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Effect of Solar outcomes on earth magnetosphere during solar cycle-24

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Today's challenge for space weather research is to quantitatively predict the dynamics of the magnetosphere from measured solar wind and interplanetary magnetic field (IMF) conditions. Correlative studies between geomagnetic storms (GMSs) and the various interplanetary (IP) field/plasma parameters have been performed to search for the causes of geomagnetic activity, which are important for space weather predictions. In this paper we have found relation between solar activity and geomagnetism during the solar cycle-24. Geomagnetic storms (GMSs) were less during the observed cycle, no severe and great storms had occurred during that cycle.Yearly occurrence of GMSs does not exactly match with phase of solar cycle-24. Similarly occurrences of Coronal mass ejection (CMEs) also do not exactly follow the phase of solar cycle but yearly occurrence of GMSs follow the yearly occurrence of Halo CMEs. Consequently, halo CMEs are responsible for the occurrence of GMSs during the solar cycle-24. The behavior of the total average interplanetary magnetic field (IMF) B_{total}, Southward component of IMF (B_z), Solar wind temperature, Solar wind density, Solar wind dynamic pressure, Solar wind velocity (V), and E_y along with geomagnetic storms (Dst index) have been analyzed in this paper. Relation of Dst with B_{total}, B_z, Speed V and E_y has been found good during the cycle-24.

Keywords: Solar cycle, Geomagnetic Storm, Solar wind, Interplanetary Magnetic Field (IMF)

1 Introduction

Sun and solar activity plays an important role in space weather variation. It was investigate in previous studies sun spots were the causes of change of earth environment. The 11-year solar activity cycle has been an open question since long time and various investigators has addressed this problem. The solar activity is directly related to space weather while geomagnetic activity rises and falls along with the solar activity. It has also been investigated major geomagnetic storms are associated with solar flares and coronal mass ejections and ultimately these all depend on solar activity[1-10].

Space weather is an extensively studied phenomenon[11-15]. Disturbance in earth magnetic field is known as geomagnetic storms (GMSs) or space weather. Sun Spots, Coronal mass ejections (CMEs), solar flares and coronal interaction region (CIR) are the most common solar activities[16-19]. Solar flare and CMEs are most probable causes of GMSs[20]. Space weather is directly related to solar activities; therefore GMSs are rise and fall along with solar activity[21-26]. It has been investigated by various groups that most of GMSs are occurred after two-three days of CMEs ejection[27-30].

A geomagnetic storm is moderate due to IMF and Solar wind which is ejected from outer atmosphere of sun. Disturbance in earth magnetic field is knows as geomagnetic storms or space weather[31-36]. Magnetic indices have been used to detection of magnetic field variation e.g., Kp, Ap and disturbed storm time (Dst).

2 Materials and Methods

2.1 Data collection and selection criteria

Ascending phase of solar cycle-24 was taken for present study, starting from year 2008. This is the hourly average of the deviation 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 negative values of Dst shows magnetic storms[37]. We have analyzed the events represented by minimum Dst decrease and selected by using the selection procedure[38, 39].

Dst is the most usable index[37]. Further, GMSs have been categories in four categories such as weak, moderate, intense and sever according to cut off value of Dst[39]. GMSs have been divided in three phase initial phase, main phase and recovery phase[40-42].

Dst data provided by the World Data Center for Geomagnetism, Kyoto, Japan (http://wdc.kugi.kyoto-u.ac.jp/dstdir) and also from the OMNI web data source maintained by National Geophysical Data

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Center (NGDC) (omniweb.gsfc.nasa.gov) is being compiled for this study for the period of 2008-2013. A list of Helo CMEs is provided by CDAW-NASA's centre to maintain CMEs data (cdaw.gsfc.nasa.gov/CME_list/). As the study period refers to the interval solar cycle-24. In the present study, we took a set of 47 GMSs with Dst ≤ -50 nT.

Hourly average heliospheric parameters, we used solar wind speed [km/s], solar wind density [cm^{-3}] and Temperature [K]. Interplanetary magnetic field (IMF) [B: nT] and southwards component [Bz: nT]. Also, we took heliospheric electric field [Ey: mVm^{-1}] data which was been taken from omniweb.gfsc.nasa.gov.

