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Time changes of solar activity, interplanetary magnetic field and solar wind velocity at the Earth's orbit in different spectral bands

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Abstract

We present the results of our analysis of the spectra of the interplanetary magnetic field (IMF) and the solar wind velocity (V) calculated on the basis of measurements near the Earth's orbit for the period 1964–1997, and of the sunspot number W. The major aim is to search for similar features in various frequency bands, with an emphasis on the $T \sim 11$ yr period of solar (sunspot) cycle and its harmonics, and on so-called "intermittent" oscillations at periods $T \sim 1.3$ yr and $T \sim 150$ d. We also extract trends from the data to determine long-period changes of IMF and V. A method of non-linear spectral analysis, which we term "the method of global minimum" (MGM) is used. MGM allows self-consistent identification of trends from data and nonstationary sinusoids and estimation of statistical significance of spectral components. The IMF and W spectra both show the main solar cycle at $T = 10.8$ yr. In addition, the spectrum of the IMF includes (at 99.8% confidence levels) harmonics of this cycle with periods of 151.3 and 136.5 d. We also detect nonstationary sinusoids at $T = 1.3$ yr in the spectra of IMF and of V and describe their parameters. The detailed description of the 1.3-yr oscillations in the solar wind is of particular interest in that the oscillations are likely to be connected to variations in the rotation rate with the same period near the base of convection zone of the Sun discovered in SOHO data. The 1.3-yr oscillations are not present in the W spectra. Instead, we find oscillations at $T = 1.014$ and 0.950 yr and suggest an explanation of their presence. Relation between the variations in the spectra of W and V is not as evident as between W and the IMF, however, it exists. In particular, harmonics of the 10.8-yr solar cycle (e.g., sinusoid at $T = 261.7$ d) are present in the spectrum of V. Components in the spectra described by high-amplitude sinusoids with $T = 198 \pm 5$ yr in the IMF spectrum and with $T = 54 \pm 4$ yr in the V spectrum make contributions to the long-term trends in these parameters. The trend of V demonstrates a 55% increase in the solar wind velocity for the period 1964–1997. The IMF trend shows a 45% increase of the IMF magnitude for the same time interval; extrapolation of this temporal variation to the past leads to a doubling of the IMF value during the last 100 yr.

Keywords: Sunspots; Interplanetary magnetic fields; Solar wind velocity; Spectral analysis

1. Introduction

The physical parameters of the Sun and the solar wind are known to vary on different time scales. A 1.3-yr periodicity was detected in data of the solar wind velocity V on board Voyager-2 and

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IMP-8 (Richardson et al., 1994). Szabo et al. (1995) found variations with the same period in the interplanetary magnetic field (IMF). We extracted, for the first time, nonstationary oscillations at period $T = 1.3$ yr in the magnitude of the IMF and the solar wind velocity V measured at a distance of 1 AU in the period 1964–1997 and evaluated all the parameters of these oscillations including the mean amplitudes, statistical significance for the studied time interval, periods with their error bars, temporal changes of the oscillations, and temporal changes of amplitudes and of phases (Kuznetsova et al., 2000; Kuznetsova and Tsirulnik, 2002). Oscillations with period of 1.3 yr are of interest due to reported variations of the rate of solar rotation at the base of the convection zone with the same period (Howe et al., 2000). Rieger et al. (1984) discovered period $T \sim 150$ d in the appearance of hard solar flares that was later found by a number of authors in various solar activity indices. The studies applied various spectral analysis methods to the different data sets and showed that the periodicity in question sometimes disappears and may reappear, with the period varying over a wide range. A number of hypotheses have been suggested to explain this behavior. According to one group of hypotheses, these variations are strictly periodic in nature. However, distortions and false lines in the spectra appear because the long-period component is not extracted accurately enough (Wolff, 1992). A second group of hypotheses are based on the assumption that the oscillations discussed here are nonstationary in nature (Lean and Brueckner, 1989) and therefore require methods of spectral analysis that are capable of identifying nonstationary harmonics. Thus to solve the problem of the discussed transient oscillations it is in fact necessary to solve two distinct problems: accurate mathematical description both of trends and of nonstationary oscillations. Long-term trends in solar wind parameters are of particular interest in itself because they can help to identify cause of growth in geomagnetic activity since the beginning of the 20th century discussed by several authors (e.g., Stamper et al., 1999). The aim of the present paper is to evaluate long-periodic changes in the IMF and in the solar wind velocity by accurate mathematical methods, similarly to compute the spectrum of the Wolf number W and to compare the components of the solar and solar wind oscillations in various frequency bands.

2. Method of analysis and data used

To solve the tasks formulated above, we use spectral ‘‘method of global minimum’’ (MGM) that we have developed. Due to lack of space, we only outline here the potential of the method and focus on the specific features that are important for the analysis discussed in this paper. MGM provides a high frequency resolution and offers a number of advantages that include self-consistent identification of data trends, nonstationary sinusoids (i.e., sinusoids whose amplitudes and phases depend on time), and of sinusoids with periods longer than the length of the input data sets (providing a mathematical description of long-term trends). MGM does not require the input series to be continuous or data gaps to be filled by arbitrary values. Traditional methods of spectral analysis usually need continuous input series, requiring such gap filling, but this procedure can lead to uncontrollable errors in the computation of the spectrum. MGM also allows errors to be estimated for the periods of all spectral components, including the nonstationary. A description of the method by which the statistical significance of spectral components is estimated can be found in Tsirulnik et al. (1997b). A complete description of MGM can be found in Kuznetsova et al. (1995) and Tsirulnik et al. (1997a). We used series of 27-day averaged $|B|$ values of the IMF based on hourly mean values measured by various spacecrafts in the solar wind near the plane of the ecliptic at a distance of 1 AU during the time period 1964–1997 obtained from the OMNI database (http://www.omni.web.gsfc.nasa.gov/). To perform a more thorough analysis of solar activity and solar wind parameters in various period ranges, we computed three Wolf number spectra. To compute a spectrum emphasizing long-period components (spectrum 1), we used annual averaged W values for the period 1700–2004. We calculated a second W spectrum based on the 55-d mean W values for the time interval (1964–1997) coinciding with the interval of IMF measurements used by us in (Kuznetsova et al., 2000) (spectrum 2). Statistically significant short period spectral lines proved to be poorly represented in this spectrum, and the accuracy of the period determination was much lower than in the spectrum of the IMF. We therefore derived a third spectrum (spectrum 3) from a data set based on 10-day-averaged W numbers during the last solar activity cycle (1996–2004).This spectrum has a well-represented