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Statistical Analysis of the Most Prominent Geo-effective Coronal Mass Ejections Associated with Intense Geomagnetic Storms during Solar Cycle 24

Saket Kumar [a++], O. P. Tripathi [b*], Rashmi Sharma [b++] and P. L. Verma [c]

[a] *Department of Physics, APS University, Rewa (M.P.), India.*
[b] *Department of Physics, AKS University, Satna (M.P.), India.*
[c] *Department of Physics, Govt. Vivekanand P. G. College, Maihar, Satna (M.P.), India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Geomagnetic storms are mostly caused by strong, long-duration, interplanetary magnetic field (IMF B) and southward interplanetary magnetic field (IMF Bz) events. In the present study, a total of 23 intense geomagnetic storms (Dst≤-100 nT) have been found during the period of solar cycle 24 and used to represent the relationship between intense geomagnetic storms and solar activity parameters. One of the main solar phenomena is CMEs, when occurred earth directed, produce

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[++] *Research Scholar;*
**Corresponding author: E-mail: omkar8415@gmail.com;*

geomagnetic storms. It is also observed that these intense geomagnetic storms are associated with disturbances in solar wind plasma parameters. Positive correlation with a correlation coefficient of 0.48 has been found between the magnitude of intense geomagnetic storms and the peak value of IMF(B), 0.37 has been found between the magnitude of intense geomagnetic storms and the magnitude of IMF(B), 0.27 between the magnitude of intense geomagnetic storms and the peak value of associated disturbances in the southward component of IMF (Bz), 0.15 between the magnitude of intense geomagnetic storms and the peak value of southward component of IMF (Bz). Also, we have observed that out of 23 intense geomagnetic storms, 23 are associated with CMEs in which 14 (61%) halo CMEs and 9 (39%) partial halo CMEs occurred.

A main contributor to space weather is geomagnetic storms especially intense ones, which can severely affect ground-based and space-borne technological systems. It is thus important to investigate that the geo-effective causes of storms at the Sun atmosphere. Hence, we conclude that mainly CMEs play a important role for geomagnetic field disturbances.

Keywords: Coronal Mass Ejections (CMEs); Geomagnetic Storms (GMs); Disturbance Storm Time index (Dst index); Interplanetary Magnetic Field (IMF); Solar Wind (SW).

1. INTRODUCTION

Sun is a magnetic inconsistent star that fluctuates on different time’s scales. Solar activities are drive due to magnetic behaviour of the Sun and IMF. Solar wind carries charged particles and magnetic clouds emitted in all directions when travels from the sun; a variety of solar wind is buffeting our magnetosphere, with attractive effects. The solar wind is a stream of energetic charge particles, mainly electrons and protons, flowing outer direction from the Sun. Coronal Mass Ejections (CMEs) are large explosions of magnetic field and plasma from the Sun’s corona. Sunspot activity cycle occurs in approximate every eleven years [1,2].

Tripathi and Verma [3], Pandey et al. [4] “Geomagnetic storm is the importance of a chain of contributing events originating from the sun and evolving into a geo-effective solar wind flow near earth-space” [5, 6]. “From the results of the past three decades, it is confirmed that CMEs are large-scale magnetized plasma structures originating from closed magnetic field regions the sun: active regions complexes, filament regions, active region, and trans-equatorial interconnecting regions [5] and drive solar wind plasma conflict in terms of the magnetic field, speed, pressure, temperature and density, due to which magnetic disturbance occurred in the magnetosphere” [7]. “Geomagnetic storms occurred when the southward component of IMF, Bz-component, impinges ahead the Earth's magnetosphere and reconnects” [2]. “Several statistical observational studies have been done to investigate the properties of solar flares and/or CMEs. Zhang indicated that in 2015 the rise time of the soft X-ray flux of a flare is around half of the decay time, and the rise and decay time increases with variation in the peak flux. Regarding CMEs, [8] investigated the frequency distributions in the energy of solar flares and power law indices of the frequency distributions for flares without CMEs are steeper than those for flares with CMEs” [7,9,10].

