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Magnetic Field Turbulence Spectra Observed By The Wind Spacecraft

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Abstract. We are presenting a new Wind MFI high time resolution data set covering 1994–2012. The time resolution of the data, normally 92 ms and occasionally 46 and 184 ms, obtained as onboard averages of the 22.7 ms measurements, allows investigation of both the inertial and dissipation ranges of the magnetic field turbulence. Using this data set we have analyzed the magnetic field turbulence spectra of more than 100,000 hourly solar wind intervals and computed the inertial and dissipation range spectral indices. Our initial results indicate that the spectral indices in the solar wind are distributed as -1.67 ± 0.22 in the inertial range and as -2.76 ± 0.72 in the dissipation range. There is a slight negative correlation between the indices and a region of overlapping inertial and dissipation range indices, where the spectral break may completely disappear.

Keywords: Solar Wind, Interplanetary Magnetic Field, Turbulence.
PACS: 96.50.Bh, 94.05.Lk

INTRODUCTION

The measurements of the magnetic field by the fluxgate magnetometers are generally limited to the frequencies up to a few tens of Hz. This range, however, is sufficient to investigate both the inertial and dissipation ranges of the magnetic field turbulence at 1 AU. The analyses of the inertial and dissipation range spectral indices have been previously done using data sets ranging from several spectra to several hundreds of spectra [e.g., 1, 2, 3]. For example, Smith et al. [2] analyzed about 800 spectra and found that the inertial range spectral indices are distributed within the range of -3/2 to -5/3, while in the dissipation range they are distributed in the range of -1 to -4. All observations also agree that the mean of the inertial range spectral index distribution is very close to the -5/3 spectral index of the Kolmogorov spectrum [4].

We are presenting a new Wind MFI high time resolution data set covering 1994-2012. Using this data set we have analyzed more than 100,000 hourly solar wind spectra and computed the inertial and dissipation range spectral indices. Here we are presenting initial results of the spectral index distributions. The same Wind MFI data have been used in a number of previous studies [e.g., 1].

WIND MFI HIGH TIME RESOLUTION DATA SET

The Magnetic Field Investigation (MFI) instrument [5], a boom mounted dual triaxial fluxgate magnetometer, onboard the Wind spacecraft provides magnetic field data with 92 ms and occasionally 46 and 184 ms resolution computed as onboard averages of the 22.7 ms measurements. The time resolution depends on the instrument operational mode and the spacecraft distance from the Earth. Figure 1 shows the time resolution of the data for years 1994–2012 indicating that the time resolution is 92 ms for about 90%, 46 ms for about 8%, and 184 ms for about 2% of the time.

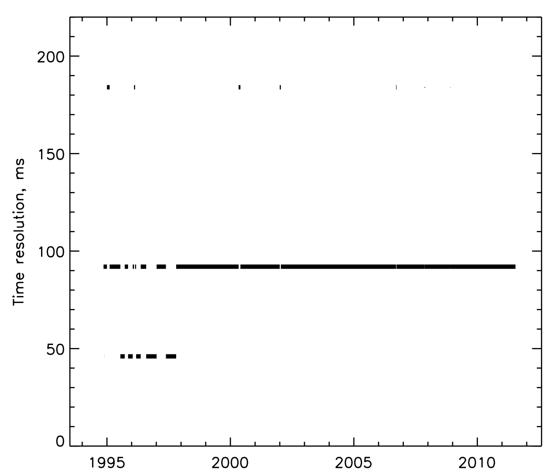

FIGURE 1. Time resolution of the Wind MFI data: 92 ms for about 90%, 46 ms for about 8%, and 184 ms for about 2% of the time.

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The new MFI high time resolution data set is publically available though the Coordinated Data Analysis Web (CDAWeb) [6]. The data set (wi_h2_mfi) is in the form of daily cdf files and it contains magnetic field vector measurements in Geocentric Solar Ecliptic (GSE) and Geocentric Solar Magnetospheric (GSM) coordinates.

