Study of Highly Geoeffective Events of Solar Cycle 23

Abstract

To understand the Solar – Terrestrial Relationship we need to Study about the outcomes of the Sun with main emphasis on Solar flares and coronal mass ejection (CME). The fact that the solar activity is directly related to space weather and geomagnetic activity does rise and fall along with the solar activity, in the whole period (1997-2008) of solar cycle-23. We have selected 80 Geoeffective Events, all are associated with solar Flares and Coronal Mass Ejection. Causing Geomagnetic storms with Dst ≤ -50nT. The classification of selected 80 significant Geomagnetic storms (GMSs) with Dst ≤ -50nT in different varying range of horizontal component of Earth's magnetic field (H) and then the external causes of these storms were investigated on individual basis Under the selection criteria 39 moderate, 29 intense ,10 severe and 02 great, geomagnetic storms have been observed. The correlation coefficient between various solar / interplanetary parameters such as- Dst(disturbance storm time) versus Velocity, Dst versus Total magnetic field (Bt), Dst versus Cosmic ray count (CR) etc., have been calculated. The correlation coefficient has been found to be reasonably high. The result may be indicate that the Solar wind Southward magnetic field component Bz has significant growth mainly during (or before) the initial phase of geomagnetic storm (not during the main phase, tested here). The correlation coefficient between velocity V and peak Dst, the correlation coefficient between Dst and temperature, between Dst and cosmic rays have been find which shows their individual results. We have noticed that geomagnetic storms are mainly occurred due to coronal mass ejection (CME) and solar flares.

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Keywords: Geomagnetic Storm, Interplanetary Magnetic Field (IMF), Disturbance Storm Time (DST), Coronal Mass Ejection (CME), Solar Cycle.

Introduction

The Sun is the source of energy for life on Earth as well as it is the strongest modulator of the human physical environment. It provide the heat, light and ionization; and through the continuous outflow of magnetized supersonic ionized gas. Eugene Parker pioneer researcher in this field has named this hot compressed and highly ionized gas as 'solar wind'. Parker (1958) has studied the properties of solar wind and gave a profound knowledge that helped us to understand the solar terrestrial effects.

The overall activities occurred on the solar surface substantially influence the earth's environment. These effects are commonly known as the 'Space weather effects'. The origin of the space weather activities is due to the continuously changing solar environment and the various plasma transient flows/ embedded within the solar wind. Space weather effects arises due to the change in dynamic conditions in the Earth's space environment which are driven by processes takes place on the Sun. The utilization of space has now become the part of our everyday lives. Our lives have become increasingly dependent on technological systems vulnerable to space weather influences. Thus the understanding and predicting hazards posed by the active solar events has become the subject of our concern. The aim of present study is to outline some of the elementary aspects of innovative and modern approach to investigate the Solar – Terrestrial Physics and more specifically to discuss the key dynamic processes of the magnetosphere and their relationship with space weather hazards.

Sun transmits vast amount of energy and plasma radiation through the interplanetary medium. The interaction of the solar wind plasma with Earth's magnetosphere produces the energy reconnection. This in turn causes the energy coupling. The magnitude of this coupling depends up on the structures present in the solar wind, the interplanetary features and their orientation at the time of reconnection (Burlaga, 1997).In this paper the focus is on identifying observations relevant to climate processes at the Earth's surface, or near the earth surface.

A solar flare is an enormous explosion in the solar atmosphere. It results in sudden bursts of particle acceleration, heating of plasma to tens of millions of degrees, and the eruption of large amounts of solar mass. Flares are believed to result from the abrupt release of the energy stored in magnetic fields in the zone around sunspots. Scientists classify solar flares according to their brightness in the x-ray wavelength. They group flares into 3 categories (X-class, M-class and C-class). C-class flares are very small and produce few noticeable effects on Earth. M-class flares are medium-size and can cause brief radio blackouts in the Polar Regions. X-class flares are major events that can trigger worldwide radio blackouts and radiation storms in the upper atmosphere.

