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A Comparative Analysis of Geomagnetic Storms in the Ascending Stage of Solar Cycle 25

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Abstract

In the present study, we have investigated the association of geomagnetic storms (GSs) with solar interplanetary features, i.e solar wind speed (Vsw), interplanetary magnetic field (IMF B), product of IMF B and Vsw, solar plasma temperature (Tsp), Ap index & Kp index, for the rising phase of solar cycle 25 (study period 2020 to 2023). From the results of the analysis, it is observed that the product of solar wind velocity and interplanetary magnetic field is highly geoeffective compared to solar wind velocity or interplanetary magnetic field alone. The correlation coefficient of geomagnetic storm indicator index Dst with these parameters has been found to be high and negative during the study period. There have been also the correlations between solar wind speed and Dst (-0.59), the interplanetary magnetic field (-0.87), the product of the interplanetary magnetic field and solar wind (-0.95), solar plasma temperature (-0.69), Ap index (-0.85) and the Kp index (-0.87). Finally, we have found out that geomagnetic storms occur on the same day when the product of the interplanetary magnetic field (IMF B), solar wind speed (Vsw), interplanetary magnetic field (IMF B) and solar wind speed (Vsw), solar plasma temperature (Tsp), Ap index and Kp index reach their peaks. On this basis the study of geomagnetic storms with various solar interplanetary features can be useful for the study of space weather phenomena.

Keywords: - Geomagnetic Storm, Interplanetary Magnetic Field, Solar Wind, Solar Cycle 25.

1. Introduction

Geomagnetic storms are geospheric disturbances that are most often caused by the interaction between the Earth's magnetic field and magnetic plasma emissions caused by various solar conditions. According to Akasofu and Chapman (1963), a geomagnetic storm is a disturbance in the Earth's magnetic field that arises due to disturbances in the interplanetary magnetic field and solar wind velocity. These disturbances are responsible for the sudden burst of geomagnetic activities. Various types of geomagnetic storms and their manifestations have been discussed by many authors (Kane, 2014; Oh, and Yi, 2004). According to Gonzalez et al., (1994), Bakare and Chukwuma (2010), geomagnetic storms play a widespread role in space weather. Although the effects of geomagnetic storms vary depending on the characteristics of different solar events, some common effects of most storms include daytime compression of the magnetosphere. The occurrence of geomagnetic storms can be attributed to any single solar interplanetary feature because they are dependent on many factors, including solar wind velocity, magnetic clouds, coronal mass ejections, and others.

The flow of charged particles coming from the Sun's upper atmosphere is known as solar wind. The temperature and speed density of the solar wind generally vary with longitude and time. Coronal heating causes solar wind particles to reach escape velocity and scatter away from the Sun. These solar winds can also disrupt Earth's magnetic field when they enter the interplanetary medium at such high speeds (Cane and Richardson 1995). The correlation between solar wind and Dst was demonstrated by Kane (2005) and Sabbah (2001) for the years 1965–2003. They also found out that the strongest southward component in the interplanetary magnetic field interaction, is the primary cause of geomagnetic storms. Furthermore, their research has shown that, compared to other interplanetary features, the product of the solar wind speed and the interplanetary magnetic field are strong predictors of geomagnetic storms.

2. Data Analysis and Method

A Chree analysis technique by superposed epoch method has been used in the current study with the occurrence day of geomagnetic storms (criteria Dst $\leq$ -50nT) as a zero day. The daily mean values of the Dst index, IMF B, solar wind speed Vsw, solar plasma temperature (Tsp), Ap and Kp index are taken from omni web data centre (**http://omniweb.gsfc.nasa.gov/form/dx1.html**) for the study period of rising phase of solar cycle 23 (2020 to 2023). The correlation coefficient between these parameters has also been calculated by taking Dst $\leq$ -50nT as a zero day, six values above it and six values below it has been considered. Further, all daily observations have been averaged and a graph has been plotted to depict the observational trend of two parameters on a day-to-day basis.

