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# A study on the major geomagnetic storms of solar cycle 23

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**Abstract**
The disturbances in the geomagnetic fields are caused by fluctuations in the solar wind impinging on the earth. In the present study the identification of 214 geomagnetic storms associated with disturbance storm time (Dst) decrease of more than -50nT to -300nT, have been made, which are observed during 2007-2016, the time period spanning over solar cycle 23. The degree of the equatorial magnetic field deviation, the measure of the magnitude of geomagnetic storms is usually given by the Dst index. The study is made statistically between the Dst strength (used as an indicator of the geomagnetic activity) and the peak value obtained by solar wind plasma parameters and IMF B as well as its components. We have used the hourly values of Dst index and the wind measurements taken by various satellites. This is the hourly average of the deviations of the H (horizontal) component of the magnetic field measured by several ground stations in mid-to low latitudes.

**Keywords:** geomagnetic storm, interplanetary magnetic field (IMF), disturbance storm time (Dst), solar cycle

## Introduction

The geomagnetic field measured at any point on the earth's surface is a combination of several magnetic fields generated by various sources. These fields are superimposed on and interact with each other. More than 90% of the field measured is generated internal to the planet in the earth's outer core. This portion of the geomagnetic field is often referred to as the main field. The main field varies slowly in time and can be described by mathematical models such as the International Geomagnetic Reference Field (IGRF) and World Magnetic Model (WMM) the external magnetic field of the earth resembles that of dipole situated at the center of the earth with the strength and direction changing slowly. Its axis makes an angle of 11.5 degree with the axis of rotation of the earth and the center shifted by about four hundred fifty kilometers. Other important sources of rest of the field arises from electrical currents flowing in the ionized upper atmosphere and the fields induced by currents flowing in the earth's crust.

Distinct periodicities from few seconds to several thousand years have been depicted by geomagnetic field. Period of 22 years is generally associated with solar phenomena while longer periodicities are mostly related to the internal structure of the earth and its core dynamics.

Geomagnetic disturbance are generally represented by geomagnetic storms and sudden ionosphere disturbance (SIDs). These are caused by the disturbances originated at solar atmosphere, interplanetary (IP) shocks and / or stream interfaces associated with high speed solar wind streams (HSSWS) (Shrivastava and Agarwal, 1990 and Kuznetsov *et al.* 1998) [1, 2]. These are associated with Coronal holes, which occur in Polar Regions or higher latitude. Fast CME produce transient IP shocks, which cause storm sudden commencement at earth. Geomagnetic storms are associated with isolated disappearing filaments (Lakhina, 1994; Loewe and Prolss, 1997 and Gopalswamy, *et al.* 2011) [3, 4, 5]. The occurrence of prominences and flares are also associated with varying phases of sunspot cycle leading to the geomagnetic storms.

As a geomagnetic storm lasts usually a few to several days in duration. However, sometimes the recovery phase of a geomagnetic storm lasts one to two weeks or even for longer durations. These kind of long-duration events were termed as High-Intensity Long-Duration Continuous AE Activity events (HILDCAA events). In a study of such events made by Firoz and Kudela 2007) [9], it was suggested that continuous injections to the ring current take place during these events in such manner that the ring current does not, or cannot, decay rapidly (Kaushik, 2005; Mishra, *et al.* 2005; Firoz *et al.* 2009 and Firoz and Kudela 2007) [6-9]. Various studies have reported that these geo-effective events are further associated with CME's, solar flares, SEPs and also with other solar wind transients (Sabbah, 2000; Firoz, *et al.* 2010 and Sabbah, 2000) [10-12].

The temporary disturbance created by the solar wind after entering inside the earth's magnetosphere when the magnetic field of solar wind interacts with earth's magnetic field (Dungey 1961) [13]. Initially the earth's magnetosphere is compressed when the solar wind pressure is increased. During the time of interaction between the earth's magnetic field and solar wind magnetic field certain amount of energy is increased and this increased energy ultimately increase the plasma level in magnetosphere and also increase the movement of electric current in magnetosphere and ionosphere (Dungey, 1961; Gosling, *et al.*, 1973) [13-14]. The geomagnetic storms are classified into the four categories as per the value of Dst as suggested as weak/small (-30nT to -50nT); moderate (-50nT to -100nT); intense (-100nT to -250nT) and very intense (-250nT an above) (Gosling, *et al.*, *et.al*; 1987)[15]. Geomagnetic activity also creates some directly and indirectly effect and among those some are health problems, satellite malfunction, weather changes etc. Similarly, auroras are produced when the solar wind extremely disturb the magnetosphere and the trajectories of charged particles in both solar wind and magnetosphere plasma, mainly in the form of electrons and protons precipitate them in the upper atmosphere where their energy is lost. Simply when the charged particles from the sun strikes to the upper atmosphere it results to the colored light in the sky which is known to be aurora (Tsurutani; *et al.* 1998) [16].