3 Results and Discussion

Researchers found good correlation between activity and geomagnetic condition during the last cycle and they expected that the year 2012 would be highly stormy year and it will be the maximum phase of next solar cycle-24. With this prediction and by study of last cycle, the study of current cycle-24 became important, therefore in present study we take cycle-24. Yearly occurrence of sunspots (SSNs), geomagnetic storms (GMSs) and Halo CMEs are given in Table1.

In the present work, the data of sunspots was collected from world data centre. We have taken yearly average of sun spots data during cycle-24, which started from 2008, as is shown in Fig. 1. It was observed that, in the whole period of solar cycle-24, the solar cycle contained one maximum peak, where sunspot number is largest and the period of that peak is termed as solar maximum activity phase. The maximum phase of solar cycle-24 has been measured during the year 2013, whereas the periods 2008-11 were the periods of minimum phase of solar activity. The current studies for Sunspot Cycle 24 give a smooth sunspot number maximum of about 98 in 2013. The smoothed sunspot number has already reached 92, the strong peak in 2011. The smoothed sunspot number has been rising again towards a second peak over the year 2013.

In the present study the Disturbance storm time (Dst) index was used to identify the geomagnetic storms which occurred in time interval 2008 to 2013. Total 47 geomagnetic storm were observed during the span of solar cycle 24 with Dst ≤ -50 nT. Using the minimum Dst value as an indicator, we have classified the storms as moderate (36), strong (11), severe (0), and great (0) during the cycle 24.

The large numbers of geomagnetic storms occurred in 2011 and 2013. It was found that maximum number of geomagnetic storms has occurred during 2012, while year 2013 was the maxima of the solar cycle-24. Therefore, geomagnetic storms do not exactly follow the phase of solar cycle and shows complex behavior like the last cycle. It is believed that no severe geomagnetic storms have occurred during sunspot cycle-24. It has been observed the solar cycle-24 quite opposite according to initial expectation. We are currently over five years into Cycle 24. The current predicted and observed size makes this the smallest sunspot cycle since Cycle 14 which had a maximum of 64.2 in 1906.

In the present work, we have analyzed about 184 Halo CMEs, which have occurred during the solar cycle-24 and recorded by space borne high resolution cameras on board SOHO-LASCO and other spacecrafts too. We have analyzed about 184 halo CMEs occurred during period 2008-2013. The number of Halo CMEs observed in each year along with the SSNs is shown in Fig. 2.

After a critical observation it is evident that in the

Table 1 — Average number of Sun spots (SSNs) per year, total number of Geomagnetic storms (GMSs) per year and Halo CMEs during 2008-2013

Year	SSNs	GMSs	Halo CMEs
2008	12	0	1
2009	14	1	1
2010	26	6	11
2011	92	12	41
2012	71	18	68
2013	98	10	62

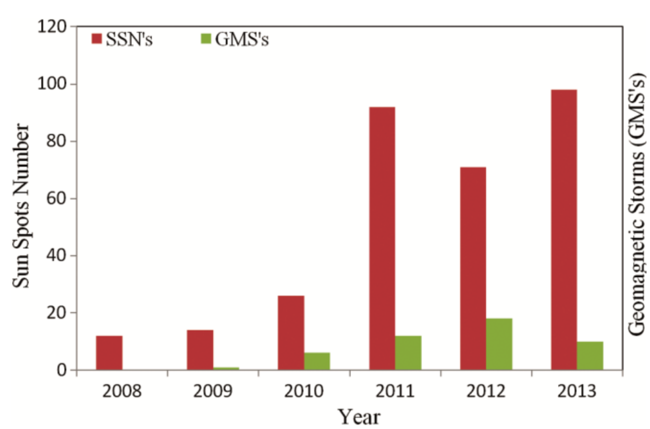

Fig. 1 — Average number of Sun spots per year and the total number of storm days per year during 2008-2013.

year 2008 and 2009 only 1 Halo CMEs were occurred. The year 2008 and 2009 represents minimum sunspot activity during ascending phase of solar cycle 24. It was also found that large numbers of Halo CMEs have occurred in the years 2012 and 2013. But in year 2012 occurrence of halo CME was large but number of Sunspots was less than year 2013. Thus, it clearly indicates that occurrence of Halo CMEs do not exactly follow the phase of solar cycle. These results similar like last cycle by Rathore *et al*.[38]. In the next figure we have taken occurrence of geomagnetic storms (GMSs) with halo CME is depicted (Fig. 3).