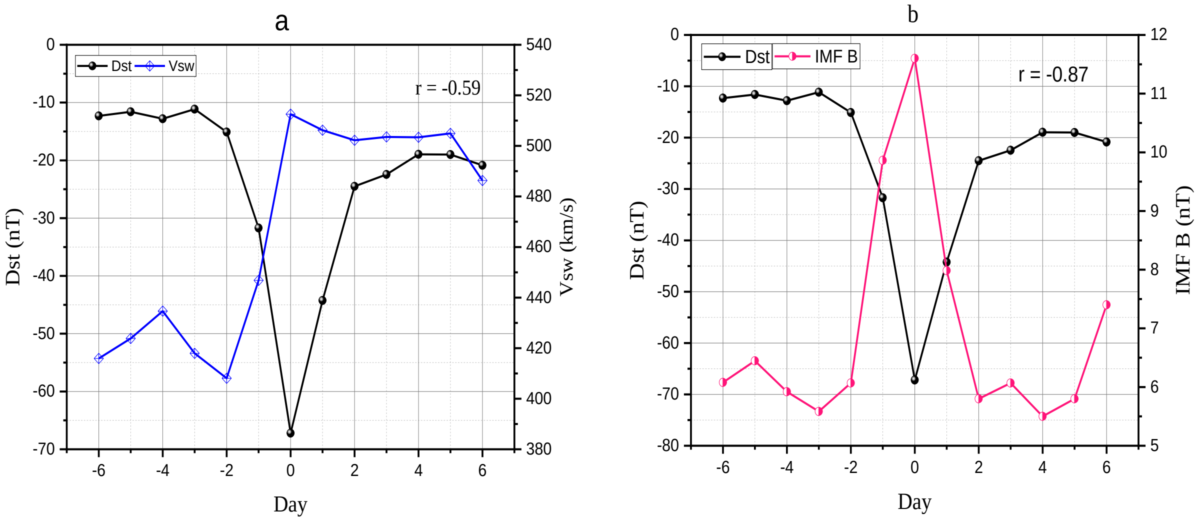
3. Result and Discussion

In this paper, the geomagnetic storms are associated with solar interplanetary characteristics such as interplanetary magnetic field, solar wind speed, product of interplanetary magnetic field and solar wind speed, Ap index & Kp index, for the rising phase of solar cycle 25 (study period 2020 to 2023). Using daily average data, a total of 20 geomagnetic storms has been found out during this study period when maximum 17 geomagnetic storms were observed in the year 2023. The highest intensity geomagnetic storm of -130 nanotesla during the year 2023 has also been tested.

The profiles of Dst index with solar wind speed (Vsw) have been compared as shown in figure 1 (a) and it has been concluded that the strongest increment in solar wind speed takes place on the occurrence day of GS (zero epoch day). The correlation coefficient between Dst index and solar wind speed was found to be moderate (r = -0.59) during the ascending phase of solar cycle 25. Figure 1 (b) focuses on comparing Dst index with IMF B and it has been inferred that these parameters are highly anti-correlated with each other (r = -0.87). it has been found out that the strongest increment in IMF B occurs on the same day when Dst achieves its minima without any time lag. The same result was also found out by Pokharia et al., 2018 for solar cycle 23 and 24, while a finite time lag of 3 hrs was found out by Saba & Gonzalez (1997). This sort of mismatch may be explained by a variation in time resolution, while the existence of time lag may also provide insight into the process underlying energy transfer.

After investigating the connection of Dst index with Vsw and IMF B independently. figure 1 (c) shows Dst index varies with the product of IMF B and Vsw (IMF B*Vsw). An interesting result namely Dst is highly anti-correlated with IMF B*Vsw has when contrasted with Vsw or IMF B alone has been arrived at. The analysis clearly demonstrates the inverse alliance between Dst and IMF B*Vsw which indicates that the strongest increment in IMF B*Vsw happens on the occurrence day of GS (zero epoch day). The average correlation between these two parameters is observed to be high (r = -0.95) during the rising phase of solar cycle 25. This result is in good agreement with the findings by Tiwari *et al.* (2011), Rathore *et al.* (2014) and Pokharia *et al.* (2018). Figure 1 (d) focused on comparing Dst index with Tsp and inferred that these parameters are highly anti-correlated with each other (r = -0.69). It has been found out that the strongest increment in Tsp occurs on the same day when Dst achieves its minima without any time lag. Additionally, two peaks on the Tsp: the first occurred on Zero Day, and the second on its third day have been discovered.

The profile of Dst and Ap index in figure 1 (e) for the ascending stage of solar cycle 25 have been compared and it has been inferred that these parameters are highly anti-correlated with each other. It has been found out that the strongest increment in Ap index occurs on the same day when Dst achieves its minima without any time lag. The same result was arrived at by Pokharia *et al.* (2018). The average correlation between these two parameters seems to be high (r = -0.85) during the rising phase of solar cycle 25. Additionally, the profile of Dst index has been compared with the Kp index as shown in figure 1 (f). It is concluded that the strongest increment in Kp index occurs on the same day when Dst achieves its minima without any time lag. The average correlation between these two parameters seems to be high (r = -0.87) during the rising phase of solar cycle 25.



