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 ($K_p > 3$) 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 ($B_z$), i.e. the negative $B_z$ component in the GSM system. The intense $B_z$ 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 $K_p$ 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 $B_z$ 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...
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. During the last four solar cycles one can use another method instead of the identification of ICMEs. ICMEs extending our previous work (Baranyi and Ludmány, 2003a,b).
on the actual geometrical situation. In this way the annual variation of the GSM $B_z$ depends on the directions of the magnetic fields of the incoming plasma streams, and it may reveal some polarity-dependent characteristic features of ICMEs. The small fraction of fast wind streams does not distort the result because their monthly means of $B_z$ are about zero (Baranyi and Ludmány, 2003a).

The first row of Fig. 1 shows the annual variation of the monthly mean GSM $B_z$ by separating the periods of positive and negative GSM $B_z$ in the case of $Kp > 3$. One can see that during P years the two opposite annual variations according to the R–M effect are much more perceivable than during A years. The second row displays the monthly mean GSE $B_z$ values for the same events. (In order to be able to study the mean GSE $B_z$ for the same set of events, we have to leave the selection criteria unchanged. Thus, the data set should remain divided into two subsets according to the sign of GSM $B_z$. In this way, the mean GSM $B_z$ and mean GSE $B_z$ values refer to the same events. If we change the criteria by using the sign of the GSE $B_y$, a small part of the cases gets from its original subset into the other one and vice versa, which confuses the results. However the result does not practically change if we select only those cases when the signs of GSE $B_z$ and GSM $B_z$ are the same (Baranyi and Ludmány, 2003b).) Two definite opposite annual variations of mean values can be seen in the A years but this pattern is weak in P years. In the A years it is remarkable that the means of GSE $B_z$ are much more negative for that direction of $B_z$ which is unfavorable for the R–M effect in the given season. In the A years the minima reach the values around −4 and −5 while in the P years they are around −2 and −3. This pattern hints at a southern excess of GSE $B_z$, which is unfavorable for the R–M effect. However the result does not practically change if we select only those cases when the signs of GSE $B_z$ and GSM $B_z$ are the same.

4. Possible reasons of the found asymmetry

As the R–M effect does not depend on the dipole cycle, we may conclude that the cause of the dipole-cycle-dependent asymmetry of annual variation of mean GSE $B_z$ comes from some kind of north–south asymmetry related to ICMEs. The southern excess of mean GSE $B_z$ during the antiparallel years may come from an already known north–south asymmetry of large-scale or small-scale magnetic fields or may refer to a new type of asymmetry. The following explanations may arise at present:

(1) Mursula and Hiltula (2003) found that the average heliospheric current sheet (HCS) is systematically shifted

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or coned southward during solar minimum times. This implies that the open solar magnetic field has a north–south asymmetry at these times, suggesting that the solar dynamo has an asymmetric component. The behaviour of the HCS is different from the north–south asymmetry of the HCS which is systematically shifted toward the northern magnetic hemisphere. Thus, during negative solar minima the HCS and the streamer belt are both shifted toward the heliographic South. However, during positive solar minima they are oppositely shifted, the HCS southward and the streamer belt northward. At present it cannot be excluded that the asymmetry described in this paper is caused by this type of large-scale asymmetry of the heliosphere.

(2) It is also possible that the asymmetry presented here may be caused by a dipole-cycle-dependent variation in the magnetic configuration of ICMEs. The southern excess of mean GSE $B_z$ in antiparallel years may come from the dominantly southward leading field of magnetic clouds at this time. Zhang et al. (2004) found that different regions of SN, NS, S, and N clouds are differently efficient. Although the geoeffectiveness is not found to be significantly different for SN and NS clouds (Li and Luhmann, 2004; Zhang et al., 2004) but the different mean $B_z$ of the different regions and their different percentages of occurrence may result in slightly different monthly mean $B_z$ values in the antiparallel and parallel years. This question can be decided if the further study planned by Zhang et al. (2004) concerning the statistical differences in $B_z$ strength and longevity observed in the different parts of magnetic clouds will be published. In addition, more samples of magnetic clouds of different time intervals are needed for conclusive statistics.

(3) Zhao and Hoeksema (1998) and Zhao et al. (2001) found that the duration and intensity of the southward IMF within magnetic clouds correlate linearly with the ecliptic latitude of the clouds’ central axial field. If there is a north–south asymmetry in the occurrence of different latitudes, this would mean an existence of a dominant direction of the central axial field. Although they found that the magnetic cloud central axial field directions are almost evenly distributed between $-90$ and $90$ degree ecliptic latitude, this result may not be decisive because of the small data set covering different types of time-intervals. The latest study by Lynch et al. (2003) is based on a much larger data set of 56 clouds observed by the ACE spacecraft between February 1998 and July 2001 during the ascending and maximum phases of the last antiparallel dipole cycle. Their histogram distribution of the model parameter of cylinder axis orientation with respect to the ecliptic shows a dominant southern direction of the axial field. This dominantly southern axial field direction is consistent with the sense of the solar dipole field at this time. If the statistically dominant axial field direction reverses with the polarity reversal, the dominant southern axial field may result in southern excess of mean $B_z$ in the antiparallel years in comparison with the parallel years of the dominant northern axial field. This hint needs further study when a well-observed time-interval of parallel years is available.

5. Conclusion

This work focused on the dipole-cycle-dependent manifestation of the R–M effect in the case of geoeffective ($Kp > 3$) ICMEs. We investigated the annual variation of monthly means of $B_z$ component depending on the GSM $B_z$ according to the R–M effect. In the parallel years the mean GSM $B_z$ values show two opposite annual variations according to the R–M effect but this effect cannot be observed in the annual variations of mean GSM $B_z$ in the antiparallel years. The probable reason of the difference is the stronger inverse annual variation of mean GSE $B_z$ because of the more negative intrinsic $B_z$ component of the plasma clouds in the antiparallel years. The minimum values of mean GSE $B_z$ of unfavorable polarities are systematically smaller with 1–2 nT in the antiparallel years. The more negative mean GSE $B_z$ values hint at a southern excess of GSE $B_z$ in the antiparallel years. This may refer to the dipole-cycle-dependent north–south asymmetry related to ICMEs which may come from the large-scale asymmetry of the heliosphere, or the different percentage of occurrence of different types of ICMEs, or the possible dominant central axial field direction of ICMEs. The interpretation of the results and the exploration of their causes need data of original ICME properties in the GSE system but without these data the selection can only be made in the GSM system (where the $Kp$ is defined) and here the R–M effect modifies the mean $B_z$. Thus, our possibilities to draw conclusions are restricted and the explanation of the results will need another approach in a later study. It is
remarkable, however, that the found trends are consistent in the independent time intervals, which raises interesting questions concerning a possible N–S asymmetry related to ICMEs. These questions are worth studying further by using databases of different solar wind components classified on the basis of their interplanetary characteristics.

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References


