Analytical Study of Severe and Great Geomagnetic Storms

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Abstract: Severe and Great Geomagnetic storms are considered to be those which have Dst less than -200nT. The investigation years are January 1996 to December 2006, which refers to 23rd solar cycle. During this period, 18 Geomagnetic storms are observed. When there are maximum number of sunspots present at the solar disk, highest number of these Geomagnetic storms are observed, which is quite obvious. The Coronal Mass Ejections responsible for these storms depict latitudinal as well as longitudinal bias showing more inclination towards northern hemisphere and western region of the solar disk. These Coronal Mass Ejections are confined between ±25° of the equator.

Keywords: Sunspot number • Disturbance-time-storm index, • Magnetosphere

Introduction

Geosphere is greatly affected by different solar features like Solar Flares (SFs), Coronal Mass Ejections (CMEs), etc. The main cause of highly energetic geomagnetic storms (GMSs) is believed to be large interplanetary magnetic field (IMF) structure (Tsurutani et al., 1988; Echer et al., 2004; Kumar and Raizada, 2008) which interact with the Earth's magnetic field and facilitate the transport of energy into the Earth's atmosphere through the reconnection process. Solar wind (SW) and CMEs occupy the forefront of solar terrestrial research because they have been identified as the primary sources of space weather (Gopalswamy, 2011).

CMEs have been identified as the most energetic events in the heliosphere which are responsible for affecting solar wind in the form of either magnetic field disturbances or speed of solar wind or its density, and hence magnetic disturbance occurs at Earth (Zhang et al., 2003). CMEs, when evolved from Sun, move in all directions. But those, which are directed towards Earth (called geoeffective CMEs) are mainly responsible for impacting the magnetosphere and hence Geomagnetostorms (GMSs) take place (Gopalswamy, 2006; Kumar and Raizada, 2010; Manoharan, 2012). CMEs are classified as Halo, partial halo and narrow depending upon their width. Ones with apparent width of 360° are termed as 'Halo', those with width less than 120° are narrow, whereas CMEs with width between 120° and 359° are said to be 'Partial Halo'. Since Halo CMEs are wider than other CMEs, they are expected to possess more energy (Zhao, 2004; Gopalswamy, 2007). Depending upon the speed of CME, at the time of its evolution at the solar disk, it's time to reach

Earth is decided, which could be anything between 24 hours to 5 days (Zhang et al., 2003). In this research paper, an attempt is made to identify the solar features and also analyze their characteristics for causing severe/ great GMSs, on the basis of disturbance storm time (Dst) index. Here, severe GMSs will be designated with -200nT > Dst ≥ −350nT and great GMSs with Dst < −350nT, as given by Loewe and Prolss in 1997.

Data analysis

The period chosen here is from January 1996 to December 2006 which covers 23rd solar cycle. During these years, 18 Geomagnetic storms falling under the category of Severe and Great are observed. There are some gaps present in the available data, may be due to weather condition or servicing/maintenance of instruments etc. Due to which, two GMSs of September 24, 1998 and October 21, 1999 are not investigated thoroughly. The data used here is freely available at internet so as to facilitate different researchers across the globe and is collected by different research centers, which are acknowledged by the author in 'References'

Results and discussion

Different number of sunspots appears at solar disk at different time which goes on increasing from minimum to maximum and then declines

back to minimum in 11 years time. Somehow, 23rd solar cycle extended till 12.3 years and marks the period from 1996 to 2008. 18 GMSs have occurred during the investigation period. Out of which 14 are of severe and 4 are of Great nature. The value of Dst, which is the indicator of commencement of GMS, starts falling many hours before the storm and attains the minimum value when the storm is at its maximum strength.

It has been observed that the frequency of CMEs varies with sunspot cycle. Lesser number of sunspots indicates less activity at solar disk and hence lesser number of CMEs evolves. The number of CMEs increases as the solar cycle progresses. Approximately 2 to 3 CMEs/day are observed when solar cycle is at its peak. Thus, large number of GMSs with Dst < -200nT are expected close to the solar maximum, which is clear from Fig. 1. Ten GMSs of severe and great nature have been observed during maximum phase (1999 to 2002), while only 2 and 6 GMSs showed up in rising (1996 to 1998) and declining (2003 to 2006) periods respectively.