In this paper the statistical study has been performed to analyze these geomagnetic storms recorded by various geomagnetic observatories identified with the help of Disturbance storm time index (Dst). This Dst index is taken as an indicator of geomagnetically disturbed condition, as it represents the depressions in the ring current as a result of its interaction with the plasma signatures having their roots originated at solar surface or from some other exotic environment. We investigated various solar parameters/ interplanetary magnetic field components which were potentially geo- effective and occurred during the solar activity period of solar cycle-23.

## Methodology

The magnetic field of the earth is continuously observed and recorded with magnetometers/ magnetograms of various observations which are situated in different regions of earth's surface. From the nature of geomagnetic field the various disturbances indices such as Ap, Kp and Dst are easily formulated and are now a days frequently used by scientific community.

In the study of solar terrestrial relationships, it is generally expected to have proper estimate of the level of dissipation of energy within the magnetosphere at any given time. For this purpose geomagnetists developed a series of indices designed to give a semi quantitative measure of the level of magnetospheric activity.

One of the most systematic features of geomagnetic disturbances recorded at low latitudes is the depression below the quiet time level of the horizontal intensity (Moos, 1910 and Sugiura, 1964)[17-18]. This depression results from the westward flowing zonal current system called the ring current. Analysis of magnetic storms reveal that the disturbance field D consists of two parts; the universal storm time variation (Dst) and the local time dependent part (Ds).

Thus

$$D = Dst + Ds$$

The Dst index gives the average depression of horizontal component in unit of nT, which is proportional to the total kinetic energy of symmetrically distributed particles injected and trapped in the Val Allen belt. However, if the particles are not symmetrically distributed the resulting magnetic field is not axisymmetric and Ds index gives the amplitude of the disturbance field as a function of dipole longitude.

We deal with the sudden, sharp and short-lived depressions in the magnetospheric ring current and simultaneous solar parameters to understand the relationship. It is known that the intensity of solar parameters (e.g., solar flare, SEP flux etc.) is registered by satellite at the geostationary orbit in the near Earth space whereas the magnetic field variation and ring current depressions are recorded by a network of observatories well located all over the world.

## Results and Discussion

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 (2007-2016) of solar cycle-23, Solar cycle contains one maximum peak, where sunspot number is maximum and the period of that peak is termed as solar maximum activity phase (Smart and Shea, 1989; Kumar *et al.* 1997 and Asai *et al.* 2006) [19-21].

**Table 1:** Showing the occurrence of the Geomagnetic storms with their classification as per year.

| S.No. | Years | Moderate | Intense | Serve | Total | Average |
|---|---|---|---|---|---|---|
| 1. | 2007 | 11 | 05 | 01 | 17 | 6 |
| 2. | 2008 | 10 | 06 | 02 | 18 | 6 |
| 3. | 2009 | 13 | 04 | 01 | 18 | 6 |
| 4. | 2010 | 16 | 08 | 03 | 27 | 9 |
| 5. | 2011 | 07 | 11 | 04 | 22 | 7 |
| 6. | 2012 | 22 | 12 | 01 | 35 | 12 |
| 7. | 2013 | 18 | 04 | 02 | 24 | 8 |
| 8. | 2014 | 10 | 06 | 01 | 17 | 6 |
| 9. | 2015 | 18 | 06 | 01 | 25 | 8 |
| 10. | 2016 | 06 | 03 | 02 | 11 | 4 |
|  | Total | 131 | 65 | 18 | 17 | 6 |

Table 1 shows the occurrence of the geomagnetic storms with their classification as per year. Under the selection criteria 131 moderate geomagnetic storms, 65 intense geomagnetic storms and 18 severe geomagnetic storms have been observed.

