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# Geomagnetic Storms: Their Occurrence and Relationship with Solar Activities during the Solar Cycles 23-24

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## Abstract

Disturbances in the geomagnetic field are mainly connected with the solar activity, Solar Cycle (SC), configuration, and strength of several interplanetary/solar features. The current study aims to examine the occurrences of Geomagnetic Storms (GSs) with minimum Dst ≤ - 50nT and find out their connection with solar activities over two SCs (SCs 23 and 24). Five hundred twenty-four GSs (moderate, intense, and severe GSs) that occurred in the period from 1996 to 2019 were selected for this purpose. The occurrences of these GSs were compared with phases of the two SCs and halo Coronal Mass Ejections (CMEs) that occurred in the same period. Results of the current study indicate that the occurrence of GSs is highly correlated with the solar/sunspot cycle. It was observed that GSs are most likely occurring in phase with these SCs. The results also show positive correlations of the selected GSs versus the Sunspot Number (SN) and the halo CMEs with reasonably high values of correlation coefficients (R) especially for intense and super GSs. In addition, the study suggests that intense and super GSs are

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strongly depending on the magnitude and duration of the fluctuations in the Interplanetary Magnetic Field (IMF) parameters with relatively high correlation coefficients.

Keywords: Geomagnetic storms, Solar cycle, Coronal Mass Ejections (CMEs), Interplanetary Magnetic Field (IMF), Disturbance Storm Time (DST).

## 1. **Introduction**

The Solar Cycle (SC), also known as the sunspot cycle, is a roughly 11-year periodic variation observed in the activity of the Sun and can be measured in terms of changes in the Sunspot Number (SN). Amounts of solar radiations, ejected solar materials, and numbers of sunspots show synchronized variations through the period of a SC, starting from a period of minimum activity to a period of maximum activity and then back again to a period of minimum activity (Hathaway, 2010; Liu et al, 2011).

Changes occurring in association with the Sun's activities can influence the near-Earth environment. The interaction of ejected solar materials during large and violent solar eruptions, which are known as Coronal Mass Ejections (CMEs), with the Earth's environment is considered the main source of several space weather phenomena (NAS, 2008). The most significant phenomenon among them is the Geomagnetic Storm (GS), which is a significant disturbance in the Earth's magnetosphere. When this interaction is strong, serious and severe GSs are observed. When CMEs occur, it usually requires about 2-3 days from the launching of these CMEs for the generated GSs to reach the Earth and to affect its magnetic field. In addition, the capability of CMEs to cause significant GSs depends on several factors such as the type of CMEs, their speed, magnetic field orientation, source regions, origin, and also their influence on solar parameters near the Earth (Singh et al., 2021; Temmer, 2021).

In addition, numerous variations in the Interplanetary Magnetic Field (IMF) parameters can play an important role in controlling the occurrence of GSs (Fairfield and Cahill, 1966). For example, the magnitude of the average IMF (B) and the change in the direction of the north-south component of the IMF (Bz) are significant factors in controlling the quantity of solar energy that can be transferred to the Earth's magnetic field causing the GSs (Arnoldy, 1971). Therefore, GSs occur due to disturbed conditions in both the IMF and solar parameters caused by several space weather events (Akasofu and Chapman, 1963).

At the ground surface, a GS is observed as a quick drop in the intensity of the measured geomagnetic field. This decrease can last for several hours, after that, the intensity of the geomagnetic field undergoes a gradual recovery over a period that can be extended to several days. The study of these global disturbances (GSs) of the geomagnetic field is significant not only in understanding the interaction processes in the solar-terrestrial environment but also because such GSs can interrupt various important infrastructures such as the electric power systems which are very vulnerable to the negative effects of GSs (Kappenman, 1996). Moreover, GSs can cause many severe problems such as satellite damage, communication failure, and navigational problems (NAS, 2008 and 2009).

For the last few decades, the cause of GSs has been examined through several correlative studies (Wu and Lepping, 2006; Verma et al., 2009; Rathore, et al., 2014; Singh et al., 2017; Balachandran et al., 2021). However, many researchers have studied the influence of solar activity on the occurrence of the GSs; the results of these studies, taken together, suggest further investigation of the impact of solar activity on the occurrence and intensity of the GSs. In the current research work, a statistical study has been performed to analyze GSs recorded during the SCs 23-24 by various geomagnetic observatories and identified with the help of the disturbance-storm time (Dst) index. Moreover, various IMF components and solar parameters were examined to identify their relationship to the occurrence of GSs.

## 2. Phases and classification of geomagnetic storms

As previously mentioned, a GS is a major turbulence in Earth's magnetic field that takes place when an efficient amount of energy is transferred from the solar wind to the space environment around the Earth. It is generally identified by variations in the DST index (Gonzalez et al., 1994). That index estimates the variations that occurred in the horizontal geomagnetic component (H-component) recorded at the magnetic equator by a number of magnetometers installed at equatorial geomagnetic observatories. The DST index is calculated based on hourly geomagnetic data and is reported in near real-time. The DST index ranges between +20 and −20 nano-Tesla (nT) during quiet times (Sugiura and Kamei, 1991).