Tripathi and Verma [3], [11,12-14] “Geomagnetic storms (Dst < - 100nT) observed during the period of 2014-2017, is identified with halo and partial halo CMEs associated with X-ray solar flares of various categories and concluded that majority of the geomagnetic storms are found that halo and partial halo CMEs associated with X-ray flares are more important event for geomagnetic storms” [4]. [15] “have concluded that H-CMEs originating from regions close to the centre of the sun are probable to be geo-effective. They have showed that, only fast H-CMEs (with space velocities greater than ~1000 km/s) and originating from the Western Hemisphere close to the solar centre could cause powerful geomagnetic storms”. [6,11] has studied “the impact of halo and partial halo CMEs to produce geomagnetic storms. He has reviewed the results obtained by previous investigators and conclude that the generation of geomagnetic storms rates can be enthusiastically explained by another definition of halo CMEs used by different authors. Partial halo CMEs are less energetic and generally originate away from the disk centre, so mostly behave like non-geo-effective and hence not produce geomagnetic storms. He has inferred those halos CMEs originating close to the disk centre are too much effective to produce geomagnetic storms. In present paper, we have studied intense geomagnetic storms associated the foremost geo-effective CMEs during solar cycle 24".

2. METHODOLOGY

Several solar and interplanetary phenomena, including coronal mass ejections and interplanetary magnetic fields, were studied using geomagnetic storms (Dst ≤-100) during solar cycle 24. Various statistical approaches, such as association auto- and cross-correlation and curve-fitting regression, were used for this investigation [3, 11, 13]. The omni-web data of the DST index was used in this paper to determine geomagnetic storms. SOHO large angle spectrometric coronagraph) and extreme ultraviolet imaging telescope (SOHO/EIT) data are used to calculate coronal mass ejections (CMEs). For the data analysis of recorded geomagnetic storms with perturbations in interplanetary magnetic field data, this study use statistical methods of association and correlation [14-18].

3. RESULTS AND DISCUSSION

In this article, we observed 23 powerful geomagnetic storms (GMSs), i.e., DST 100 nT, of which 23 coronal mass ejections are related with the CME catalogue. As indicated in Figs. 1 and 2, data analysis of geomagnetic storms and accompanying perturbations in interplanetary magnetic fields (B) was performed. All of the strong geomagnetic storms are connected with perturbations in interplanetary magnetic fields (B), with a lowest peak value of 4.2 nT to a highest peak value of 31.5 nT and a magnitude ranging from 3.7 nT to 23.7 nT. The majority of greater-magnitude geomagnetic storms are associated with considerably higher peak-value perturbations in IMF (B). The trend line of the scatter plot between the magnitude of powerful geomagnetic storms and the peak value of IMF (B) shown in Fig. 1 and the magnitude of disturbances in IMF (B) shown in Fig. 2 reveals a positive correlation. Statistical methods revealed a positive correlation with a correlation coefficient of 0.48 between peak values of disturbances in the IMF (B) and the magnitude of strong geomagnetic storms and 0.37 between the magnitude of disturbances in the IMF (B) and the magnitude of strong geomagnetic storms.

Strong geomagnetic storms and related disturbances in a southerly component of interplanetary magnetic fields (Bz) as depicted in Figs. 3 and 4. All of the strong geomagnetic storms are associated with disturbances in the southward component of interplanetary magnetic fields (Bz) with lowest peak value -7.6 nT to highest peak value -26.3 nT. Also, all of the strong geomagnetic storms are associated with disturbances in the southward component of interplanetary magnetic fields (Bz) with lowest magnitude -5.4 nT to highest magnitude 24nT. The scatter plot trend line between the size of intense geomagnetic storms and the jump in IMF (Bz) shown in Fig. 3 and the magnitude of severe