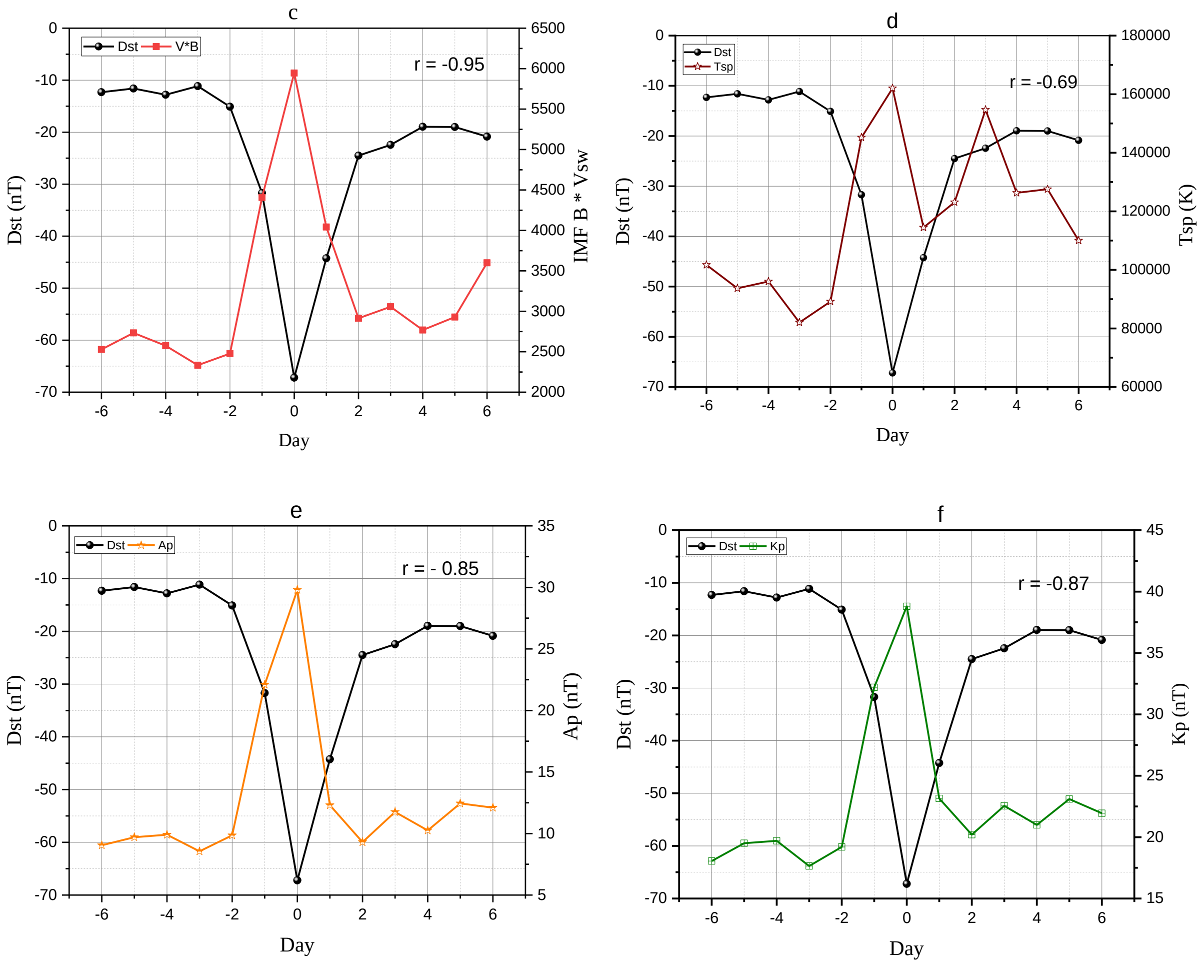


Figure-1 The result of Chree analysis from -6 days to +6 days with respect to zero epoch day (a) the variation of mean value Dst and Vsw, (b) The variation of mean value Dst and IMF B, (c) The variation of mean value Dst and IMF B*Vsw, (d) The variation of mean value Dst and Tsp, (e) The variation of mean value Dst and Ap index, (f) The variation of mean value Dst and Kp index. The variation of mean value of these parameters is plotted to depict the observational trend of two parameters on day-to-day basis for rising phase of solar cycle 25

4. Conclusion

From the present study, it is concluded that

- Dst is highly anticorrelated with IMF, Ap and Kp index.
- The correlation coefficient of Dst with IMF (r = -0.87)) and Kp index (r = -0.87) is found to be same and high while with Ap index (r = -0.85) which clearly exhibits that IMF B, Kp index and Ap index is geoeffective parameter.
- Dst is highly anti-correlated with IMF B*Vsw when contrasted with IMF B or Vsw alone.
- Geomagnetic storms occur on the same day when the product of the interplanetary field (IMF B) and solar wind speed (Vsw), interplanetary magnetic field (IMF B), solar wind speed (Vsw), solar plasma temperature (Tsp), Ap index and Kp index achieve their maxima.

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Conflict of Interest

The authors have declared that there is no conflict of interest in the manuscript.

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