Generally, a GS has three phases: the initial, main, and recovery phases, as shown in Figure 1. The initial phase is characterized by an increase of the DST index (or one-minute data of the H-component) by 20 - 50 nT in a short time (tens of minutes). The initial phase is also mentioned as a Storm Sudden Commencement (SSC). It is worth mentioning that not all GSs have an initial phase and not all abrupt increases in DST index are followed by GSs. The main phase of a GS is defined by DST index decreasing to less than −50 nT. Selecting the (−50 nT) as a value to define a GS is to some extent arbitrary. The main phase typically lasts for 2–8 hours. The recovery phase starts when the DST index increases from the minimum value up to the quiet time value (Gonzalez et al., 1994). The duration of recovery phase can vary from several hours to a few days. The size of a GS is classified according to the minimum DST index as moderate (−50 nT ≥ minimum of DST > −100 nT), intense (−100 nT ≥ minimum DST > −250 nT) or super-storm (minimum of DST ≤ −250 nT), see Cander and Mihajlovic (1998) for more details.

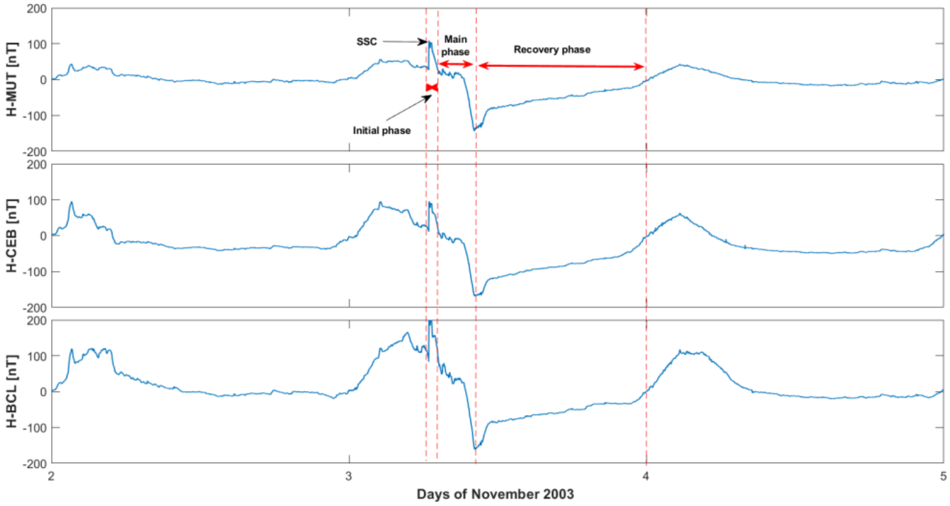

**Figure 1:** Geomagnetic data recorded at three geomagnetic stations located at equatorial and very low latitude regions showing geomagnetic storm occurred on 4 November 2003.

## 3. Data sources and selection criteria

The DST index data, provided by the World Data Center (WDC) for Geomagnetism, Kyoto, is used as the key to define and select the GSs. Three types of DST data are available, which are the real- time, provisional, and final DST indices. The occurrence of GSs, identified by the DST index data, is compared with the SN data, IMF components (B and Bz in nT), and solar parameters (Flow Pressure in nPa, and Electric Field Ey in mV/m), provided by the OMNI website (www.omniweb.gsfc.nasa.gov). The data of CMEs have been taken from the CME catalogue, which is produced at the CDAW Data Center by NASA and the Catholic University of America in cooperation with the Naval Research Laboratory.

Identification and selection of GSs, depending on the Dst index, follow the procedures of Loewe and Prölss (1997). According to the above-mentioned classification of GSs and depending on the Dst index data, five hundred twenty-four storms (DST ≤ -50 nT) that occurred during the SCs 23-24 from 1996 to 2019 were selected. In some events, DST data is found to show two minima before restoring to the quiet values. If a distinguished separation and a recovery period are observed between the two relative minima, they are considered as two GSs. On the contrary, if the two DST minima do not have a clear separation or recovery period, the GS is treated as a single event (Kamide et al., 1998).

## 4. Data analysis and results

The connection between solar activity and SC is known since long time ago. The solar activity can be measured by the occurrence of sunspots. As solar activity increases, the occurrence of sunspots does (Owens et al., 2021). According to that, the SC can be distinguished during its 11-year periodic variation into four phases, which are the minimum, ascending, maximum, and descending. The GSs have been observed after the appearance of sunspots, which indicates a connection between them (McIntosh et al., 2020). In addition, the occurrence of GSs depends on the phase of the SC. Since GSs and their effects on both space and ground-based infrastructures are of great interest to various research fields, several studies had investigated the long-term correlation between solar and geomagnetic activities.

