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Effect of Coronal Mass Ejection on Earth's Magnetic Field during Ascending Phase of Solar Cycles 23-24

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Abstract

We have studied the width and speed of coronal mass ejections (CMEs) and geomagnetic disturbance storm time (Dst) Index during ascending phase of solar cycles 23 and 24. We have classified total CMEs according to angular width and speed for the ascending period 1996-2002 and 2008-2014. We have found that the width of 62% CMEs is narrow, and 3% are Halo for the solar cycle 23 and 73% CMEs are narrow, and 2% CMEs are Halo for the solar cycle 24. The speed distribution of 65% CMEs has speed ≤ 500 km/sec and 4% CMEs has speed > 1000 km/sec for solar cycle 23 and 84% CMEs has speed ≤ 500 km/sec and 1% CMEs has speed > 1000 km/sec in cycle 24. The relationship between width and speed is more pronounced for fast ejecta (>1000 km/sec.), while slower ejecta shows more astronomically immense scatter. We have reported that the correlation between Dst and CMEs for ascending phase of solar cycle 24 is less than as compare to ascending phase of solar cycle 23.

Keywords

CME, Dst, SSN

1. Introduction

Now it is very well known that the coronal mass ejections (CMEs) play a central role in the enhancing of interplanetary and geomagnetic activity [1] [2] [3]. The disturbance storm time index (Dst) is a measure of geomagnetic activity used to assess the magnetic storms and it is affected by solar output. Many researchers show the relationship between CMEs and geomagnetic storms [4] [5] [6] [7]. Coronal mass ejections (CMEs) are identified in the images of the solar corona obtained by the Solar and Heliospheric Observatory (SOHO) mission's Large Angle and Spectrometric Coronagraph (LASCO) since 1996. Coronal mass ejections (CMEs) with strong magnetic fields caused geomagnetic storms [8].

CMEs travel outward from the Sun, typically at an average speed of about ~483 kilometers per second but be slow as ~100 kilometers per second or faster than ~3000 kilometers per second [9] [10]. The fastest CMEs erupt from large sunspot active regions, powered by the strongest magnetic field concentrations on the Sun. These fast CMEs can reach Earth in a little time as ~14 - 17 hours and caused major geomagnetic storms. It is well-known that the most solar cycles show a double peak due to the out-of-phase activity in the two hemispheres [11]. The double peak in SSN during solar cycle 24 is the second peak is larger than the first one by ~20%. Such a behavior was observed only a few times since the 1800s [12].

In order to address the fundamental problem of prediction of geomagnetic storms, it is important to examine the Halo CMEs first observed by Howard [13]. A Halo CMEs appears to surround the occulting disk of the observing coronagraph in sky plane projection. Halo CMEs constitute only approximate 3% of all CMEs and represent an energy population because most of the CMEs that produce major geomagnetic storms are Halo [14]. There only 11 CMEs that caused major storms during cycle 24 until the end of period 2014 [15]. CMEs number shows a double peak and similar to seen in sunspot number [16].

In this study, we analyze the correlation between Dst and CMEs (Fast and Halo) during the ascending phase of solar cycles 23 and 24. In this paper, we have studied the variation of Dst and CMEs (speed and width) for the selected period.

2. Data Detection and Method of Analysis

We have taken CMEs and Dst data during the ascending phase of solar cycle 23 and 24. We have selected the first 7 years of both solar cycles 23 and 24 *i.e.* (1996-2002 and 2008-2014). We found total 7180 CMEs events in solar cycle 23 and 11,690 CMEs in solar cycle 24 for our selected period. In the present study, we have selected CMEs events data on the basis of angular width and speed from SOHO/LASCO (cdaw.gsfc.nasa.gov/CME_list/). In this analysis, we have distributed CMEs events in Narrow (width ≤ 60˚), Moderate (width 61˚ ~ 120˚), Partial Halo (width 121˚ ~ 359˚), and Halo (width=360˚). For speed distribution we have classified CMEs in such categories as ≤500 km/sec, 501 ~ 1000 km/sec, 1000 ~ 1500 km/sec, >1500 km/sec. The values of the annual average of geomagnetic disturbance storms time Index (Dst) (based on daily data) from the OmniWeb (https://omniweb.gsfc.nasa.gov/form/dx1.html).