A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere that occur when the interplanetary magnetic field turns southward and remains southward for an prolonged period of time. A geomagnetic storm is defined by the changes in the DST (disturbance – storm time) index (Sugiura 1964). The Dst index estimates the globally averaged change in the horizontal component of the Earth's magnetic field at the magnetic equator, based on measurements from a few magnetometer stations. The main phase of a geomagnetic storm is defined by Dst decreasing to less than -50 nT. The minimum value of Dst during a storm remains in between -50 and -600 nT.

Selection Criteria And Data Analysis

The disturbances in the geomagnetic field are caused by fluctuation in the solar wind impinging on the earth. The disturbances may be limited to the high-latitude polar region, unless the interplanetary magnetic field (IMF) carried by the solar wind has long periods (several hours or more) of southward component ($B_z < 0$) with large magnitudes. The occurrence of such a period stresses the magnetosphere continuously, causing the magnetic field disturbance to reach the equatorial region. The degree of the equatorial magnetic field deviation is usually given by the Dst index. This is the hourly average of the deviation of H (horizontal) component of the magnetic field measured by several ground stations in mid to low-latitudes. Dst = 0 means no deviation from the quiet condition, and Dst ≤ -50nT means magnetic storms.

We have analyzed the events represented by maximum Dst decrease and selected by using the selection procedure of Loewe and Prolss (Rathore 2011). A list of magnetic storms, based on the Dst indices had been compiled for this study for the period 1997-2008. The Disturbance storm time index (Dst) is provided by the World Data Center for Geomagnetism at the University of Kyoto, Japan database. The study period refers to the interval solar cycle 23. We have used the Omni Web Data Results provided by the National Space Science Data Center (NSSDC). The Coronal Mass Ejection data used for the present study was adopted from the SOHO LASCO CME catalogue being maintained and provided by CDAW. The flares observed by PRL's "Solar X-ray Spectrometer (SOXS) were also used. The SOXS provides solar flare observations in X-ray waveband in the energy range of 4-56 keV. We have obtained the data of occurrence of halo CMEs from the database (Gonzalez,1994) and analyze the cosmic ray intensity detected by neutron monitors (NM) located at high altitudes from 1990-2000.

Review of Literature

In the early 1960s, solar physicists realized that the solar wind carries the Sun's magnetic field out to the far reaches of the solar system. This extension of the Sun's magnetic field is called the interplanetary magnetic field and it can join with geomagnetic field lines originating in the polar regions of Earth. This joining of the Sun's and Earth's magnetic fields is called magnetic reconnection, and happens most efficiently when the two fields are anti-parallel. Through reconnection the magnetic fields of Sun and Earth become coupled together. Solar wind particles approaching Earth can enter the magnetosphere because of reconnection and then travel along the geomagnetic field lines.

The relationship between the solar activities, its propagation through the space to the Earth and the geomagnetic activity are not yet well understood sufficiently, despite the close observations of the Sun through the coronagraph. During the last three-decade lot of the new information have been provided by the various spacecrafts, namely ISEE-3, IMP-8, ACE, SOHO, Hinode, SOXs, Tesis etc.

The hot ionized, compressed gas emitted from the Sun is known as the solar wind. This Solar wind is responsible for the overall shape of Earth's magnetosphere and fluctuations in its speed, density, direction, and entrained magnetic field strongly affect Earth's local space environment. It is now well established fact that the solar transients; namely the Coronal Mass Ejections (CME's) (Drake.et.al,2003), Solar Flares, Sun Spots Magnetic field variation, prominences, solar filaments, surges and jets are the key factor in controlling the space weather activities. The basic question whether the CME or a solar flare emits first is still a long addressed problem of space physicists. The present work is an effort to undertake this long lasting problem and we'll be considering mainly these transients in to consideration.

Aim of the Study

Aim of the study is to observe the relation between various solar interplanetary parameters and find the actual cause which is responsible for the occurrence of Geomagnetic storms.