The selected GSs during the 23 and 24 SCs are classified into two categories; four hundreds and four of them are classified as moderate GSs (-50 nT ≥ minimum Dst > -100 nT), while one hundred and twenty of them are classified as intensive and severe GSs (minimum Dst ≤ -100 nT). The current study refers to intense and super GSs as large GSs. The occurrences of the selected GSs were examined with the SN during the above-mentioned SCs to clarify the relationship between them. Figure 2 shows the selected GSs, compared with the sunspot cycle for SCs 23-24. In this figure, the yearly mean of the sunspots number is compared with the yearly number of all selected GSs with minimum Dst ≤ −50 nT (panel A), moderate GSs (panel B), and with large GSs (panel C). This figure clearly shows that GSs occur during all SC phases. For GSs with DST ≤ -50 nT, they exactly follow the phase of SCs, as shown in panel (A) of Fig. 2. During solar minima, few numbers of GSs occurred. Also, it is found that maximum numbers of GSs have occurred during solar maxima. Therefore, according to Fig. 2, the degree of the geomagnetic activities is comparative to that of the solar activities, which means that the occurrence rate of GSs tends to follow the SC pattern. In addition, moderate storms (panel (B) of Fig. 2) show similar temporal distribution where their occurrence is almost a coincidence with the phases of SC. On the contrary, large GSs do not exactly follow the phase of SCs and show different behavior mainly during the ascending and descending phases of the SCs, as shown in panel (C) of Fig. 2. Large GSs are mainly increased around the ascending, maximum, and descending phases of the SC-23. For SC 24, large GSs slightly increased during the ascending phase and with notable decrease during 2013.

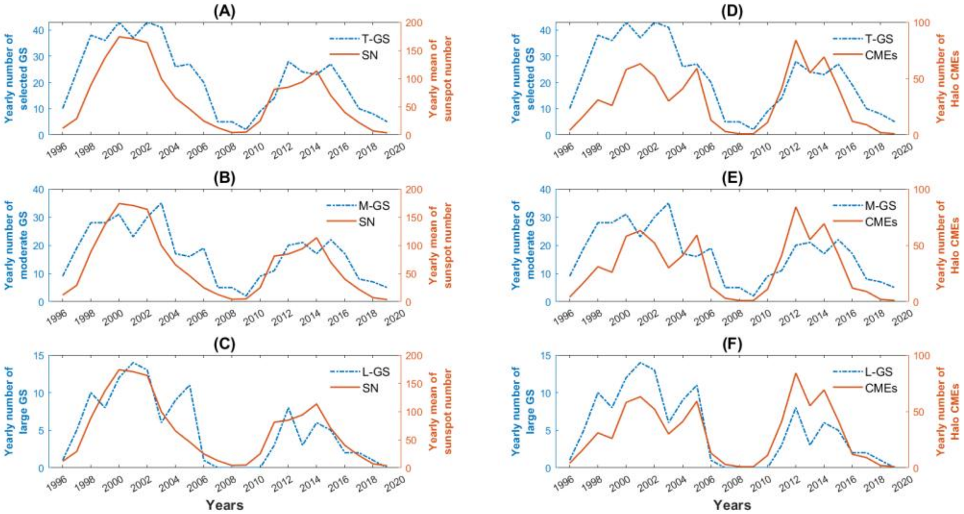

**Figure 2:** Yearly mean of SN during SCs 23 and 24 is superimposed on yearly numbers of all selected (T), moderate (M), and large (L) GSs (panels A, B, and C, respectively) while yearly number of halo CMEs during SCs 23 and 24 is superimposed on yearly numbers of all selected, moderate, and large GSs as presented in panels D, E, and F, respectively.

Since the occurrence of GSs varies in-phase with the sunspot cycle, correlations between SN and the GSs have been studied. Generally, scattered plots clarify the relation between pairs of datasets that have relationships varying with time. Thus, a similar approach is followed to test the nature of relationships and correlation between different categories of GSs and the SN. Moreover, the correlation coefficients (R) between them are calculated during the SCs 23-24. Figure 3 shows the correlation graphs between the SN and all selected GSs (panel A) with R= 0.87, moderate GSs as shown in panel B with R=0.82, and with large GSs (panel C) with R=0.84. These results confirm that the occurrence of GSs is highly correlated with the SN and phases of SCs.

An important observation is that the large GSs tend to occur more often during the ascending and descending phases of the SCs. (see panel (C) in Figure 2). Such an increase in the occurrence of large GSs during the ascending and descending phases of SCs can be linked with some space weather events, such as the CMEs. Therefore, the study is extended to examine the possible connection and influence of CMEs on the occurrence of GSs.