It is explicitly clear from the Fig. 2 that the GMS were large during the maximum phase of solar cycle-24. It is clear from Fig. 3 that the GMSs are exactly following the occurrence rate of Halo CMEs. Thus, we can conclude that Halo CMEs are the possible cause of GMSs during the cycle-24. The present results were supported by findings of previous researchers[24].

Dst index estimates the globally average change in horizontal component of Earth's magnetic field at magnetic equator, which was measured by magnetometer situated different locations of earth. The major geomagnetic storms are associated with coronal mass ejections and solar flares[24]. Total 47 GMSs were observed during the selected study period. Most severe cases were selected for detailed analysis out of 47 events during the active period of solar cycle 24. We analyzed interplanetary magnetic field B, Z-component of magnetic field Bz, Solar wind velocity (v), Solar proton density (Np), Temperature, Pressure and Electric field with Dst for each case. Variation in solar wind parameters such as magnetic field, Bz, Solar wind velocity (V), Solar density, Temperature (T), Pressure and Electric field are shown in Figs. (4 and 8).

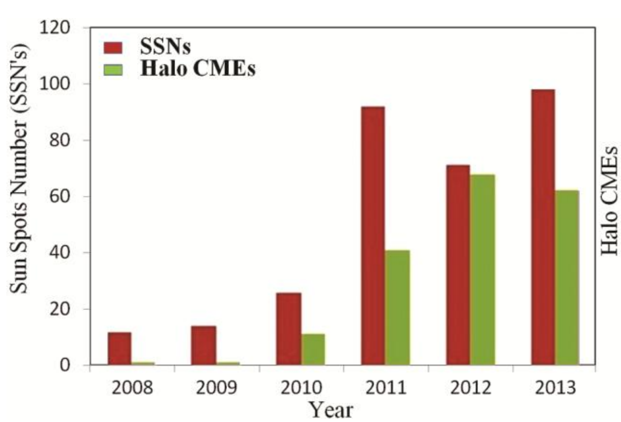

Fig. 2 — Average number of Halo CME per year and the total number of SSNs per year during solar cycle-24.

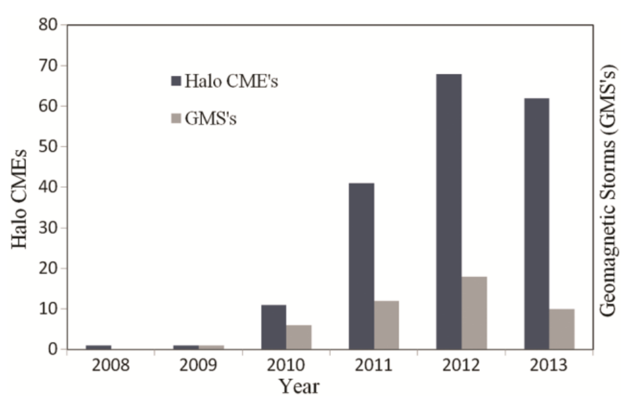

Fig. 3 — Average number of Halo CME per year and the total number of storm days per year during solar cycle-24.

Figure 4 displays the variation of different solar wind and geomagnetic parameters during September 04-16, 2011. Figure 4 indicates that Dst reaches its minimum (-64 nT) on September 10, 2011 at 05:00UT. It is comprehended from above graph that the value of B_{total} become high at the same day before some hours of Dst minimum, Southward component Bz also has rapid change. Solar wind speed V and density were very high at that particular day, reported as 560 km/second, 41.2 cm^{-3} respectively. Pressure and Temperature (T) all show a lead in Fig. 1. Instead of all electric field E_y=V x B_z shows a peak in figure.

Figure 5 reveals the case of the intense storm during the period September 27-28, 2011. It is also depicted from the Fig. 5 that Dst reaches its minimum (-101nT) on September 26, 2011 at 24:00UT. Total magnetic field B_{total} and southward component Bz become high during the initial phase. In this particular case solar wind density becomes maximum (30.7 cm^{-3}) on 24 September after some hours it's come back at their average value and sustained same average value during initial phase of geomagnetic storms, solar wind velocity reaches 704km/sec during main phase of geomagnetic storms. This means that solar wind velocity enhances at the time of main phase. Like case first Electric field E_y have same high value at the time of GMSs.

