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Dependence of Geomagnetic Storms on Diverse Solar Wind Parameters, Interplanetary Magnetic Field, Interplanetary Conditions for Solar Cycle 23

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ABSTRACT

In order to find the association of geomagnetic storm (GS) with various solar wind parameters, interplanetary magnetic field (IMF B), interplanetary conditions (such as By, Bz and Ey), we incorporate the analysis technique by superposed-epoch method. The current analysis depict that solar wind parameters (such as solar wind speed V and plasma proton temperature), interplanetary conditions (such as Bz and Ey) and IMF B are geo-effective parameters while By component is not a geo-effective parameter. By the comparision of different indices and finally we conclude that Kp index is a powerful indicator of geomagnetic activity.

Keywords: Solar wind parameters, Interplanetary conditions, Interplanetary magnetic field, Geomagnetic storm.

1. INTRODUCTION

A geomagnetic storm (GS) is a transitory disturbance in the earth's magnetosphere. The main cause of such disturbance is the alternation of solar wind and shock wave with the magnetic field of the earth. Generally, there are two main causes for GS to occur. The first cause is that the sun occasionally emits coronal mass ejection, which is a strong surge in the emission of charged particles with a resulting increase in the velocity and density of the solar wind. When the surge hits earth's magnetosphere, usually 3-5 days after the solar event, the magnetic field is disturbed and oscillates which in turn generates electric currents in earth's ionosphere and near-earth space environment. The electric current turn to generate additional magnetic field variations. The second cause is the large region on the sun's corona become cooler indicating the sun's magnetic field lines are stretching far out in to interplanetary medium. These field lines may directly link with the earth's magnetic field, a process is termed as magnetic reconnection. Charged particles can then travel along the magnetic field lines and enter earth's magnetosphere which causes geomagnetic field to vary. This variations in geomagnetic field is known as GS whose durability is measured by Dst or Kp index (Gonzalez *et al*., 1994). For our study we used the Dst index as a sign of GS. The Dst index is a measure of the deviation of northward component of magnetic field near the earth's equator. However, an ideal GS has four phases i.e sudden commencement, an initial phase, main phase and recovery phase. The initial phase may be slow and depicted by an abrupt change in the Dst, called sudden commencement. The impacts of an interplanetary irregularity causing a sudden change in the sudden commencement (Smith *et al*., 1986). When the Dst undertake negative values, there is a beginning of the main phase of GS and it ends when it reaches to minimum decrease. Likewise the recovery phase, usually the longest one, is characterized by the returning of Dst to its pre-sudden commencement values. In order to study the most important phenomena i.e GS in the present paper, we have taken main phase in to consideration which is caused by the inflation in magnetosphere due to the ring current injection which is caused by southward IMF and resulting strong convection. The span of this phase is usually 2-8 hours. The day with Dst $\leq$ -50nT was taken as a trigger day for super-posed epoch analysis. When a magnetic storm is in progress, it is depicted with the negative sign of Dst index. When the intensity of magnetic storm is very high, it tends to the negative sign of more Dst index. The positive value of the Dst index is due to the compression of magnetosphere which is due to increase in solar wind pressure. The durability of GS also depend upon the solar wind, whereas CME is also one of the most important parameter accountable for geomagnetic storm.

Enormous solar flares are escort by coronal mass ejection (CMEs) which can bring about geomagnetic storm. Coronal mass ejections (CMEs) and solar flares are the fundamental sources of solar cosmic rays. CMEs and Solar flare, both of them are vigorous events which expel enormous quantities of material from the sun at a speed of about 400-1000 km/s. When such a great magnetic disturbance of CMEs arrives on earth, produces geomagnetic storms that have been known to immobilize satellites and knock out terrestial electric power grids for lengthened periods of time. Hence CME events are also accountable for the major disruption in the solar wind and IMF.

Solar wind can be described as the flow of charge particles originating from the upper atmosphere of the sun. Solar wind generally change its speed, density and temperature with time and longitude. On account of its tremendous energy, its particle get away from the sun's gravity. The disruption in the earth's magnetic field whose intensity rely upon the nature of ejecta is produced, when the solar wind enters the interplanetary medium (Cane and Richardson 1995; Loewe and Prolss 1997). Slow solar wind and fast solar wind are the two major components of solar wind in which it can be categorized. The high speed solar wind stream (HSSWS) are found to be effacious in bringing forth immense transient decrease in CRI (Shrivastava and Jaiswal, 2003). HSSWS produces transient decrease in CRI and enhancement of geomagnetic activity (Hatton, 1980).