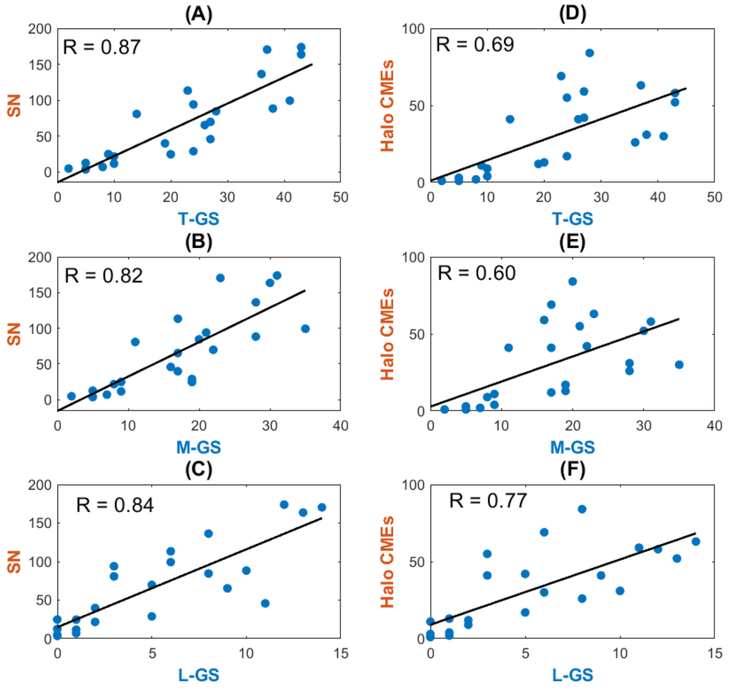

**Figure 3:** scattered pots of yearly mean of SN versus yearly numbers of all selected (T), moderate (M), and large (L) GSs during SCs 23 and 24 (panels A, B, and C, respectively) while scattered plots of yearly number of halo CMEs versus yearly numbers of all selected, moderate, and large GSs during SCs 23-24 are presented in panels D, E, and F, respectively. The regression lines are shown in solid black.

CMEs are the most common form of solar activity. The CMEs that are directed to the Earth are called halo CMEs (angular width = 360°). They got that name because of the way they look in coronagraph images (Howard et al., 1982). The halo CMEs are considered the main drivers of geomagnetic activity (Zhang et al., 2003). Thus, we have studied the correlation between halo CMEs and the selected GSs that were observed during the period of 1996-2019. In addition, we aimed to examine the expected association between the large GSs and the halo CMEs. Panels [D], [E], and [F] of figure

2 respectively show the relationship between the halo CMEs and selected, moderate, and large GSs. The large GSs are found to be in a good correlation with the halo CMEs (panel F) with peaks corresponding to the ascending and descending phases of SCs. The correlation plots of the halo CMEs against the selected, moderate, and large GSs are presented in panels [D], [E], and [F] of Figure 3 with correlation coefficients of 0.69, 0.6 and 0.77 respectively. This indicates that the occurrence of large GSs agrees with the occurrence of halo CMEs.

Since the space weather events such as CMEs are widely recognized as being responsible for generating disturbances in the solar parameters as well as Earth's magnetic field, we examined the temporal variations of some interplanetary and solar parameters along with the occurrence of GSs. The occurrence of GSs depends on various solar and interplanetary parameters (Akasofu, 1983, Gosling, 1993, Adebesin and Chukwuma, 2008). Therefore, the influence of magnitude of IMF (B), IMF (Bz), Flow Pressure (FP), and the Electric field (Ey) on the occurrence of GSs (as revealed from the DST index) for one month (continuous hourly data sets of April 2001) was investigated to determine the geoeffective parameters that are controlling the concurrence of GSs, as shown in figure 4. From visual inspection, there is a good correlation between the examined parameters during the occurrence of GSs (expressed by DST index), as shown in the period marked by red rectangles in Figure 4. On the other hand, periods of disturbance in the interplanetary and solar parameters were observed but with no corresponding remarkable change in the DST index (means no GSs) as it presented by the blue rectangles in Figure 4. For better understanding of this observation, the correlation between the DST index and other parameters was examined and plotted in Figure 5, which indicates low correlation coefficients between the DST index and other parameters. The correlation coefficients of DST index versus IMF (B), IMF (Bz), FP, and Ey were (-0.41), (0.25), (-0.23), and (-0.24) respectively. The reason behind the obtained low correlation coefficients is that the occurrence of GSs can be controlled by other parameters or conditions such as the direction & magnitude of IMF, the solar wind speed, and the type of CMEs & solar flares.

