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The distribution of spectral index of magnetic field and ion velocity in Pi2 frequency band in BBFs: THEMIS statistics

Q. Wu[a,b,c], A.M. Du[a,*], M. Volwerk[d], G.Q. Wang[e]

[a] Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China
[b] University of the Chinese Academy of Sciences, Beijing 100049, China
[c] Key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[d] Space Research Institute, Austrian Academy of Sciences, Graz, Austria
[e] CAS Key Laboratory of Geospace Environment, Department of Geophysics and Planetary Science, University of Science and Technology of China, Hefei, China

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Abstract

A statistical study of the THEMIS FGM and ESA data is performed on turbulence of magnetic field and velocity for 218 selected 12 min intervals in BBFs. The spectral index α in the frequency range of 0.005–0.06 Hz are Gaussian distributions. The peaks indexes of total ion velocity V_i and parallel velocity $V_\parallel$ are 1.95 and 2.07 nearly the spectral index of intermittent low frequency turbulence with large amplitude. However, most probable α of perpendicular velocity $V_\perp$ is about 1.75. It is a little bigger than 5/3 of Kolmogorov (1941). The peak indexes of total magnetic field B_T is 1.70 similar to $V_\perp$. Compression magnetic field $B_\parallel$ are 1.85 which is smaller than 2 and bigger than 5/3 of Kolmogorov (1941). The most probable spectral index of shear $B_\perp$ is about 1.44 which is close to 3/2 of Kraichnan (1965). Max $V_\perp$ have little effect on the power magnitude of V_T and $V_\parallel$ but is positively correlated to spectral index of $V_\perp$. The spectral power of B_T, $B_\parallel$ and $B_\perp$ increase with max perpendicular velocity but spectral indexes of them are negatively correlated to $V_\perp$. The spectral index and the spectral power of magnetic field over the frequency interval 0.005–0.06 Hz is very different from that over 0.08–1 Hz.

Keywords: BBF; Spectral index; THEMIS

1. Introduction

As a non-linear physical phenomenon, turbulence can be observed in many space plasmas (Zimbardo et al., 2010). It is a common feature in magnetic fields and plasma flows in the Earth's magnetotail plasma sheet and is concerned by many researchers (Borovsky and Funsten, 2003; Vörös et al., 2004a). However, the origin of multiscale turbulence in the magnetotail plasma sheet is poorly understood. Borovsky and Funsten (2003) pointed out that its appearance clearly relies on the dissipation and driving mechanisms that characterize a fluctuating process. Fluctuations of magnetic field and plasma flows have been studied by many authors (Borovsky et al., 1997; Coroniti et al., 1980; Neagu et al., 2002). The plasma shear flows have been considered as a driving source of fluctuations. Statistical studies based on the observation of AMPTE/IRM in the near geomagnetic tail have already demonstrated the existence of high speed flows with sunward orientation in the plasma sheet (Baumjohann et al., 1989, 1990). Subsequent studies have shown that high speed flows organize themselves as bursty bulk flows (BBFs) with duration time of about 10 min. Although the duration time is short, BBFs

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* Corresponding author.
E-mail addresses: wuqi@mail.iggcas.ac.cn (Q. Wu), amdu@mail.iggcas.ac.cn (A.M. Du), Martin.Volwerk@oeaw.ac.at (M. Volwerk), guowang@mail.ustc.edu.cn (G.Q. Wang).

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carry the main mass, momentum, and magnetic flux (Angelopoulos et al., 1992, 1994; Schödel et al., 2001). When BBFs propagate Earthward, the plasma will be heated by the stochastic acceleration due to the moving magnetic structures (Perri et al., 2009, 2011). Besides, Greco et al. (2015) pointed out that the average ion energy in the leading edge of BBFs will incease with the front velocity. Simulation (Guo et al., 2015a) showed that BBFs are also related to the shear and kinetic waves which can lead to ion heating in the near-Earth magnetotail (Guo et al., 2015b). So BBFs can efficiently affect the magnetic field and the plasma inside the magnetotail plasma sheet. Studying the statistical properties of bursty bulk flows is important for understanding the plasma energization in the magnetotail plasma sheet.

A common method for studying turbulence is spectral analysis, which is based on the variance of fluctuations at different scales. It has been shown that the spectral power P is proportional to the frequency as $f^{-\alpha}$ (α is called spectral index) in the considered frequency range. Different spectral indices correspond to different characteristics of turbulence. The spectral index of neutral fluid turbulence is generally about 5/3 (Kolmogorov, 1941). The incompressible isotropic conductive fluid MHD turbulence has a spectral index about 3/2 (Kraichnan, 1965). Due to the limiting of gradient of magnetic field on the z-direction, turbulence in this region is two-dimensional, corresponding to the spectral index of $\sim$3 (Frisch, 1995; Volwerk et al., 2003).