In present study, we have used Dst data, that record the number and severity of geomagnetic storms during solar cycle-23. We have plotted this data and we can give answer several question having to do with how often geomagnetic storms occur during the year, and the frequency of their severity. Firstly we have investigated 214 geomagnetic storms with Dst ≤ -50 nT, are occurred during 2006 to 2016. During this period 214 geomagnetic storms have been found to satisfy selection criteria and will compare with sunspots cycle-23.

Figure 1 gives the averaged sunspot number for that year and figure 2 gives the number of days in which geomagnetic storms were more severe than Dst < -50 nT and shown are the total number of storm days per year. Here, we have analyzed about 214 geomagnetic storm occurred during period 2007-2016. The number of geomagnetic storm observed in each year along with the sunspot number is shown in figure 1 and figure 2.

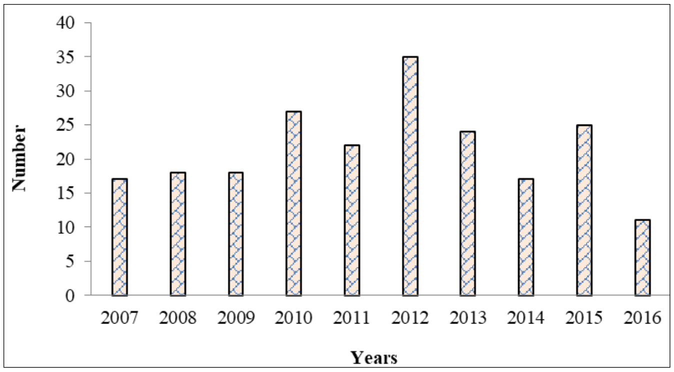


**Fig 1:** The total number of storm days per year during 2006-2016

However the exact time span and intensity are up for dispute our data in figure 2 shows that the second descending phase geomagnetic peak occurs only 18-24 months after solar maximum. This data also shows that the descending phase peak seems to be larger, which means more activity occurs during that period, than the ascending phase peak. Therefore no significant correlation between the maximum and minimum phases of solar cycle and yearly occurrence of geomagnetic storm has been found.

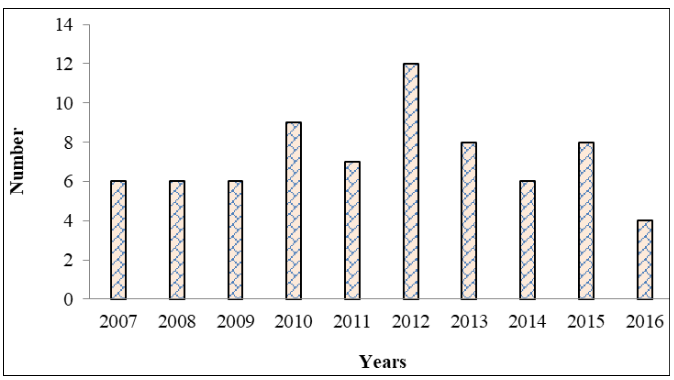


**Fig 2:** Average number of sun spots per year during 2006-2016

Based on 214 geomagnetic storms (Dst magnitude <-50nT) occurred during year 2007 to 2016, we have classified geomagnetic storms with respect to their Dst magnitude in four categories according to Loewe and Prolss [9], a geomagnetic storm can be weak (Dst > -50nT), moderate (-100nT < Dst ≤ -50nT), intense (Dst ≤ -100nT), and severe (Dst ≤ -200 nT).

**Conclusion**

The maximum phase of solar cycle-23 has been measured during the year 2011 whereas the periods 2007-2010 and 2012-2016 are the periods of minimum phase of solar activity. Which clearly follow the phase of sunspots cycle. It is evident that in the year 2016 (solar minimum year) only 11 geomagnetic storm have occurred. It is also found that maximum number of geomagnetic storm have occurred in year 2012 while year 2013 is the maxima of the solar cycle-23, the year 2016 represent minimum sunspot activity during the descending phase of solar cycle-23. The largest geomagnetic storm of solar cycle-23 occurred on 20 November 2012, with a Dst index of -472 nT and the large numbers of geomagnetic storm have occurred in the year 2012 and 2011, which do not exactly follow the phase of solar cycle and show complex behavior. 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 behavior.

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