Though we tried to provide as clean data as possible, the data users should be aware of the following caveats. Occasionally, the spacecraft generated stray magnetic field may change faster than the calibration procedure time resolution. This may result in the spacecraft spin tone (about 0.33 Hz) and, to a much smaller extend, second harmonic visible in the X and Y components defining the spacecraft spin plane (the spin plane approximately corresponds to the XY plane in GSE coordinates). To demonstrate this, Fig. 2 shows an example from 2 January 1995 of about two minute long magnetic field measurements in GSE coordinated indicating a sudden appearance of the spin tone in the X and Y GSE components. Such intervals are relatively rare; nevertheless the data users should be aware of this.

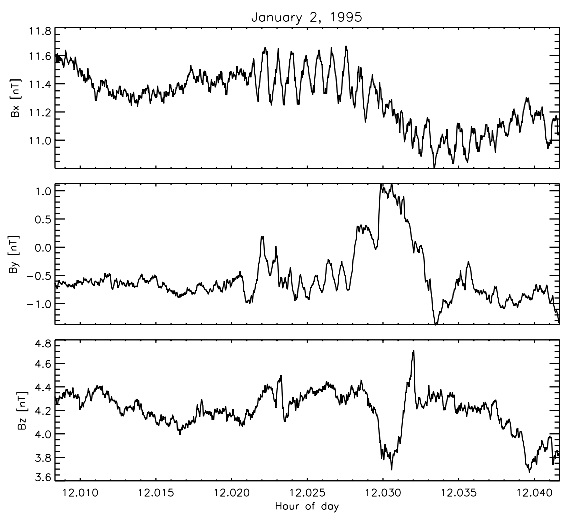

FIGURE 2. Example of a sudden appearance of the spin tone noise in the X and Y GSE components of the Wind MFI data due to fast change in the spacecraft stray magnetic field.

The spacecraft generated stray magnetic field may have discontinuous changes with the spacecraft spin period due, for example, to switching between the solar arrays or turning the battery on and off. This results in the spin tone harmonics visible in every component. Figure 3 shows an example of the Fast Fourier Transform (FFT) power spectral density (PSD) of the Bx component in GSE coordinates computed on a daylong time interval before the final data processing is done. The spin tone harmonics and the aliasing of the spin tone harmonics (elevated PSD at high frequencies) are clearly visible in the spectrum. After the final processing (Fig. 4), the spin tone harmonics are generally eliminated and only occasionally some harmonics can be visible in the final data. On the other hand, the aliasing observed for the spin tone harmonics (Fig. 3) must also be present for the true magnetic field measurements. Thus, the data users must be cautious when interpreting the high-frequency end of the spectrum.

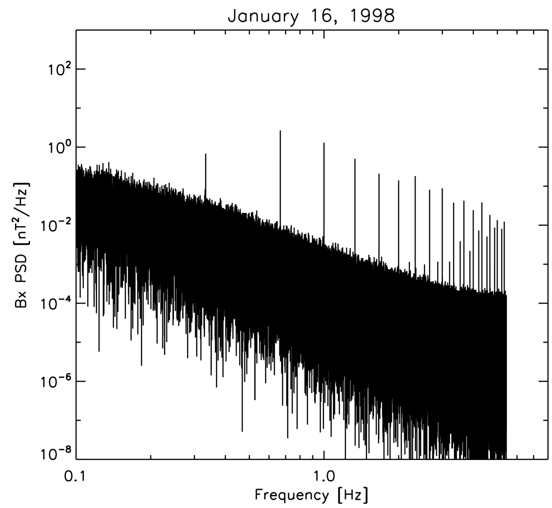

FIGURE 3. Example of FFT PSD of the Bx component in GSE coordinates showing the spin tone harmonics and their aliasing.

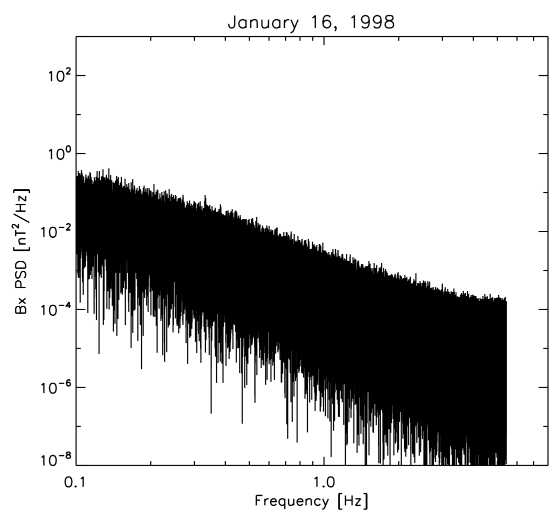

FIGURE 4. FFT PSD of the same data as in Fig. 3, but after the final processing, showing elimination of the spin tone harmonics.

