

**Statistical Analysis of the Most Prominent Geoeffective Coronal Mass Ejections  
Associated with Intense Geomagnetic Storms in Solar Cycle 24**

**Abstract**

A main contributor to space weather, geomagnetic storms especially intense ones, can severely affect space-borne and ground-based technological systems. Thus, it is important to investigate the geo-effective causes of storms at the Sun and in the solar atmosphere. Geomagnetic storms are primarily caused by intense, long-duration, and southward interplanetary magnetic field (IMF) events, associated with intense and long-lasting interplanetary fields. In the present study, a total of 23 intense geomagnetic storms ( $Dst \leq -100$  nT) have been found during the period of solar cycle 24 and used to represent the relation between intense geomagnetic storms and solar activity parameters. One of the main solar phenomena is CMEs, when occurred earth directed, produce 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 ( $B_z$ ), 0.15 between the magnitude of intense geomagnetic storms and the peak value of associated disturbances in the southward component of IMF ( $B_z$ ). 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. Hence, we conclude that CMEs play a crucial role in geomagnetic storms.

**Keywords-** Coronal Mass Ejections (CMEs), Geomagnetic Storms (GMs), Disturbance Storm Time (Dst), Interplanetary Magnetic Field (IMF).

**1. Introduction**

The sun is a magnetic variable star that fluctuates on different time's scales. All solar activity is driven by the solar magnetic field. As the wind travels from the sun, it carries charged particles and magnetic clouds

emitted in all directions; some of the solar wind is constantly buffeting our magnetosphere, with interesting effects. The solar wind is a stream of energized charged particles, primarily electrons and protons, flowing outward from the Sun. Coronal Mass Ejections (CMEs) are large expulsions of plasma and magnetic field from the Sun's corona. Sunspot activity cycle occurs in approximate every eleven years<sup>4,5</sup>. A geomagnetic storm is the consequence of a chain of causative events originating from the Sun and ultimately evolving into a geo-effective solar wind flow near earth space<sup>1,6</sup>. 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, filament regions, active region complexes, and trans equatorial interconnecting regions<sup>5</sup> and drive solar wind (SW) disturbances in terms of the magnetic field, speed and density, which in turn cause magnetic disturbance in the magnetosphere<sup>11</sup>. It has been established by now that geomagnetic storms occur when the southward component of interplanetary magnetic field (IMF),  $B_z$ , impinges upon the Earth's magnetosphere and reconnects<sup>5</sup>. Several statistical observational studies have been done to investigate the properties of solar flares and/or CMEs. <sup>12</sup>indicated that the rise time of the soft-X-ray flux of a flare is approximately half of the decay time, and the rise and decay times increase with variations in the peak flux of the soft X-ray. Regarding CMEs, <sup>9</sup>investigated the frequency distributions in the energy of solar flares and found that the power law indices of the frequency distributions for flares without CMEs are steeper than those for flares with CMEs.<sup>8</sup>have studied geomagnetic storms ( $Dst < -100nT$ ) observed during the period of 2014 -2017, with halo and partial halo coronal mass ejections associated with X-ray solar flares of different categories and concluded that they have concluded that majority of the observed geomagnetic storms are found that halo and partial halo CMEs associated with X ray solar flares are most potential candidates for production of geomagnetic storms. <sup>7</sup>have concluded that halo coronal mass ejections (H-CMEs) originating from regions close to the centre of the sun are likely to be geoeffective. They have showed that, only fast halo CMEs (with space velocities higher than  $\sim 1000$  km/s) and originating from the Western Hemisphere close to the solar centre could cause intense geomagnetic storms. <sup>6,10</sup>has studied the role of halo and partial halo CMEs in producing geomagnetic storms. He has reviewed the results obtained by previous investigators and concluded that the generation of geomagnetic storms rates can be readily explained by the different definition of halo CMEs used by different authors. Partial halos are less energetic and generally originate far from the disk centre, so most of them behave similar to the non-geo-effective CMEs and hence most of the partial halo CMEs may not produce geomagnetic storms. He has inferred that halo CMEs originating close to the disk centre or very much effective in producing geomagnetic storms. Since coronal plasmas are heated to 10–20 MK during solar flares, the characteristics of solar flares are often identified through

X-ray observations. The magnitude of a solar flare is usually defined by the peak flux of the soft-X-ray measured by the Geostationary Operational Environmental Satellite (GOES) and classified into several classes (A, B, C, M, and X). In this investigation, we have studied intense geomagnetic storms associated the foremost geo-effective coronal mass ejections during solar cycle 24.

