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Analysis of Sequential Geomagnetic storms as Single and Separate Entity

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Abstract: The Geomagnetic Storms which occur one after the other within the time gap of 24 hours or which occur before the previous one has ended are investigated. Only those Geomagnetic storms for which Dst index falls below -100nT are chosen and the period selected is from 1996 to 2006. The investigation is done in two ways: 1) by considering each storm separately and 2) by considering the storms occurring in succession as single storm and assessing their cumulated effect. For doing so, the solar and interplanetary data like solar wind speed, interplanetary magnetic field etc. are observed and correlated with Dst index. Thus, the two ways of investigations are compared and analyzed.

Key Words Solar wind plasma, Interplanetary magnetic field, Disturbance-storm-time index.

Introduction

Solar eruptions which move towards Earth direction either create disturbance in the magnetosphere leading to geomagnetic storms (GMSs) of varying intensities or interact with Earth's atmosphere through accelerated Solar Energetic Particles (SEPs).This has fascinated researchers to study Solar-terrestrial events and establish a relationship between the two. Our planet is affected by different solar features like solar flares, coronal mass ejections (CMEs) etc. in a number of ways. One of them is by causing GMS wherethe energy is transported into geomagnetosphere (Gopalswamy, 2006). For GMS to occur, the southward component of interplanetary magnetic field (IMF) and Earth's magnetic field gets reconnected (Tsurutani et al, 1988; Kumar and Raizada, 2010).

Disturbance-storm-time (Dst) index is used to measure Geomagnetic activity. More negative the value of Dst index, more intense is the GMS.The GMSs having Dst< -100nT, which are termed as strong, severe and great by Loewe and Prolss, 1997or intense and superintense by Kumar and Raizada, 2008, are studied in this paper from January 1996 to December 2006. Halo CMEs being more energetic are mainly responsible for such type of highly intense GMSs (Cane et al, 2000; Burlaga et al, 2002; Zhang et al, 2003). The CME, which evolves at the solar disk, takes around 24 hours to 120 hours i.e. between 1 to 5 days to reach 1AU distance (Zhao, 2004; Gopalswamy, 2016). Sometimes, more CMEsappear, in succession one after the other and move towards Earth. Thus, giving rise to sequential GMSs i.e.two or more GMSs occur in sequence, one after the other. It may also be possiblethat second GMS commences before ending of the previous one i.e., they overlap each other. This could enhance the intensity as well as duration of GMS (Kappenman, 2003; Manoharan, 2012; Raizada, 2021).

Some researchers have considered such type of overlapping GMSs as single storm and have investigated their cumulative outcome (Zhang et al, 2003; Gopalswamy et al, 2007) whereas these storms may be considered as separate entity (considering each storm as individual) since they are found to be associated with different CMEs.

In this paper, an attempt has been made to compare the following two behaviors and assess which way of investigation is more accurate:

Considering overlapping/ non-overl0 appingstorms occurring in succession as one storm and analyse its combined effect. These storms are termed as 'single storm' in the present discussion. Here the term non-overlapping storms applies to the behaviour where second storm occurs within the span of 24 hours after the end of first storm.

Considering each storm as individual entity since they are observed to be associated with different solar feature and analyse the effect of each and every GMS separately. These storms are called here as 'separate storm'

Hence, a term 'single storm' is used when the cumulative effect of two or more GMSs is assessed whereas the term 'separate storm' is used when each storm is assessed on individual basis.

Data analysis

Presently 25th solar cycle is going on which has started recently in December, 2019 and expected to continue till 2030. Thus, the available data is only for 2.5 years which is too small. The data of entire 24th solar cycle is available but the geomagnetic activity is observed to be low in solar cycle 24. Hence, it is declared as the weakest cycle in last 100 years by the scientific community. Moreover, we have analysed only intense geomagnetic storms with Dst<-100nT, which have occurred rarely in 24th solar cycle. Thus, the most recent data which justifies our analysis is available in 23rd solar cycle hence it is chosen in the present investigation and the period covered is from 1996 to 2006.' The analysis done is depicted by Figures 1 to 5. In each figure, the single and separate storms are plotted so that the comparison can be made. The regression line is shown as solid-line for separate storm (mentioned as series 1) whereas line of regression is depicted by dashed-line for single storm (described as series 2). The correlation coefficient is designated by 'r' and 'R' for separate and single storms respectively.