SPECTRUM ANALYSIS TECHNIQUE

We used the Wind MFI high time resolution data set for years 1994–2012 to analyze the magnetic field spectra observed in the solar wind. The solar wind intervals were selected based on the Wind spacecraft position only; no other constraints were imposed on the data. We computed the PSD of each of the three magnetic field components in GSE coordinates using the Morlet wavelet transform in the frequency range of about 0.006 to 5.5 Hz, which was selected to include both the inertial and dissipation ranges. The highest frequency in the spectrum (5.5 Hz) corresponds to about 2 s interval of significant periods of Morlet wavelet, while the lowest frequency (0.006 Hz) corresponds to about 32 minute interval. The component PSDs were then added to obtain the total PSD. The spectra were computed every 30 s, giving 2880 spectra per day. The 30 s interval between the spectra was selected to provide good time resolution at high frequencies (as indicated above, for the highest frequency of 5.5 Hz the significant wavelet interval is only about 2 s). As an example, Figure 5 shows a daylong spectrogram (5 January 1995) composed of the spectra separated by 30 s intervals.

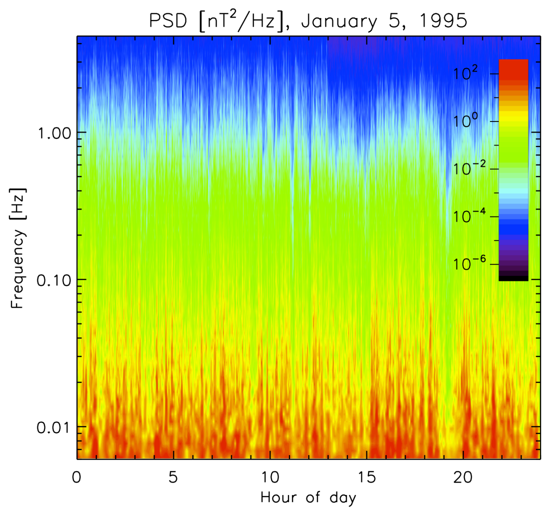

FIGURE 5. Example of a daylong spectrogram composed of the Morlet wavelet transform spectra separated by 30 s intervals.

For the consequent analysis, the spectra were averaged into hourly spectra (all spectra centered on times inside the hour were averaged), and the hourly spectra were used for the computation of the inertial and dissipation range spectral slopes. To demonstrate the general form of the magnetic field spectrum, Figure 6 shows an example of the 5 January 1995 spectrum computed as the average of all spectra during that day. The example spectrum shows that in the inertial range (below about 0.2 Hz) the spectral slope is well approximated by the -5/3 exponent, while the slope is significantly steeper in the dissipation range (above about 0.6 Hz). At the frequencies close to the Nyquist frequency the spectrum becomes flatter, in part probably due to the aliasing explained above. We would like to point out that though this example shows daylong averaged spectrum for better visibility, for the analysis we use hourly spectra. We compute the inertial range spectral slope in the frequency range of 0.02–0.2 Hz. For the dissipation range, we compute two slopes in the 0.38–1 Hz and 0.8–2.2 Hz ranges and select the steepest slope.

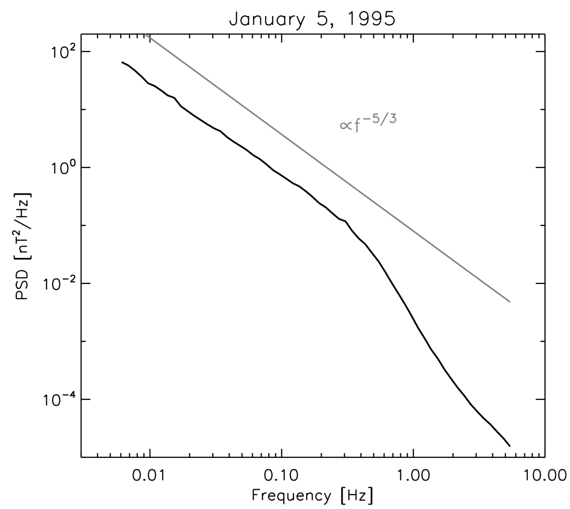

FIGURE 6. The 5 January 1995 spectrum computed as the average of all spectra during that day.