3. Results and Discussion

According to speed distribution, we have taken the ascending phase of solar cycle 23 and 24.We have considered the interval 1996 to 2002 for solar cycle 23 and 2008 to 2014 for solar cycle 24. We have divided CMEs events in speed wise into four categories 1) CMEs with speed ≤ 500 km/sec 2) CME with speed 501 ~

1000 km/sec 3) CMEs with speed 1001 ~ 1500 km/sec 4) CMEs with speed > 1500 km/sec. Figure 1 shows the pie diagram for the distribution of CMEs according to above four categories for solar cycles 23 and 24. From Figure 1 we have observed that the CMEs with speed ≤ 500 km/sec for solar cycle 23 is 65% and for solar cycle 24 is 84%. It is noted that the CMEs with speed ≤ 500 are larger in solar cycle 24 as compared to solar cycle 23.

Figure 2(a) shows the annual occurrence of fast CMEs (>1000) during the solar cycles 23 and 24. From Figure 2(a) it is found that the fast CMEs have double peaks in the ascending phase of solar cycle 23 (2000 & 2002) and the ascending phase of solar cycle 24 (2012 & 2014). We have observed that the time-lag for fast CMEs (>1000) between the first maximum to the second

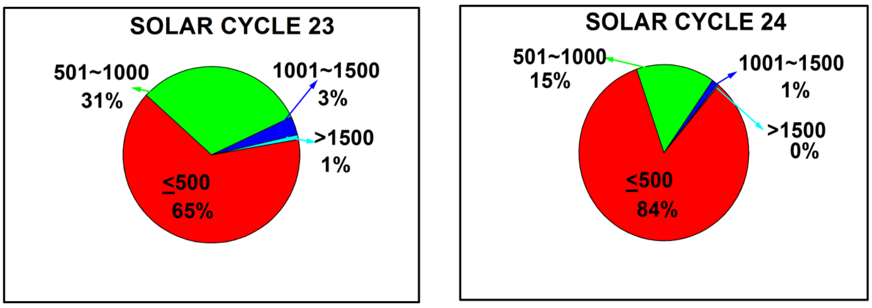
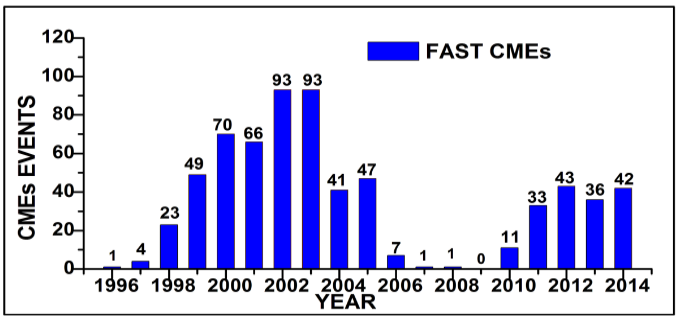
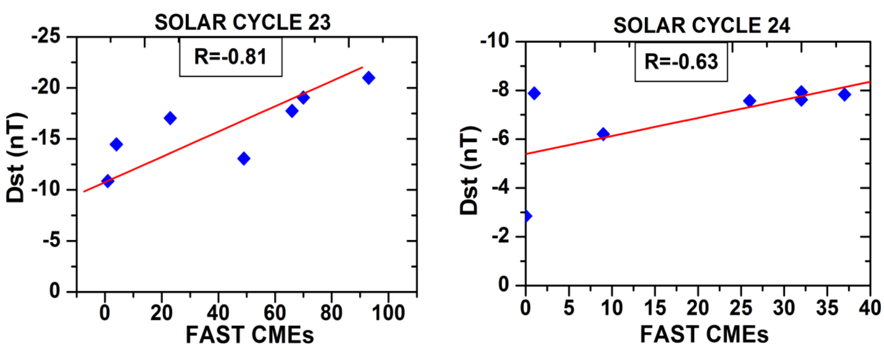


Figure 1. Shows the distribution of total CMEs according to CME's speed for ascending phase of solar cycles 23 and 24.