The data used here is collected by different research groups at various research centers across the globe and is freely available at their websites. These researchers are acknowledged in 'References' by the authors.

Results and discussion

From January 1996 to December 2006, 11 GMSs are observed which have Dst<-100nT and occur in succession. Out of these 5 are found in overlapping mode where second storm occurs before the ending of first storm,3 are non-overlapping and another 3 are of mixed type. In case of mixed behaviour, three GMSs are found in succession, out of which two storms show overlapping nature while third storm commences in less than 24 hours duration of previous storms. The Dst value starts decreasing at the time of commencement of the storm, attains its lowest minimum during the peak of GMS and then shows recovery trend until it is hit by another solar feature so as to initiate another storm.

Fig. 1 depicts the variation of speed of solar wind with minimum value of Dst attained, when storms occurring in succession are considered as single entity and for separate entity as well. The correlation coefficient is observed to ber = -0.52for separate and R = -0.59 for single storms respectively, which are almost similar suggesting that both the ways of investigations do not make much difference.

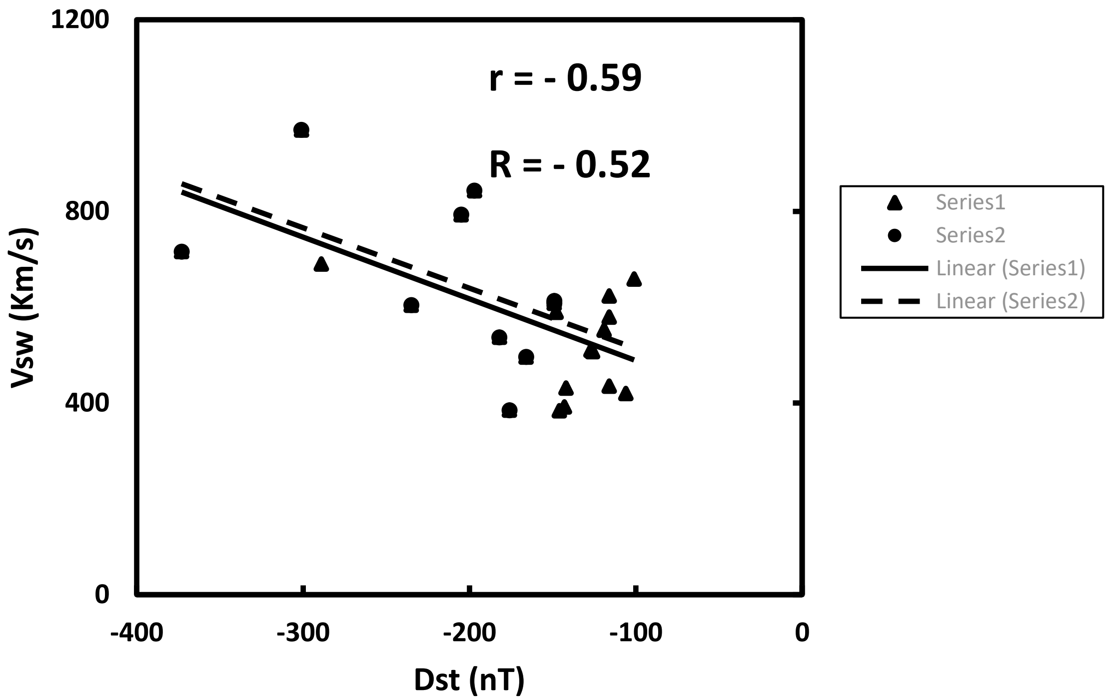

Fig. 1. Speed of solar wind (Vsw) against minimum Dst-index value for separate (▲) and single (●) GMS.

