STUDY OF INTERPLANETARY PARAMETERS EFFECT ON GEOMAGNETIC FIELD

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The solar output and its variations have been quantified by several interplanetary parameters generated for near earth space at 1AU. The continuously changing interplanetary plasma and field values are known to produce geomagnetic field disturbances. Earlier studies had established the relative role of the solar wind speed (V) as well as of the magnitude of the interplanetary magnetic field (B) in generating the geomagnetic field disturbances. Later results have shown much better correlations for the product VB. We have further studied the relative role of the geoeffectiveness of V, B and of VB, both on a long-term basis as well as on a short-term basis, including the anomalous period of long duration HSWS events of the year 2003. In all cases we find confirmatory evidence that the product VB is the most effective parameter for producing larger geomagnetic disturbances.

Key words: Solar wind, interplanetary magnetic field, geomagnetic field, correlation study.

INTRODUCTION

The in situ observation of solar wind parameters and interplanetary magnetic field began in 1962. Various investigators have used these observations to establish statistical relationships between the geomagnetic indices and the solar wind parameters [1, 2, 3]. Among the interplanetary parameters, the solar wind velocity (V) was the first one to be explored for such a relationship with geomagnetic activity. They [1, 2] examined the relationships between solar wind, interplanetary magnetic field (IMF) parameters and geomagnetic activity with linked data sets. Rangrajan and Barreto [4], further examined these relationships for a much longer period of time from 1964 to 1998 using daily values. Fairly systematic increase in Ap in association with changes in V was observed throughout the period. Moreover, associated changes in Ap magnitude have also been reported with the increasing magnitude of IMF (B). In fact, they have studied the changes in sixteen...
solar wind and IMF parameters as well as their variability in various combinations. It was suggested that the magnitudes of southward IMF tends to be responsible for greater magnitudes of geomagnetic disturbances.

Jurac and Richardson’s [5] has classified the most geoeffective events characterized by $A_p > 100$ and $Dst < 100$. They found that different dependences are correlations on the perpendicular spacecraft separation are seen for geoeffective versus non-geoeffective events. High correlation clearly visible in plasma parameters over larger perpendicular distances for the most geoeffective feature. Using $A_p$ and $Dst$ indices as a measure for the level of geomagnetic disturbances, it was found that correlations of plasma density, $|B|$, $B_z$, and $B_y$ are about 0.85 for the most geoeffective events.

Kane [6] has worked to stabilizes relationship between $V$ and $Dst$ between 1973-2003, they found that geomagnetic storms occur due to several interplanetary features including magnetic clouds, but it is only when the magnetic field of the interplanetary feature engulfing the Earth has a strong southward component $B_z$, a good relationship is obtained between the $Dst$ and the product $VB_z$. On the long-term study for sunspot cycles 12 to 23, Kane [7] has analyzed relationship between sunspot number $R_z$ and $aa$ index, it was found to be very well correlated with the functions $BV$ and $BV^2$. Sabbah [8] examined the dependence of the solar plasma parameters observed near 1AU for the period 1965-1997; they found the product $VB$ more effective to the geomagnetic disturbances than the other interplanetary parameters. For the three continuous solar cycles Sabbah [9] also found the geomagnetic activity well correlated with the product $VB$. Crooker et al. [10] showed that when long-term averages were considered, the correlation between geomagnetic activity and the solar wind speed is indeed very striking. Later, however, Crooker and Gringauz [11], had found that in solar cycle 21, $BsV^2$ correlates much better with $A_p$ rather than $V$ or $V^2$. $Bs$ is taken to be $(B_z)$ when $B_z$ is negative and $= 0$ when it is positive. King [12], found that (i) IMF $B$ has a minimum at solar minimum and (ii) $V$ is maximum during the declining phase of solar activity. Rangrajan and Barreto [4], examined the time variations in $V$ and $B$ using the monthly averages, for the period 1965 to 1998. They have found quite stable conditions in the statistical study between $A_p$ and different solar wind parameters over three solar cycles, though solar cycle 21 exhibits somewhat different behavior particularly under disturbed conditions. Bieber et al. [13], found that the association between sunspot cycle and low frequency IMF turbulence waves, was more prominent in cycle 21 as compared to cycle 22. In contrast, the association between $B$ and $A_p$ appears almost linear over a considerable range of geomagnetic activity. Similarly, solar wind electric field, represented by VBs is also linearly correlated with $A_p$. Similar relationship is also seen for the variability in other components of $B$. Wang et al. [14] has made attempt to analyzed 105 geomagnetic storms with $Dst$ peak value <50 nT during 1998-2001. They found
that \( -VB \) is much more important than \( \Delta t \) (duration) for the formation of geomagnetic storms. Gonzalez and Echer [15] analyzed relationship between the geomagnetic storms index Dst and the southward component Bz of the interplanetary magnetic field for the period 1997–2002; they found some association of the interplanetary electric field with Bz. [16,17] found that in the interplanetary space the interplanetary parameters density, solar wind speed (V), interplanetary magnetic field (B), showed short time peak structure but mostly not matching with Rz peaks, geomagnetic indices (aa, Dst) had peak structures, which did not match with Rz peaks but were very well related to V and B particularly to the product VB.

