Comparative Study of Isolated and Successive Geomagnetic Storms

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**Abstract:** The intense Geomagnetic Storms (GMSs) with Dst < -100 nT have been investigated for the period from Jan 1996 to Dec 2006. Seven GMSs of doublet and four of triplet nature are observed. Firstly, each GMS has been studied separately as if they are associated with independent Coronal Mass Ejections (CMEs). Secondly, for each doublet and triplet, the accumulated effect on GMS has been investigated and correlated with Dst index so as to understand the geoeffectiveness of Successive Intense GMSs. Majority of the successive intense GMSs have occurred during maximum phase of Solar cycle. During the occurrence of overlapping successive storms Dst falls abruptly. For non-overlapping successive storms, the Dst value falls gradually to minimum, showing a trend of recovery before the geosphere is hit by another storm. When the GMSs are considered as separate entity, the correlation coefficient of Interplanetary Magnetic Field (IMF) parameters B and Bz and further, their products Vsw.B and Vsw.Bz correlated with Dst index are found to be -0.65, 0.72, -0.66 and 0.77 respectively; whereas, the coefficients are much better with the respective values of -0.7, 0.87, -0.78 and 0.90, for the accumulated effect of GMSs. Thus, it is preferable to investigate the accumulated effect of CMEs causing successive GMSs as compared to their isolated effects.

**Keywords:** Coronal Mass Ejections, Geomagnetic Storms, Interplanetary Magnetic Field.

1 Introduction

In recent years a number of investigations have been carried out to understand the solar-terrestrial relationship and to ascertain factors that are responsible for Geomagnetic Storms (GMSs) [1, 2]. It is believed that the GMS is the response to Interplanetary (IP) phenomena arising as a consequence of a Solar event. The geospheric environment is highly affected by the Sun and its features such as Solar Flares (SFs), Active Prominences and Disappearing Filaments (APDFs), Coronal Holes (CH), Coronal Mass Ejections (CMEs) etc.

Due to the combination of Flare and CME events, a GMS of longer than average duration may result as it is possible that the Earth could sustain two successive CME passages over the next few days [3]. In fact, sometimes the next GMS starts just after the end of previous storm or while the previous storm is in progress. Such storms are called successive [4] or long lived [5] or multistep [1] GMSs by different authors. These types of storms occur mostly when successive CMEs are ejected from the Sun and have an impact on Earth [5].

In this paper, the successive GMSs of intense nature i.e. Dst < -100 nT, have been identified from Jan 1996 to Dec 2006. Each GMS has been studied separately as if they are associated with independent CMEs and then their accumulated effect is investigated. The isolated and cumulative effects causing successive GMSs are compared. Further, the IP parameters are correlated with Dst index so as to understand the geoeffectiveness of successive intense GMSs.

2 Data and its analysis

As given in Table-1, seven GMSs of doublet and four of triplet nature are observed from Jan 1996 to Dec 2006. Out of which two doublet events are not investigated for IMF values since the hourly data of IMF for these events is not available online. The values of Dst indices are taken from World Data Center, Japan. Solar Geophysical Data and SOHO/LASCO CME Catalogue are used to study Storm Sudden Commencement (SSC) and manifestations of CMEs causing intense GMSs. On the basis of Solar Wind Velocity (Vsw), Solar features have been identified taking into consideration that SW takes 1 to 5 days in reaching the Earth from the Sun.
OMNIWEB data is used to obtain the values of SW while ACE data helped in providing the IMF values.

3 Results and discussion

During Solar Cycle 23, eleven GMSs have been observed which are successive and intense in nature. The time of occurrence of GMS is taken as the arrival time of SSC [6]. Out of these eleven GMSs, 18% are observed in rising (from 1996 to 1998) and declining (from 2003 to 2006) phases each; whereas, 64% have occurred during the maximum (from 1999 to 2002) phase of Solar cycle when the Sun is passing through maximum activity period with maximum number of Sunspots (SSNs). Majority of successive GMSs occurring during maximum phase, may be due to the steady rise in the rate of production of CMEs at Solar disk.