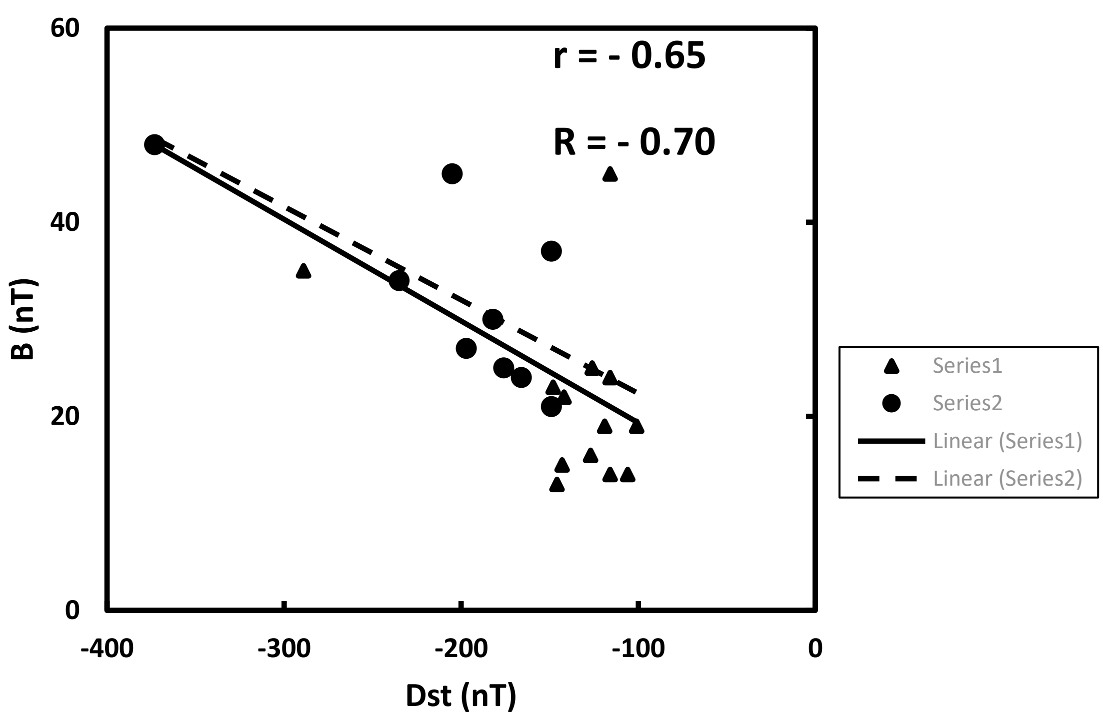

Fig. 2. IMF B against minimum Dst-index value for separate (▲) and single (●) GMS.