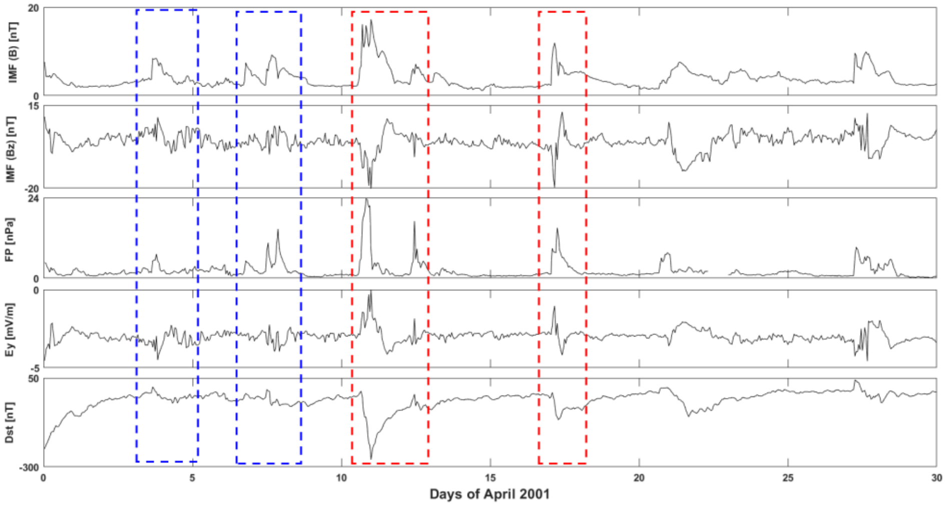

**Figure 4:** One-month hourly data of the IMF (B), IMF (Bz), FP, Ey and DST index during April 2001. Red rectangles indicate good correlations between the occurrence of GSs (expressed by DST index) and the fluctuations in IMF (B), IMF (Bz), FP, and Ey parameters, while blue rectangles indicate periods of disturbance in these parameters but with no corresponding GSs (no remarkable change in the DST index).

A series of powerful solar flares and CMEs erupted from the Sun during April 2001 and November 2003 (Lakhina et al., 2006). The impact of these events on the ground magnetic field measurements at polar and equatorial stations was studied to understand the obtained low values of correlation coefficients as revealed from Figure 5. The polar geomagnetic stations are Kotel'nyy (KTN) and Tixie (TIK), while the equatorial geomagnetic stations are Bac Lieu (BCL) and Cebu (CEB). (See Table 1).

**Table 1:** Geographic and geomagnetic coordinates of the geomagnetic stations used in the current study from MAGDAS/CPMN Network.

| **Station Name** | **Abbrev.** | **Country** | **Geographic Latitude** | **Geographic Longitude** | **Geomagnetic Latitude** | **Geomagnetic Longitude** |
|---|---|---|---|---|---|---|
| **Kotel'nyy** | KTN | Russia | 75.94 | 137.71 | 69.94 | 201.02 |
| **Tixie** | TIK | Russia | 71.59 | 128.78 | 65.67 | 196.88 |
| **Muntinlupa** | MUT | Philippine | 14.37 | 121.02 | 4.95 | 193.26 |
| **Cebu** | CEB | Philippine | 10.36 | 123.91 | 1.06 | 196.26 |
| **Bac Lieu** | BCL | Vietnam | 9.32 | 105.71 | -0.36 | 178.36 |

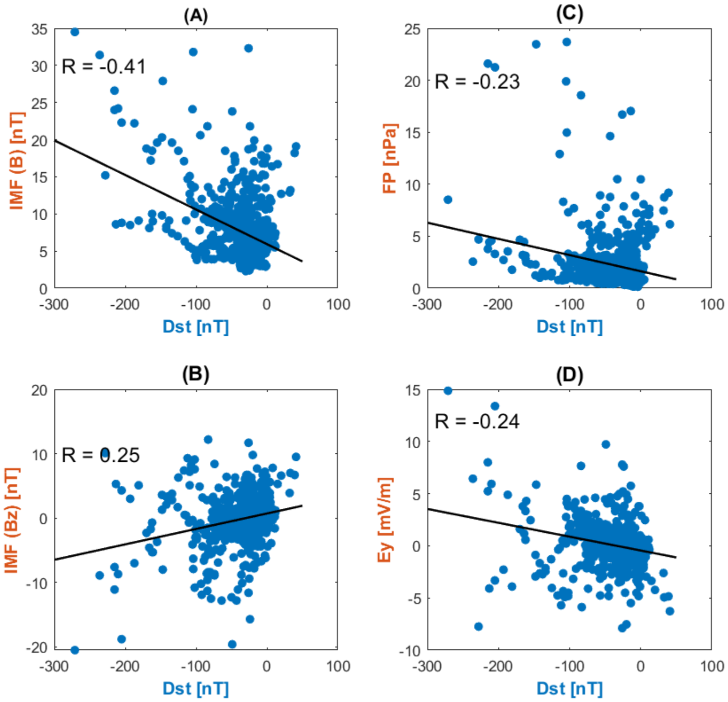

**Figure 5:** Scattered plots of the DST index against the IMF (B), IMF (Bz), FP, and Ey for one month (April 2001) are presented in panels (A), (B), (C), and (D) respectively. The regression lines are shown in solid black.

