

Relation between interplanetary parameters and geomagnetic field variations during solar cycle 24

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The Earth's magnetosphere is highly dynamic with large scale variations due to energy coming from solar wind. The magnetosphere continuously readjusts itself to the ever-changing solar wind. This creates geomagnetic field variations. The relationship between solar wind parameters, such as solar wind speed (V), interplanetary magnetic field (B) and geomagnetic activity index (A_p) is studied in the present paper. The results show significant positive correlation between A_p index and solar wind parameters. But a very high correlation is found between the product VB and A_p index.

Keywords: Solar wind speed, Interplanetary magnetic field, Geomagnetic activity index

1 Introduction

During the last four decades, solar wind and magnetosphere interaction has extensively been studied in terms of correlation between solar wind parameters and geomagnetic indices. The magnetised collision-less solar wind plasma confines the magnetic field of the earth to a region around the planet called magnetosphere. The mutual interaction between the solar wind plasma and magnetic field of the earth is due to particle gyration effects. The *in-situ* observations of interplanetary magnetic field (IMF) and solar wind began in 1962. The observations have helped in establishing several useful statistical relationships between indices of geomagnetic activity and the causative solar wind parameters^{1,2}. Among the interplanetary parameters, the solar wind velocity (V) was the first one to be explored for such a relationship with geomagnetic activity. From the early observations of solar wind bulk speed, Snyder *et al.*³ were able to establish its close correlation with geomagnetic activity. The geomagnetic activity is the result of a complex solar wind-magnetosphere interaction process and solar wind velocity is only one of the possible contributing factors.

When long term averages are considered, the correlation between geomagnetic activity and solar wind is very striking for solar cycle 20⁴. But, this correlation breaks down for cycle 21⁵. Sabbah⁶ examined the dependence of the solar plasma

parameters observed near 1 AU for the period 1965-1997 and found that the product VB is more effective to geomagnetic disturbances than the other interplanetary parameters.

In the present paper, the relationship between solar wind parameters and geomagnetic activity through a correlation analysis has been studied. Geomagnetic field disturbance (A_p) index has been used as an indicator of geomagnetic activity. The results show that significant positive correlation exists between A_p index and solar wind parameters, namely solar wind speed (V) and total interplanetary magnetic field (B). But a very high correlation is found between the product VB and A_p index, which supports the previous studies. The study sharpens the knowledge of important interplanetary physical quantities that can influence geomagnetic activity. Moreover, since the geomagnetic disturbances are controlled by the local parameters of the solar wind⁷, one can also forecast geomagnetic activity.

2 Data and Method of Analysis

Solar wind plasma speed (V) data, interplanetary magnetic field (B) data and geomagnetic field disturbance index (A_p) data have been used from Omniweb Data Explorer (<http://omniweb.gsfc.nasa.gov>) for the period 2008-2015 for solar cycle 24.

Each solar cycle can be represented by 4 phases, namely, minimum solar activity period, ascending phase, maximum solar activity period and descending phase. The present study starts from the year 2008,

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which is of minimum activity; and is carried out up to 2015, which is the first year of the declining phase.

For the analysis, correlation coefficients are calculated between: (i) solar wind velocity (V) and A_p index; (ii) IMF (B) and A_p index; (iii) the product VB ; and A_p index using daily average values. The correlation between these parameters is found in each year separately. Then, using annual average values, the correlation between the parameters for the entire data during the solar cycle 24 is calculated.

3 Results and Discussion

The correlation of daily averaged values of solar wind velocity and A_p index are obtained for the period 2008-2015 to study the relationship between solar wind velocity and A_p index. Figure 1(a) shows the scatter plot of solar wind velocity versus A_p index for each year. The correlation coefficients obtained are 0.67,

0.52, 0.55, 0.49, 0.45, 0.49, 0.47, 0.47, respectively for each year during 2008-2015. The highest correlation is obtained in the year 2008, which has very deep solar minimum. This is because in solar minimum conditions, the effect of solar wind is maximum; and during solar maximums, CME's and SEP's originating from solar surface play more prominent role than normal solar wind in the solar wind magnetosphere interactions⁸.