## **2. Methodology**

In this paper various solar and interplanetary phenomena such as: coronal mass ejections, and interplanetary magnetic fields data have been analyzed with geomagnetic storms ( $Dst \leq -100$ ) during solar cycle 24 (5). For this analysis different statistical methods such as association auto and cross correlation, curve fitting regression have been used. For this paper, the omni web data of Dst index have been used to determine geomagnetic storms, The data of coronal mass ejections (CMEs) is taken from SOHO – large angle spectrometric coronagraph (LASCO) and extreme ultraviolet imaging telescope (SOHO/EIT) data. This study uses statistical method association and correlation for data analysis of the observed geomagnetic storms with disturbances in interplanetary magnetic field data.

## **3. Data analysis and results**

In this paper, we have been observed 23 geomagnetic storms (GMSs) which are of intense i.e., ( $Dst \leq -100$  nT) have been selected, out of which 23 coronal mass ejections are found to be associated CME catalogue. From the data analysis of geomagnetic storms and associated disturbances in interplanetary magnetic fields (B) is shown by (fig.1,2). It is observed that all the strong geomagnetic storms are associated with disturbances in interplanetary magnetic fields (B) with lowest peak value 4.2 nT to highest peak value 31.5nT and lowest magnitude 3.7 nT to highest magnitude 23.7 nT. Most of the strong geomagnetic storms of higher magnitudes are associated with relatively higher peak value disturbances in IMF (B). The trend line of scatter plot between the magnitude of strong geomagnetic storms and the peak value of IMF (B) given in (fig. 1) and magnitude of strong geomagnetic storms and magnitude of disturbances in IMF (B) given in (fig. 2) shows positive correlation. A positive correlation with correlation coefficient 0.48 between peak values of disturbances in IMF (B) and magnitude of strong geomagnetic storms and 0.37 between the magnitude of disturbances in IMF (B) and magnitude of strong geomagnetic storms have been obtained by statistical methods (Loewet al. 1997).

