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# Effects of solar polarity reversals on geoeffective plasma streams

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**Abstract.**
The present work focuses on the annual/semiannual behaviour of those parameters which can be considered to be the most relevant factors from the point of view of geoeffectiveness. These are the interplanetary magnetic field (IMF) components, $B_z$ and $B_y$ (in both the Geocentric Solar Magnetospheric (GSM) system and Geocentric Solar Ecliptic (GSE) system), the bulk speed of the plasma, and the number of hours spent by the Earth in domains of either positive or negative GSM $B_y$. In all cases monthly mean values were used. As a criterion of geoeffectiveness we adopted the values $Kp>3$. The consecutive solar dipole cycles were separately studied, and definite differences were found between the annual variations of the mean values. When the solar dipole is opposite to the terrestrial one, the mean $B_z$ does not exhibit the Russell-McPherron effect in the GSM system because there are strong inverse annual variations in the GSE system. However, the Russell-McPherron effect can be detected in the occurrence of the negative and positive GSM $B_y$ values. The case is opposite in those years when the solar and terrestrial dipoles are parallel: the Russell-McPherron effect is detectable in the opposite annual variations of the mean GSM $B_z$ but not in the occurrence of GSM $B_y$ values. The mean bulk speed of geoeffective events also shows a dipole cycle dependence in its average value, and it shows a semiannual character in the parallel years.

## 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, but the solar energy flux density associated with magnetospheric disturbances also depends on the velocity of the wind [*Akasofu*, 1981]. High dynamic pressure also increases geoeffectiveness [*Fenrich and Luhmann*, 1998].

There are two types of interplanetary structures which can cause geomagnetic storms and related atmospheric effects: the coronal mass ejections (CMEs) and the high-speed wind streams [*Gonzalez et al.*, 1999]. The CMEs are interplanetary structures formed by plasma and magnetic fields that are expelled from the Sun often associated with erupting filaments and X-ray long duration events [*Webb*, 2000, 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 region of solar wind ahead of the ejecta caused by the interaction of CME with the surrounding interplanetary field. If a CME is faster than the upstream solar wind, it is driving a shock, and a sheath region of shock-compressed slow wind is formed behind the shock [*Tsurutani et al.*, 1988]. In the sheath region substantial $B_s$ are generated by three distinct mechanisms: shock compression of the IMF where the shock front is inclined to field lines, draping around the CME by mass flow convection, and distortion of the IMF by rarefraction waves trailing the CME [*Odstrcil and Pizzo*, 1999]. The magnetic clouds are especially geoeffective CMEs [*Burlaga et al.*, 1981]. 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. Intense storm can be caused if $B_s$ is higher than ~10nT during more than ~3 hours, and CMEs with small or highly fluctuating $B_s$ can cause only a small or moderate storm [*Gonzalez and Tsurutani*, 1987]. The intensity of a storm and its variation in time also depend on the structure reaching the Earth. *Huttunen et al.* [2002] found that the $Kp$ 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. The last type is usually caused by interaction regions or fast wind streams. The interaction regions are formed by interaction of high-speed streams emanating from coronal holes with streams of lower speed. They are composed of compressed and accelerated slow wind ahead of the stream-stream interface, as well as compressed and decelerated fast wind in the trailing part. At 1 AU they almost never have forward shocks and usually do not have reverse shocks. The main factors of the impact of the compressed region are strong (> 20 nT) and highly fluctuating magnetic fields and enhanced dynamic pressure [*Tsurutani et al.*, 1999; *Gonzalez et al.*, 1999]. Behind the interaction region the fluctuation of $B_z$ does not cease because of the continuously present large amplitude Alfvén waves in the high-speed streams [*Tsurutani et al.*, 1994]. Although the average $B_z$ is nearly zero in both regions, they may be geoeffective to different extents because the fluctuations usually provide large enough $B_s$ to the coupling process.