Figure 6 deals, with the moderate storm that occurred during March 7-8, 2012. Overall the figure compares the Dst among solar wind speed, solar density and Temperature. Dst goes down to minimum (Dst = -85 nT) on March 7, 2012 (Fig. 3).

Figure 6 shows the variation of various interplanetary and geomagnetic parameters, for the period of March 7-8, 2012. The average interplanetary

Fig. 4 — Variation of Dst-index, interplanetary magnetic field (IMF) and solar wind parameter during September 4-16, 2011.

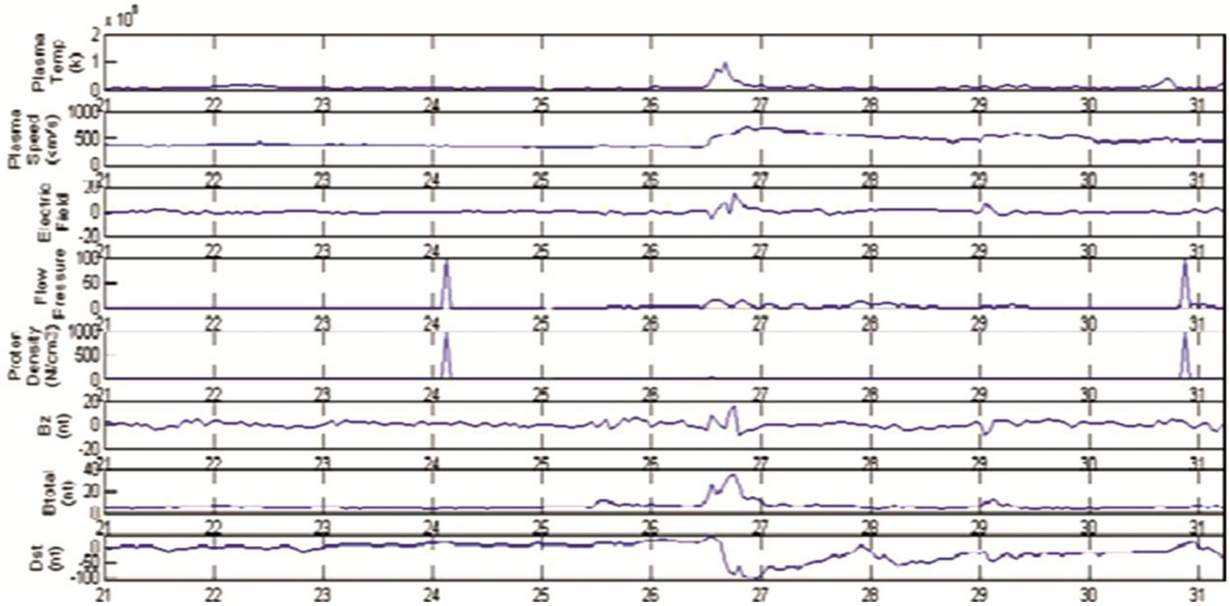

Fig. 5 — Variation of Dst-index, interplanetary magnetic field (IMF) and solar wind parameter during September 21-31, 2011.

magnetic field is of the order of 5 to 7 nT except at the rare part, where it jumps to around 23nT. At this rare position of the ejecta, the magnetic field was pointing substantially southward, thus causing the Dst to fall up to –85 nT. We also observed that solar wind velocity becomes higher during the main phase of magnetic storms.

Figure 7 deals with the intense storm that occurred during March 9-10, 2012. Dst goes down to minimum (Dst = -143 nT) on March 9, 2012 (Fig. 7). It is clear from figure that solar wind velocity becomes higher during the main phase of magnetic storms as well as B_{total} and B_z also become high. In the meantime, solar density becomes high during the initial phase of geomagnetic storms. This means that solar wind density approaches the Earth's magnetosphere, leading to development of the initial phase of magnetic storms and we see that geomagnetic storm occurred when solar wind density is very low and solar wind velocity is very high, temperature also was high before initial phase of storm.

