Effect of solar wind speed variations on other interplanetary parameters

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The daily values of interplanetary solar wind parameters as well as that of the geomagnetic disturbance index (Ap) have been used for the years 1965-2006. Long-term averages have been calculated for all those days when simultaneous data is available for all these parameters (V, B, Bz and Ap). Earlier reports have usually underlined the importance of V in producing terrestrial effects. As such, individual days have been grouped, in accordance with the limited range of V, in seven groups by the method of iteration using K-mean clustering (data mining) technique. Having selected days in each of the seven groups (ranges), the group averages, have been calculated for the entire period for V, B, VB and Ap along with their standard errors. The method has been further repeated for the individual solar cycles. These group averages have been used to investigate the statistical relationships between V, B, VB and Ap in different combinations. The results so obtained can be summarized as: (i) the monotonic increase of group average V is almost similar to that of increasing average values of Ap, and VB from groups 1 to 7; (ii) For each of the seven groups, VB vs Ap and B vs Ap have been always found to be better correlated (‘r’ larger) on a day-to-day basis, whereas V vs Ap has low values of ‘r’; (iii) the direction of Bz when negative is very much effective in producing larger Ap as compared to days when Bz is positive, in all the seven groups (more prominently in the last four groups of larger V). The statistical results obtained signify that the product VB is very effective in producing large scale geomagnetic disturbances.

Keywords: Solar wind, Interplanetary magnetic field, Geomagnetic field, Correlation study

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1 Introduction

The solar-terrestrial relationship includes the effect of solar output and its variations. It also includes propagational effects in the interplanetary medium, which ultimately produces disturbances in geomagnetic field. As such, the near-earth interplanetary plasma and fields are expected to have a direct relationship with geomagnetic disturbance indices. In-situ measurements of IMF and solar wind parameters began in late 1962 and now cover more than four solar cycles. The observations have helped in establishing several useful statistical relationships between indices of geomagnetic activity and the causative parameters1-3 including solar wind speed V (ref. 4). The data have also been examined for their long-term variability in terms of the eleven-year solar cycle component5-7. From early observations of solar wind bulk speed, Snyder et al.4 were able to establish its close correlation with geomagnetic disturbance index Kp. Crooker et al.8 showed that when long-term averages (covering duration of 6 months or more) are considered, the correlation between geomagnetic activity and the solar wind speed is indeed very striking. Later, however, Crooker & Gringauz9 found that in solar cycle 21, BsV2 correlated much better with Ap than V or V2. Many other researchers have also reported such relationships, mostly involving solar wind speed (V), interplanetary magnetic field (Total IMF B) as well as the southward component of IMF, to study the effect on geomagnetic field represented by parameters Kp, Ap, Dst and AE. Later on, more significant relationships have been obtained for B, and in particular for the product of V and B (electric field). Sabbah10-11 has shown that instead of V, or for that matter B alone, is not sufficient to depict the geomagnetic disturbances or cosmic ray variations. Dwivedi et al.12 also reported the relationship between the interplanetary parameters and geomagnetic disturbance index Ap for a long period (1965-2007). Similar conclusions have been reported in some of the other recent publications13-21. Many of these results are for the medium or large scale geomagnetic storms of short durations22-23. Therefore, the characteristic variations of V, B, as well as of product VB (electric field) have been examined in the present study to understand
their effect on the geomagnetic field disturbances on statistical basis over a long period (1965 to 2006) covering four solar activity cycles (20–23).

2 Data analysis
The daily values of the interplanetary parameters (V, B and Bz) for a fairly long period of time (during 1965-2006) covering solar cycles 20–23 have been taken for the present study (www.omniweb.gsfc.nasa.gov). Similarly, the geomagnetic field disturbance indices have been downloaded from www.ngdc.noaa.gov which includes the mid-latitude Ap index. As such, all types of successive days (having very low or very high values of V during the chosen interval) have been considered. For this work, the results are obtained by dividing the set of days into various groups consisting each of a limited range of the solar wind speed (V) for the same data set during 1965-2006.

The limits of the ranges of the groups of V have been selected through the method of iteration using all the daily values (only good days) of V during 1965-2006 (total number of days - 12038). For the present study, ‘good days’ signify that all the three parameters of the solar wind, viz. V, B and Bz as well as of Ap are simultaneously available on all those days. For the present purpose, the method of iteration has been used (for dividing V in seven groups) by applying the k-mean clustering technique (a method associated to data mining). This is an iterative technique for finding the mean of k-clusters. Here, one can randomly assume k-means for each cluster by keeping in mind that no chosen mean value is greater than the maximum possible value of V. However, to reduce the number of iteration, k-mean values should be assumed carefully.

After selecting suitable k-mean values, all the V values are classified and assigned to the cluster whose mean value is nearer to V. After performing this step repeatedly, one can compute the new k-mean values for each cluster and iteratively perform the same process unless the new k-mean values do not change significantly. These k-mean values are the mean of different k-clusters. Now by taking the advantages of these k-means, one can further find k-1 class boundaries by taking the mean of two successive clusters and the highest class boundary value can be taken as the value which is maximum to all the values of V. Having selected days in each groups, as above, the averages for the entire period (1965-2006) have been calculated for V, B, VB and Ap in each of the seven groups. These various group averages obtained for the entire period (1965-2006) have been first used to derive the statistical relationships to obtain significant correlations between V, B, VB and Ap in different combinations.