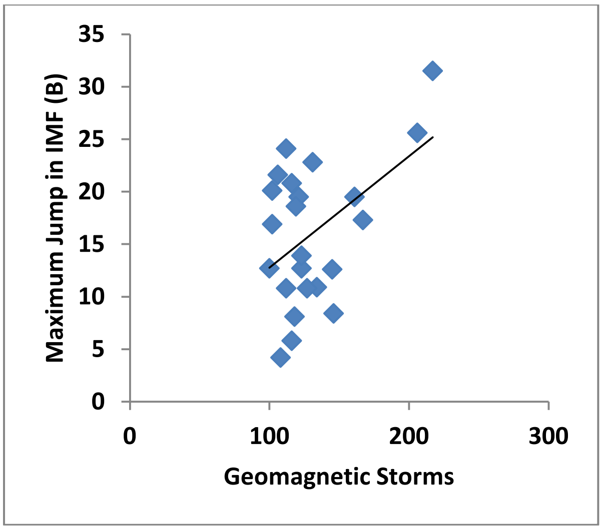

Fig. 1. Scatter plot between geomagnetic storms and maximum Jump in IMF (B)

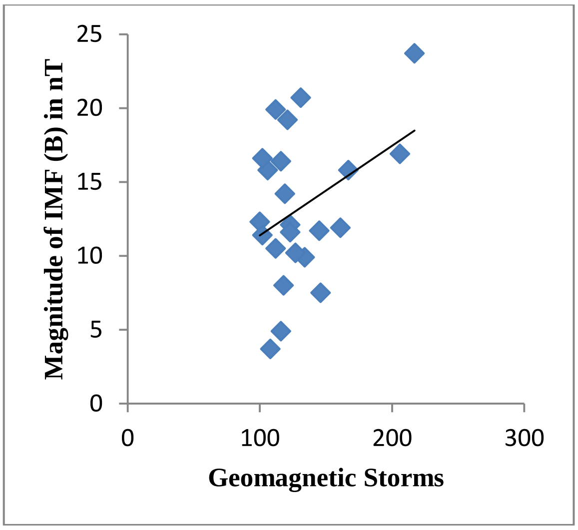

Fig. 2. Scatter plot between geomagnetic storms and magnitude of IMF (B)

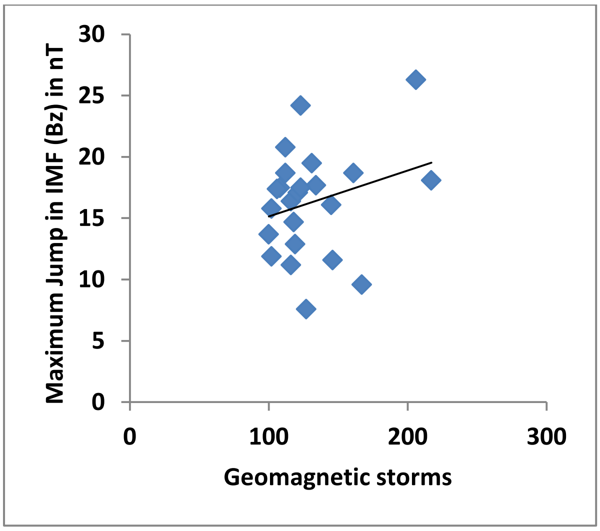

Fig. 3. Scatter plot between geomagnetic storms and maximum jump in IMF (Bz)

