Solar and interplanetary disturbances responsible for geomagnetic storms

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Abstract. The geomagnetic storms (GSs) are the large disturbances in the earth’s magnetic field. We have selected 142 GSs (Dst \(\leq -150\) nT) during the period 1996-2007. Isolated geomagnetic storms typically have a main phase of 3-12 hours and a recovery phase exceeding –3 days. Coronal mass ejections (CMEs) associated with radio bursts are major solar events that are responsible to produce large geomagnetic storms (Dst \(\leq -50\) nT). Out of 142 events, 77 GSs (-100 nT \(\leq\) Dst \(\leq -50\) nT), 50 GSs (-200 nT \(\leq\) Dst \(\leq -100\) nT) and 15 events (Dst \(\leq -200\) nT) of different magnitudes are found during the said period. The percentage of GSs associated with CMEs is \(\approx 58\) %, with type II burst is \(\approx 32\) % with type IV burst is \(\approx 12\) % and the percentage of GSs associated with bright flare is \(\approx 32\) %.

1. Introduction
The geomagnetic field measured at any point on the earth’s surface is a combination of several magnetic fields generated by various sources. Intense geomagnetic storms generally occur when solar wind having intense, long-duration southward interplanetary magnetic fields (IMF) interact with earth’s magnetosphere. It has been known that the intensity of geomagnetic storm is proportional to the interplanetary dawn-dusk electric field \(E = -V_{sw} \times B_z\), where \(V_{sw}\) is the solar wind flow speed and \(B_z\) is the southward component of the IMF [1, 2]. It is now well established that coronal mass ejections (CMEs) are the major cause for large geomagnetic storms [3 - 8]. High-speed streams (HSS) in corotating interaction regions (CIRS) cause only moderate to weak storms (-100 nT \(\leq\) Dst \(\leq -50\) nT). The earth’s main field varies slowly in time and creates a cavity in interplanetary space called the geomagnetosphere, where the earth’s magnetic field dominates in the magnetic field of the solar wind. The study of geomagnetic field variations and history of geomagnetic storms are the great area of interest because it is related with space weather environment. In recent years, in situ data have resulted in explosive growth in our knowledge and understanding of solar-terrestrial processes. By using analytical data obtained from various magnetometers and satellites, many researchers have shown the various types of solar – interplanetary - terrestrial relationship. It is necessary to define a clear aspect for geomagnetic field disturbances based on morphology of different types of geomagnetic storms and their possible solar and interplanetary causes. Present work deals with the solar-interplanetary - geomagnetic coupling process in a certain new way on the basis of various latest theories and mechanism.
Solar storm consists of three major components; solar flares, solar proton events (SPEs) and coronal mass ejections (CMEs). CMEs can interact with earth’s magnetic field and produce a geomagnetic storm. When a CME strikes earth, the compressed magnetic fields and plasma in their leading edge smash in to the geomagnetic field like a battering ram, which causes a world-wide disturbance of earth’s magnetic field called a geomagnetic storm. It also produces a temporary disturbance of earth’s magnetosphere and an equatorial ring currents, differential gradient and curvature drift of electrons and protons in the near earth region. In the past, solar flares held center stage in descriptions of solar activity effects on the earth and its technological systems. Without question, the generation of bursts of energetic photons at UV, X-ray and sometimes gamma ray wavelengths produce ionospheric effects within the light travel time of the flare’s occurrence on the sun. Similarly flare-associated radio bursts interfere with communications around the time of the flare; new appreciation has been gained for the importance of the coronal eruptions called CMEs in producing “space weather” disturbances events. [9]. Now the CMEs can be regarded as perhaps the greatest challenge for space weather forecasting. In the present paper, we have analyzed the association of geomagnetic storms with various solar and interplanetary features.

2. Selection criteria & Data analysis
The disturbances in the geomagnetic fields are caused by fluctuations in the solar wind impinging on the earth. The disturbances may be limited to the high-latitude polar regions, unless the interplanetary magnetic field (IMF) carried by the solar wind has long periods (several hours or more) of southward component (Bz<0) with large magnitudes (greater than 50nT). 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 deviations 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 large storms. There is another type of moderate storms, which recur with periods of approximately 27 days, (the solar rotation period), and are associated with the high-speed solar wind originating in “coronal holes” at the sun. Severe storms tend to be non recurrent and are difficult to predict. In the present study, we have analyzed the Geomagnetic storm with Dst ≤-50nT, ≤-100nT, ≤-200nT and their relationship with solar flare, radio bursts (type II & Type IV) and coronal mass ejections, occurred during current solar cycle 23. The radio bursts data has been taken from the GOES Satellite which is supported by National Geophysical Data Center (NGDC). For the present study we have considered the different types (II & IV) of radio bursts and H alpha solar flare data from the various reporting stations published in the solar geophysical data. CMEs are routinely observed by the LASCO telescope on board the SOHO satellite. The extrapolated CMEs onset time is close to the associated type II and IV bursts. The properties of CMEs are collected from the data available through website; http//www.cdaw.gsfc.gov.cmelist/. The catalog contains a list of all visible CMEs with information of their date and time of the first appearance in the field of view of c2 coronagraph, central position angle, angular width and speed acceleration obtained from quadratic fitting etc.
3. Results and Discussion

Several workers have reported the significant relationship among various solar interplanetary and geomagnetic parameters. Recently the observational findings regarding solar activity and their inter-relationship have been reported [10]. It is known for the last 40 years that space weather affects the earth; which is buffeted by a ‘wind’ from the sun. The latest finding of SOHO mission may overturn previous ideas about the origin of the ‘fast’ solar wind which occurs in most of the space around the sun. Earlier results from SOHO establish that the gas of the fast wind leaks through magnetic barriers near the sun’s visible surface [11]. Although most of CMEs are accompanied by flares, it is now understood that flares and CMEs are related phenomena, but one does not cause the other [12].