Figure 6 represents two different ground geomagnetic measurements in response to fluctuations in the interplanetary and solar parameters during two intervals of time. The ground geomagnetic measurements at polar and equatorial stations along with the variation in the interplanetary and solar parameters during the period between 10-14 April 2001 are presented in the left side panels of Figure 6 while in the right side panels for the period from 5-9 November 2003. One-minute data of the IMF (B), IMF (Bz), and Ey in the upper three panels are compared with the geomagnetic data recorded at two geomagnetic stations in the lower two panels. In the left side of this figure, the interplanetary and solar parameters show very intense fluctuations [IMF (B) 40nT nT and IMF (Bz) -35nT] from 10-14 April 2001. The impact of these intense fluctuations produced strong GS at both the polar (TIK) and equatorial (CEB) geomagnetic H-component data, with minimum values of -1960nT and -325nT respectively. On the other hand, the fluctuations during the period 5-9 November 2003 were limited, compared with those of 10-14 April 2001 where IMF (B) and IMF (Bz) were 15nT and -8nT respectively. In this case, a clear GS (-633nT) at only the polar station (KTN) was observed. At the equatorial station (BCL), such GS couldn’t be observed due to the small amplitude fluctuations of IMF (B) and IMF (Bz) as well as their short duration. From this figure, it is clear that the intensity of the GS is controlled mainly by the magnitude of the IMF (B) and the negative IMF (Bz) as well as their duration. For that reason, a large magnitude of the southward IMF (Bz) with a long duration could give rise to stronger GS on 11 April 2001 than on 6 November 2003.

This result means that the geomagnetic disturbances observed by ground-based magnetometers can be limited to the polar region unless the fluctuations in the IMF (B) and IMF (Bz) magnitudes are significant and also have a long duration (several hours). This observation is very important and can be used to explain the obtained low correlation coefficients between the DST index and the interplanetary and solar parameters shown in Figure 5. When the fluctuations in interplanetary and solar parameters don’t meet the requirements (concerning the intensity and duration) for generating equatorial GSs, they still are able to generate polar GSs, and since the DST index is computed from equatorial ground geomagnetic stations only, low correlations between the DST index and other interplanetary and solar parameters can be observed as shown in Figure 5.

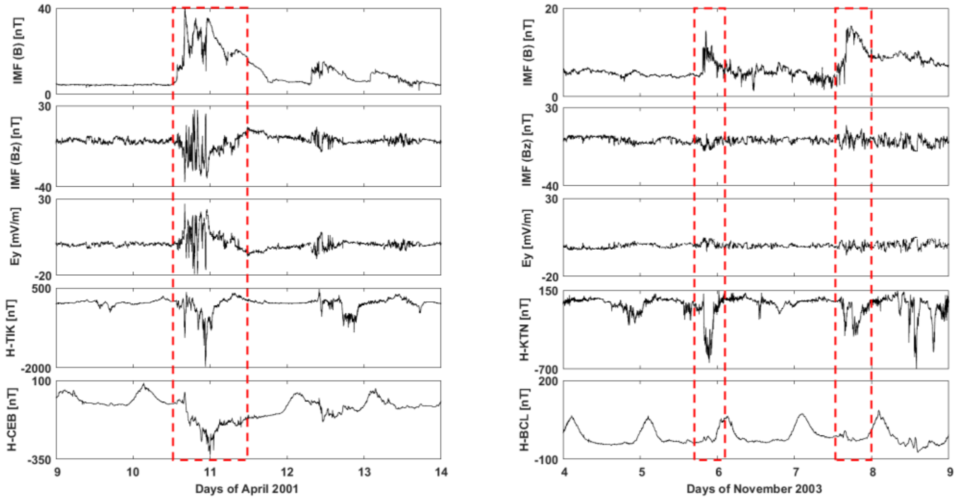

**Figure 6:** Left side (10-14 April 2001), the IMF (B), IMF (Bz), and Ey are presented in the top 3 panels respectively, while the variations of the horizontal geomagnetic component recorded at the TIK and CEB geomagnetic stations are presented in the bottom 2 panels, respectively. Right side (5-9 November 2003), the IMF (B), IMF (Bz), and Ey are shown in the top 3 panels, respectively, while the variations of the horizontal geomagnetic component recorded at the KTN and BCL geomagnetic stations are presented in the bottom 2 panels, respectively.

Moreover, the variations of the above-mentioned interplanetary and solar parameters were examined during the 120 large GSs that occurred in the period from 1996 to 2019 to confirm that observation and also to clarify their impact on the occurrence of GSs. All GSs were studied at their main phases (starting from the maximum values of DST index that occurred prior to the major decrease until reaching their minimum values). The interplanetary/solar parameters were examined during the same main-phase time frame. Thus, the correlations between these parameters and large GSs were examined. Figure 7 shows scattered plots and correlation coefficients of minimum DST index versus other parameters. The correlation coefficients of Dst index versus IMF (B), IMF (Bz), FP, and Ey were (-0.74), (0.76), (-0.52), and (-0.62), respectively. A high correlation of the DST index versus the IMF (B) and IMF (Bz) was observed. This analysis allows obtaining a remarkable degree of correlation between them. The correlation coefficients obtained from this research work strongly suggest that the magnitude and duration of IMF (B), and IMF (Bz) fluctuations play a key role in generating GSs.