The mean value of the speed of solar wind velocity (Vsw) for the storms under investigation is 614Km/s with minimum speed of 362Km/s and maximum of 866Km/s. The minimum value attained by Dst index for a particular GMSs against Solar wind velocity (Vsw), has been plotted in Fig. 2.
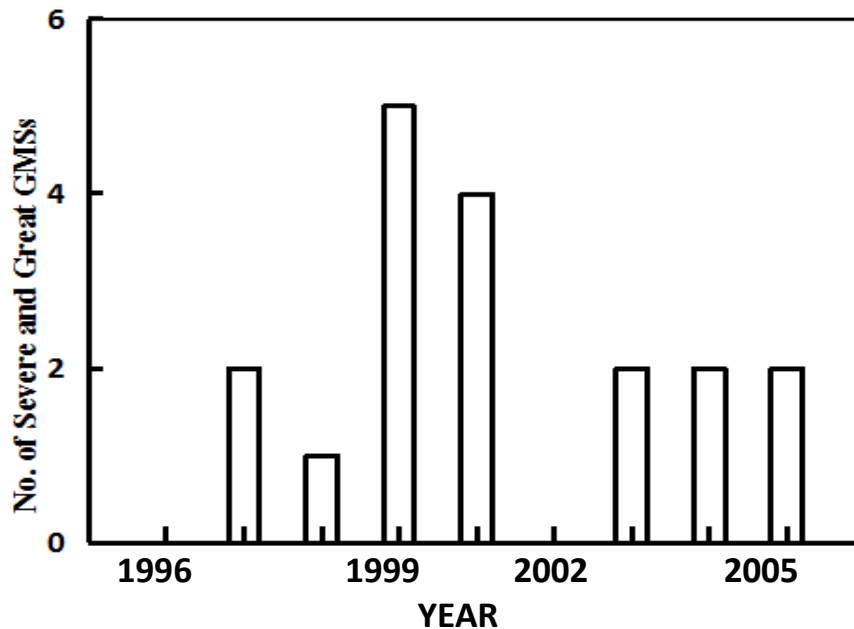
Fig.1 Yearly variation of Severe and Great GMSs during Solar cycle 23

The CME accelerates or decelerates during its propagation from solar disk towards Earth, in comparison to its speed at the time of its evolution, which is termed as initial speed. The minimum initial speed of CMEs due to which these GMSs occur, is found to be 453Km/s and maximum is2459Km/s respectively with an average value of 1682Km/s which is pretty high. Fig. 3 shows the minimum value attained by Dst index against initial speed of CME.

The investigation reveals that CMEs are responsible for all the events (severe and great both) to take place. It could be possible that more than one CME is involved in the process. Thorough investigation shows that Active Prominences and Disappearing Filaments, which is one of the many solar features, are also associated with 23% events. Besides this, all the events are associated with SFs of M and X class i.e. of high importance. SOHO observations support that the flare and CME are two manifestations of the same energy release (Gopalswamy, 2016).

The locations of CMEs for these severe and great GMSs have been plotted in Fig. 4 which clearly depicts that the location of these geoeffective CMEs is not symmetrical over the solar surface. 37% evolve from eastern side while 63% from western side. Thus, longitudinal distribution shows more inclination towards west side. Further, 81% of the total events observed are the disk events where the longitude

is confined within ±45° of the central meridian and not the limb events where the longitude is confined between 45° and 90° which is similar to the findings of Gopalswamy et al., 2007. Fig. 4 also suggests the hemispherical bias in location of these CMEs. 69% of these CMEs are observed to have occurred in north part and 31% in south part of solar disk. However, looking at the latitudinal position from the equator, the geoeffective CMEs are found in the vicinity of ±25° from the position of equator.
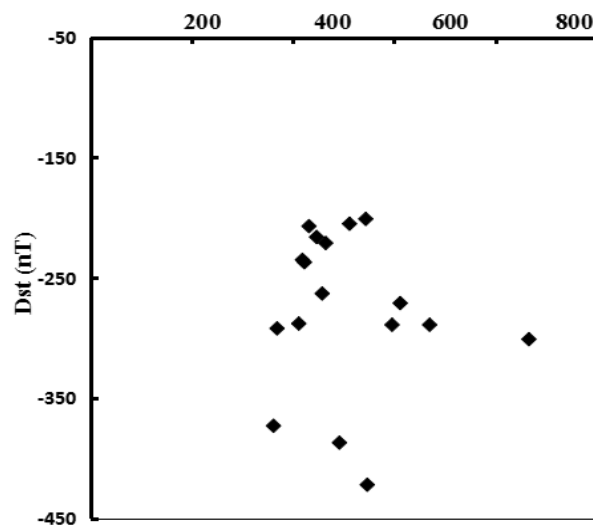