Figure 8 deals another event of geomagnetic super storm observed during July 9-10, 2012. Dst index

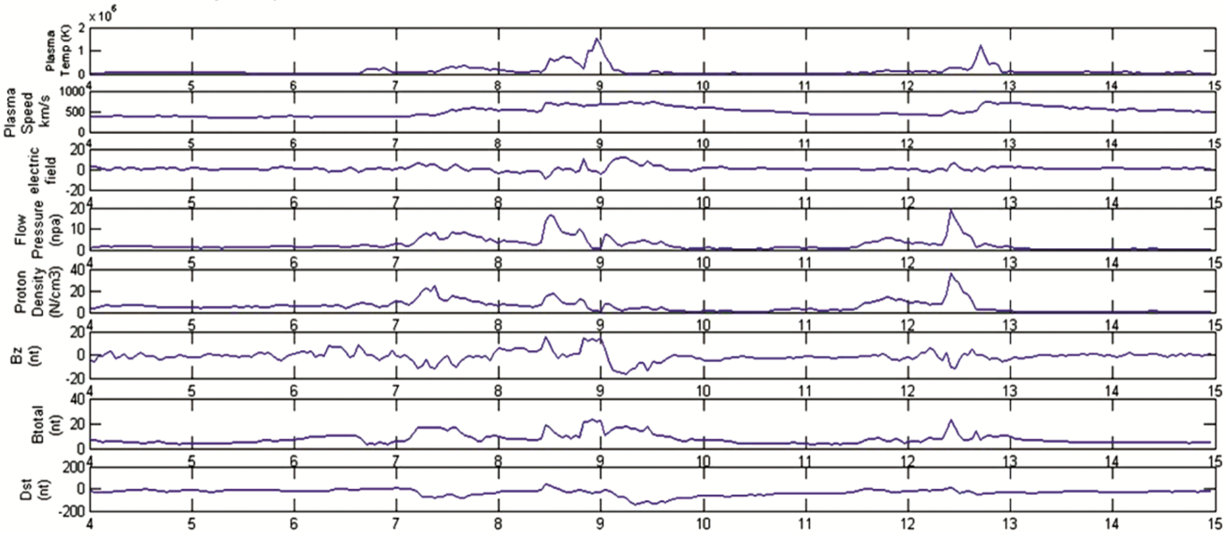

Fig. 6 — Variation of Dst-index, interplanetary magnetic field (IMF) and solar wind parameter during March 4-15, 2012.

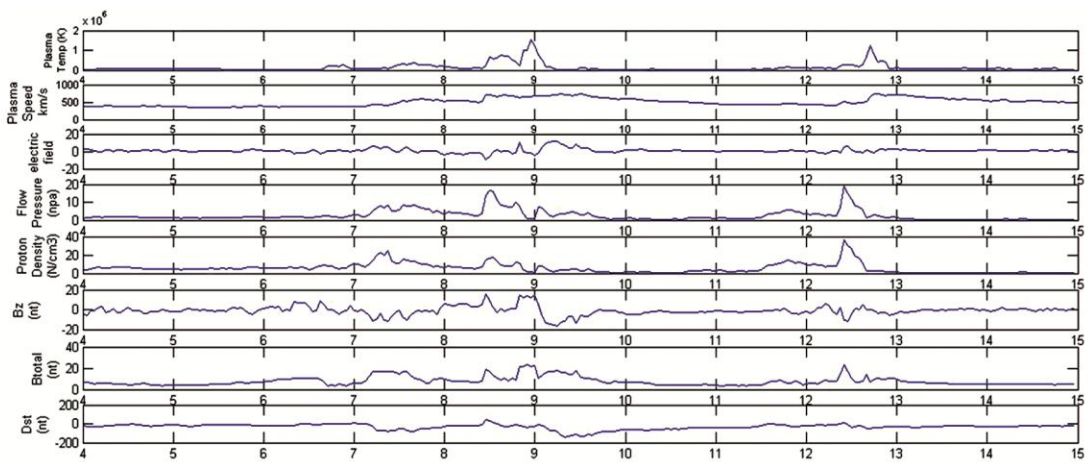

Fig. 7 — Variation of Dst-index, interplanetary magnetic field (IMF) and solar wind parameter during March 4-15, 2012.