(a)



(b)

Figure 2. (a) Shows the graph of annual occurrence of fast CMEs during solar cycles 23 and 24 (b) scatter graph between fast CMEs and Dst Index during ascending phase of solar cycle 23 and 24.

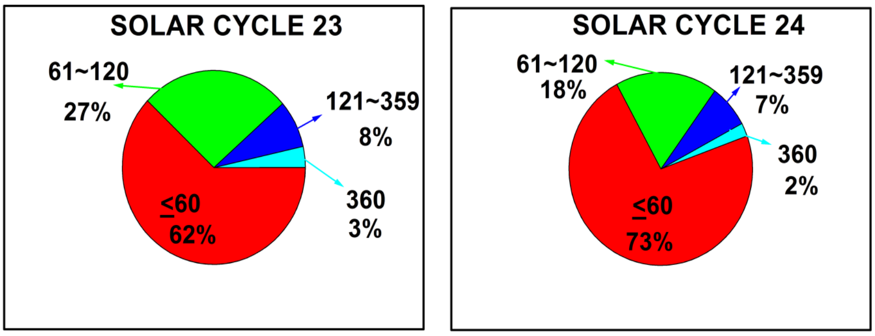


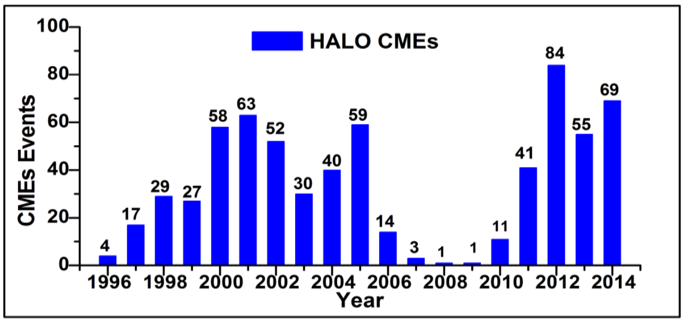
Figure 3. Shows the distribution of total CMEs according to Angular width for the ascending phase of solar cycles 23 and 24.

maximum is ~1 years during the ascending phase of solar cycles 23 and 24. Fast CMEs are often causing major Geomagnetic storms (**Figure 2(b)**). **Figure 2(b)** shows the scatter graph between fast CMEs and Dst index. The correlation coefficient between fast CMEs and Dst index for solar cycle 23 is R = −0.81 and for solar cycle 24 is R = −0.63. From **Figure 2(b)** we have found that the correlation coefficient between Dst and fast CMEs (>1000) is larger in ascending phase of solar cycle 23 as compared to cycle 24. We have reported that the solar activity is larger in cycle 23 as compared to cycle 24.