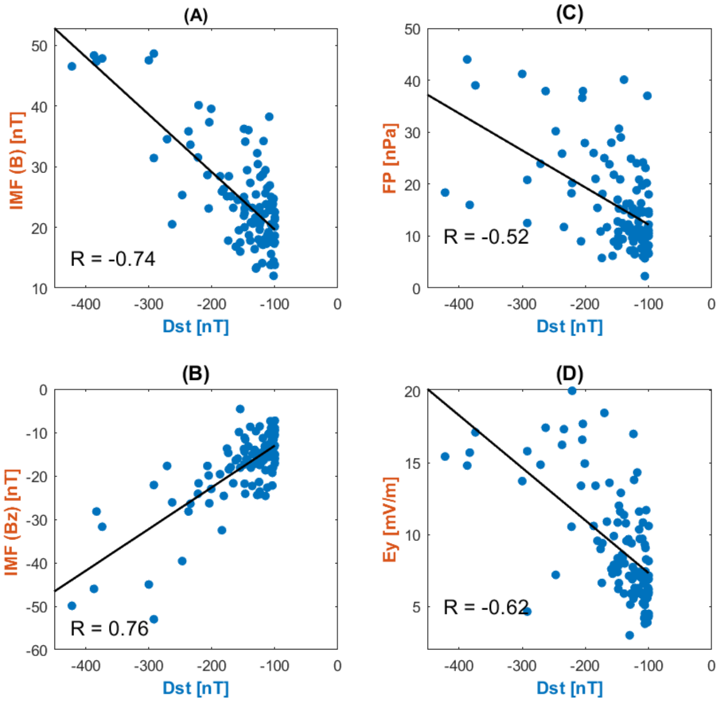

**Figure 7:** Scattered plots of the minimum DST index corresponding to large GSs occurred during the SCs 23-24 against the IMF (B), IMF (Bz), FP, and Ey are shown in panels (A), (B), (C), and (D) respectively. The regression lines are shown in solid black.

## 5. Conclusion

Several solar events cause abnormal fluctuations in the IMF and solar plasma emissions, which in turn cause GSs. Studying these GSs is important for space weather research. GSs with DST ≤ -50 nT (a total of 524 GSs) that occurred during the SCs 23-24 were selected to examine their occurrence and relationship to the solar activities. Occurrences of the selected GSs were compared with phases of the SCs and halo CMEs. The comparison showed that the geomagnetic activities tend to show a similar activity to the solar activities (SC). The occurrence of the selected GSs was in coincidence with phases of the SC. A significant relationship between GSs and both SN and halo CMEs was observed. In addition, large (intense and super) GSs are found to occur in association with the halo CMEs, as revealed by the correlation coefficients. The correlation of DST index versus several interplanetary and solar parameters was examined. The correlation coefficients obtained from this research work strongly suggest that the magnitude and the fluctuation duration of IMF (B) and IMF (Bz) have a strong impact and influence on the generation of GSs.

Thus, the study of solar events and their relationship with geomagnetic storms is essential for predicting space weather and its potential impacts. These insights allow for proactive measures to safeguard infrastructure, protect satellite systems, and enhance the safety and reliability of various communication and navigation systems. This contributes to the resilience of technological and societal systems in an increasingly space-dependent world.

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## Statements and Declarations

- Ethics approval and consent to participate.

Not applicable.

- Consent for publication

All authors approved the final manuscript.

- Availability of data and materials

Please contact the authors for data requests

- Competing interests

The authors declare that they have no competing interest.

- Funding

Not applicable.

## References

Adebesin, B. O and Chukwuma, V. U. (2008). On the variation between Dst and IMF Bz during Intense and very intense geomagnetic storms. Acta Geod. Geoph. Hung., Vol. 43(1), Pp. 1- 15. doi:10.1556/AGeod.43.2008.1.1

Akasofu, S. I., and Chapman, S. (1963). Magnetic storms: The simultaneous development of the main phase (DR) and of polar magnetic substorms (DP). Journal Of Geophysical Research, 68, 3155-3158.

Akasofu, S.I. (1983). Solar-wind disturbances and the solar wind-magnetosphere energy coupling function, Space Sci. Rev., 34, 173-183.

Arnoldy, R. L. (1971). Signature in the interplanetary medium for substorms, J.Geophys. Res.,7 6 (22), 5189– 5201., doi:10.1029/JA076i022p05189.

Balachandran, R., Chen, L. J., Wang, S. and Fok, M. C. (2021). Correlating the interplanetary factors to distinguish extreme and major geomagnetic storms. Earth Planet. Phys., 5(2), 180–186. http://doi.org/10.26464/epp2021015.