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The Sun's magnetic field can be approximated as a tilted dipole distorted by the higher harmonics. At the solar wind source surface the dominant multipoles are the dipole, the hexapole and the quadrupole, in the given order [*Bravo and Gonzalez-Esparza*, 2000]. The orientation and the magnitude of the dipole as well as the contribution of the higher harmonics are time dependent. Their cyclic variation is similar to the sunspot cycles but it is shifted in phase. The polarity reversals at the poles happen somewhat (~1 year) after the sunspot maxima. The interval between two polar reversals is called "dipole cycle" by *Legrand and Simon* [1991]. Two consecutive dipole cycles together with the related sunspot cycles form the 22-year solar magnetic or Hale cycle. Although the dipole and sunspot cycles are in close connection and overlapping in space and time, in many cases there is a need to separate the cycles in the time-series of solar or geomagnetic data, and decide whether the polarity of the sunspot groups (sunspot cycle) or the orientation of the main dipole (dipole cycle) dominate in the studied feature.

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 the heliospheric current sheet. If the solar dipole reverses at about the sunspot maximum, the away and toward polarities of IMF are connected to the other poles. It is obvious that the high-speed wind streams coming from the polar coronal holes are governed by the dipole cycle, but there are signatures, that the orientation of the main dipole also has a dominant effect on the CMEs. *Kahler et al.* [1999] found that most ejecta do not disturb the polarity structure of the interplanetary magnetic field, instead their magnetic field bend into the IMF large-scale sector structure. *Bothmer and Rust* [1997] , *Bothmer and Schwenn* [1998] and *Mulligan et al.* [1998, 2000] found that the leading magnetic polarity of flux ropes lying in the ecliptic plane tends to follow the direction of the solar dipole.

*Bothmer and Rust* [1997] and *Bothmer and Schwenn* [1998] found that the flux rope type of a magnetic cloud tends to follow the magnetic structure of the associated filament. Near sunspot minimum, a branch of filaments appears near latitude 30° in each hemisphere. The band of these filaments drifts toward the latitude of about 55° until sunspot maximum, and remains there until the next minimum then drifts again poleward until the next maximum. Although both sunspot minima and maxima are turning points during this process, the dipole cycle plays obviously dominant role in the structure of filament-related magnetic clouds. The correlation between the solar dipole orientation and cloud leading field was confirmed at about 4:1 rate. Both correlating and anticorrelating clouds were only observed with similar frequency at about the polar reversals. *Mulligan et al.* [1998, 2000] confirmed these results by extendeding the work without investigating the possible filament associations. They confirmed the predominance of the dipole cycle but also found that the inclination of the cloud axes vary with the phase of the cycle. The above results are in accordance with each other independently from the differences in the suggested heliospheric current sheet topologies, and they show that the dominant direction of the leading field of magnetic clouds follows that of the large-scale dipole. Although there are also signatures that in the case of CMEs associated with active region sigmoids the effect of the sunspot cycle may not be ignored [*Leamon et al.*, 2002], the assumption that the dipole cycle dominates the large-scale IMF structures seems to be well-based at present [*Crooker*, 2000].

The fractions of solar wind structures causing geomagnetic activity also depend on the solar cycle. During sunspot minima the high-speed streams cause most of small, medium and large storms, while CMEs dominate only among the major storms. The geomagnetic activity is dominated by the high-speed wind streams (~70%), the CME related structures contribute by ~10%. During maximum years CMEs are dominant causes of all kinds of storms. The contribution of CMEs is ~50% , and that of the corotating streams is ~33% [*Richardson et al.*, 2000, 2001, 2002].

The geoeffectiveness also varies on a yearly time-scale. The level of the geomagnetic activity shows semiannual variation characterized by a higher level of geomagnetic indices and higher occurrences of intense storms at about the equinoxes than at the solstices [*Cliver and Crooker*, 1993; *Cliver et al.*, 2000, 2002]. This variation is generally attributed to three mechanisms: Russell-McPherron effect as well as axial and equinoctial mechanisms.

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 $B_y$ is sinusoidal reaching negative extreme after the September equinox (11 Oct.). The sinusoidal variation of the GSM $B_z$ projected by negative GSE $B_y$ takes its negative extreme after the March equinox (7 Apr.). Thus, the semiannual variation consists of two opposite annual variations according to the positive and negative $B_y$. When the GSE $B_y$ projects negative GSM $B_z$ in the given season, we say that its direction is favorable for the Russell-McPherron effect to contribute to the geoeffectiveness.