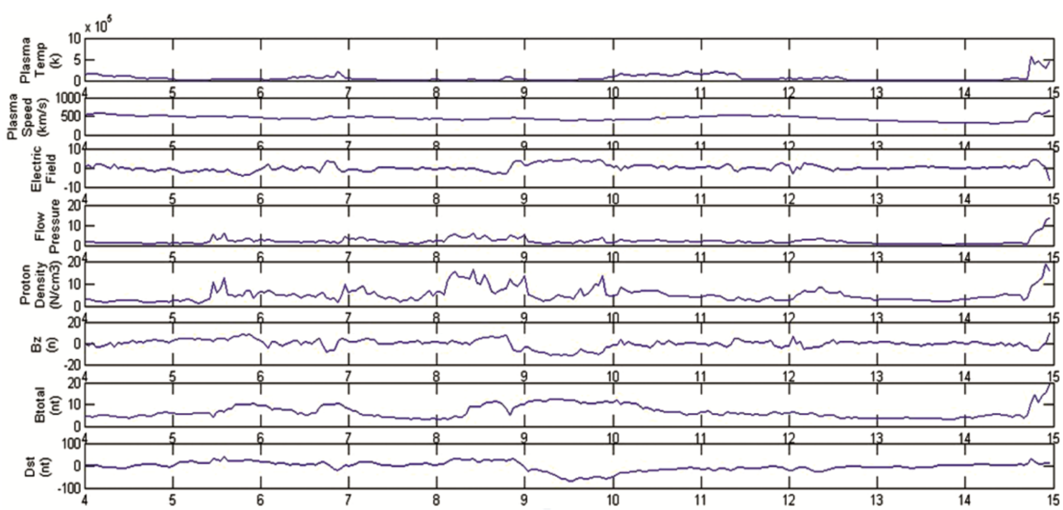

Fig. 8 — Variation of Dst-index, interplanetary magnetic field (IMF) and solar wind parameter during July 4-15, 2012.

reaches its minimum (- 69 nT) on July 9, 2012 at 13:00 UT. In Fig. 5, it can be seen that the average value of B_{total}, Bz and the solar wind velocity and density becomes higher during the initial and main phases and decreases during recovery phase. This indicates that high solar wind speed is responsible for the development of geomagnetic storm.

Above discussion concludes that solar wind parameter like Bz, velocity and density are responsible for geomagnetic storm.

It is evident that after the analysis of all five cases B_{total} and Bz get the high value at time of commencement, similarly solar wind speed and plasma temperature get the similar high value in all the above cases, electric field E_y also shows a peak during GMSs but another parameter solar wind density and solar pressure were not found with any specific relation with GMSs.

4 Conclusion

According to the present study, the maximum phase of solar cycle-24 was measured during the year 2013, whereas the periods 2008-11 were the periods of minimum phase of solar activity. The current studies for Sunspot Cycle 24 gave a smooth sunspot number maximum of about 98 in the 2013. Yearly occurrence of Geomagnetic storms does not exactly follow the phase of solar cycle during cycle-24.

In the present study the Disturbance storm time (Dst) index is used to identify the geomagnetic storms which occurred in time interval of 2008 to 2013. Total 47 geomagnetic storms have been observed during the span of solar cycle 24 with Dst $\leq$ -50 nT. Using the minimum Dst value as an indicator, we have classified the storms as moderate (36), strong (11), severe (0), and great (0) during the cycle 24.

Occurrences of Halo CMEs also do not exactly follow the phase of solar cycle but yearly occurrence of GMSs follow the yearly occurrence of Halo CMEs. Consequently, halo CMEs were responsible for the occurrence of GMSs during the solar cycle-24. It has been observed that the B_{total} and Bz-component of IMF are reasonably high during the geomagnetic storms, which shows that B_{total} is a good indicator of geomagnetic storm arrival and also has been observed that Bz-component of IMF takes southward turning during the initial phase which initiates a geomagnetic disturbance. Similarly solar wind speed and plasma temperature are also high before the commencement time. Other parameters (density and pressure) do not have any specific value during the geomagnetic storms in all five cases during cycle-24. In all cases the electric field E_y=V x B_z has also reached at peak values during storms.

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