2. Data and Method

In order to find the GS variations in relation to various solar wind parameters, IMF B and interplanetary conditions, we used a chree analysis by the superposed epoch method. The daily mean values of various solar wind parameters, GSs, IMF B and interplanetary conditions were taken from the omniweb data center (omniweb.gsfc.nasa.gov/form/dx1.html). We also calculate the correlation coefficient between these parameters. In order to calculate the correlation coefficient between these parameters, we used unbinned data (data not divided in to intervals) with time resolution of one day (daily mean average). The daily mean average values are selected for accurate outcome. The occurrence days of GSs are used as a zero days with criteria Dst $\leq$- 50nT. Now the above quoted 6 values are taken into consideration which is assumed as -1,-2,-3,-4,-5,-6 days. Similarly below quoted 6 values are taken in to consideration which is assumed as +1,+2,+3,+4,+5,+6 days. Proceeding in an identical manner a table with the column of information is drafted for solar cycle 23. The average value of these days (-6 to +6) are calculated and the graph is outlined between two parameters.

3. RESULTS AND DISCUSSION

As a result, we analyse the upshot of various solar wind parameters (such as plasma proton temperature, solar wind speed V), interplanetary conditions (such as By, Bz, Ey), interplanetary magnetic field IMF B on geomagnetic storm for solar cycle 23. From the following analysis diverse outcomes has been observed which are discussed below-

3.1 GS and Solar wind parameters

Solar wind parameters plays a remarkable role in the initiation of various space weather activities such as geomagnetic storm and on the other hand give rise to auroras (Ahluwalia, 2003). When the charged particles from the sun hit to the upper atmosphere it results to the coloured light in the sky known as auroras (Tsurutani and Gonzalez, 1997).

We analyse the connection of GS with various solar wind parameters such as solar wind speed V and plasma proton temperature. From figure '1' it is easy to perceive that the strongest increment in solar wind speed V occurs on the happening day of GS. No time delay found between the extreme value of solar wind speed V and least value of GS. A high and negative correlation (r = - 0.98) found between solar wind speed V and GS which demonstrate that solar wind speed V is an effective parameter for causing GS decrease. The outcome is in good favour with the result of Kharayat *et al*., 2017, who concluded that solar wind speed is highly effective in causing GS decrease during the period 1998 to 2005.

Likewise, we analyse that the strongest increment in solar wind parameter such as plasma proton temperature occurs on the happening day of GS. No time delay found between the extreme value of plasma proton temperature and least value of GS. The correlation coefficient between plasma proton temperature and GS is found to be -0.94, which is excellent and well satisfactory.

From above, we can conclude that solar wind parameters chosen in the given study are highly effective for causing GS decrease.

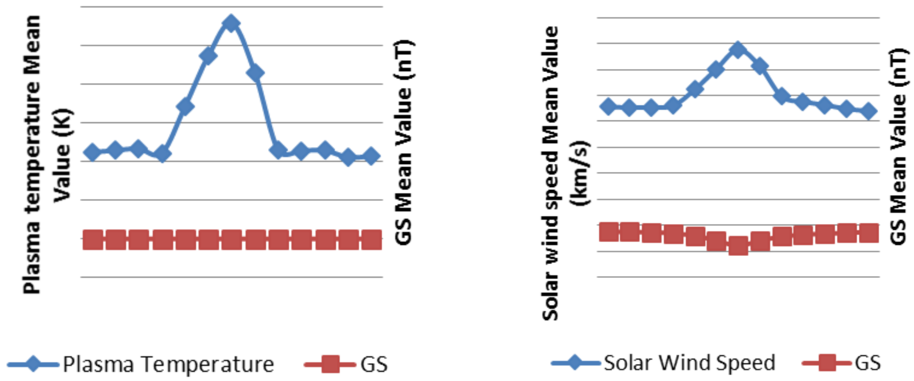


Figure 1 The conclusion of superposed epoch analysis from -6 to +6 days with respect to zero epoch day. The discrepancy of mean value of solar wind parameters such as solar wind speed, plasma proton temperature and GS is demonstrated where zero day as the trigger day of happening of GS during 1996-2008.

3.2 GS and Interplanetary magnetic field

Interplanetary magnetic field is a constituent of sun's magnetic field that is fetch in to interplanetary space by the solar wind. IMF strength and its vacillations are accountable for GS variation (Fairfield and Cahill, 1996).