In the axial hypothesis, geomagnetic activity peaks when the Earth is at one of its highest heliographic latitudes at 7 March above the southern hemisphere and at 9 September above the northern hemisphere. Since the geomagnetic activity correlates with the solar wind speed, and the average wind speed increases from the equator [*Hundhausen et al.*, 1971], the higher heliographic latitudes are favourable for increased geomagnetic activity. The effects coming from the sunspot region belt may also reach the Earth with higher probability because it is best aligned with any radially propagating CMEs [*Webb*, 2002]. In addition, as the Earth's heliographic latitude increases, there is a statistical tendency to observe the polarity of the related solar hemisphere (Rosenberg-Coleman effect) [*Rosenberg and Coleman*, 1969]. When the southern pole is negative, at about March the negative polarity of the southern hemisphere reaches the Earth more often than the positive polarity of the northern hemisphere, but the polarity of the northern hemisphere dominates in the second half of the year. In this case the dominant polarity is favorable for the Russell-McPherron effect in both halves of the year, and its contribution to the semiannual variation should be larger than in the case of reversed dipole [*Russell and McPherron*, 1973].

In the equinoctial hypothesis the geomagnetic activity reaches its maximum when the angle between the Earth's magnetic axis and the direction of solar wind flow along Sun-Earth line is about 90 degree at equinoxes (21 March, 23 September). At these times three mechanisms have increased efficiency: *(a)* the flanks of the magnetopause are most unstable to Kelvin-Helmholz boundary waves when the solar wind is directed perpendicular to the magnetic axis [*Boller and Stolov*, 1970]; *(b)* the configuration of the magnetic field lines at the dayside magnetopause is more favourable for $B_s$ coupling at about equinoxes than at about solstices [*Crooker and Siscoe*, 1986; *Cliver et al.* 2000]; *(c)* geomagnetic activity peaks when the nightside auroral zones of both hemispheres are in darkness, as happens at equinox [*Lyatsky et al.*, 2001]. In this case no conducting path exists in the ionosphere to complete the currents required by solar wind-magnetosphere-ionosphere coupling, and geomagnetic disturbances maximize.

The rates of contribution of these mechanisms to semiannual variation are still under debate. Recent studies [*Cliver et al.*, 2000, 2002] show that the equinoctial effect is the principal contributor but the other mechanisms also play some role in the semiannual variation of geomagnetic activity.

The present work focuses on those effects which depend on the polarity of the IMF and the dipole cycle: Russell-McPherron effect and Rosenberg-Coleman effect. Our previous studies [*Baranyi et al.*, 1998; *Baranyi and Ludmány*, 1997, 2002a,b] showed that there are polarity-dependent solar-terrestrial effects: the atmospheric response can distinguish between high-speed wind streams and CMEs, and it shows a dipole cycle-dependent semiannual variation. In this context the following questions arose: which kind of characteristics of solar plasma streams show polarity-dependent annual variation, and how do they depend on the solar dipole cycle? This paper is addressed to these questions without interpreting their connection with our earlier results.

The vectorial variables change with the dipole cycle, so they may be the main factors in the above features, but the wind speed may contribute to the effect. The $B_z$ component determines the rate of energy transfer: when $B_z$ is negative then more energy penetrates into the near-Earth environment than in the case of positive $B_z$. The $B_y$ component can modulate this process, causing marked asymmetries in magnetospheric convective flow patterns at high latitudes and the related ionospheric effects [*Khan and Cowley*, 2001]. Thus, the $B_z$ and $B_y$ components, the durations of periods in which the Earth is exposed to an impact, and the bulk speed are scrutinized. (The $B_x$ has a relatively weak effect on the coupling process, and it is not studied here.) We use the GSM system if we want to study how the Earth is affected, and the GSE system if we want to study how the given structure appears in the heliosphere.

## 2. Data sets and selection criteria

The components of the interplanetary magnetic fields, bulk speed and $Kp$ index data were obtained from the Near-Earth Heliospheric data set (OMNI), which is maintained and updated by the National Space Science Data Center. It contains hourly averaged interplanetary plasma and magnetic field data gathered by several spacecraft, as well as some solar and geomagnetic activity indices. It now spans 1963-2002, and provides a unique opportunity to the long-term solar-terrestrial studies [*e.g. Papitashvili et al.*, 2000].