Observation

The fact that the solar activity is directly related to space weather and geomagnetic activity does rise and fall along with the solar activity, in the whole period (1997-2008) of solar cycle-23. We have selected 80 Geoeffective Events, all are associated with solar Flares and Coronal Mass Ejection. Causing Geomagnetic storms with Dst ≤ -50nT. The maximum phase of solar cycle-23 has been measured during the year 2001 whereas the periods 1997-99 and 2002-07 are the periods of minimum phase of solar activity. Under the selection criteria 39 moderate geomagnetic storms, 29 intense geomagnetic storms and 10 severe and 02 great, geomagnetic storms have been observed. It is evident that in the year 1997 (Solar minimum year) only 2 geomagnetic storm have occurred and maximum numbers of geomagnetic storm have occurred in year 2001 and 2003 while year 2000 is the maxima of the solar cycle-23; the year 2006 represents minimum sunspot activity during the descending phase of solar cycle-23, But no geomagnetic storms observed during the year 2007 and 2008.

Result and discussion

Geomagnetic storms are magnetospheric disturbances. They have been studied for more than 200 years (Gonzalez et al., 1994; and references therein). They are characterized by enhanced particle fluxes in the radiation belts. A standard measure of the Dst index is proportional to the total kinetic energy of ~20–200 keV particles within the outer radiation belt. Hence it is a good quantitative measure of the intensity of the geomagnetic storm (Gonzalez, 1987).

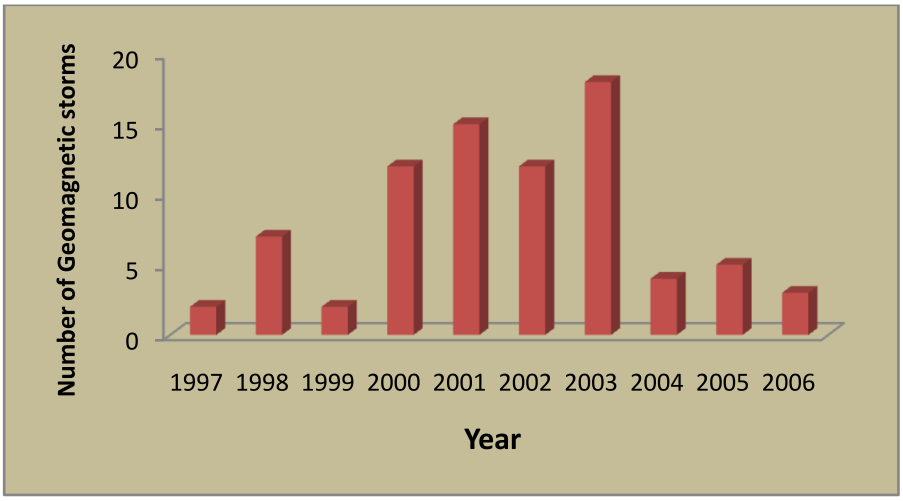
During the study period almost 80 geomagnetic storms caused due to various solar transients have been analyzed, which have been found to satisfy selection criteria. The event details are presented in the table 1.

Table 1: Shows the occurrence of the geomagnetic storms with their classification as per year. Under the selection criteria 39 moderate geomagnetic storms, 29 intense geomagnetic storms and 10 severe and 02 great, geomagnetic storms have been observed

Year	Moderate	Intense	Severe	Great
1997	--	02	--	--
1998	02	03	02	--
1999	02	--	--	--
2000	09	01	02	--
2001	06	06	03	--
2002	04	08	--	--
2003	12	03	01	02
2004	--	03	01	--
2005	02	02	01	--
2006	02	01	--	--

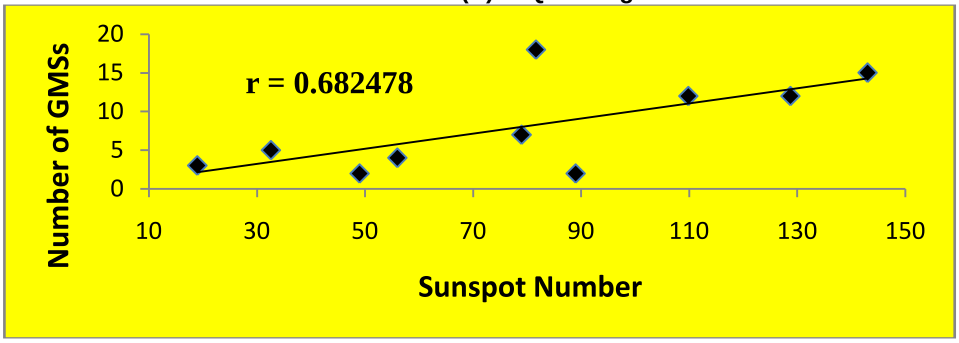
The histogram given below presents the details of number of storms occurred versus the occurrence time /year. From figure 1 it is evident that in the year 1997 (Solar minimum year) only 2 geomagnetic storm have occurred.