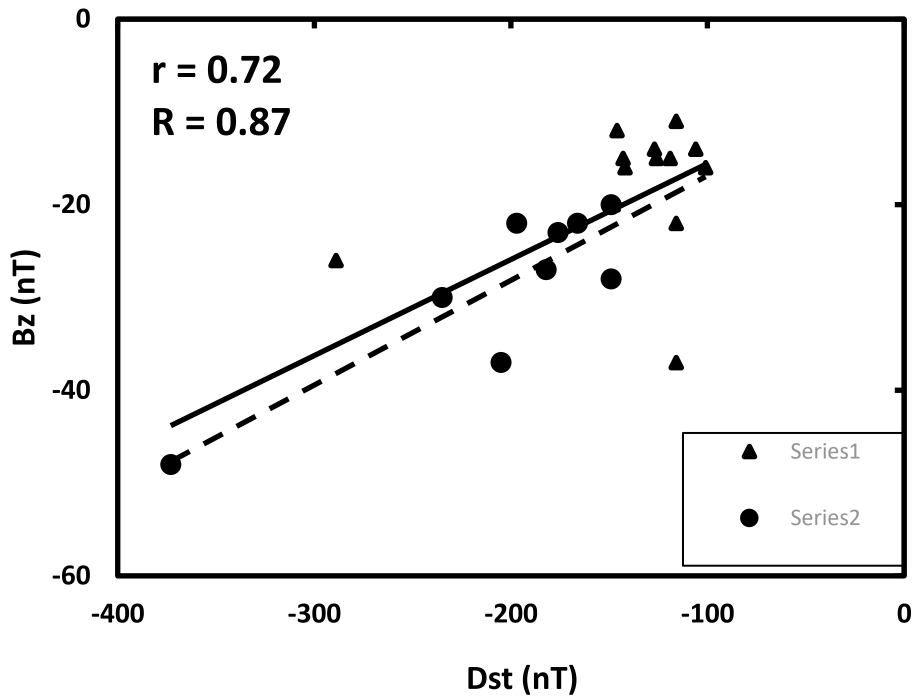

Fig. 3. IMF (north-south component) Bz against minimum Dst-index value for separate (▲) and single (●) GMS.

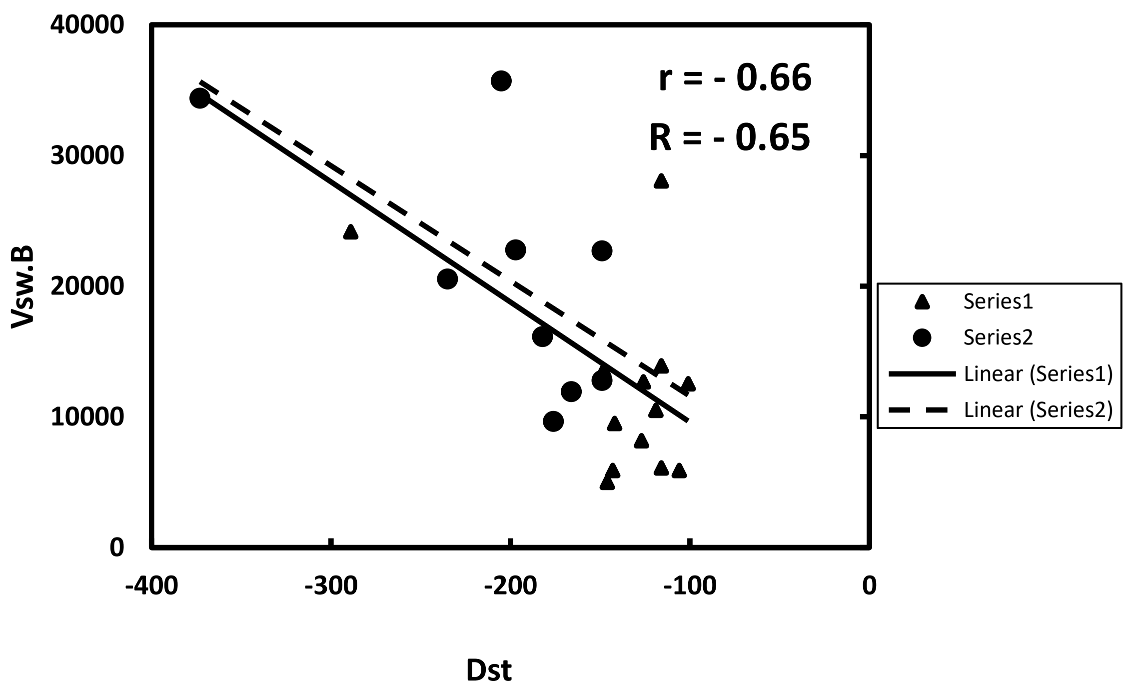

Fig. 4. Combined impact of Vsw and B against minimum Dst-index value for separate (▲) and single (●) GMS.

