Study of Long term time based relationship between Coronal Mass Ejections and geomagnetic storms

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Abstract:
Huge, violent explosions of plasma and magnetic fields from the Sun's corona are called coronal mass ejections (CMEs). These are the reasons for geomagnetic storms. CME shock waves produce solar energetic particles (SEPs), which are high-energy particles containing electrons, coronal solar wind ions (mainly protons). When CMEs head towards the Earth, create disturbances that affect the Earth's magnetic field. A coronal mass ejection takes approximately two to three days to reach Earth and to create a geomagnetic storm after launching from the Sun. In this study, we have selected 328 geomagnetic storms (Dst≤-60nT) for the time period 1996 to 2020, which cover the solar cycle 23 & 24 completely. It is revealed from present study that the occurrence of halo coronal mass ejection is maximum in the time period of 42-48 hour before the onset time of geomagnetic storm and the occurrence of partial halo coronal mass ejection is maximum in the time period of 66-72 hour before the onset time of geomagnetic storm. The moderate geomagnetic storms occur during 42 to 54 hours after the occurrence of Halo coronal mass ejections and 66 to 72 hours after the occurrence of partial halo CMEs, the intense geomagnetic storms occur during 42 to 48 hours after the occurrence of Halo CMEs and 54 to 60 hours after the occurrence of partial halo CMEs and the major geomagnetic storms occur during 42 to 48 hours after the occurrence of Halo CMEs and 48 to 54 hours after the occurrence of partial halo CMEs. In the present study the correlation coefficient between CMEs occurrence in the time period ninety hours before the starting of the main phase of geomagnetic storm and no. of geomagnetic storm is 0.881.

Keywords: Coronal Mass Ejections, geomagnetic storm, Disturbance storm time (Dst), solar cycle et
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Introduction:

Coronal Mass Ejections (CMEs) are plasma explosions from the solar atmosphere consisting of a closed field region, which are ejected into an interplanetary medium. Amount of plasma ejected into interplanetary space is about 10^{11}-10^{13}kg with a kinetic energy 10^{22}-10^{24}Jule [Horward et. al, 1985]. The onset of CMEs can be connected with flares and filament eruptions both [Webb, 1994; Feynman and Hundhausen, 1994]. Although, most of the energy is connected with the ejected mass and shock wave, it is not connected with the flares. There is a critical connection between CMEs and geomagnetic storms .It has occurred that the southward component of the magnetic field in magnetic clouds is also the reason for the storms [Wilson, 1997]. CMEs play an important role in reinforcing interplanetary and geomagnetic activity [Tsurutani et. al,1988; Goslin,1993 and Jadeja et. al 2008]. Several researchers have shown the connections between CMEs and geomagnetic storms [Shrivastava et. al,2002; Gopaiswamy,2006; Ji et.al,2010 and Richardson,2013]. Geomagnetic storms are created by CMEs with strong magnetic fields [Gopalswamy, 2007].

A temporary disturbance of the magnetosphere of the Earth caused by solar wind shock waves connected with CMEs or solar flares is called a geomagnetic storm. The capacity of CMEs to create geomagnetic storms is said to be geo-effectiveness. It is calculated in terms of "Dst (disturbance storm time) index". Longitudinal average of horizontal intensity of Earth's magnetic field is known as Dst index. It is measured at low and middle latitude observatories. Dst index is the best indicator to represent the degree of solar variability.

Several studies have shown that coronal mass ejections are most geo-effective solar events. Angular width, speed and acceleration are the properties of CMEs. Angular width range of CMEs is from 5^0 to 360^0. If CME appears to surround the occulting disc and have 360^0 of angular width it is called halo CME (Earth directed). CME has more than 120^0 of angular width around the disc is called partial halo CME.

Halo CME is the main cause of large geomagnetic storms. 95% severe geomagnetic storms are produced by halo coronal mass ejections. Geomagnetic storms occur 36 to 72 hours after the onset of Halo CME while majority of GSs are seen within 60 to 70 hours range[Tiwari et. al,2005].

