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Possible north–south asymmetry related to the mean B_z of interplanetary coronal mass ejections

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Abstract

The annual/semiannual behaviour of monthly mean of B_z component of interplanetary magnetic field (IMF) separated by positive and negative B_y components were studied. The study was confined to the ascending phases of the four recent sunspot cycles when interplanetary counterparts of coronal mass ejections (ICMEs) dominate among the sources of geoeffectiveness. Definite differences were found between the annual variations of the monthly mean B_z values of geoeffective ($Kp > 3$) ICMEs. When the solar dipole is parallel to the terrestrial one, the Russell–McPherron effect is detectable in the opposite annual variations of the mean GSM B_z as is expected. However, when the solar and terrestrial dipoles are antiparallel, the mean B_z does not exhibit the Russell–McPherron effect in the GSM (Geocentric Solar Magnetospheric) system because there are strong inverse annual variations in the GSE (Geocentric Solar Ecliptic) system. This kind of smaller minima of the curves of mean GSE B_z during the antiparallel years indicate that the ICMEs may have much stronger negative GSE B_z values during these years. The southern excess may come from the large-scale north–south asymmetries of the heliospheric magnetic field or from the characteristics of magnetic clouds (direction of the axial field or polarities of the leading and trailing fields).
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1. Introduction

The primary causes of geomagnetic storms are solar wind structures with intense southward interplanetary magnetic fields which interconnect with the Earth's magnetic field and allow solar wind energy transport into the Earth's magnetosphere. There are two types of interplanetary structures which can cause geomagnetic storms: the coronal mass ejections (CMEs) and the high-speed wind streams (Gonzalez et al., 1999). The ICMEs are interplanetary structures formed by plasma and magnetic fields that are expelled from the Sun during CMEs (e.g. Webb, 2002). The decisive factors in their geoeffectiveness are the intensity and the duration of the southward component of the IMF (B_s), i.e. the negative B_z component in the GSM system. The intense B_s may be a projection of the internal field of CME ejecta or may be formed in the shock and/or sheath region of solar wind ahead of the ejecta caused by the interaction of CME with the surrounding interplanetary field. The geomagnetic *Kp* and *Dst* indices respond differently to disturbances caused by different drivers: shock and sheath, shock and CME, CME ejecta alone, or streams with no shock nor ejecta associations (Huttunen et al., 2002) showing that the intensity of a storm and its variation in time depends on the structure reaching the Earth. The magnetic clouds are especially geoeffective ICMEs. Their most impressive signature is the smooth rotation of the magnetic field direction over a large angle, which results in a substantial and sustained B_s in a part of its transit time. Different levels of geomagnetic activities have different occurrence percentages due to different cloud field: sheath, the leading, the axial, the trailing field, and their combined effects (Zhang et al., 2004).

It is well known that the large-scale structure of the heliospheric magnetic field mainly depends on the direction of the solar main dipole, i.e. on the dipole cycle. When the

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solar north pole is positive, the direction of IMF is away from the Sun above the heliospheric current sheet, and it is toward the Sun under that. If the solar dipole reverses at about the sunspot maximum, the away and toward polarities of IMF are connected to the other poles. The high-speed wind streams coming from the polar coronal holes are obviously governed by the dipole cycle, but the orientation of the main dipole also has a dominant effect on the ICMEs (Crooker, 2000). The north–south asymmetry of dipole cycle may result in large-scale and small-scale asymmetries of the interplanetary magnetic field. At present the most known asymmetry is that the dominant direction of the leading field of magnetic clouds follows that of the large-scale dipole (Bothmer and Rust, 1997; Bothmer and Schwenn, 1998; Mulligan et al., 1998, 2000). Li and Luhmann (2004) found that the predominance of the magnetic cloud polarity reverses within the later part of the declining phase near the solar minimum, showing that both dipole cycle and the active region polarity cycle may affect the magnetic cloud polarity. Our aim is to search for other asymmetries depending on the dipole cycle related to ICMEs extending our previous work (Baranyi and Ludmány, 2003a,b).