To clarify the impact of interplanetary conditions on the magnetosphere, the strength of IMF and its southward component denoted by B and Bz respectively are examined and plotted against the minimum value of Dst observed for these GMSs.The values of correlation coefficient are pretty good in all the cases, which is clear from Fig. 2 and Fig. 3 respectively. However, the correlation coefficients are much better when the storms are considered as single entity.

Since during storm, Sun-Earth parameters get coupled and hence leads to GMS.Therefore, it becomes necessary to consider the combined impact of solar wind speedand B (or Bz). Fig. 4 and Fig. 5 depict the behaviour of Dst with Vsw.B and Dst with Vsw.Bzrespectively. Here also the correlation value is good in all the cases but is significantly high for storms when they are taken as single entity.

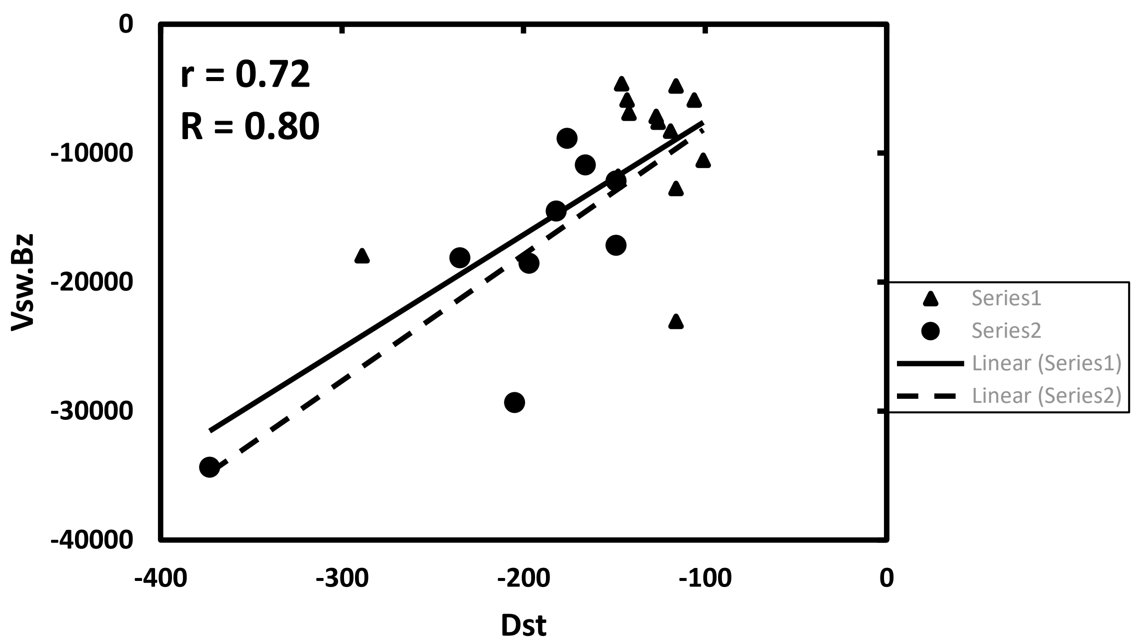

Fig. 5. Combined impact of Vsw and Bz against minimum Dst-index value for separate (▲) and single (● GMS.

Conclusions

It has been observed that Dst index, which measures the intensity of geomagnetic storm, falls drastically when GMSs overlap.Whereas for non-overlapping cases, Dst value recovers significantly before another CME strikes the geomagnetosphereleading to turbulence and finally causing another storm.Hence, the Dst index, which was in recovery phase, again starts falling. When the GMSs occur in succession, it becomes complex suggesting complicated conditions in magnetosphere and IP space. Reasonable correlation coefficient between Vsw and DstsuggestsVswto be considered as reliable indicator of GMSs. Better correlation value obtained for single GMSs(depicted by 'R') as compared to separate GMSs(depicted by 'r'),indicates that it is advisable to treat the GMSs occurring in successionas single entity and investigate them as one GMS.

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