Frequency of occurrence of Coronal mass ejections is maximum during high Solar activity and minimum during low Solar activity [Shrivastava et. al,2009]. The long term profile of Dst index and CMEs occurrence rate are positively related [Shrivastava et.al, 2011]. CME location is also a parameter which can decide the geo effectiveness of CMEs. Halo CMEs (earth directed) play the key role in producing the geomagnetic activities [Prasad et. al, 2013].

The size of geomagnetic storms is classified as moderate (-100nT ≤Dst ≤ -60nT), intense (-200nT ≤Dst ≤ -100 nT) , and major (Dst ≤ -200nT) storms. All three types of storms used in the present work. Recently, [Parsai et. al, 2019] reported that 23% of Halo CMEs are good indicators for intense geomagnetic storms.

Most of the previous studies have been focused on the relation between CMEs and geomagnetic storms after the occurrence of CME events. None of the studies was reported to observe the relationship between the occurrence of CME events and geomagnetic storms before the onset of geomagnetic storms. Hence the present study conducted a detailed study to derive the long term time based relations between coronal mass ejections and geomagnetic storms during the period of 1996 to 2020 which covers the all phases of solar cycles 23 and 24.

Data and Methods of Analysis:

In present work, the geomagnetic storms (Dst) hourly data have been used over the period of 1996 -2020 to find the association of CMEs with moderate, intense and major GSs. These data have been taken from the omniweb data center from website (http://nsdc.gsfc.nasa.gov/omniweb) . We have selected 328 geomagnetic storms of (Dst ≤-60 nT) for the analysis. During the study period we observed 222 moderate (-100nT≤Dst ≤ -60nT) GSs , 87 intense (-200nT ≤ Dst ≤ -100 nT) GSs and 19 major (Dst ≤ -200nT) GSs. We have used the website (https// cdaw.gsfc. nasa.gov/CME list) of Soho Lasco CME catalog to obtain the events of Halo CMEs and Partial Halo CMEs. The frequency of occurrence of halo CMEs and partial halo CMEs are listed for last four days from the starting day of geomagnetic storm separately. The starting day of geomagnetic storm istaken as zero day. We have sorted CME data (no. of occurrence of CMEs) for time interval of 6-6 hours for last 96 hours before the starting time (onset time) of geomagnetic storm. To find the long term time based relations between CMEs and geomagnetic storms we here used graphical and correlative methods.

Results and Discussions:

The inference based on the data of 25 years of two complete solar cyclesit was observed that 328 geomagnetic storms occurred and 2283 CMEs ejected from solar corona in which 711 were halo CMEs and 1572 were partial halo CMEs. We have presented the data using histograms for moderate, intense and major geomagnetic storms separately by taking 6 hours interval. The number of occurrence of CMEs are plotted against time intervals of 6 hour for last 96 hours from the onset of geomagnetic storms as shown in histograms.

Figure 1 represents the no. of events of CMEs during solar cycle 23 and 24. Halo CMEs have appeared maximum in year 2001 in solar cycle 23 which implies that solar activity cycle is maximum in the period of 2001. For solar cycle 24 the occurrence of no. of halo CMEs is maximum for year 2012, which is maximum of solar cycle 24. In case of partial halo CMEs and total no. of CMEs , maximum of solar cycle 23 is same in the year of 2001 while maximum no. of CMEs (patial halo and total no. of CMEs) have appeared in year 2014 which is anisotropic.

A graph is drawn between total no. of CMEs and total no. of geomagnetic storms for solar cycle 23 and 24 presented in figure 2. As the occurrence of no. of CMEs is increases, no. of events of GSs is increases. There is a discrepancy in solar cycle maxima for solar cycle 24. No. of CMEs shows maxima in year2014 and near to 2015 while GSs shows minima in that year. As we discussed above the maxima of solar cycle 24 for halo CMEs is year 2012, that means the geomagnetic storms are mostly followed by halo CMEs.