The annual averaged values of solar wind show a positive high correlation with A_p index with correlation coefficient of 0.62 as shown in scatter plot in Fig. 2(a).

The solar wind velocity determines the momentum flux of the solar wind impinging on the Earth's magnetic field. The magnetosphere converts kinetic energy of the moving plasma into electrical energy, which is dissipated in the magnetosphere ultimately. When solar wind velocity increases, kinetic energy and

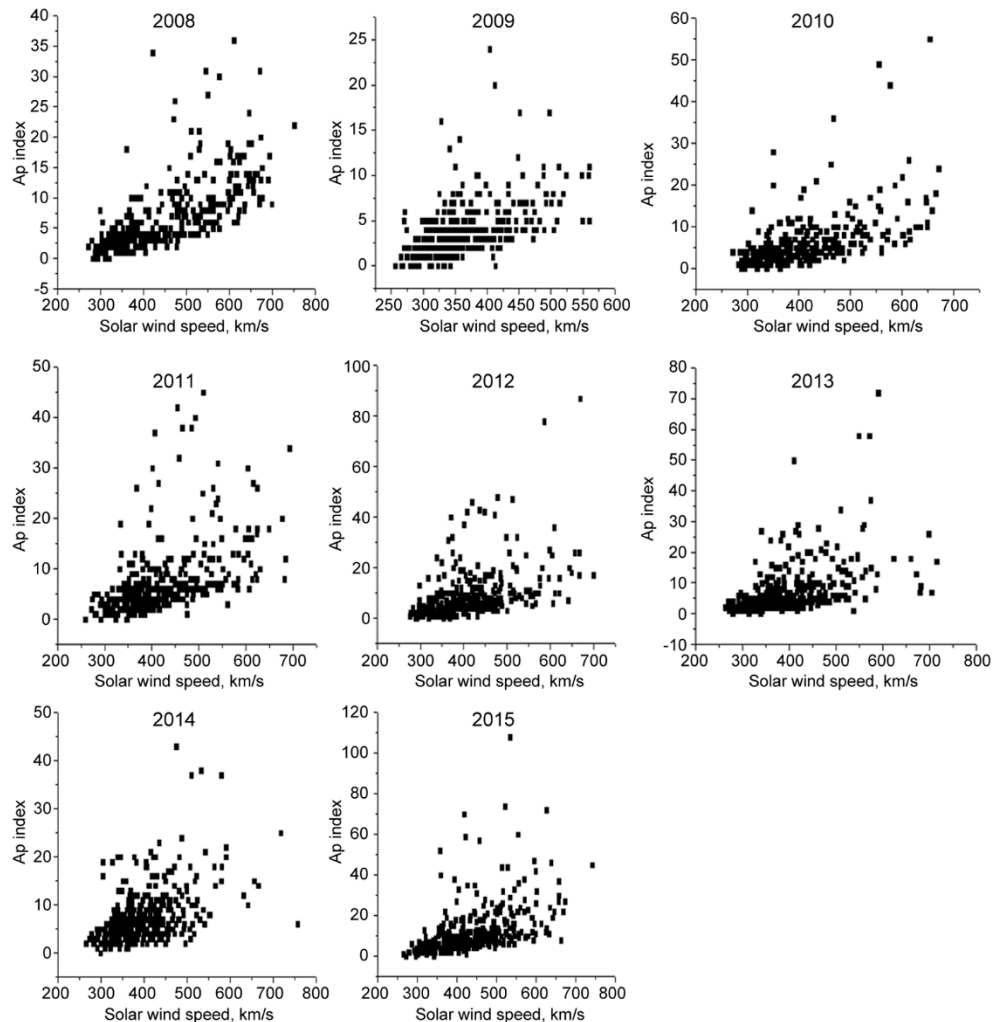


Fig. 1(a) — Scatter plot of solar wind speed versus A_p index for each year during 2008-2015