Here we have considered geomagnetic storms, bright solar flares; solar radio bursts (type II and IV) during the solar cycle 23, for the detailed analysis. Figure 1 shows the occurrence of type II bursts, type IV bursts and partial Halo CMEs with sunspot number. The occurrence of type II bursts and partial Halo CMEs is maximum in 2001 (which is maxima of sunspot cycle), and minimum in 1996 (which is minima of sunspot cycle) showing the association with phase of sunspot cycle. In case of type IV bursts the association was ambiguous with sunspot cycle.

Figure 1 shows the occurrence of type II bursts, type IV bursts & partial halo CMEs (PHCMEs) with sunspot number.

Figure 2 shows the association between type II radio bursts with GSs(Dst ≤-50nT, ≤-200nT) and sunspot number. Maximum association has been observed in year 2000, 2003 which is one year before and two year after sunspot cycle maxima, whereas minimum association is found in year 1996, which do not exactly follow the phase of solar cycle and show complex behaviour. Type II bursts with GSs ≤-100nT is maximum in year 2001 (which is maxima of sunspot cycle) and minimum in year 1996 (which is minima of sunspot cycle) showing the correlation with the phase of solar cycle.

Figure 3 shows the number of bright solar flares occurred in North, East direction (maximum in year 2000) which is one year before sunspot cycle maxima and minimum in 1996, which do not exactly follow the phase of solar cycle, whereas solar flares in south and west direction is maximum in year 2001 (which is maxima of sunspot cycle), and minimum in 1996 (which is minima of sunspot cycle), which follow the phase of solar cycle.
Figure 2 shows association between type II radio bursts with GSs (Dst ≤ -50nT, ≤ -100nT, ≤ -200nT) and sunspot number.

Figure 3 shows the occurrence of bright flares in north, south, east, west direction with sunspot number.

Figure 4 shows the association of bright flares with GSs in North, South, East, and West direction with sunspot number. Flares associated with GSs in East and West direction is found to be maximum in year 2001 (maxima of sunspot cycle) and minimum in year 1996 (minima of sunspot cycle) which follow the phase of solar cycle. Flare associated with GSs in North and South direction is maximum in year 2000 which is one year before of sunspot cycle maxima and minimum in year 1996, which indicates complex behaviour.
Figure 4 shows the association of flares with GSs in north, south, east, west direction with sunspot number.

The GSs associated with bright flares (1B, 2B, 3B) along with sunspot number (fig.5) shows the complex behaviour of solar cycle dependence.

Figure 6 shows the association of GSs with CMEs, flares, solar radio bursts and sunspot number which is maximum in year 2001 (maxima of sunspot cycle and minimum in 1996 (minima of sunspot activity) which clearly follow the phase of sunspot cycle.

Figure 7 shows the occurrence of total GSs associated with bright flares (maximum in year 2000 and minimum in 1996) which do not exactly follow the phase of solar cycle.

Figure 8 shows the association of solar wind velocity (≥450 km/s) with GSs(Dst ≤ -50nT, ≤ -200nT ) along with sunspot number. The maximum number of events is found to be in year 2000 and 2003, which do not exactly follow the phase of solar cycle, whereas GSs (Dst ≤-100nT) is maximum in year 2001 and minimum in 1996 which follow the phase of sunspot cycle.

Figure 9 shows the association of type IV bursts with GSs(Dst ≤-50nT, ≤-100nT, ≤-200nT). The occurrence pattern of events clearly depicts the complex behaviour of solar cycle dependence.
Figure 5 shows the GSs association with bright flares (1B, 2B, 3B), along with sunspot number.

Figure 6 shows the association of GSs, with CMEs, flares, radio bursts and sunspot number.

Figure 7 shows the occurrence of total GSs associated with flares and sunspot number.
Figure 8 shows the solar wind velocity associated with GSs ($\leq -50\text{nT}$, $\leq -100\text{nT}$, $\leq -200\text{nT}$) with sunspot number.

Figure 9 shows type IV bursts associated with GSs ($\leq -50\text{nT}$, $\leq -100\text{nT}$, and $\leq -200\text{nT}$) and sunspot number.

The results indicate that the disturbances observed in space near earth are dominated by the level of solar activity in general and the complex and intense magnetic field behaviour of solar active regions in particular on the solar surface. Due to the peculiar behaviour of particular solar active regions some time disturbances shows deviation from general level of solar activity cycle.

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