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Statistics of low-frequency variations in solar wind, foreshock and magnetosheath: INTERBALL-1 and CLUSTER data

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Abstract

The properties of small-scale ion flux and magnetic field fluctuations in the regions of undisturbed solar wind, foreshock and magnetosheath have been investigated. The systematic measurements of these parameters with very high time resolution, which were obtained onboard INTERBALL-1 spacecraft during 1996–2000, make it possible to examine their variations in a broad range of timescales (1–1800 s). The results from similar analysis of CLUSTER data are then compared with those from INTERBALL-1 data. The magnetic field variations from these two different satellites data are consistent not only in quality but also in quantity. Statistical results show that the level of the relative variations of parameters in magnetosheath and foreshock is about 3 times larger than those in undisturbed solar wind. Very intensive fluctuations in the magnetosheath are observed even under the "quiet" conditions of upstream solar wind. Properties of the small-scale fluctuations in the magnetosheath are strongly controlled by the angle Θ_{Bn} between the interplanetary magnetic field vector and the bow shock normal, i.e. the level of fluctuations grows while the angle Θ_{Bn} decreases. Wave properties of the plasma and magnetic field fluctuations are also very different in undisturbed solar wind, foreshock, quasi-parallel and quasi-perpendicular magnetosheath.

Keywords: Magnetosheath; Solar wind; Interplanetary magnetic field; Foreshock; Turbulence

1. Introduction

Intensive fluctuations of plasma and magnetic field can be considered as the common feature of the magnetosheath and foreshock. The fluctuations in these regions are much more intensive than those in undisturbed solar wind, and are often nonlinear with amplitudes of more than 10% (Zastenker et al., 1999a, b; Nemecek et al., 2001, 2002). Preliminary investigations on some properties of the small-scale plasma turbulence in solar wind, foreshock and magnetosheath regions have been conducted (Shevyrev et al., 2003; Shevyrev and Zastenker, 2005). In the previous papers, we have discussed the general properties of small-scale plasma and magnetic field fluctuations in the different regions, and have also gotten their statistical distributions under different solar wind conditions. Statistical study has showed that the orientation of the interplanetary magnetic field with respect to the bow shock normal is a key parameter which strongly affects the properties of the ion flux, the magnetic field fluctuations, and their distributions inside the magnetosheath.

In this paper, we continue the statistical investigation of the properties of small-scale ion flux and magnetic field variations in regions of undisturbed solar wind, foreshock, quasi-parallel and quasi-perpendicular magnetosheath. The number of ion flux data used for this study was substantially increased and the results of statistical analysis of the magnetic field measurements onboard INTERBALL-1 are added as well, therefore the results from this study will be more reliable. On this large statistics the method of ion foreshock selection from undisturbed solar wind is checked up. The characteristics of plasma and magnetic field fluctuations on different timescales are also

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investigated. We also compare the results from INTERBALL-1 data analysis with those from statistical analysis of CLUSTER magnetic field measurements.

2. Observations

The study is based on the data obtained by the plasma and magnetic field instruments onboard INTERBALL-1 spacecraft during the period from January to October 1995–2000. The spacecraft crossed bow shock and magnetopause twice in each circuit of the Earth in 4 days. The continuous measurements of ion flux (Safrankova et al., 1997) and magnetic field (Nozdrachev et al., 1998) with high time resolution (up to 1/16 s) make it possible to investigate the properties of plasma and magnetic field fluctuations in regions of undisturbed solar wind (SW), foreshock (FSH) and magnetosheath (MSH) in a wide range of timescales. The simultaneous operation of INTERBALL-1 together with a fleet of other spacecraft such as IMP 8, GEOTAIL, WIND and ACE provides a good opportunity to investigate the influence of various processes in the undisturbed solar wind on fluctuations in foreshock and magnetosheath, and reveal their relationship as well. The magnetic field, ion density and ion velocity measurements from WIND and ACE spacecraft are used to monitor the undisturbed solar wind. Using these sets of data, we could estimate the location and shape of magnetopause and bow shock (Spreiter et al., 1966; Shue et al., 1997), and then calculate the orientation of interplanetary magnetic field with respect to the bow shock normal (angle Θ_{Bn}). The detailed description of the data selection and processing could be found in our previous work (Shevyrev and Zastenker, 2005).