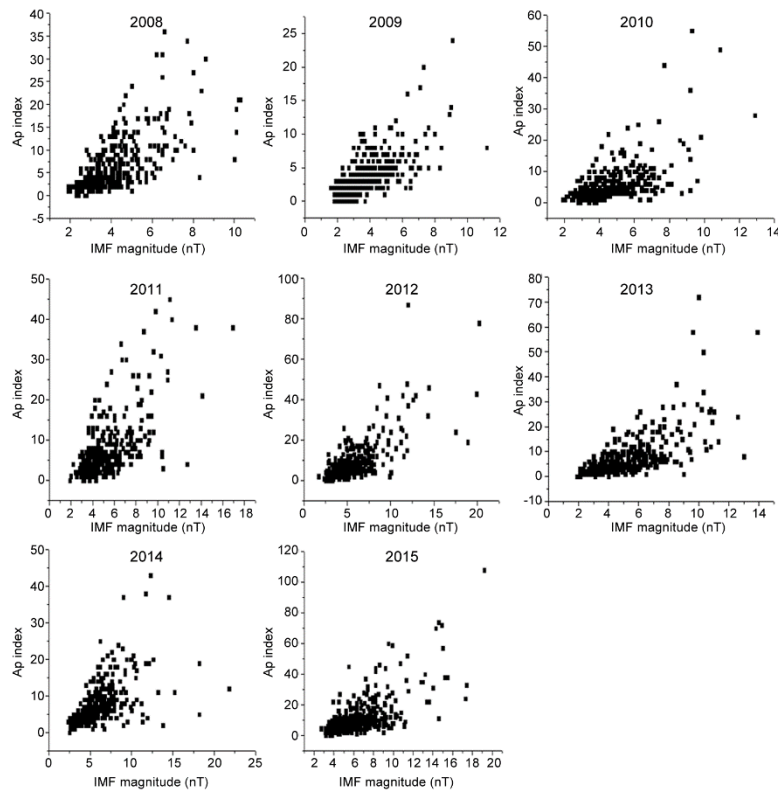


Fig. 1(b) — Scatter plot of IMF versus A_p index for each year during 2008-2015

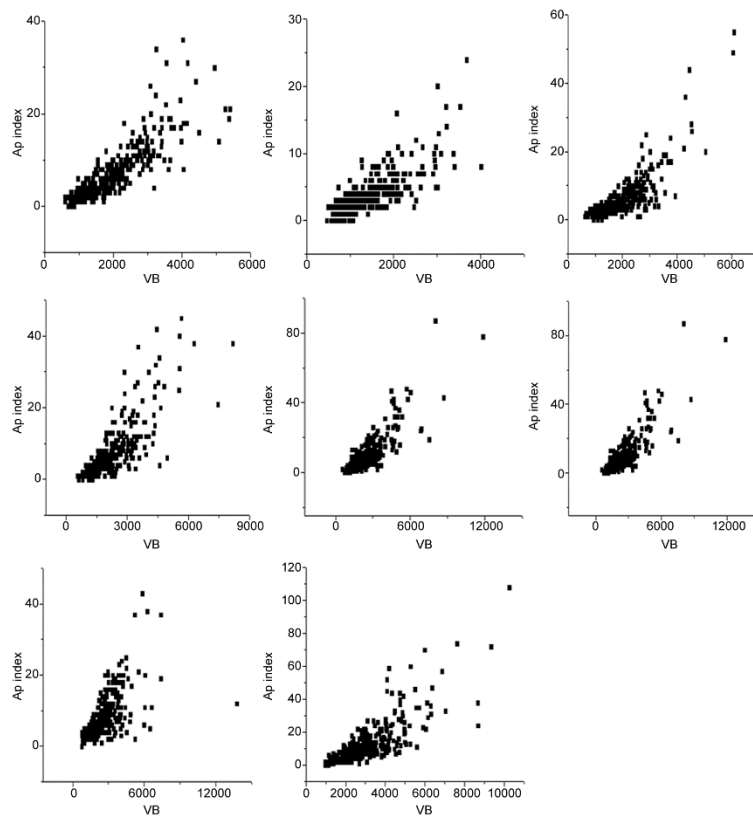


Fig. 1(c) — Scatter plot for VB versus A_p index for each year during 2008-2015

momentum flux increases, which causes more interaction with magnetosphere resulting in increased rate of geomagnetic activity. That is why solar wind velocity correlates with geomagnetic activity.

Stamper *et al.*⁹, in their study about the connection between geomagnetic activity and solar causes for the solar cycles 20-22, found out that increased geomagnetic activity was caused by rise in interplanetary magnetic field. When the solar wind plasma streams over the polar regions, the dawn side of the magnetosphere becomes positively charged and the dusk side becomes negatively charged by the $V \times B$ force, which in turn depends on the IMF (B). Depolarising currents along high latitude magnetic field lines pass through the polar ionosphere. This results in the transfer of some of the solar wind

momentum to the ionospheric and magnetospheric plasma producing a magnetospheric boundary layer of retarded solar wind plasma. The geomagnetic field lines through the boundary layer become stretched downstream forming the magnetotail. So, kinetic energy of moving plasma is converted into electrical energy, which is dissipated within the magnetosphere.