We analyse the effect of interplanetary magnetic field (IMF B) on GS. From figure '2' it is easy to perceive that the strongest increment in IMF B occurs one day before the happening day of GS. Thus, a time delay of 0 to 1 day observed between the extreme value of IMF B and least vaue of GS. A high and negative correlation (r = - 0.76) between these two parameters demonstrate that IMF B is an effective parameter for causing GS decrease. The outcome is in good favour with the result of Kharayat *et al*., 2016; Tiwari *et al*., 2010; Rathore *et al*., 2014, who concluded that IMF B is an effective parameter in generating geomagnetic field disturbances.

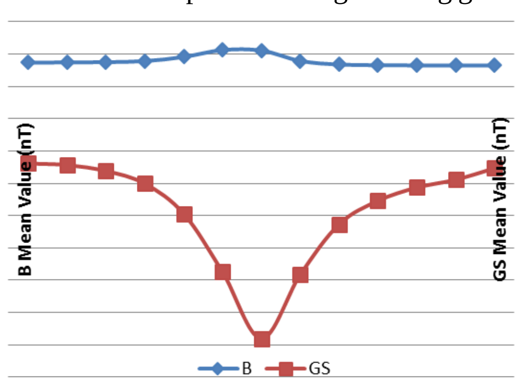


Figure 2 The conclusion of superposed epoch analysis from -6 to +6 days with respect to zero epoch day. The discrepancy of mean value of IMF B and GS is demonstrated where zero day as the trigger day of happening of GS during 1996-2008.

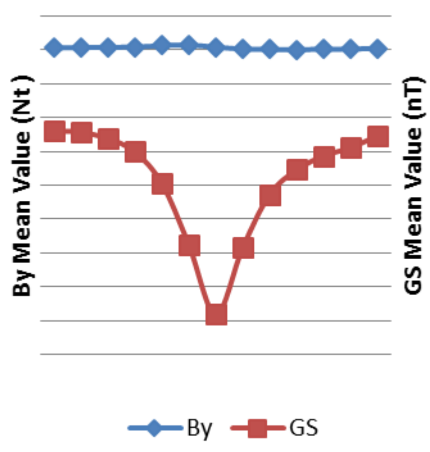
3.3 GS and Interplanetary conditions

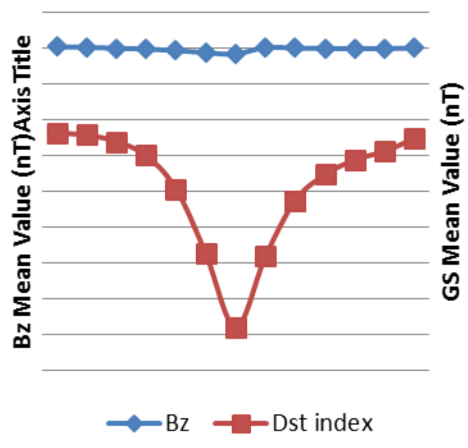
We analyse the effect of interplanetary conditions such as By, Bz, Ey on GS. As we know that Bx, By and Bz are the three basic components of IMF. Bx is corresponding to the x-axis in cartesian coordinate which always points toward the center of the sun from the vantage point of the earth in its orbit. By is corresponding to the y-axis in cartesian coordinates which lies at a right angle to Bx and points in the anti-orbital direction of the earth's orbit. Bz is corresponding to the z-axis in cartesian coordinates which lies at a right angle to both Bx and By and it lies parallel to ecliptic plane and is one of the most important ingredient for the auroral activity.

From figure '4' it is easy to perceive that the strongest increment in By occurs one day before the happening day of GS. There is a time delay of 0 to 1 day between the extreme value of By and least value of GS. The correlation coefficient between By and GS is found to be -0.26, which is very poor. It suggest that By is not at all valuable for auroral activity.

Likewise, the strongest decrement in Bz occurs on the happening day of GS. No time delay found between these two parameters. A high and positive correlation (r= 0.76) found between Bz and GS, which sugest that Bz is one of the most important ingredient for auroral activity. This might be due to the fact that when Bz is oriented southward, it connect with the Earth's magnetospher point towards northward. With a southward Bz, solar wind particles have much easier time entering our magnetosphere. Thus for a geomagnetic storm to develop, it is important that the direction of IMF B turns southward. In particular, the discrepancy of the north-south component of the IMF (Bz), when rendered in the geocentric solar-magnetospheric (GSM) coordinate system, plays a significant role in determining the amount of solar wind energy transferred to the magnetosphere (Arnoldy, 1971). Cane *et al*., 2000, found that the intensity of geomagnetic storm is strongly correlated with the magnitude of Bz.

Further, we observed that the strongest increment in Ey occurs on the happening day of GS. No time delay found between these two parameters. A high and negative correlation (r= -0.92) between Ey and GS demonstrate that Ey is highly effective for causing GS decrease.