We used the three-hourly $Kp$ index to separate the geomagnetically active and quiet hours. It can be seen in the Figure 3 by *Richardson et al.* [ 2001] that the most probable value of $Kp$ associated with CMEs or corotating fast wind streams from coronal holes is about 3. If we want to study the most probable characteristics of these kind of events, we have to choose the range of $Kp$ containing this peak at least partially. In addition, it had to be taken into account that the slow wind, which usually causes geomagnetically quiet hours ($Kp$~1-2), sometimes can be associated with higher $Kp$ values. To make a compromise, we selected those hourly IMF data when $Kp$ was larger than 3 (30 in the OMNI format), and the associated streams are called "geoeffective" in this sense. In this way, we can study the large part of the effects caused by CMEs or fast wind streams while omitting the largest part of slow wind from the statistical study.

One of the new aspects in our study is the separation of data by solar dipole cycle as well as sunspot cycle. The studied time intervals can be seen on Figure 1. The dipole cycle is called "parallel" (-1968, 1982-89) if the solar and terrestrial dipole fields are parallel, and it is called "antiparallel" (1972-80, 1992-99) if they have opposite directions. (These intervals are called in cosmic ray studies as A<0 and A>0 epochs respectively.) The parallel-antiparallel subsets of years were separated by the solar dipole field polarity after *Makarov and Makarova* [1996] and *Makarov et.al* [2000].

In the OMNI era there are four ascending phases and three descending phases of sunspot cycles. We selected for the study of ascending phases the years after sunspot minima and before the polar reversals as follows: 1966-68 (P2), 1977-80 (A2), 1987-89 (P4), and 1997-99 (A4). For descending phases the three-year intervals before sunspot minima are studied: 1973-75 (A1), 83-85 (P3), and 1993-95 (A3).

The other new aspect is the study of annual variations of monthly means depending on the direction of $B_y$ component. For all these intervals we selected the hourly data

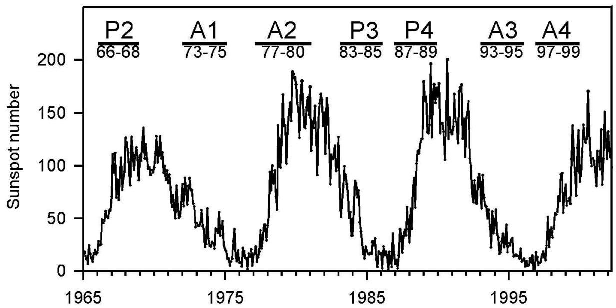


**Figure 1.** Monthly mean relative numbers and the studied intervals.

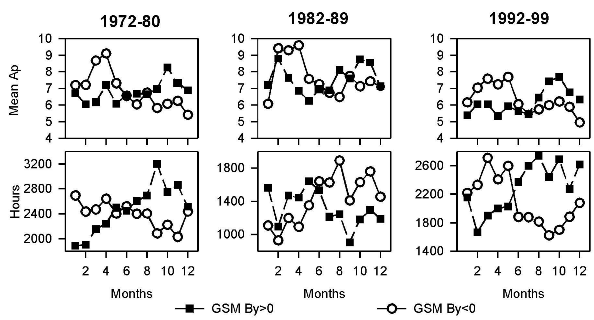


**Figure 2.** Annual variation of monthly mean $Ap$ index and the number of hours spent in domains of either positive or negative GSM $B_y$ in the given months during whole interval.

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 whether the monthly means of $B_z$ component show two opposite annual variations depending on the GSM $B_y$ according to the Russell-McPherron effect. If yes, we can decide whether the separation of the two curves is smaller or larger in comparison with the other cases. These data sets allow us to study the polarity-dependent characteristic features of geoeffective plasma streams depending on the dipole cycle and the phase of the sunspot cycle.