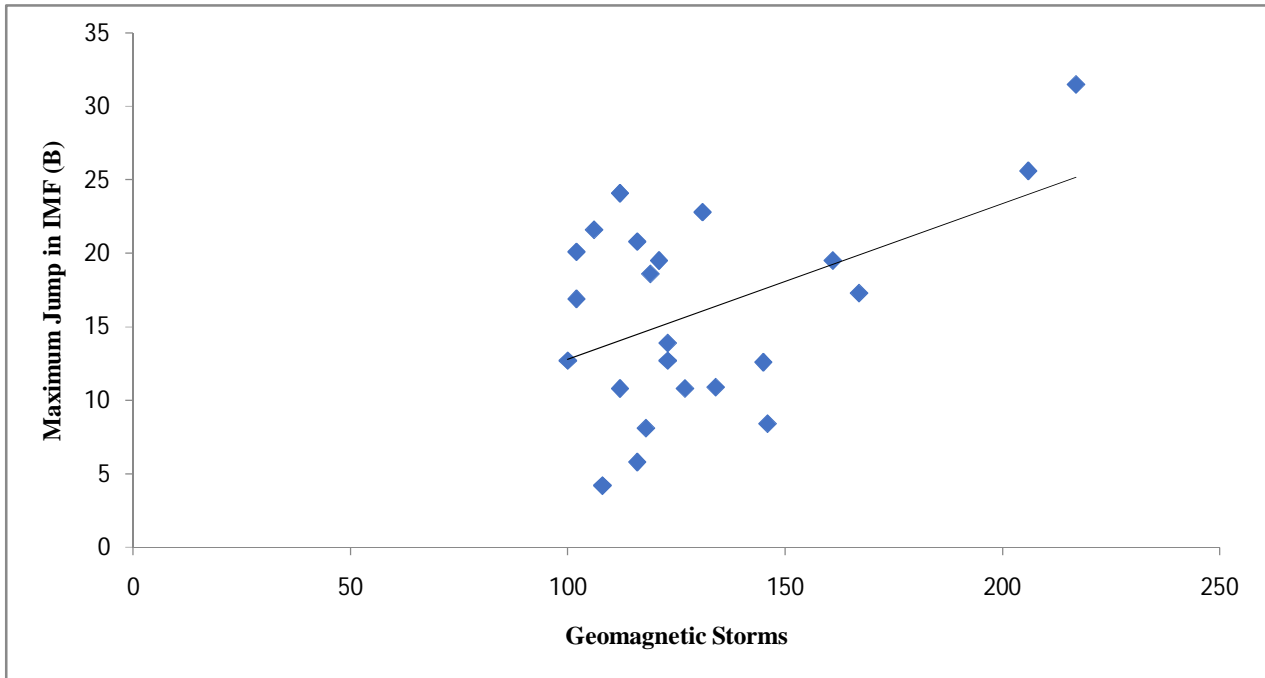


Fig. 1- Scatter plot between geomagnetic storms and maximum Jump in IMF (B)

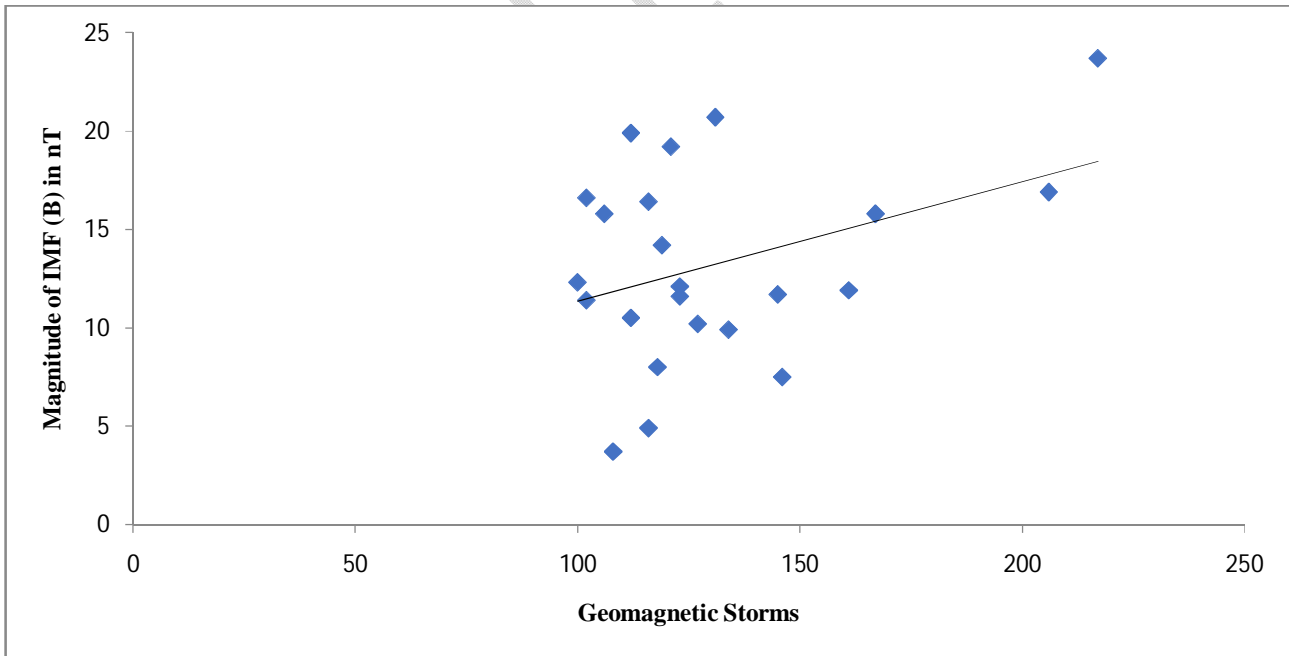


Fig. 2- Scatter plot between geomagnetic storms and magnitude of IMF (B)

From the data analysis of strong geomagnetic storms and associated disturbances in a southward component of interplanetary magnetic fields (Bz) shown in (fig. 3 and 4). It is observed that all 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 and lowest magnitude  $-5.4$  nT to highest magnitude  $24$  nT. The trend line of scatter plot between the magnitude of strong geomagnetic storms and the Jump in IMF (Bz) given in (fig. 3) and magnitude of strong geomagnetic storms and magnitude of disturbances in IMF (Bz) given in (fig. 4) shows positive correlation. A positive correlation with correlation coefficient  $0.27$  between peak values of disturbances in IMF (Bz) and  $0.15$  between the magnitude of disturbances in IMF (Bz) and magnitude of intense geomagnetic storms obtain by statistical methods.