Cander, L. R., and Mihajlovic, S. J. (1998). Forecasting ionospheric structure during the great geomagnetic storms. Journal of Geophysical Research: Space Physics. 103 (A1): 391–398.

Fairfield, D. H., and L. J, Cahill, Jr. (1966). Transition Region Magnetic Field and Polar Magnetic Disturbances, J. Geophys. Res., 71, 155-169.

Gonzalez, W. D., Joselyn, J. A., Kamide, Y., Kroehl, H. W., Rostoker, G., Tsurutani, B. T., and Vasyliunas, V. M. (1994). What is a geomagnetic storm? J. Geophys.Res., 99, 5771–5792.

Gosling, J.T. (1993). The solar flare myth. J. Geophys. Res., 98, 18937–18949, DOI: 10.1029/93JA01896.

Hathaway, D.H. (2010). The Solar Cycle. Living Rev. Sol. Phys. 7, 1. https://doi.org/10.12942/lrsp-2010-1

Howard, R.A., Michels, D.J., Sheeley Jr., N.R. and Koomen, M.J. (1982). The observation of a coronal transient directed at Earth. Astrophys. J. Lett., 263, L101–L104, DOI: 10.1086/183932.

Kamide, Y., Yokoyama, N., Gonzalez, W., Tsurutani, B. T., Daglis, I. A., Brekke, A., Masuda, S. (1998). Two step development of geomagnetic storms, J. Geophys. Res.,103, pp 6917-6922.

Kappenman, J. G. (1996). Geomagnetic Storms and Their Impact on Power Systems,‖ IEEE Power Engineering Review.

Lakhina, G. S., Alex S., Mukherjee S., and Vichare G., (2006). On magnetic storms and substorms , ILWS WORKSHOP 2006, GOA, FEBRUARY 19-24.

Liu, L. B., Wan, W. X., Chen, Y. D., et al. (2011). Solar activity effects of the ionosphere: A brief review. Chinese Sci Bull, 56: 1202−1211, doi: 10. 1007/s11434-010-4226-9.

Loewe, C. A., and Prölss, G. W. (1997). Classification and Mean Behavior of Magnetic Storms, J. Geophys. Res. 102, 14209.

McIntosh, S. W., Chapman, S., Leamon, R. J., Egeland, R., & Watkins, N. W. (2020). Overlapping magnetic activity cycles and the sunspot number: Forecasting sunspot cycle 25 amplitude. Solar Physics, 295(12), 163. https://doi.org/10.1007/s11207-020-01723-y

NAS (National Academy of Sciences) (2008). Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report, National Academies Press, Washington, D.C.

NAS, (2009). Severe Space Weather Events—Understanding Societal and Economic Impacts: A Workshop Report - Extended Summary, National Academies Press, Washington, D.C.

Owens, M. J., Lockwood, M., Barnard, L. A., Scott, C. J., Haines, C., Macneil, A., (2021). Extreme Space-Weather Events and the Solar Cycle. Solar Physics. 296 (5):82. doi:10.1007/s11207-021-01831-3. ISSN 1573-093X. S2CID 236402345.

Rathore, B.S., Gupta, D.C. and Parashar, K.K. (2014). Relation between Solar Wind Parameter and Geomagnetic Storm Condition during Cycle-23. International Journal of Geosciences, 5, 1602-1608. http://dx.doi.org/10.4236/ijg.2014.513131.

Singh, A.K., Bhargawa, A., Siingh, D., Singh, R.P. (2021). Physics of Space Weather Phenomena: A Review. Geosciences, 11, 286.

Singh, S., A. C. Panday, Kalpana Singh & A. P. Mishra, (2017). Effect of geomagnetic storms and their association with solar wind velocity and IMF during solar cycle 23 and 24, International Journal of Pure and Applied Physics. ISSN 0973-1776, 13, Number 1, pp. 35-43.

Sugiura, M., Kamei, T. (1991). Equatorial Dst index 1957–1957–1986. In: Berthelier A, Menvielle, M. (eds) IAGA bull 40. International Service of Geomagnetic indices, Saint-Maur-des-Fosses.

Temmer, M. (2021). Space weather: the solar perspective. Living Rev Sol Phys 18, 4.

Verma, P.L., Tripathi, A.K. and Sharma, S. (2009). Geomagnetic Storms In Relation With Halo and Partial Halo Coronal Mass Ejections and Disturbances in Solar Wind Plasma Parameters, J. Plasma Fusion Res. SERIES, Vol. 8.

Wu, C. C., and Lepping, R. P. (2006). Solar cycle effect on geomagnetic storms caused by interplanetary magnetic clouds. Annales Geophysicae, 24 (12), pp.3383-3389.

Zhang, J., Dere, K. P., Howard, R. A., and Bothmer, V. (2003). Identification of Solar Sources of Major Geomagnetic Storms between 1996 and 2000, Astrophys. J. 582, 520.