Generally people worked with relationship between Ap and VBz, the product of velocity and southward component of IMF B. Here in an average we had tried to understand the relationship between Ap and VB, the overall component of IMF B.

The purpose of the present study is to examine the characteristics of the selected High Speed Solar Wind Stream (HSWS) events and their impact on geomagnetic fields, as well as the relationship with other interplanetary parameters for the anomalous year 2003, in which very large number of long duration HSWS were observed for the first time.

### DATA AND METHOD OF ANALYSIS

**EXPERIMENTAL DATA**

We have used solar wind plasma speed(v) data and interplanetary Magnetic field data at 1AU obtained from satellite observations provided by national space science data center (NSSDC) through the OMNIWEB (http://www.nssdc.gsfc.nasa/omniweb.html). Here Ap is used as an indicator of geomagnetic field disturbance, it is known as geomagnetic field disturbance index (Ap), measured by ground-based observatories. The data (Ap) has been obtained from the national Oceanic and atmospheric administration (NOAA) home page (http://www.sec.noaa.gov/).

While examining the average behavior of the solar wind speed(v) for over two solar cycles, we have found that the annual average speed is substantially high during the year 2003. Moreover, while examining the occurrence of events of high-speed solar wind streams (HSWS), we have come across large number of such events of HSWS during the year 2003. The selection criteria to choose HSWS events is when plasma speed was enhanced to at least 450km/s. for more than continuous four days. However, if the stream (HSWS) is of long duration (> 8 days) then a day in between is also included as a event. In between December 2002 and December 2003, twelve events have been observed, in seven events, the
duration of HSWS is even more than 10 days. In fact, in the previous solar cycle, hardly two events are observed of such a long duration. It appears therefore, that the year 2003 is quite anomalous as far as the solar wind speed is concerned, both in terms of the average speed as well as the occurrence of larger frequency of long duration HSWS. We have identified that all these twelve anomalous HSWS are associated with coronal holes. As such, we have studied these anomalous events by using daily averages of various interplanetary parameters to examine their effect on the geomagnetic field disturbance represented by Ap index.

RESULTS

The yearly variations of V, B and VB, as well as of Ap, are depicted in fig. 1 (1986 to 2004), which clearly shows the anomalous increase of the average solar wind speed as well as significant increase in Ap in the year 2003. However, any significant simultaneous change for B is not observed in the year 2003. Nevertheless, the product VB is significantly enhanced in the year 2003, because of the high values of “V” alone. More enhanced value of VB (11.08) is seen in the year 1991 but now it is due to the enhanced value of B (9.27) and not V (462.3). In fact, we find that in both the cases (i.e., in the year 2003 as well as 1991) the values of Ap are quite significantly enhanced.

The years 1994 as well as 1989 also signify increased Ap, which are because of enhanced “V” and “B” respectively. Therefore, looking to the four conspicuous peaks of Ap seen during the years 1989, 1991, 1994 and 2003; we observe enhanced magnitude of VB in all cases. However, in two cases only “V” is enhanced (1994 and 2003), whereas in the other two cases (1989 and 1991) only “B” is enhanced. This implies that it is the product of VB, which is more effective in generating geomagnetic field disturbances.