Fig 1: The Total Number of Geomagnetic Storms Occurred Plotted Against The Occurrence Time/ Days Per Year. The Whole Events Studied Were Occurred During Solar Cycle 23, i.e. The Study Period



Cross-correlation analysis provides correlations between data of two time series or waveforms. The observations of one data series are correlated with the observations of another data series at various lags and leads. Cross-correlations help to identify variables which are leading indicators of other variables or how much one variable is predicted to change in relation with the other variable. A typical cross-correlation graph shows enough lags in both negative and positive directions to show the cyclical relationship of the two sets of data. Detailed explanations on cross-correlation theorem, mathematical expressions and computation process can be studied in several books and papers (Joshi.et.al, 2011). Results of cross plots between the number of geomagnetic storms occurred versus the sunspot numbers are presented below in figure 2.

Fig 2: The Cross Plot Between The Occurrence of Geomagnetic Storms (Gmss) During the Solar Cycle 23 and The Sun Spots Numbers. The Correlation Coefficient (R) is Quiet High ~ 68 % for These Events.



On the other hand the cross plots among the Disturbance storm time index, which the true representation of the depression in the geomagnetic field variation and the interplanetary magnetic field IMF Bt (nT) and its Z component of IMF (IMF Bz) are given below in figure 3 and 4, respectively. Statistically, the occurrence of more intense geomagnetic storms (negative Dst magnitudes ~150 nT or less) is lower (~10% of the storms considered). In this figure, a linear correlation between Btotal and Dst can be seen, that is, the strength of the geomagnetic storm is strongly dependent on the total magnetic field Btotal. The correlation coefficient has been found to be reasonably high (-0.72083).

A linear correlation between Bz and Dst can be seen, that is, according to previous studied the strength of the geomagnetic storm is strongly dependent on the southward component Bz. But in present study the correlation coefficient has been found to be high (0. 211074). This result may be obvious Solar wind Southward magnetic field component Bz has significant growth mainly during (or before) the initial phase of geomagnetic storm (not during the main phase, tested here). Absence of high linear correlation between density and Dst during the main phase does not mean that solar wind Southward magnetic field component Bz is not a geo-effective parameter, which is considered above. Studies shows the delay between the peak negative Dst and the negative Bz (at the time of Dst peak).

Fig 3: Presents the Dst (nt) versus the interplanetary magnetic field Bt (nt)