In this era there were three dipole cycles observed from beginning to end. For these intervals the first row of Figure 2 shows the two annual variations of monthly mean $Ap$ index and the number of hourly data in which the GSM $B_y$ was negative or positive respectively. It can be seen that the two opposite annual variations of mean $Ap$ exist in all the intervals, but the separation of the curves seems to be a little bit more definitive in the antiparallel years. The second row shows the dipole cycle-dependent Rosenberg-Coleman effect. In the antiparallel years those polarities are dominant which are favorable for the Russell-McPherron effect and cause higher level of geomagnetic activity. In the parallel years the dominant polarities are unfavorable for this effect, and the less frequent polarities cause larger $Ap$. The separation of the curves is also smaller in this case. (According to the calculations of *Russell and McPherron* [1973], this difference may contribute to the difference between the curves of the semiannual variation of the geomagnetic indices of antiparallel and parallel cycles.)

## 3. Dependence on the solar dipole cycle

### 3.1. Ascending phases of sunspot cycles

Although the geometrical transformation related to Russell-McPherron effect causes always the same projectional effect, the two sinusoidal annual variations may not be perceived in all cases. If the magnetic vector has a $B_z$ component in the GSE system, 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 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 solar plasma streams. The study of these annual variations may reveal some statistical characteristics of the geoeffective plasma streams.

The first row of Figure 3 shows the annual variation of the monthly mean $B_z$ values in the GSM system by separating the periods of positive and negative GSM $B_y$ in the case of $Kp>3$. One can see that during parallel years the two opposite annual variations according to the Russell-McPherron effect are much more perceivable than during antiparallel years, although one would anticipate a stronger or at least similar signal in the latter case on the basis of Figure 2. This somewhat unexpected result is supported by two independent intervals for both (antiparallel and parallel) cases. This difference between the annual variations of mean GSM $B_z$ of antiparallel and parallel years hints that there are substantial differences between the magnetic configurations of the studied plasma streams in these two cases.

We think that the reason of this feature may lay in the behaviour of the $B_z$ components in the GSE system. 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 GSM $B_y$. 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. If we select only those cases when the signs of GSE $B_y$ and GSM $B_y$ are the same, the result does not change, but it is not shown here.)

The second row displays monthly mean GSE $B_z$ values for the events studied in the first row. Two definite opposite annual variations of means can be seen in A2 and A4 but this pattern is weak in P2 and P4. In the antiparallel years it is remarkable that the means of $B_z$ are much more negative for that direction of $B_y$ which is unfavorable for the Russell-McPherron effect in the given season. This pattern may compensate the Russell-McPherron effect. In the first half of the year, negative GSE $B_y$ projects negative GSM $B_z$, whereas at this time much more negative GSE $B_z$ coincides with positive $B_y$, which still remains negative after the transformation into the GSM system. The case is opposite in the second half of the year. The result is that mean GSM $B_z$ values are about the same for the two subsets. In the parallel years there are no large differences between the GSE $B_z$ values, thus the Russell-McPherron effect has better chance to manifest itself in the mean GSM $B_z$.

The third row displays the number of geomagnetically active hours ($Kp>3$) spent in domains of either positive or negative $B_y$ during the whole interval. In the antiparallel years one can see the same two opposite annual variations as in the second row of Figure 2, although in this case the study is constrained to the the geomagnetically active hours. However, the constraint leads to a perceivable change in the parallel years, because this type of annual variation cannot be seen. In each season of this interval the Earth is mainly affected by that polarity which projects positive $B_z$, and causes only geomagnetically quiet hours. However, if there is a large negative $B_z$ in the incoming magnetic field of this polarity because of some fluctuation or CME, it may still cause geomagnetic activity because in this case the Russell-McPherron effect only decreases the absolute value of $B_z$, but it remains negative. This may happen about as frequently as the polarity favoured by the Russell-McPherron effect can occasionally cause a geomagnetic disturbance, and

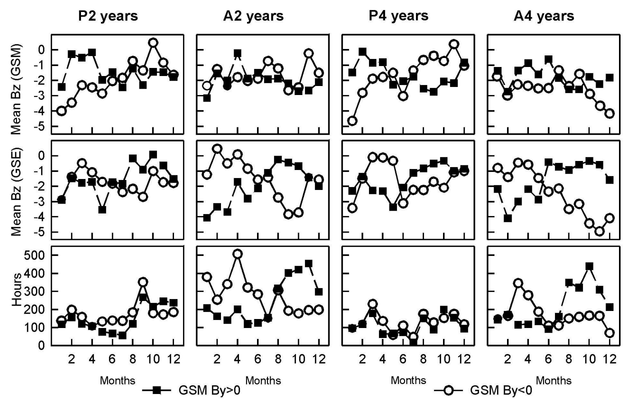


**Figure 3.** Annual variations of monthly mean $B_z$ in the GSM and GSE systems, and the number of hours spent in domains of either positive (square) or negative GSM $B_y$ (circle) during the ascending phase of sunspot cycle if $Kp>3$.

in about one half of the active hours the $B_y$ is positive and in the other half it is negative in each season.