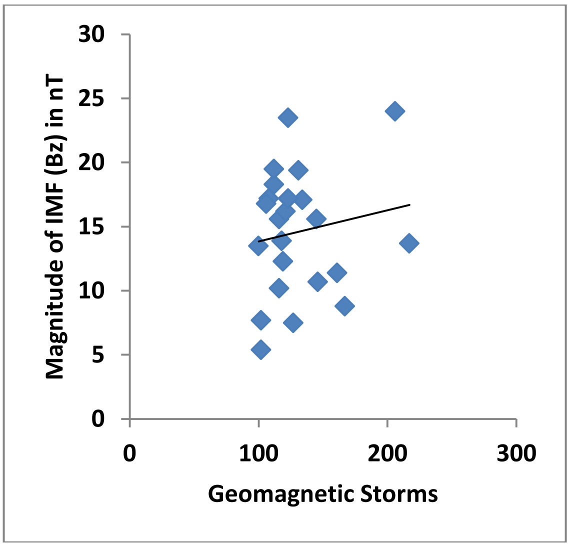

Fig. 4. Scatter plot between magnitude of strong geomagnetic storms and magnitude of IMF (Bz)

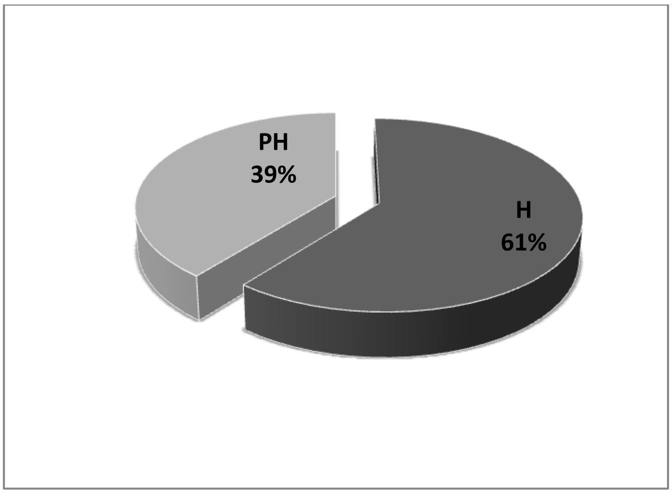

Fig. 5. Pie diagram of associated CMEs in percentage

geomagnetic storms and the amplitude of disturbances shown in Fig. 4 reveals a positive correlation. Statistical methods revealed a positive link with a correlation coefficient of 0.27 between peak values of disturbances in the IMF (Bz) and 0.15 between the magnitude of disturbances in the IMF (Bz) and the size of intense geomagnetic storms.

According to the data analysis of significant geomagnetic storms during solar cycle 24, 61% of HALO CMEs and 39% of partial HALO CMEs were caused by protracted proton events that occurred over the last several years, as shown in Fig. 5.

4. CONCLUSION

During the solar cycle 24, 23 geomagnetic storms (GMSs) based on Dst index are revealed in the current investigation. The following conclusions are obtained from data of geomagnetic storms and their association with the southern component of the interplanetary magnetic field (Bz), the interplanetary magnetic field (B), and coronal mass ejections:

1- The high-speed solar wind plasma may take the form of CMEs, or it may cause GMSs. As a result, VSW can be used to predict the strength of GMSs.
2- There is no correlation between storm duration and the quantity of CMEs involved in its occurrence. The number of CMEs that cause the storm to occur has little effect on the strength of the GMSs.
3- The IMF (B) value in GSE coordinates has a superior association and a high positive correlation with the DST index. Statistical methods revealed a positive correlation with a correlation coefficient of 0.48 between peak values of disturbances in IMF (B) and the magnitude of strong geomagnetic storms, as well as a correlation coefficient of 0.37 between the magnitude of disturbances in IMF (B) and the magnitude of strong geomagnetic storms.
4- The IMF (Bz) value in GSE coordinates has a superior association and a high positive correlation with the DST index. Statistical methods revealed a positive correlation with a correlation coefficient of 0.27 between peak values of disturbances in the IMF (Bz) and the magnitude of strong geomagnetic storms and 0.15 between the magnitude of disturbances in the IMF (Bz) and the magnitude of strong geomagnetic storms.
5- 61% of HALO CMEs are responsible for the strong geomagnetic storms.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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