3 Results and Discussion
Soon after the data for solar wind parameters were available, Snyder et al. had reported a good correlation between solar wind velocity (V) and the geomagnetic index (Kp). For individual geomagnetic storms lasting for a few tens of hours, magnetic field reconnection between the southwardly directed IMF and the geomagnetic field is the most widely accepted mechanism for magnetospheric energization. Several coupling functions that correlate well between solar wind parameters and geo-magnetospheric dissipation parameters are used and these can be derived as particular cases of general expressions for the momentum and energy transfer at the magnetopause due to large-scale reconnection. Possible interplanetary mechanisms for the creation of very intense geomagnetic storms are discussed in detail by Gonzalez et al. However, for the long-term averages of solar wind, the effects of individual storms are obliterated and only steady-state characteristics prevail. Even though, initially Crooker et al. had reported a high correlation between solar wind speed and geomagnetic activity, however, later results report a low correlation for the years after 1976 (ref. 9). For solar cycles 20, 21 and 22 (1964–1995), Kane has observed a long term trend in B parallel to Rz (solar activity) and only +0.73±0.04 for cycle 22 (decreasing trend) indicating that some other factors are needed for a better relationship with the aa or Ap index. In a recent publication using the data (annual mean values) for the period 1963-1998, Ahluwalia has observed a long term trend in B parallel to Rz (solar activity) and has also found very good correlations between the variations of Ap and VB. Such relationships have been further investigated by using V, B VB and Ap for the entire period (1965-2006) as well as by dividing them into individual solar cycles (20-23).

The group averages for Ap, V, B, and VB, as well as the number of days in each of the seven groups for the entire period of study (1965-2006) has been depicted in Fig. 1. The figure very clearly reveals that the monotonic increase of the averages of Ap is...
almost similar to that of increasing average values of V and VB for all groups (1–7). However, the variation of B shows large skewness starting at group 4 with almost no increase in the magnitude of B. In other words, the initial increasing trend of B tapers down after group 4 (i.e. beyond the average solar wind speed of \( \geq 500 \text{ km s}^{-1} \), B does not increase though Ap continues increasing steadily). Such a tapering after group 4 (or enhanced value of B at group 4) is not at all apparent either in V or VB or Ap. The averages have also been calculated by dividing days in accordance to the direction of IMF pointing southward (Bz < 0) and pointing northward (Bz \( \geq 0 \)). As far as V, B, and VB are concerned, any differences between these two sets could not be found. Nevertheless, increase of Ap index in the two cases are distinctly different (Bz < 0 always shows much higher values of Ap as compared to that for Bz \( \geq 0 \)).

The overall correlations between V and Ap, B and Ap, as well as with VB and Ap for the entire period of study (1965-2006) taken together has been further investigated. Moreover, the correlation coefficients (r) for all the seven individual groups for the three cases (V vs Ap, B vs Ap and VB vs Ap) have also been calculated. These values are depicted in Fig. 2 for all the seven groups (1-7) as well as for all the groups taken together on the rightmost part of the diagram indicated by larger size of symbols. The indistinguishable differences observed between B and VB for all the seven groups where the value of ‘r’ is always greater than 0.6, whereas the value of ‘r’ for V vs Ap is almost negligible (r<0.2), except for the seventh group, where the values of ‘r’ for V vs Ap is \( \approx 0.4 \). On the contrary, when all the days are considered together, the value of ‘r’ for V vs Ap

Fig. 1 — Groups average values of: (bottom) V and B; (top) VB and Ap as well as number of days in each group shown by dotted lines (the scale on the right is for which the given Ap scale is to be multiplied by100).

Fig. 2 — Correlation coefficients for each of the seven groups during 1965-2006 obtained for the solar wind speed (V), total IMF (B) and product VB with the geomagnetic disturbance index Ap. The \( \pm 1\sigma \) probable errors of ‘r’ are also shown. The three symbols on the right depict the values of ‘r’ when all the data (all groups taken together) are considered. The error bars for this set of ‘r’ (for all data) is less than the size of the symbol.
significantly increases to more than 0.5. In any case, even for all the days together the value of \( r \) is least for \( V \) vs \( Ap \) (\( r = 0.53 \)), moderate for \( B \) vs \( Ap \) (\( r = 0.61 \)), but quite significantly high for \( VB \) vs \( Ap \) (\( r = 0.77 \)). Probably this needs further investigations.

4 Conclusions
In a previous study, Dwivedi et al.\(^1\)\(^2\) has noted that the statistical results obtained over a long period of time manifest that the most effective parameter for producing the large-scale geomagnetic disturbances is the total interplanetary electric field or in other words it is the product of \( V \) and \( B \) during 1965-2007. The same statistical analysis has been further carried out for seven groups in the present paper and obtained that \( VB \) is the most effective parameter in producing the large scale disturbances in geomagnetic field. The present result very clearly indicates that neither \( V \) nor \( B \) is significantly effective in producing geomagnetic disturbances. Rather, it is competing effects of \( B \) and \( V \) together, which are quite effective in producing large-scale geomagnetic disturbances. To further confirm these results, the possibility of using mining techniques of directed data analysis is being explored.

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