The difference between the annual variations of mean $B_z$ seems to be important enough to be further studied. The $Kp$ values are averages for three-hour intervals during which the hourly mean of GSM $B_z$ may vary between less effective positive values and geoeffective negative values but the negative subintervals may raise the level of $Kp$ above the selected threshold. The original subset selection was only based on the $Kp$ but the differences between the parallel and antiparallel years can be seen much more clearly if we make a further restriction to the hours of negative GSM $B_z$ (by keeping the $Kp>3$ criterion). Figure 4 shows the monthly means of GSE $B_z$ if GSM $B_z$ is negative. These curves show as to what kind of characteristics the plasma streams have in the GSE system when they are geoeffective in the GSM system. In this figure a virtually inverse Russell-McPherron pattern is perceivable in both antiparallel and parallel years. This kind of variation is conceivable for the following reasons: when the direction of IMF is unfavorable for the Russell-McPherron effect, the stream can only reach the threshold of $Kp>3$ if its GSE $B_z$ has much stronger negative values to compensate its disadvantage. In the favorable cases the GSE $B_z$ can even be positive: if it is not too large, it will be negative in the GSM. Thus, for the favorable cases the mean GSE $B_z$ is about zero. Taking this fact into account, we can expect more negative mean $B_z$ in the cases of unfavorable $B_y$ than in the cases of favorable $B_y$ at any time. However, the separation of the curves of $B_z$ is much larger during the antiparallel years than in the parallel years. If the separation is small then the situation is close to the case when the magnetic field lies in the ecliptic plane. In this case the Russell-McPherron effect has a good chance to manifest itself in the annual variation of mean $B_z$. When the separation is large, the $B_z$ components of unfavorable polarities have higher chance to remain negative in the GSM system while the fields of favorable polarities gain enhanced negative $B_z$ components in the GSM system. Thus, the difference between the annual variations of mean $B_z$ of favorable and unfavorable polarities shows only a random character in the GSM system.

The larger separation of the curves of mean GSE $B_z$ during the antiparallel years hints that the geoeffective plasma streams may have much stronger negative GSE $B_z$ values during these years. At about sunspot maxima the effects of CMEs dominate over the effects of high-speed wind [*Richardson et al.*, 2000, 2001]. Thus, it is plausible to suppose that at this time the CMEs have the largest statistical weight in the calculated means. The difference between the annual variations of means may refer to a dipole cycle-dependent variation in the magnetic configuration of CMEs. The larger separation in antiparallel years may come from the southward leading field of magnetic clouds [*Bothmer and Rust*, 1997; *Bothmer and Schwenn*, 1998], or some impact of their central axial field direction [*Zhao et al.*, 2001] may play some role. These hints need further study, and any other explanations cannot be excluded at present.

### 3.2. Descending phases of sunspot cycles

During the descending phases high-speed streams are the primary causes of the geomagnetic activity while the percentage contribution of CME-related events is small [*Richardson et al.*, 2000, 2001]. The separation of these types of events needs an elaborated method, but from the point of view of this statistical study it seems to be enough to separate on the basis of bulk speed. According to the Figure 5 by *Richardson et al.* [2000] the average wind-related speed during the descending phase is generally above 500 km/s while the average CME speed is usually between 400 and 500 km/s. If we select the streams with bulk speed larger than 550 km/s, they are likely wind streams because the fraction of CME-related events is neglectable. One can estimate that CMEs constitute the largest fraction among the streams with bulk speed of less than 450 km/s, and the fraction of other types of streams may not be larger than during the ascending phase. By studying the years before sunspot minimum, we can check whether the results found in the previous section depend only on the dipole cycle or they show some kind of connection with the sunspot cycle. Figure 5 shows the behavior of the mean $B_z$ in the GSM and the GSE systems. The upper panel is for geoeffective slow streams (speed<450km/s, $Kp>3$), and the lower panel is for high-speed streams (speed>550km/s, $Kp>3$).

