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Comparison of measured and calculated magnetic fields along the Ulysses orbit

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Abstract

The existence of close relations between the temperature, density and velocity of the solar plasma and the heliospheric magnetic field (HMF) was shown along the space probe Ulysses orbit. A simple mathematical formula describing a relation between the HMF and the solar plasma temperature and density was introduced and the expected values of the HMF were calculated using daily and hourly Ulysses data. Correlation coefficients and regression equation between the values of the measured and calculated magnetic fields have been defined. An origin of the peaks in the magnetic field which are observed in the heliospheric sector zone near the corotating interaction regions is discussed as well as the specific role of plasma density and temperature in the formation of magnetic peaks.

Keywords: Heliospheric magnetic field; Solar wind; Plasma density; Plasma temperature

1. Introduction

In this work we have considered a possibility to express the magnetic field in the heliosphere by means of the local parameters of heliospheric plasma – temperature and density. The proposed relationship between the magnetic field and the plasma parameters is expressed in the following form (Svirzhevsky et al., 2014):

$$B_{calc} = Kn\sqrt{T} + B_0, \quad (1)$$

where n is the proton number density and T is the temperature of the heliospheric plasma, K and B_0 are parameters, which were defined from comparison of measured and calculated magnetic fields along the Ulysses orbit. The measured magnetic fields, in dependence on the distance r to the Sun, can be described by two sets of K and B_0 parameters, namely, at $r = 1$–2.5 AU $K = 0.003$ and $B_0 = 0.6$ nT, and at $r = 2.5$–5.4 AU $K = 0.006$ and $B_0 = 0.2$ nT.

The derivation of Eq. (1) is given in the Appendix. The derivation is based on the assumption that the thermal movement of electrons with the average velocity exceeding the average thermal velocity of protons violates the neutrality of the plasma and causes the formation of the negative volume charge and the electric field in the heliospheric plasma. As a result of that the proton current occurs in the plasma which tends to restore its neutrality, as well as creates the magnetic field in it. The dependence of the magnetic field on the plasma density and temperature was obtained in a preliminary model which does not take into account some feature of the heliospheric magnetic field, in particular, its Parker spiral form.

We also intend to discuss below the relationship between corotating interaction regions (CIRs) and peaks in the magnetic field which are observed in the heliospheric sector zones. The interactions between fast solar wind from coronal holes and slow solar wind from the belt of coronal

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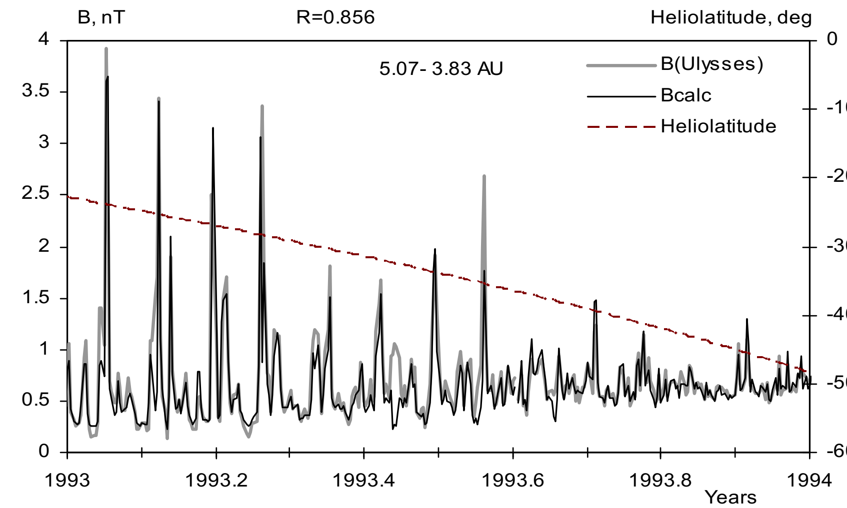

Fig. 1. Comparison of the measured magnetic field B_{Ulys} (grey) and calculated magnetic field B_{calc} (black) in the presence of fast solar wind streams from a coronal hole. The heliolatitude of the spacecraft is shown by a dashed line. Ulysses' distances from the Sun at the beginning and end of the examined time interval and the correlation coefficient R between two sets are also shown.

streamers form regions of compressed plasma with enhanced density and temperature.

These interactions, which lead to the formation of the CIRs, are considered as one of the primary processes shaping the structure of the interplanetary medium (Riley et al., 1996). Usually the CIRs are well developed at the distance of 1 AU (Hundhausen, 1973; Broiles et al., 2012). In some cases, observed at 1 AU CIRs may be identified as individual CIRs or/and as merged ones at a distance of about 5 AU (Broiles et al., 2013; Jian et al., 2011). At distances of 5–15 AU single CIRs merge into the corotating merged interaction region zones (CMIR zones), whose existence was confirmed by Voyager 2 observations (Burlaga et al., 2003).

Many of the observed onboard the Ulysses spacecraft CIR characteristics were identified and examined in details in Gosling et al. (1993, 1995), Bame et al. (1993), Riley et al. (1996), Gosling and Pizzo (1999), Broiles et al. (2012). Various theoretical approaches to the modeling of corotating interaction regions were considered (Pizzo and Gosling, 1994; Lee, 2000; Odstrcil, 2003; Jian et al., 2011). We want to point out some features of CIRs, which can be set using the magnetic field strength, plasma density and temperature values. In particular, it will be shown that the forward and reverse shocks, bounding the CIRs, coincide with the forward and rear fronts of magnetic peaks. We can also note the difference between the magnetic peaks occurring in the interactions of fast and slow solar winds and created by shocks from coronal mass ejections. Different role of plasma density and temperature in the formation of magnetic peaks will also be shown.

2. Measured and calculated magnetic fields along the Ulysses orbit

Ulysses was the first space probe which made observations of the magnetic fields and heliospheric plasma along

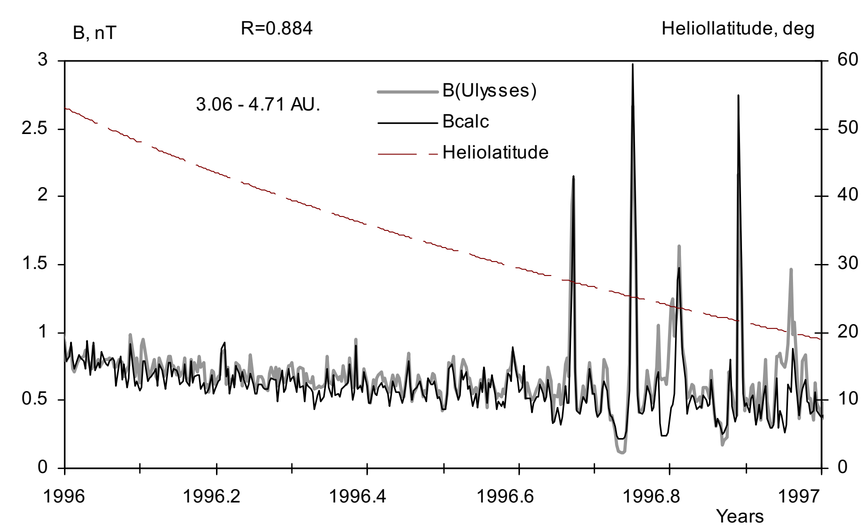

Fig. 2. Comparison of the measured B_{Ulys} and calculated B_{calc} magnetic fields during the 1996 solar activity minimum. Notations in the figure are the same, as in Fig. 1. Adopted from Svirzhevsky et al. (2014).