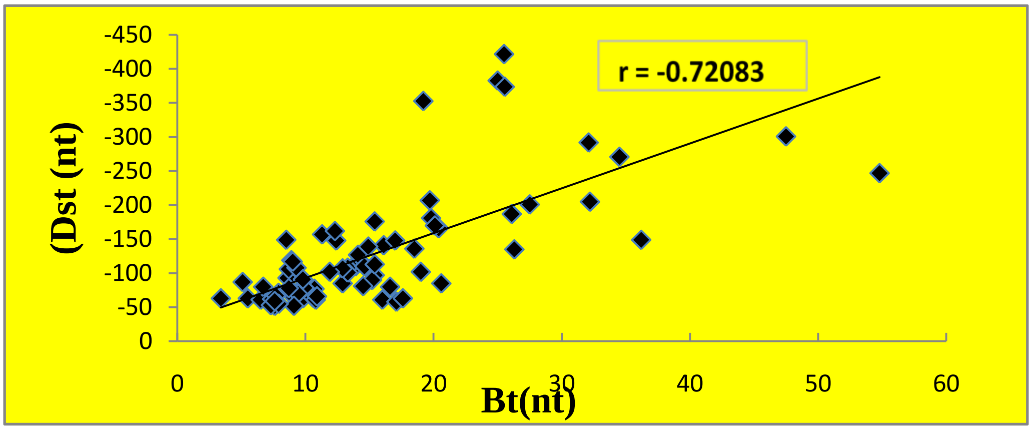
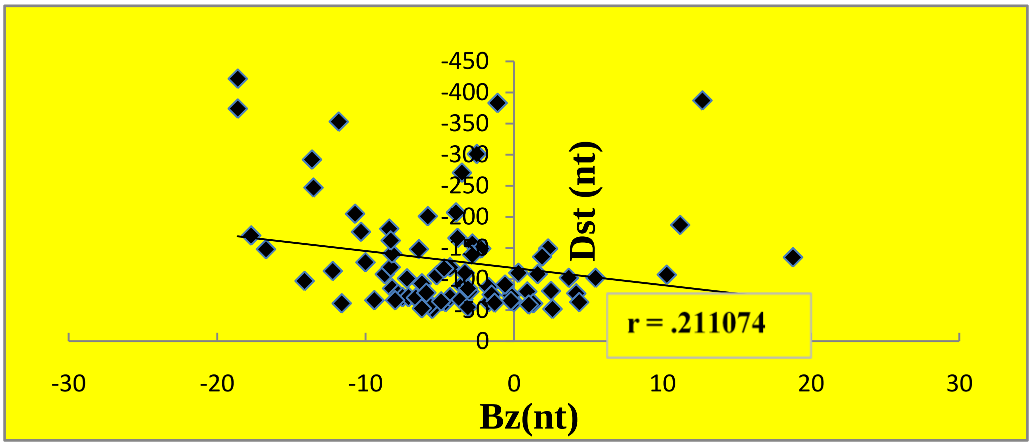


Fig 4: Presents the Maximum of DST Versus The Z Component Of Interplanetary Magnetic Field Bz (nt)



The maximum Dst (negative) versus the peak proton density. No definite relationship between both these parameters is found. It can be seen the greater intensity geomagnetic storms are not necessarily associated with greater values of solar wind density. This means that there is a high probability that intensity of a geomagnetic storm is not determined by the increased density. The correlation coefficient between both these parameters is very low (r = -0.11221). The correlation coefficient between Dst maximum strength versus the maximum number of counts of cosmic ray intensity is also very high r = 0.37077.

Fig 5: Maximum value reached by Dst Versus Density Np (N/cm3)