RESULTS OF THE SPECTRUM ANALYSIS

Using the above described technique, we obtained more than 100,000 hourly magnetic field spectra in the solar wind and the corresponding inertial and dissipation range spectral indices. Figure 7 shows the probability distributions of the spectral indices in both ranges. The spectral indices in the inertial range are distributed as -1.67 ± 0.22 (mean ± standard deviation), with the mean almost exactly equal to -5/3. In the dissipation range the spectral indices are significantly steeper and their distribution is much wider (-2.76 ± 0.72).

Figure 8 shows the joint probability distribution of the inertial and dissipation range indices. As can be seen from the figure, there is a slight negative correlation between the indices (Pearson's correlation coefficient r = -0.25). Figures 7 and 8 also show that there is a region of overlapping inertial and dissipation range indices, where the spectral break may completely disappear.

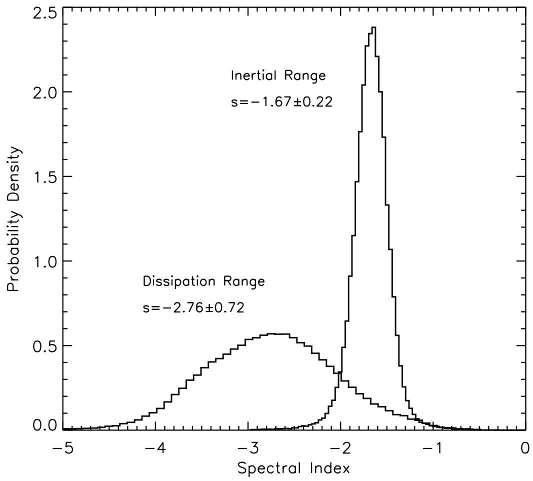

FIGURE 7. Probability distributions of the inertial and dissipation range spectral indices based on more than 100,000 spectra.

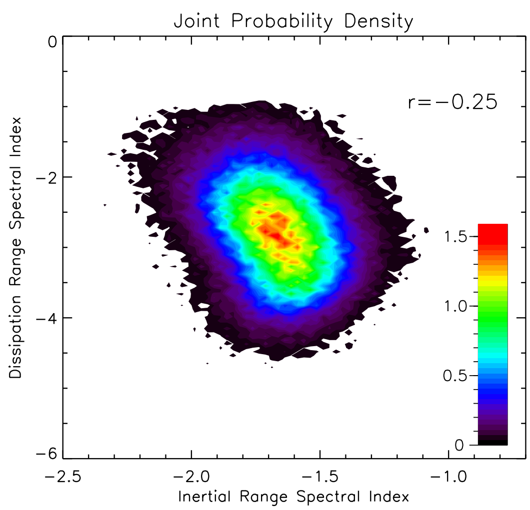

FIGURE 8. Joint probability distribution of the inertial and dissipation range indices showing slight negative correlation between the indices.

CONCLUSIONS

We have presented a new Wind MFI high time resolution data set covering 1994–2012. The time resolution of the data is normally 92 ms and occasionally 46 and 184 ms, obtained as onboard averages of the 22.7 ms measurements. The data set is publically available though the Coordinated Data Analysis Web (CDAWeb) [6]. We have also discussed the main caveats that the data users should be aware of.

Using this data set we have analyzed the magnetic field turbulence spectra of more than 100,000 hourly solar wind intervals. Our initial results indicate that the spectral indices in the solar wind are distributed as -1.67 ± 0.22 in the inertial range and as -2.76 ± 0.72 in the dissipation range. We have also found a slight negative correlation between the indices and a region of overlapping inertial and dissipation range indices, where the spectral break may completely disappear. A more complete study of spectral indices as a function of solar wind conditions will be presented in a separate paper.

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