The curves in the upper panel are similar to the curves for the ascending phases (although the number of cases is smaller here because of the constraint on the speed). In the antiparallel years the values of mean $B_z$ do not show any perceivable regularity in the GSM but they show two opposite annual variations in the GSE system. In contrast,

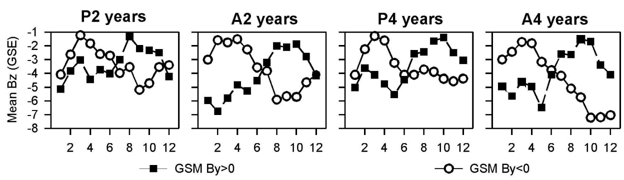


**Figure 4.** Annual variations of monthly mean GSE $B_z$ during the ascending phase of sunspot cycle if GSM $B_z$ is negative, GSM $B_y$ is either positive or negative), and $Kp>3$.

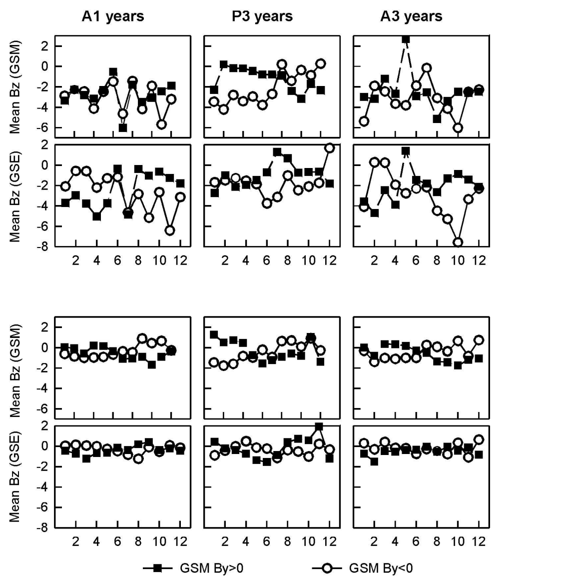


**Figure 5.** Annual variations of monthly mean $B_z$ in the GSM and GSE systems in the intervals of positive or negative GSM $B_y$ during the descending phase of sunspot cycle if $Kp>3$ and bulk speed<450km/s (upper panel) and bulk speed>550km/s (lower panel).

in the parallel years there are no such inverse annual variations of mean GSE $B_z$, and the Russell-McPherron effect can be observed in the GSM system. We can conclude that the existence or lack of the strongly separated inverse annual variations of mean GSE $B_z$ depends only on the dipole cycle but not on the phase of the sunspot cycle.

In the case of higher speed streams (lower panel) one cannot see any substantial differences between the curves of antiparallel and parallel years. The Russel-McPherron effect is weak but recognizable in the GSM because the means in the GSE are practically not separated by $B_y$. This means that the largest part of this subset of high-speed streams are really wind streams which flow roughly parallel to the ecliptic plane, and the mean of the fluctuating GSE $B_z$ is about zero. This supports the hint that the dipole cycle-dependent opposite annual variations of mean $B_z$ in the GSE system refers to such kind of magnetic structure (probably CME) which differ from the structure of the regular wind.

### 3.3. Mean bulk speed of geoeffective solar plasmas

Figure 6 shows the annual variation of monthly mean bulk speed of geoeffective $Kp>3$ plasmas during the ascending phases of sunspot cycles. It is remarkable that the mean bulk speed tends to be higher in the parallel years than in the antiparallel years. Furthermore, in the parallel years the curves show a stronger semiannual character.

*Zieger and Mursula* [1998] and *Mursula and Zieger* [2001] found partially similar dipole cycle-dependent variations in the solar wind speed. They showed that the two semiannual maxima of solar wind speed are systematically unequal, leading to a dominant annual variation in wind speed around solar minima. The annual wind speed maximum is observed at the highest southern heliographic latitudes during solar minima of antiparallel years and at the highest northern heliographic latitudes during parallel years. *Mursula et al.* [2002] found that the cause of this effect is the difference between the effective latitudinal gradients of wind speed across the northern and southern magnetic hemispheres, which implies a persistent displacement of the minimum solar wind speed locus toward the northern magnetic hemisphere.