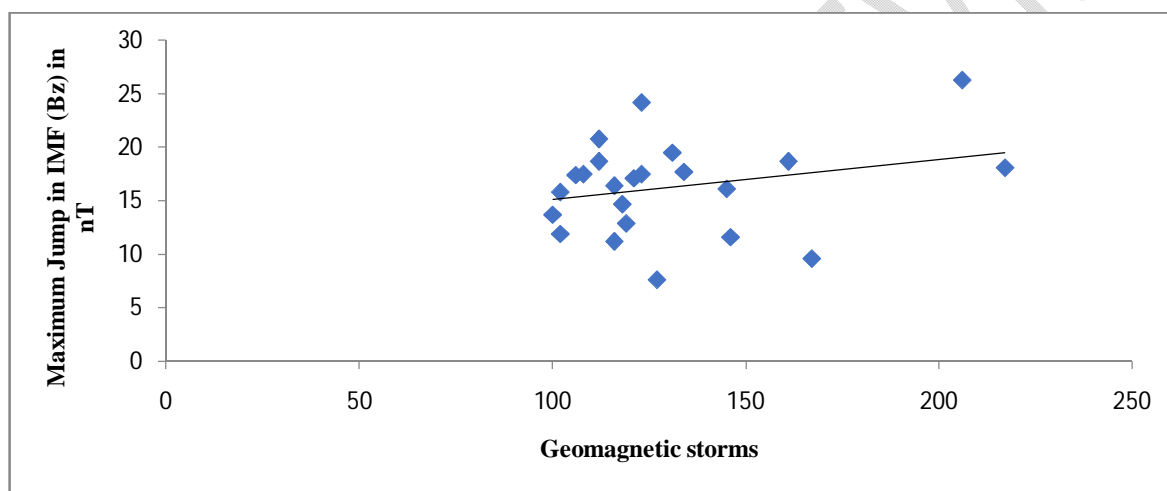


Fig. 3- Scatter plot between geomagnetic storms and maximum jump in IMF (Bz)

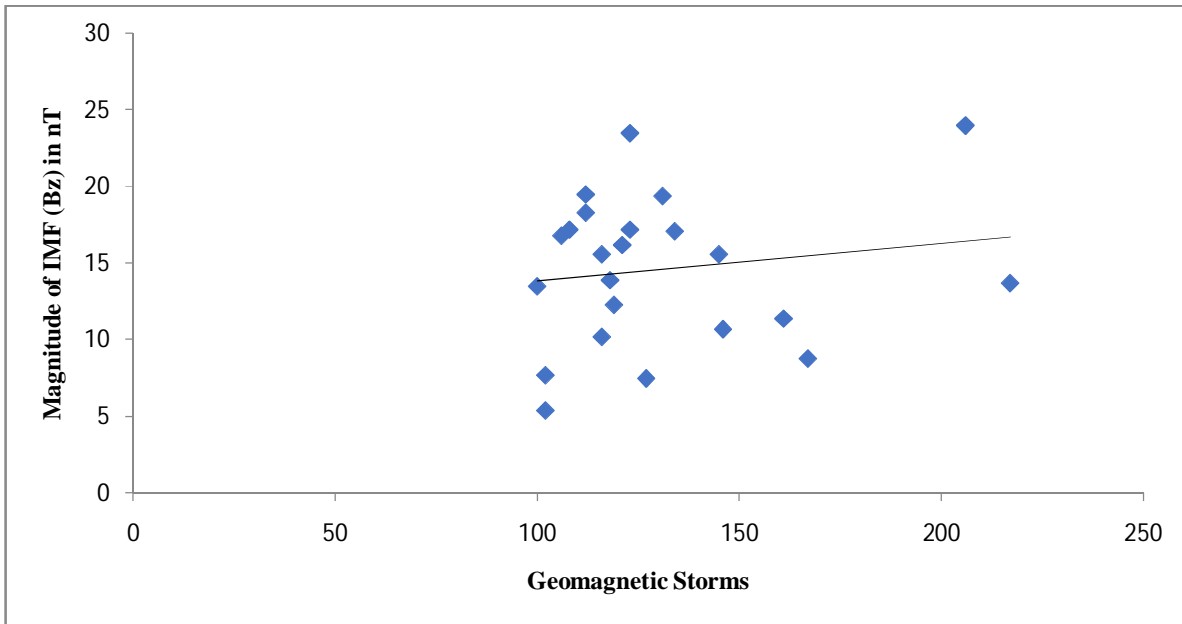


Fig. 4- Shown Scatter plot between magnitude of strong geomagnetic storms and magnitude of associated disturbances in IMF.