The correlation of daily average values of IMF and daily average values of A_p index are studied during 2008-2015 to study the relation between IMF and A_p index. Figure 1(b) shows the scatter plot for IMF versus A_p index for each year. The correlation coefficients obtained are: 0.65, 0.65, 0.59, 0.64, 0.72, 0.65, 0.55, 0.65, respectively for the years 2008-2015. The highest correlation is obtained in the year 2012, which is near solar maximum.

The annual averaged value of IMF shows a positive high correlation with A_p index with correlation coefficient of 0.84 as shown in the scatter plot in Fig. 2(b). This correlation supports the findings of Stamper *et al.*⁹ IMF shows greater correlation than solar wind velocity with A_p index.

Figure 1(c) shows the scatter plot for the product VB versus A_p index for each year. The correlation coefficients obtained are: 0.84, 0.77, 0.81, 0.78, 0.83, 0.78, 0.63, and 0.79, respectively for the years 2008-2015. The annual averaged value of VB shows a very high positive correlation with A_p index. The correlation coefficient obtained is 0.96, which is shown in scatter plot in Fig. 2(c). So, it is evident that the factor VB highly determines the rate of geomagnetic activity. This supports the results of Kane¹⁰.

The geomagnetic field variations are caused by the interplanetary electric field $E = V \times B$. When solar wind enters the magnetosphere, low energy particles spiral around the geomagnetic field lines and hit the