Our result may be a consequence of this north-south asymmetry, but any other effects cannot be excluded. The difference between the mean speed during the ascending phases of antiparallel years and parallel years may come from a 22-year variation of the average solar wind speed. According to the Figure 1 by *Mursula et al.* [2002] the average wind speed is smaller during the ascending phases of antiparallel years than in parallel years. However, this does not explain as to why the semiannual character is stronger in one case and weaker in the other. In addition, we cannot find any definite asymmetry between the maxima of the March and September equinoxes, which could be attributed to a north-south asymmetry. This may come from the fact that the asymmetry is the largest at about sunspot minima, i.e. it is weaker in the ascending phase. The other possible explanation is that in Figure 6 only those cases were studied when $Kp>3$, i.e. not all the streams were included contrary to the means of all measured speed values by *Mursula et al.* [2002]. This threshold may play some role in the explanation because the streams have different chances to reach this threshold at different times. During the parallel years the dominant orientation of IMF is usually unfavorable for the streams to be geoeffective but in the cases of faster streams the larger speed may compensate this disadvantage. The other possible reason may come from the compression of a magnetic cloud by the following fast wind streams [*Fenrich and Luhmann*, 1998] resulting in an enhanced plasma density, speed, and magnetic field strength at the tail end of the cloud. In the parallel years compression often occurs simultaneously with the southward IMF period, so the geoeffective events may coincide with higher mean speed values.

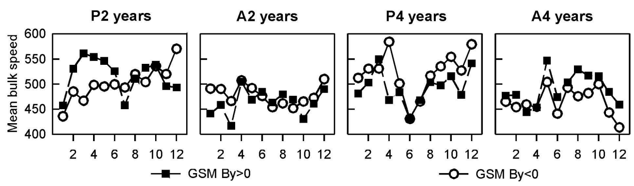


**Figure 6.** Monthly mean bulk speed of geoeffective ($Kp>3$) plasma streams.

## 4. Conclusion

This work focused on those effects which depend on the polarity of the IMF and the dipole cycle: Russell-McPherron effect and Rosenberg-Coleman effect. We investigated whether the monthly means of $B_z$ component show two opposite annual variations depending on the GSM $B_y$ according to the Russell-McPherron effect. We tried to decide whether the separation of the two curves is smaller or larger in the antiparallel years than in the parallel ones so that we may reveal characteristic features of geoeffective ($Kp>3$) solar streams depending on the solar dipole cycle. The ascending and descending phases of the sunspot cycles were separated to reveal any dependences on these phases, but we found only dipole cycle-dependent features.

The curves for the ascending phases and the curves of slow streams (speed<450 km/s) for the descending phases are similar: In the parallel years the mean GSM $B_z$ values show two opposite annual variations according to the Russell-McPherron effect but this effect cannot be observed in the annual variations of mean GSM $B_z$ in the antiparallel years. In the latter case we found strong inverse annual variations of GSE $B_z$ which may compensate the Russell-McPherron effect. The inverse annual variations of GSE $B_z$ are weak in the parallel years. This may refer to the dipole cycle-dependent magnetic configurations of these streams. The curves of the high-speed (>550 km/s) streams for the descending phases do not show any perceivable difference between the antiparallel and parallel years, which agrees with their regular Parker spiral structure.

The occurrence of the geoeffective hours in domains of either positive or negative GSM $B_y$ also changes with the dipole cycle. In the parallel years there is no difference between occurrences of the geoeffective hours with negative and positive directions of $B_y$ but in the antiparallel years they show opposite annual variations. The scalar parameters of the plasma may also show solar dipole cycle dependence. The monthly mean bulk speed of geoeffective events shows a stronger semiannual character in the parallel years, and in these years it has larger values in average than in the antiparallel years. These dipole cycle-dependent differences in the annual variations of mean $B_z$, in the occurrence of negative and positive $B_y$, and in the mean bulk speed of geoeffective plasma streams may play an important role in 22-year modulation of terrestrial effects of solar plasma streams, and they need further investigation.

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