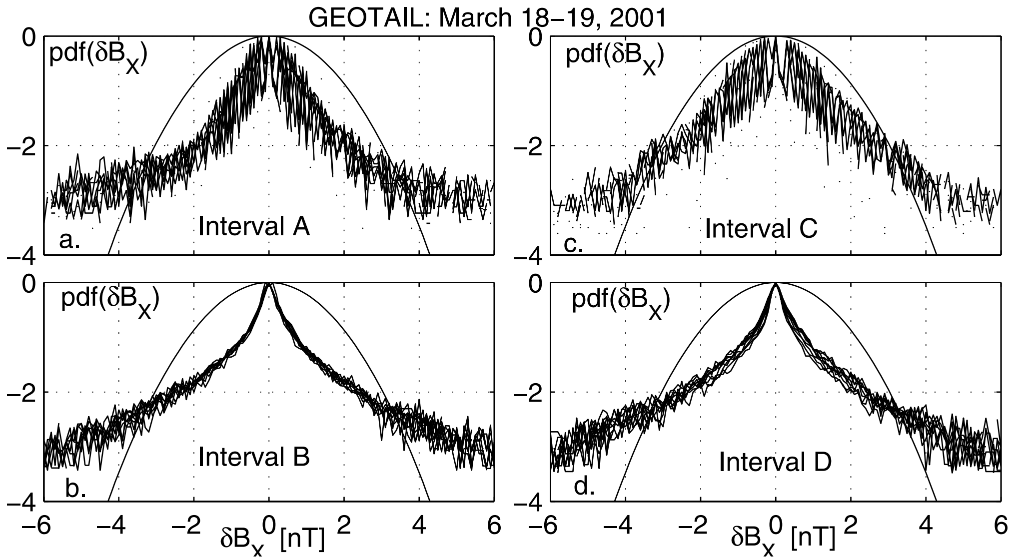

Figure 2. PDFs estimated in the Earth's plasma sheet for differences (Equation 2.1) of the X component of magnetic field; Gaussian PDFs are depicted by smooth continuous lines

A and C contain practically no B_X fluctuations and are associated with plasma sheet flows $|V_X| < 200$km/s (Figure 1e) and solar wind bulk flows $|V_X| \sim 300$km/s (Figure 1b). The electric field measured by ACE is $|E_Y| < 3$mV/m. Except the interval C, IMF B_Z exhibits well visible fluctuations. Both intervals B and D are associated with rapid bursty bulk flows (BBFs) and intense B_Z fluctuations. All solar wind parameters exhibit values characteristic for intense geomagnetic storms only during the interval D.

Figures 2 a-d are semilogaritmic plots of PDFs computed from two-point differences (Eq.2.1) of B_X in the plasma sheet. The maxima of PDFs are normalized to 1. Each set of curves in different subplots correspond to the time delays $\tau = 3, 6, 9, ..., 21$ s. The related spatial scales are roughly $\sim 200 \div 15000$ km during the intervals A and C, and $\sim 200 \div 20000$ km during the intervals B and D. At the same time the spatial size of a typical flow channel (the large-scale of the flow) in the plasma sheet is between 10000 and 20000 km (Nakamura et al. 2004). Turbulent flows are characterized by the presence of self-similarity in the inertial range. That is on the spatial scales smaller than the energy injection scale (in our case $\sim 10000 \div 20000$ km) and much larger than the dissipative scale ($<< 10000$km) we expect

$$PDF[B_X(t+\tau) - B_X(t)] \sim PDF[B_X(t+k.\tau) - B_X(t)] \tag{2.2}$$

with values of $k.\tau$ typical for the inertial range. Self-similarity and non-Gaussianity of the PDFs is evident for BBF associated intervals (Figures 2 b, d). In fact, high speed plasma sheet flows described in (Baumjohann et al. 1990) are carriers of decisive amounts of mass, momentum and magnetic flux, therefore can be the drivers of intermittent non-Gaussian turbulence in the plasma sheet (Borovsky & Funsten 2003b; Vörös et al. 2003).

Figures 3 a-c show the mean PDFs computed for magnetic field components B_X, B_Y, B_Z in the solar wind from ACE, during the intervals shifted by 1.5 h relative to the intervals B, C, D (being too short, the PDF for the interval A is not shown). Mean PDFs are computed for $\tau = 16, 32, ..., 256$ s. The largest deviations from the Gaussian occur during the interval D, then the interval B follows. PDFs during C are the closest to the Gaussian curve. Moreover, PDFs show anisotropic features, having different shapes for

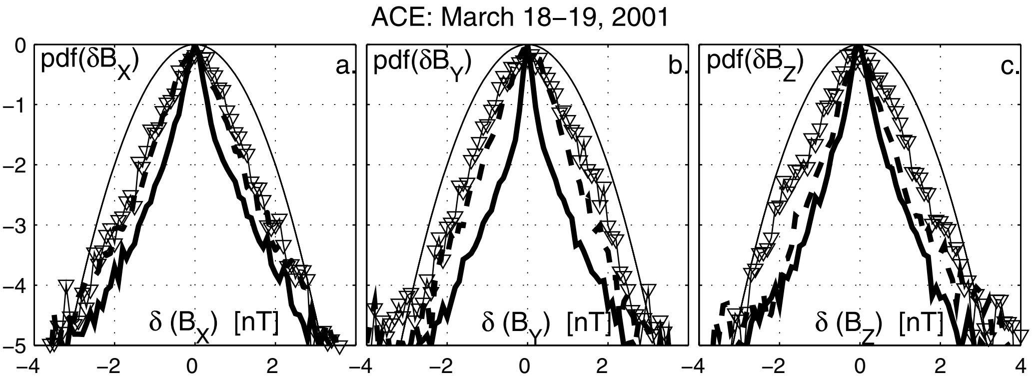

Figure 3. PDFs estimated in the solar wind for differences (Equation 2.1) of the a. X, b. Y, c. Z components of magnetic field; Gaussian PDFs are depicted by smooth continuous thin lines; thick dashed lines: interval B; triangles: interval C; thick continuous lines: interval D.

the different components. The deviations from the Gaussian for the individual intervals in the solar wind (Figure 3) correspond well to the corresponding deviations observed in the plasma sheet (Figure 2). Therefore the possible drivers of plasma sheet turbulence can include both BBFs in the plasma sheet and intermittent upstream turbulence in the solar wind.

3. Conclusions

We have demonstrated that the non-Gaussian characteristics of magnetic turbulence in the solar wind and the occurrence of intermittent magnetic turbulence in the plasma sheet can be interconnected. In this respect a comparative analysis of the solar wind magnetic and plasma parameters with the time evolution of the geomagnetic indices is insufficient. A wider statistical study, including the consideration of intermittency parameters in the solar wind and key regions of the Earth's magnetosphere is needed, however, to explore fully the role of turbulence in the solar wind-magnetosphere interaction processes.

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