Figure 3 is a plot between frequency of occurrence of CMEs before 90 hours from the starting time of geomagnetic storm and no. of geomagnetic storms. Time period of 90 to 96 hours before the onset time of geomagnetic storm is not of interest due to very less occurrence of CMEs. The correlation coefficient between frequency of occurrence of CMEs before 90 hours from starting time of geomagnetic storm and no. of geomagnetic storms is found to be 0.881 which is high and positive. This shows that frequency of occurrence of CMEs before 90 hours and no. of geomagnetic storms is highly correlated.

From figure 4 it is clear that the moderate geomagnetic storms occur during 42 to 54 hours after the occurrence of halo CME and 66 to 72 hours after the partial halo CME. Occurrence of total no. of CMEs is maximum in time interval of 84 to 90 hours for moderate geomagnetic storms.

Figure 5 is plotted to find out the effect of coronal mass ejections on intense geomagnetic storms. The effect of total no. of CMEs is maximum in time period of 54 to 60 hours for intense GSs. Frequency of occurrence of halo CME is high during 42 to 48 hours before starting time of intense GSs while in case of partial halo CMEs, frequency of apparent is large in the time interval of 54 to 60 hours.

Figure 6 is plotted to draw the effect of coronal mass ejections on major geomagnetic storms. The effect of halo CME is high during 42 to 48 hours for major geomagnetic storms. The frequency of occurrence of total no. of CMEs is maximum in time period of 42 to 48 hours before the onset time of geomagnetic storm.Major geomagnetic storms are affected uniformly 48 to 96 hours after occurrence of partial halo CMEs.

CMEs contain large amount of coronal plasma and magnetic flux rope structure. This is a stable magnetic field structure. This structure consists southward magnetic field component, which interacts with the magnetosphere at the dayside magnetopause. In this interaction, solar wind energy is transmitted to the magnetosphere. This magnetic reconnection produces geomagnetic storms. When the magnetic field has a southward component in thesheath region, an interplanetary shock produced by magnetic flux rope structure helps to develop the geomagnetic storms. A strong geomagnetic storm is triggered when a strong southward magnetic field is produced by interconnection between a high speed solar wind and CMEs.

Conclusions:

1- The study of long-term time-based relations between CMEs and GSs during solar cycle 23 and 24 shows that total 328 geomagnetic storms occurred in which 222 moderate, 87 intense and 19 major storms are seen from 1996 to 2020. Total 2283 CMEs are observed in which 711 halo CMEs and 1572 partial halo CMEs occurred during the study period.

2-The study is performed for all phases of solar cycle 23 and 24. In the maximum phase of solar activity cycle, the occurrence of no. of CMEs and no. of geomagnetic storms were large. In the ascending and descending phases of solar cycles the no. of CMEs and the no. of GSs were increasing and decreasing. This implies that the no. of events of CMEs and GSs are reliable parameters to understand the solar variability.

3-The study reveals that the large no. of intense and major geomagnetic storms occurs 42 to 48 hours after the event of halo CMEs. The frequency of occurrence of partial halo CMEs is maximum in time period of 54 to 60 hours before the starting time of intense and major GSs.

4- It is also concluded that the moderate geomagnetic storms occur during 42 to 54 hours after the occurrence of halo CME and 66 to 72 hours after the partial halo CME. This indicates that halo CMEs creates faster geomagnetic activities than partial halo CMEs. These results of study support to earlier findings that halo CMEs are more responsible for producing all types of geomagnetic storms than partial halo CMEs.

5- The correlation coefficient between the occurrence of CMEs before 90 hours from starting time of geomagnetic storm and no. of geomagnetic storms is found to be 0.881. This revealed that both parameters are highly correlated. This study may be useful for space – weather effects.

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Table: 1 year wise representation of occurrence of halo CMEs, partial halo CMEs, total no. of CMEs, moderate GS, intense GS, major GS and total GS.