Five successive storms are found to be of overlapping nature i.e. the next GMS starts while the previous storm is in progress; three storms are of non overlapping type i.e. the next GMS starts within 24 hours after the end of previous storm and three storms are of mix nature.

For overlapping successive storms, the fall in Dst is found to be gradual at the onset of GMS. However, as soon as the magnetosphere is hit by another preceding storm, the Dst falls abruptly which is also observed by Yousef et al. [7]. It continues to maintain its minimum value for 15 to 34 hours. Therefore, the second storm might result in re-energisation of the GMS that is underway and hence, the GMS activity has the potential to persist for a day or more [3, 5]. For non overlapping successive storms, the Dst value falls gradually to minimum, shows recovery and falls again when hit by preceding storm. Figs. 1 and 2 depict cases of overlapping and non-overlapping events respectively; whereas, Fig. 3 depicts the behaviour of mix type of triplet GMSs. When these GMSs are investigated as separate entity, it is observable from Fig. 4 that the combined effect of GMSs make it complex by having the magnetosphere disturbed continuously and abruptly for a long period, which is also stated by Gopalswamy [8]. The duration of the storm does not show significant correlation (corr.coeff.= 0.38) with number of CMEs responsible for the occurrence of successive GMSs; somehow, it is not in agreement with the observations of Gopalswamy [8] who found corr. coeff. of 0.78.

The main cause of Intense GMSs is believed to be large IMF structures which have an intense, long duration and southward magnetic field component (Bz). They interact with the Earth’s magnetic field and facilitate the transport of energy into the Earth’s atmosphere through the reconnection process. The correlative study between Dst and the product of Vsw with IMF parameters is helpful in understanding the SW-magnetospheric interaction. The correlation coefficients of B, Bz, Vsw,Bz and Vsw:B with Dst are given in Table-1 which clearly reflect that the correlation is better for accumulated effect than for isolated effect.

Figure 1. The hourly variation of Dst index for the overlapping successive intense GMSs occurred on Jul 14th and 15th, 2000. The solid lines show the arrival and ending of first storm; whereas, dotted lines show the arrival and ending of second storm.

Figure 2. The hourly variation of Dst index for the non-overlapping successive intense GMSs occurred on Aug 10th and 11th, 2000. The solid lines show the arrival and ending of first storm; whereas, dotted lines show the arrival and ending of second storm.

Figure 3. The hourly variation of Dst index for the mix nature of successive intense GMS occurred on Oct 1st, 2nd and 3rd, 2002. The solid lines show the arrival and ending of first storm; dotted lines show the arrival and ending of second storm; whereas, dashed lines show the arrival and ending of third storm.
5 Acknowledgements

The authors are highly indebted to various experimental groups for providing data online through Internet.

6 References


4 Conclusions

Based on the present investigation, the following important conclusions have been derived:
(i) Majority of the successive intense GMSs have occurred during maximum phase of Solar cycle 23.
(ii) For overlapping successive storms Dst falls abruptly. For non-overlapping successive storms, the Dst value falls gradually to minimum and shows a trend of recovery before the geosphere is hit by another storm.
(iii) The intensity of GMS is observed to be much higher and storm duration much longer for the successive storms than for the isolated storms.
(iv) The duration of successive GMS does not show significant relationship with number of participating CMEs.
(v) Bz, B, Vsw.Bz and Vsw.B show better correlation with Dst index for accumulated effect than for isolated GMS. However, the correlation is highly significant for Vsw.Bz.
(vi) It is preferable to investigate the accumulated effect of CMEs causing successive GMSs as compared to their isolated effect.

Table 1. Correlation coefficients between Solar/IP Parameters (Sp/IP) and Dst minimum value during a particular event for isolated and accumulated effect of successive intense GMSs

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<td>Vsw</td>
<td>Dst</td>
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<tr>
<td>B</td>
<td>Dst</td>
<td>-0.65</td>
<td>-0.7</td>
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<td>Bz</td>
<td>Dst</td>
<td>0.72</td>
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<td>Vsw.B</td>
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Figure 4. Duration of isolated storm (hollow bars); and that of successive storm (solid bars) in hrs have been plotted for different events.