From the data analysis of strong geomagnetic storms during the period of solar cycle 24, we have found 61% of HALO CMEs and 39% of Partial Halo CMEs due to prolonged proton events occurred due to the last several years which is shown in (fig. 5).

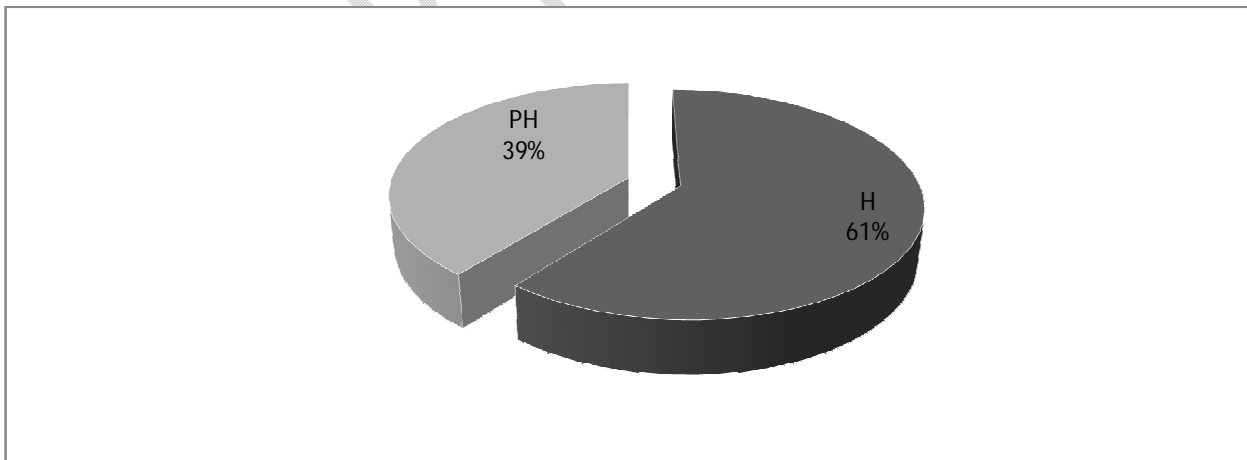


Fig. 5 Pie diagram of associated CMEs in percentage

## 4. Conclusion

In present study, 23 geomagnetic storms (GMSs) ( $Dst \leq -100$ ) are found during the period solar cycle 24. On the basis of geomagnetic storms association with southward component of interplanetary magnetic field ( $B_z$ ), interplanetary magnetic field ( $B$ ) and coronal mass ejections data are analyzed with following conclusions:

- 1- The high-speed solar wind plasma may be in the form of CMEs or else is more likely to cause the GMSs. Hence, VSW may be taken as a reliable indicator of strength of GMSs.
- 2- No relationship is observed between storm duration and the number of CMEs involved in its occurrence. The intensity of the GMSs is also independent of the number of CMEs causing the occurrence of the storm.
- 3- The IMF ( $B$ ) value in GSE coordinates shows better relationship with Dst index and shows a strong positive correlation. A positive correlation with correlation coefficient 0.48 between peak values of disturbances in IMF ( $B$ ) and magnitude of strong geomagnetic storms and 0.37 between the magnitude of disturbances in IMF ( $B$ ) and magnitude of strong geomagnetic storms have been obtained by statistical methods.
- 4- The IMF ( $B_z$ ) value in GSE coordinates shows better relationship with Dst index and shows a strong positive correlation. A positive correlation with correlation coefficient 0.27 between peak values of disturbances in IMF ( $B_z$ ) and magnitude of strong geomagnetic storms and 0.15 between the magnitude of disturbances in IMF ( $B_z$ ) and magnitude of strong geomagnetic storms have been obtained by statistical methods
- 5- 61% of HALO CMEs are responsible for the strong geomagnetic storms.

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