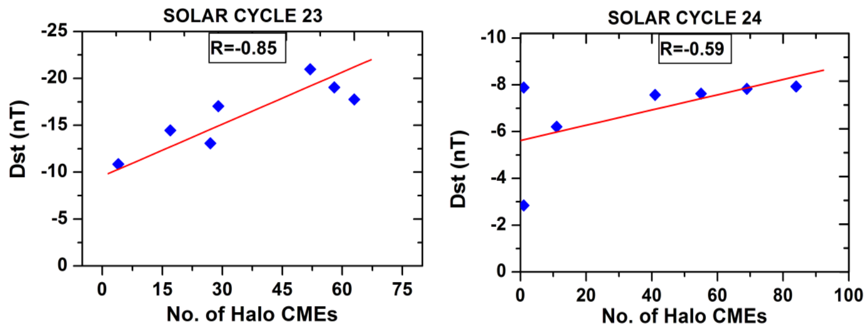
From **Figure 3** we have divided all annual occurrence of total CME events for angular width in following four categories for the ascending period of 1996-2002 and 2008-2014: (1) Narrow (width ≤ 60˚) (2) Moderate (width 61˚ ~ 120˚) (3) Partial Halo (width 121˚ ~ 359˚) (4) Halo (width = 360˚). From **Figure 3** we have observed that the Narrow CMEs have the highest percentage in total CMEs during the ascending phase of solar cycles 23 and 24. In total, Halo CMEs are only 3% in solar cycle 23 and only 2% in solar cycle 24.

Annual occurrence of Halo CMEs is shown in **Figure 4(a)** during solar cycles 23 and 24. It is clear that Annual occurrence of Halo CMEs has a double peak structure in solar cycles 24 (2012 & 2014). From **Figure 4(a)** we have found that the time-lag for Halo CMEs (width = 360˚) between the first maximum to the second maximum is ~1 years during ascending phase of solar cycle 24. **Figure 4(b)** shows the scatter graph between Halo CMEs and Dst Index during the ascending phases of solar cycles 23 and 24. It is observed that the Halo CMEs is the strongest correlation with Dst during the ascending phase of solar cycle 23 *i.e.* for the period 1996-2002. We have found correlation coefficient between Halo CMEs and Dst for solar cycle 23 is R = −0.85 and for solar cycle 24 is R = −0.59 during the ascending phases of solar cycles 23 and 24. We have reported that the geomagnetic activity is depending on the CMEs during ascending phase of solar cycles 23 and 24. It is clear that the correlation coefficient between Halo CMEs and Dst for solar cycle 23 is greater than the solar cycle 24.

From **Figure 5** we have found that the annual average Dst is maximum for the ascending phase of solar cycle 23 in the period 2002 and for solar cycle 24 in the period 2012. We have reported that the maximum value of the annual average of



(a)



(b)

Figure 4. (a) Shows the annual variation of Halo CME during solar cycles 23 and 24 (b) Scatter graph between the annual value of Halo CMEs and Annual average value of Dst (nT) index for the ascending phase of solar cycles 23 and 24.

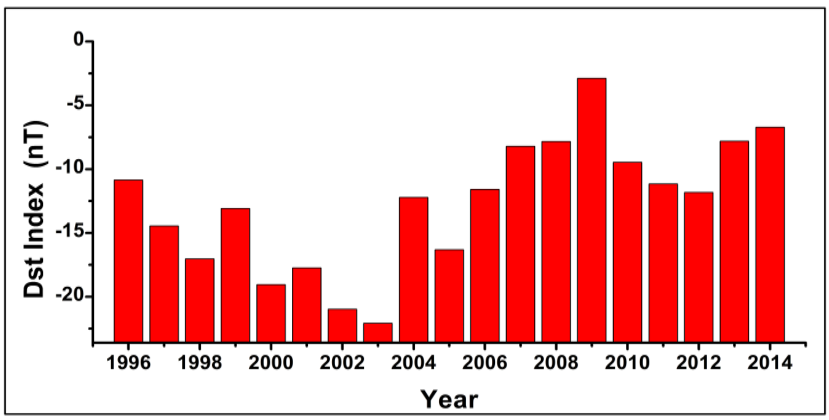


Figure 5. Shows the bar graph of the annual average of Dst Index for the year 1996-2014.

Dst is produced in the solar cycle 23 as compared to solar cycle 24. We have observed that the annual average of Dst is maximum in the period 2009 during the solar cycle 24. It is observed that the Dst is depending on the CMEs during the study period [7].