3. Small-scale fluctuations in solar wind and foreshock: INTERBALL-1 data

Using the ion flux data obtained by VDP device, we can determine the crossing time of the bow shock with an accuracy about 1 min. Therefore, we can select the INTERBALL-1 solar wind observations which include both undisturbed solar wind and foreshock observations from the whole data. The ion foreshock region is typically observed in the upstream side of the quasi-parallel bow shock (with $\Theta_{Bn}<45°$), which is characterized by enhanced ULF fluctuations. These fluctuations are due to the interaction of solar wind plasma flow with the ions reflected at the bow shock (Greenstadt, 1976). As a result, fast magnetosonic waves are generated with an in-phase relationship between ion flux (F) fluctuations and magnetic field magnitude (B) fluctuations. High positive correlation $r(F/B)$ between them is always observed in the foreshock region, and the typical value is generally larger than 0.7 (see Zastenker et al., 1999a). In the undisturbed solar wind region, these parameters are generally negatively correlated or not correlated at all (except fast shocks). So such a correlation coefficient can serve as an effective indicator of whether ion foreshock is observed or not.

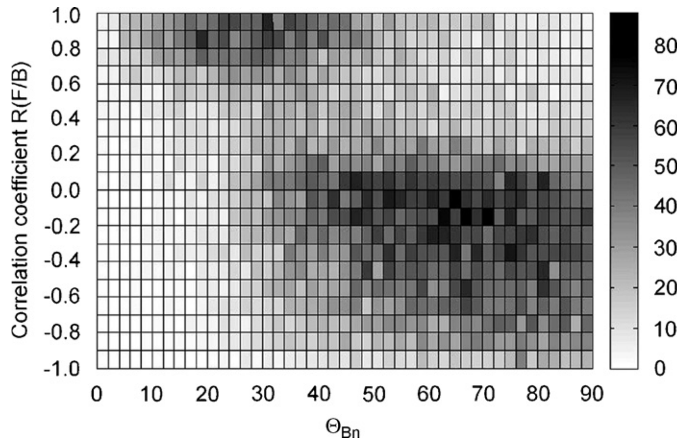

Fig. 1. Distribution of correlation coefficients $r(F/B)$ versus Θ_{Bn} for the whole observations in solar wind (including foreshock).

In this work the INTERBALL-1 observations in the upstream side of the bow shock during 02.1998–09.1999 with time resolution of 1 s are considered. The data include about 2000 h of measurements in solar wind (including foreshock). To separate observations of the foreshock from undisturbed solar wind, the angle Θ_{Bn} and correlation coefficient $r(F/B)$ of the ion flux and magnetic field magnitude variations are calculated from the original data in 5-min intervals. The distribution of correlation coefficients $r(F/B)$ versus Θ_{Bn} is shown in Fig. 1. One can see that it is easy to separate all the points into two distinctive groups:

- Those with zero or negative correlation and large Θ_{Bn}.
- Those with high positive correlation and small Θ_{Bn}.

The first group corresponds to undisturbed solar wind, while the second group corresponds to ion foreshock. As the method used to calculate Θ_{Bn} is not precise enough, only the INTERBALL-1 data with $\Theta_{Bn}>40°$ and correlation $r(F/B)<0.2$ are considered to be obtained in undisturbed solar wind. And only the data with $\Theta_{Bn}<45°$ and correlation $r(F/B)>0.5$ are used for the foreshock analysis. These restrictions on Θ_{Bn} and $r(F/B)$ parameters should not affect the statistical properties of undisturbed solar wind and foreshock fluctuations, because the data are not restricted in the amplitudes of fluctuations, locations of the spacecraft with respect to bow shock (the further the spacecraft is located away from the bow shock, the weaker the foreshock fluctuations are), or any other waves properties.

We use the value of the relative standard deviation RSD, calculated as the ratio of standard deviation to the average value of parameter in the particular time interval, as the measure of intensity of observed ion flux and magnetic field fluctuations. In this paper, we analyze the value of the relevant parameter in a 5-min long interval to investigate