The overall relationship between V, B and VB with Ap, has also been investigated for the period 1986 to 2004, by using their annual average values, which are already depicted in Fig. 1. The correlation graphs between V and Ap, B and Ap, as well as VB and Ap, are shown in Fig. 2, where the correlation coefficients (r) are also marked. It is very clear from the graph that, even though the value of ‘r’ for Ap, is quite large for the correlation with V and B, however, it is very significantly high for the product VB (r =0.94). As such, here again we find that the product VB is very effective in producing geomagnetic field disturbances. We also notice that the value of B is minimum (years 1986 and 1996) during the solar activity minimum and is high during solar activity maxima, and which was also the case reported for earlier solar cycles till 1979 [9]. Nevertheless, instead of a primary peak at solar activity maxima, the secondary peak of V is anomalously high, for a year, during the two declining phases of the solar activity cycles (1994 and 2003).
Fig. 1 – Shows the yearly average values for solar wind speed (V), IMF magnitude (B), product (VB) and the geomagnetic field disturbance index (Ap) for the years 1986 to 2004. The left hand scale represents solar wind speed divided by 10. The scales for all other parameters are represented on the right hand side, where the scale value of VB is divided by 400.
Fig. 2 – Shows the crossplot for solar wind speed (V), IMF magnitude (B) and product VB with geomagnetic field disturbance Ap for their annual average values for the years 1986 to 2004. The correlation coefficients (r) are also marked in each case, (the regression lines are also shown).
Fig. 3 – Shows the crossplot for the whole year 2003, for the solar wind speed (V), IMF magnitude (B), and product VB with geomagnetic field disturbance index Ap by using their daily values. The correlation coefficients (r) are also marked in each case. The regression lines are also shown.
Fig. 4 – Shows the solar wind speed variation with days of all 12 HSWS events in year 2003.
Fig. 5 – Shows the correlation coefficients for the 12 HSWS events for solar wind speed (V), IMF magnitude (B) and the product VB with geomagnetic field disturbance index Ap. The 13th point depicts the values of r by considering all the 248 daily values (for all the 12 events) taken together.
Fig. 6 – Shows the crossplot of all the 248 days of HSWS included in all the 12 events (in all 248 days), for solar wind speed (V), IMF magnitude (B), product (VB) with the geomagnetic field disturbance index (Ap).
The significant effect of the product VB on Ap has also been found when their daily values are considered. This has been found true for all the years. We have depicted in Fig. 3 the cross correlations for the year 2003, similar to that shown in Fig. 2, but by using the daily values of V, B, VB, and Ap. We notice from the figure that the correlation is quite high for the case of VB vs Ap (r =0.80). Further, we notice that on a day-to-day basis, B is better correlated with Ap (r =0.64) rather than V vs Ap (r =0.41).

With the above background in mind, we have analyzed the relationships for the 12 HSWS events observed in between December 2002 to December 2003. The solar wind speed of all 12 HSWS events has been depicted in Fig. 4 for the event time period. The solar wind speed is almost constant for the whole events time period except in some events. The correlation coefficients (r) of each of these 12 events for V, B and VB with Ap are shown in Fig. 5, along with the correlation coefficients for all the days (of all the 12 events) at point number 13. (i.e. the overall average values). In most of the cases, the correlation coefficients for V is generally lower than that for B and VB. Moreover, we find that in almost all the cases, the correlation coefficient of the product VB is maximum (except for the event no.11, and marginally for the event no. 4). In some cases, the values of r are almost 1 for VB vs Ap (event number 8: r =0.95; and event number 10: r =0.98). The figure naturally demonstrates that the product VB is significantly more effective than V or B even during the period of HSWS. This is further confirmed from the correlation graph shown in Fig. 6, where the daily values of all the 12 events (248 days) are depicted in a manner similar to that shown in Fig. 3. Here again we find that the value of r is maximum for the case of VB vs Ap (r =0.66), though it is significantly smaller than that found for the whole year of 2003 for the case of VB vs Ap (r =0.80). As such, from our study we find that on a long term basis, and on a day-to-day basis, as well as for the specific events of HSWS, it is the product of VB which is always more effective in producing larger geomagnetic field disturbances.

**CONCLUSION**

From the study presented here, we conclude that both the solar wind speed (V) as well as the magnitude of IMF (B) are effective in generating geomagnetic field disturbances, but their impact varies considerably during different time periods. However, we find that the product VB is the most effective interplanetary parameter for significantly larger effect on geomagnetic field disturbances, both on an yearly averages basis, and also on day-to-day basis, as well as for high speed solar wind stream time periods. As such, in all cases our results confirm the geo-effectiveness of the parameters VB in contrast to V or B.
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