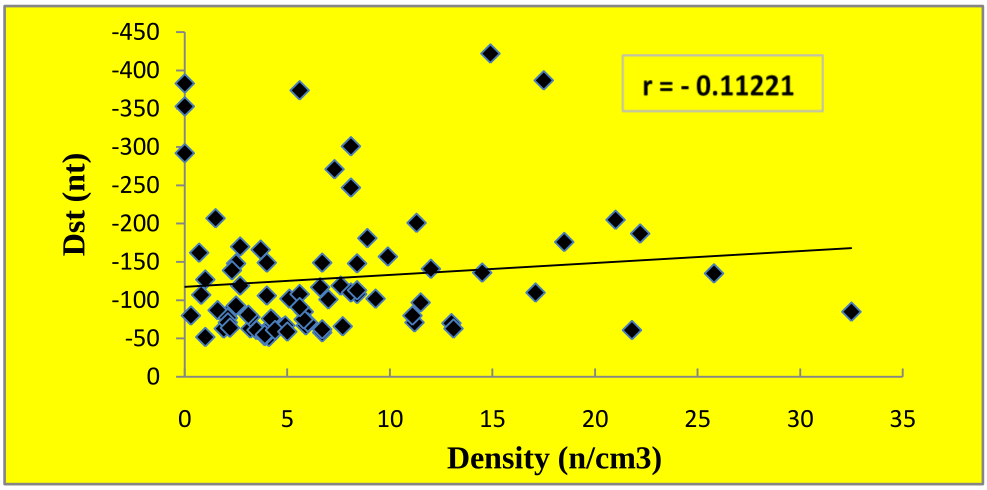
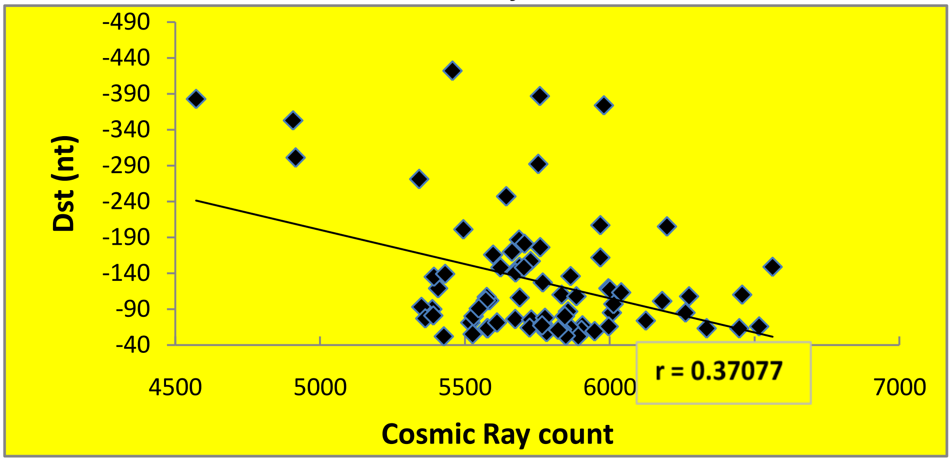


Fig 6: Above Figure Depicts DST Maximum Strength Versus The Maximum Number of Counts of Cosmic Ray Intensity



Conclusions

From the rigorous analysis of data presented in the previous sections, the following conclusions have been drawn, taking a base of solar flare, 80 events were observed. It is evident that in the year 1997 (solar minimum year) only 2 geomagnetic storms have occurred. It is also found that maximum number of geomagnetic storms have occurred in year 2001 while year 2000 is the maxima of the solar cycle-23, the year 2006 represent minimum sunspot activity during the descending phase of solar cycle-23. The large numbers of geomagnetic storm have occurred in the year 2001 and 2003, which do not exactly follow the phase of solar cycle and show complex behaviour. It is believed that the majority of intense geomagnetic storm occur during the maximum phase of sunspot cycle because many solar active region appear during this time while a few of the geomagnetic storms are observed during the minimum phase of sunspot cycle, which do not exactly follow the phase of solar cycle and show complex behaviour. Although the year 2008 is rising year of solar cycle-24 but no GMSs have observed during the year due to solar flare. Similarly solar flares also do not exactly follow the phase of solar cycle but yearly occurrence of GMSs follow the yearly occurrence of solar flares. Thus solar flare is responsible to occurrence rate of GMSs during the solar cycle 23.

The present work has considered the peak values of the various parameters which are further correlated with the peak depression in the geo-magnetic perturbed conditions. It is widely recognized that the solar and interplanetary causes produce geomagnetic disturbances. In present research work, a linear correlation between Btotal and Dst can be seen, that is, the strength of the geomagnetic storm is strongly dependent on the total magnetic field Btotal.

The correlation coefficient has been found to be reasonably high (-0.72083). According to previous studied the strength of the geomagnetic storm is strongly dependent on the southward component Bz. But in the present study the correlation coefficient has been found to be low (0.211074). This result may be obvious Solar wind Southward magnetic field component Bz has significant growth mainly during (or before) the initial phase of geomagnetic storm (not during the main phase, tested here). Thus, in this study period had something special which need to be understood, Bz is not essentially peak at the time of Dst peak value. This shows time delay between Bz and Dst peak. It is also found that maximum numbers of geomagnetic storm have occurred in year 2001 and 2003 while year 2000 is the maxima of the solar cycle-23; the year 2006 represents minimum sunspot activity during the descending phase of solar cycle-23, in the year 2003 the large numbers of geomagnetic storm have occurred. But no geomagnetic storms observed during the year 2007 and 2008 due to solar flare.

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