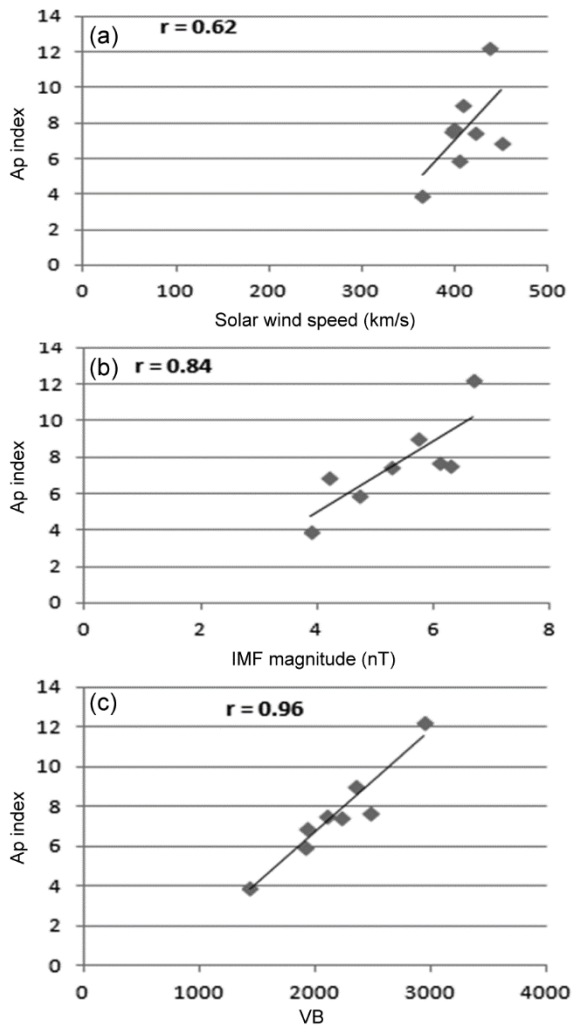


Fig. 2 — Scatter plot for annual averaged values of: (a) solar wind velocity (V); (b) IMF(B); and (c) VB with A_p index [Correlation coefficients (r) also marked in each case]

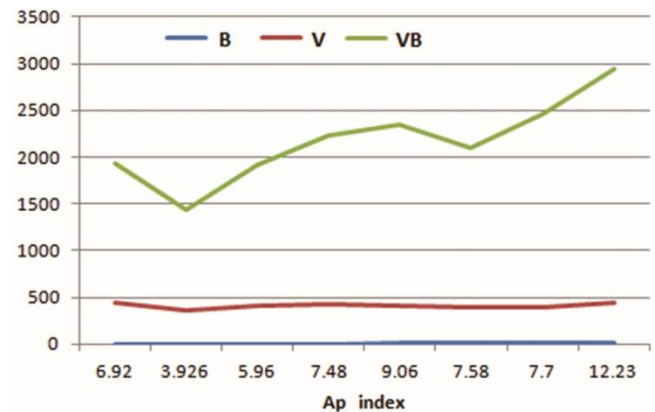


Fig. 3 — Plot of V , B and VB against A_p index

terrestrial atmosphere in polar regions causing aurora. Higher energy particles move towards the earth and divert around the earth in circular orbits in the equatorial plane and cause geomagnetic storms. In circular orbits, the velocity and magnetic field are mutually perpendicular. So, the product of average values of V and B is taken.

The dependence of A_p index on the product VB can be interpreted. The transport of energy and momentum to the magnetosphere is done through reconnection by allowing solar wind to cross magnetopause. The number of interplanetary magnetic field lines that are brought up to the magnetosphere per unit time and unit area for reconnection and subsequent momentum transfer depends on the product of magnetic flux density B and solar wind speed V . Hence, VB is a factor which determines the rate of geomagnetic activity. The plot of V , B and VB against A_p index is shown in Fig. 3.

3 Conclusions

The role of solar wind streams and IMF (B) in shaping planetary magnetic activity index (A_p) has been studied using solar wind data for the period 2008-2015. The results can be summarized as:

- (i) Daily averaged value of A_p index is correlated with the daily averaged values of solar wind speed (V) and IMF (B). This correlation is also clear in their daily averaged values. So, both 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 the solar cycle 24.
- (ii) A very high positive correlation is found between the product VB and A_p index both in daily

averaged and yearly averaged values. Hence, it can be concluded that the product VB is the most effective interplanetary parameter, which produces significantly larger effect on geomagnetic field disturbances, both on a yearly average basis and on day-today basis.

Hence, it has been established that geomagnetic activity indeed can be used as a measure of solar wind parameters. Moreover, the geomagnetic disturbances are controlled by the local parameters of the solar wind.

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