Later, it was noted that BBFs have an impact on the spectral index. Vörös et al. (2004b) found that small-scale (0.08–0.3 s) magnetic fluctuations have same spectral index $\alpha \sim 2.6$ while the large-scale (0.7–5 s) magnetic fluctuations occurring during BBF-associated periods. During non-BBF associated periods, the α of large-scale fluctuations is about 1.7. Volwerk et al. (2003) found that $2.5 < \alpha < 3.5$ when $150 < V_{\perp,\,\max} < 1100$ km/s. BBFs also have effect on the energy magnitude of turbulence. The results from Bauer et al. (1995a) showed that the spectral power first increases strongly with increasing flow velocity, whereas at high flow velocities the graph seems to flatten. Volwerk et al. (2003) confirmed this result by using the CIS-CODIF data within 12 min intervals. They also showed that the compressional wave power at 0.1 Hz is strongly dependent on the maximum plasma flow velocity and highly correlate to the Pi2 power. Vörös et al. (2004b) showed that during BBFs, energy transfer takes place from large scale to small scale.

Volwerk et al. (2003) analyzed the distribution of α in the frequency range of 0.08–1 Hz and the trend in which the spectral power at 0.1 Hz changes with perpendicular ion speed. The authors also fitted the frequency range of 0.005–0.06 Hz. However, they did not further study this frequency band. In this current paper, we find in our data that the inflection point is around 0.08 Hz in 12 min BBF intervals. In this paper we statistically investigate the spectral index α of the flow velocity and the magnetic field inside BBFs in the frequency range of 0.005–0.06 Hz. The fit spectral power $E_{0.06}$ at 0.06 Hz is selected as the typical spectral power in this frequency band. It is beyond the dissipation frequency 0.08 Hz and like the intercept at the right edge of our frequency band. We can check the energy transfer from the spectral power at this frequency and the spectral index. Then the dependence of spectral power $E_{0.06}$ at 0.06 Hz and the spectral index of these parameters on velocity and radial distance is analyzed. The paper is organized as follows. In the next section we introduce our data set and the criteria of BBFs. Section 3 show how to choose BBFs and spectral index of turbulence based on case studies. The statistical results also are presented in this section. Discussion and conclusions are exhibited in Section 4.

2. Data and method

In this study, we use data from the identical instruments on THEMIS (Angelopoulos, 2008; Sibeck and Angelopoulos, 2008). The THEMIS mission consists of five probes, all of which have orbital trajectories through the Earth's magnetotail. The perigees of the five satellites are $\sim$1.5 R_E, while the apogees vary from $\sim$10 R_E for the innermost probes to $\sim$30 R_E for the outermost probe THEMIS B (THB or P1). THEMIS B and THEMIS C have been sent to the moon since 2010. In this paper we choose the data observed by these five probes when they are located in the tail during 2008–2011.We only selected data observed from $-9\ R_E$ to $-30\ R_E$ in the X_{GSM} direction because few BBFs were detected beyond this region. $|Y_{\mathrm{GSM}}| < 10\ R_E$ is used to exclude the magnetopause boundary layer excursions and $|Z_{\mathrm{GSM}}| < 5\ R_E$ is used to remove events outside of the plasma sheet. The plasma-Beta $\beta > 0.5$ is used to insure that all events are located in the central plasma sheet. The THEMIS magnetic field data come from the fluxgate magnetometer (FGM) (Auster et al., 2009). The ion velocities are derived from the electrostatic analyzer (ESA) instrument (McFadden et al., 2008). All of these data from THEMIS are formatted to 3 s resolution in the GSM coordinate system. The compressional and shear components of the magnetic field and ion velocity are relate to the current wedge and the generation of high latitude Pi2 (Kepko and Kivelson, 1999; Kepko et al., 2001). Studying the statistical properties of these component will be help to understand the energy transfer of velocity and magnetic field. Besides, we also want to compare the compressional waves in our frequency range with Volwerk et al. (2003). So, the compressional and shear components of the magnetic field and ion velocity are also analyzed in this study. In order to do this, the magnetic data and ion velocity is rotated into a local Mean-Field-Aligned (MFA) coordinate system (Takahashi et al., 1990). The three components of the MFA system are denoted as e_x, e_y, and e_z. The compressional component is parallel to e_z which is a unit vector along the 10 min moving-average magnetic field direction. 10 min being selected as the window is because it is beyond the double