Table 1 shows the fastest CMEs events (≥2200 km/sec) in ascending phase of solar cycle 23 and 24. It is observed that CMEs with speed ≥ 2200 km/sec are only 6 in solar cycle 23 as well as 4 in solar cycle 24. In our discussions we adopt a simpler scheme: *D*st > −50 nT denotes storm level (no storm); −100 nT < *D*st ≤ −50 nT denotes moderate storms while *D*st ≤ −100 nT denotes intense storms.

Table 1. Shows the fastest CMEs events (≥2200 km/sec) in ascending phase of solar cycle 23 and 24.

First CME Appearance	Time [UT]	Speed [km/s]	Angular Width [deg]	Geomagnetic Storm
2000/05/12	23:26:05	2604	Halo	No
2000/11/25	01:31:58	2519	Halo	No
2001/04/02	22:06:07	2505	Halo	No
2001/04/10	05:30:00	2411	Halo	Intense
2001/04/18	02:30:05	2465	Halo	Moderate
2001/09/24	10:30:59	2402	Halo	No
2011/06/04	22:05:02	2425	Halo	Moderate
2012/01/27	18:27:52	2508	Halo	No
2012/03/07	00:24:06	2684	Halo	Moderate
2013/05/14	01:25:51	2625	Halo	No

We analyze that these CMEs are producing geomagnetic storm or not. We have found 2 geomagnetic storms, (one moderate and one intense) during ascending phase of solar cycle 23 and 2 geomagnetic storms (both are moderate) during ascending phase of solar cycle 24. We have also observed that there is no intense geomagnetic storm during ascending phase of solar cycle 24 but ascending phase of solar cycle 23 has one intense geomagnetic storm.

4. Conclusions

The main conclusions as follows: (1) we have found that the occurrence of fast CMEs (>1000 km/sec) are only 1% in solar cycle 24 and 4% in solar cycle 23. Therefore we have reported low solar activity in solar cycle 24 as compared to solar cycle 23. (2) Fast CMEs have a double peak structure in solar cycle 24 as well as solar cycle 23. (3) The occurrence of CMEs of higher width *i.e.* Halo CMEs is 3% in ascending phase of solar cycle 23 and 2% in ascending phase of solar cycle 24. (4) Double peak structure in the occurrence of Halo CME events is found in only solar cycles 24. (5) The correlation between the annual occurrence of fast CMEs and an annual average of Dst index is lower in solar cycle 24 as compared to solar cycle 23. (6) The correlation coefficient between annual Halo CMEs and Dst index is lower in solar cycle 24 as compared to solar cycle 23. It is observed that the total Halo CMEs for ascending phase of solar cycle 23 is less than as compared to solar cycle 24. We have suggested that the speed of CMEs with fast and Halo are responsible for producing strong geomagnetic storms. (6) On the basis of correlation, the geo-effectiveness of CMEs events *i.e.* Earth directed to CMEs for ascending phase of solar cycles 24 are less than in solar cycle 23, for our selected period (whereas the total number of CMEs in ascending phase of solar cycle 24 is greater than the ascending phase of solar cycle 23). We have reported that the Fast CMEs and Halo CMEs with Dst are strong correlation during the ascending phase of solar cycles 23 and 24. Therefore we have concluded that in the above discussion the Dst (nT) have more negative value *i.e.* major geomagnetic storms are produced. We have reported that the fastest CMEs events (≥2200 km/sec) are occurred Halo CMEs with an angular width (360˚) for ascending phase of solar cycle 23 is larger as compared to cycle 24. We have concluded that the fastest CMEs events (≥2200 km/sec) produce intense and moderate geomagnetic storms during ascending phase of solar cycle 23 in the same month (for intense 10/04/2001 and for moderate 18/04/2001) but in solar cycle 24 we have found time lag (~09 months) between two moderate geomagnetic storms (for first moderate 04/06/2011 and for second 07/03/2012).

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