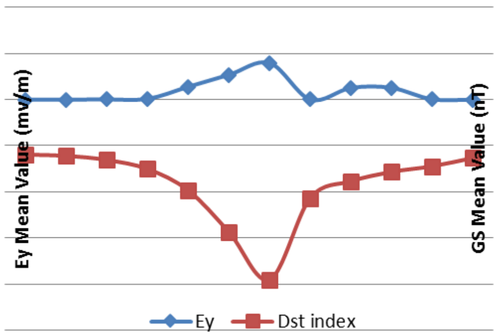


Figure 3 The conclusion of superposed epoch analysis from -6 to +6 days with respect to zero epoch day. The discrepancy of mean value of interplanetary conditions such as By, Bz, Ey and GS is demonstrated where zero day as the trigger day of happening of GS during 1996-2008.

3.4 Comparision of different indices with Dst index

We analyse the connection of different indices with Dst index. The AE, Ap, Kp, indices are taken in to account as a sign of GS. The AE index is used to measure the durability of the elecrojet. Kp index is used to estimate the fluctuation of the extremely interrupted horizontal component of the magnetic field. The Ap index is used to describe the general level of geomagnetic activity above the globe for a given day.

From figure '4' it is easy to perceive that the strongest increment in Ap, Kp, AE index occurs on the happening day of GS. No time delay found between the extreme value of Ap, Kp, AE index and least value of GS. The correlation coefficient of Dst index with different indices are found to be -0.89 for AE index, -0.86 for Ap index and -0.90 for Kp index.

From above we concluded that Kp index is one of the powerful indicator of geomagnetic activity.

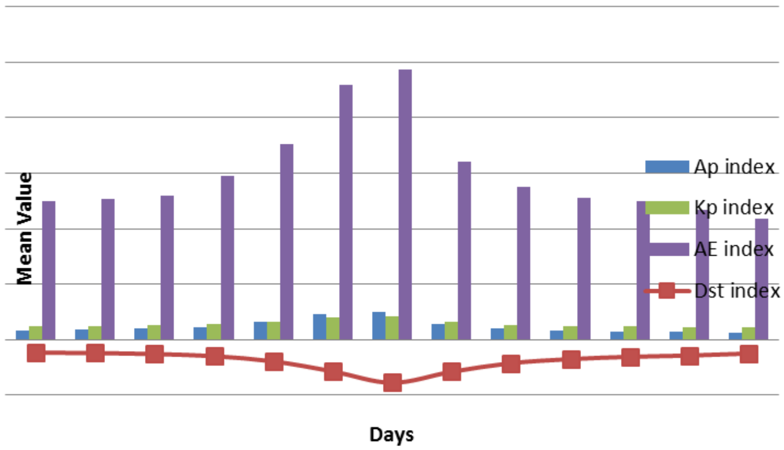


Figure 4 The conclusion of superposed epoch analysis from -6 to +6 days with respect to zero epoch day. The discrepancy of mean value of different indices such as Kp, Ap, AE and Dst index is demonstrated and zero day as the trigger day of happening of GS during 1996-2008.

4. SIGNIFICANCE

From the association of GS with diverse solar wind parameters, interplanetary conditions and interplanetary magnetic field, it is clear that solar wind parameter such as solar wind speed V and plasma proton temperature are effective in causing geomagnetic field disturbances. This analysis proves to be useful to anticipate the space weather phenomena. Interplanetary conditions (such as Bz and Ey) and Interplanetary magnetic field (IMF B) are also a geo-effective parameters. One of the most important conclusion represent in the current analysis is that the superior gauge of disturbance in the earth's magnetic field is Kp index that can be used to determine whether geomagnetic alerts and warning need to be broadcast for users who are disturbed by these disturbances.

5. CONCLUSIONS

After the detailed analysis of our study various conclusions has been observed and are discussed below-

1 During our investigation for the said period, solar wind parameters such as plasma proton temperature and solar wind speed V are geo-effective parameters. No time delay found between the extreme value of plasma proton temperature, solar wind speed V and least value of GS.

2 The correlation coefficient between solar wind parameters and GS are found to be -0.98 for solar wind speed, -0.94 for plasma proton temperature.

3 IMF B is a geo-effective parameter with correlation coefficient -0.76.

4 North-south direction of IMF (Bz) is a geo-effective parameter with correlation coefficient 0.76.

5 Ey is a geo-effective parameter while By is not a geo-effective parameter.

6 The correlation coefficient between Ey and GS is found to be -0.92, which is very good.

7 Kp index is a powerful indicator of geomagnetic activity.

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