2. Selection of ICMEs

Recently several statistical investigations of ICMEs have become available thanks to the new group of satellites: SOHO, WIND, ACE (e.g. Cane and Richardson, 2003; Lynch et al., 2003; Zhang et al., 2004). However, on the longer time-scale the number of available data of identified ICMEs or magnetic clouds is quite low. For example, Mulligan et al. (1998) identified 56 magnetic clouds during 1979–1988 using PVO data. In comparison, Zhang et al. (2004) used a list of 104 clouds observed by WIND and ACE between 1998 and 2001. It is plausible to assume that the occurrence rate of magnetic clouds did not change to such a large extent but the observational technique was improved during the last decade. The case may be similar in the case of non-cloud ICMEs.

By studying the average statistical characteristics of ICMEs during the last four solar cycles one can use another method instead of the identification of ICMEs. The components of the interplanetary magnetic fields gathered by several spacecraft since 1963, and Kp index data are available in the Near-Earth Heliospheric data set (OMNI). Richardson et al. (2001) found that the most probable value of Kp associated with CMEs or corotating fast wind streams from coronal holes is about 3 while the slow wind usually causes geomagnetically quiet hours ($Kp \sim 1$–2). If those hourly IMF data are selected when Kp is larger than 3, then the largest part of the effects caused by ICMEs or fast wind streams can be studied. In order to study the characteristics of ICMEs, the time intervals of ascending phases of sunspot cycle can be used when the effects of ICMEs dominate over the effects of fast wind (Richardson et al., 2001). Thus, we can use the three-hourly Kp index to separate the geomagnetically active hours associated mainly with ICMEs. This method has advantages and disadvantages in comparison with the identification technique. Its advantages are that a large statistical sample can be gathered including the small and hardly identifiable ICMEs. Its disadvantages are that the separation of ICMEs and fast wind streams is not perfect, and the different regions of ICMEs can not be studied separately. However, the largest problem is that the selection of ICMEs cannot be independent from the Geocentric Solar Magnetospheric (GSM) system and the Russell–McPherron effect (R–M effect) if one wants to compare the ICMEs independently from their terrestrial effects.

The Russell–McPherron effect is caused by the transformation of the magnetic field vector from the GSE system into the GSM system (Russell and McPherron, 1973). This transformation modifies the value and/or direction of the B_z component depending on the direction of the B_y component. If the magnetic vector lies in the ecliptic plane, the GSM B_z depends only on the GSE B_y. In the first half of the year negative GSM B_z is projected by negative GSE B_y, and positive GSM B_z is projected by positive GSE B_y. In the second half of the year the role of the GSE B_y components reverses. The annual variation of the GSM B_z projected by the positive GSE B_y (away polarity) is sinusoidal reaching negative extreme after the September equinox. The sinusoidal variation of the GSM B_z projected by negative GSE B_y (toward polarity) takes its negative extreme after the March equinox. Thus, the semiannual variation consists of two opposite annual variations according to the positive and negative B_y. This effect makes the interpretation difficult when the results derived in the GSM system are transformed back to the GSE system.

3. Data sets and results

In this study we investigated the annual variations of monthly means of B_z in the GSM and GSE systems depending on the direction of B_y component. The dipole cycle is called "parallel (P)" if the solar and terrestrial dipole fields are parallel, and it is called "antiparallel (A)" if they have opposite directions. In the OMNI era there are four ascending phases defined by the years after sunspot minimum and before the polar reversal as follows: 1966–1968 (P years); 1977–1980 (A years); 1987–1989 (P years); 1997–1999 (A years). For all these intervals we selected the hourly data when $Kp > 3$, and separated them into two subsets for the positive and negative directions of GSM B_y. In this way, we can investigate the actual manifestation of the R–M effect. Although the geometrical transformation related to this effect causes always the same projectional effect, the two annual variations may not be perceived in the same form in all the cases. If the magnetic vector has a GSE B_z component, the GSM B_z depends on both the GSE B_y and the B_z. The absolute value of the GSM B_z may be larger or smaller than that of the GSE B_z and their sign may be the same or opposite depending

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