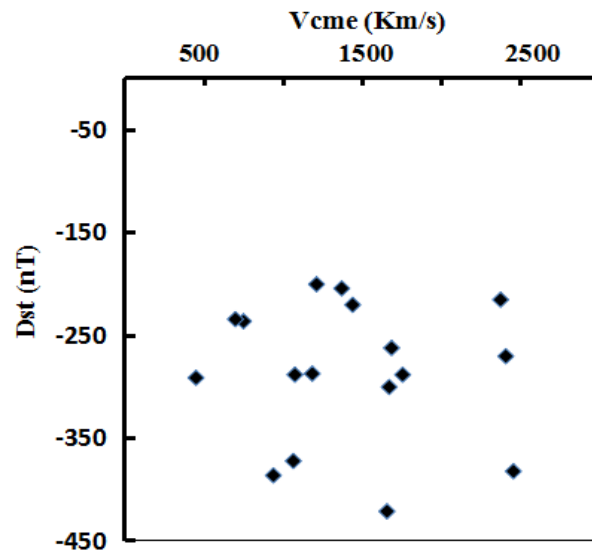**Fig 2: Dst (minimum) value versus Solar Wind speed**

Fig. 3 Dst (minimum) versus CME speed.

Conclusions

The analytical study reveals that the largest number of severe and great GMSs happen during maximum phase of solar cycle. The high speed Solar Wind Plasma, could be responsible for these severe/ great Geomagnetic storms. These GMSs are mainly associated with halo CMEs followed by SFs of high importance. The geoeffective CMEs causing severe and great GMSs show longitudinal as well as hemispherical bias. These CMEs are generally confined close to the equator and are mainly the disk events. The correlation coefficient has not been calculated for Vsw against Dst as well as for Vcme against Dst because the data sample is too small for statistical analysis. The study can be extended with considerable data sample so as to find solar and interplanetary parameters for predicting these storms.
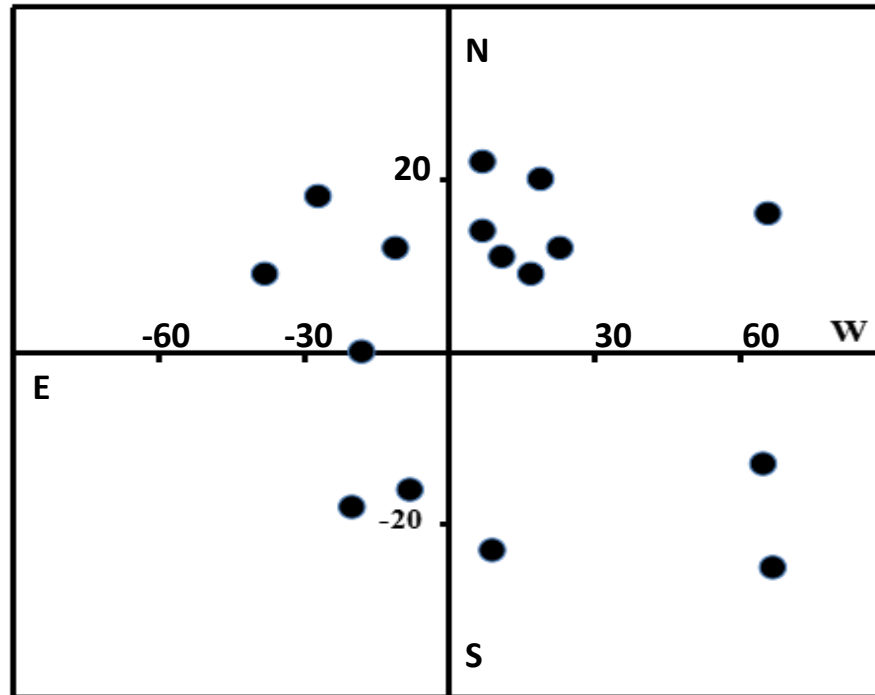
Fig. 4 Geoeffective CMEs' location on Solar disk.

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