Year	CMEs			Geomagnetic Storms (GS)			
	HCME	PHCME	Total CME	Moderate (-100 ≤ Dst < -60 nT)	Intense (-200 ≤ Dst< -100 nT)	Major (Dst < -200 nT)	Total Geomagnetic Storm
1996	4	6	10	3	1	0	4
1997	17	17	34	14	5	0	19
1998	28	34	62	11	7	2	20
1999	27	94	121	15	4	1	20
2000	56	108	164	19	8	4	31
2001	63	135	198	13	12	4	29
2002	51	110	161	27	13	0	40
2003	30	65	95	24	5	3	32
2004	39	70	109	10	5	2	17
2005	55	65	120	17	7	1	25
2006	14	18	32	6	1	0	7
2007	3	6	9	2	0	0	2
2008	1	7	8	1	0	0	1
2009	1	1	2	1	0	0	1
2010	11	30	41	7	0	0	7
2011	39	112	151	9	3	0	12
2012	84	157	241	8	8	0	16
2013	53	150	203	11	2	0	13
2014	68	217	285	6	1	0	7
2015	40	106	146	18	2	2	22
2016	12	43	55	0	0	0	0
2017	9	14	23	0	2	0	2
2018	1	0	1	0	1	0	1
2019	1	3	4	0	0	0	0
2020	4	4	8	0	0	0	0
Total	711	1572	2283	222	87	19	328

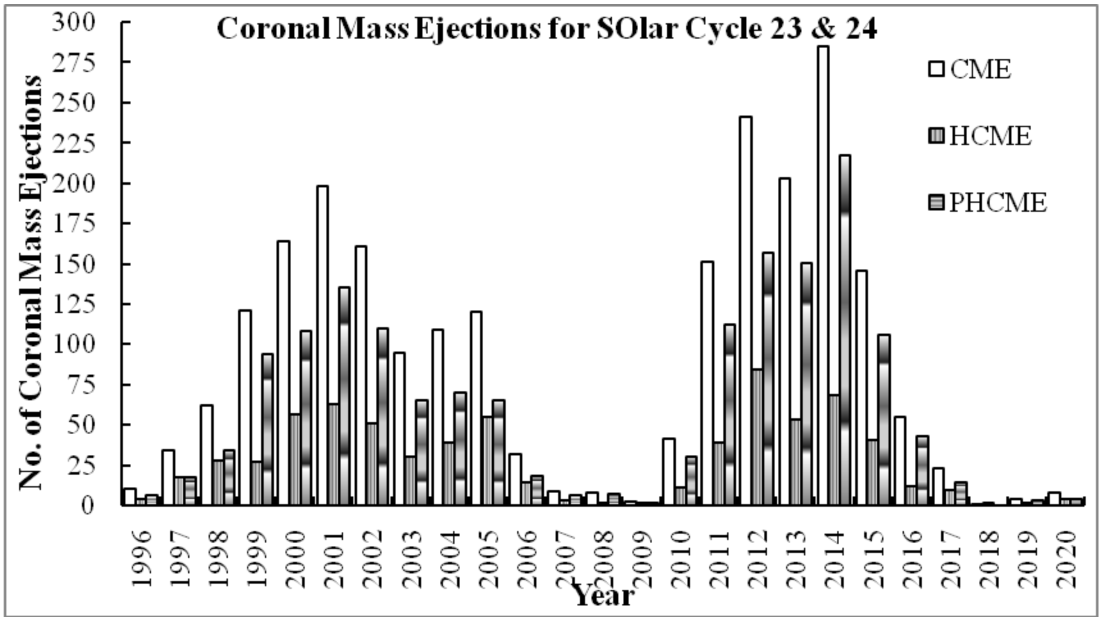

Figure: 1 showing the histograms of distribution of total no. of CMEs, halo CMEs and Partial Halo CMEs for time period of solar cycle 23 and 24

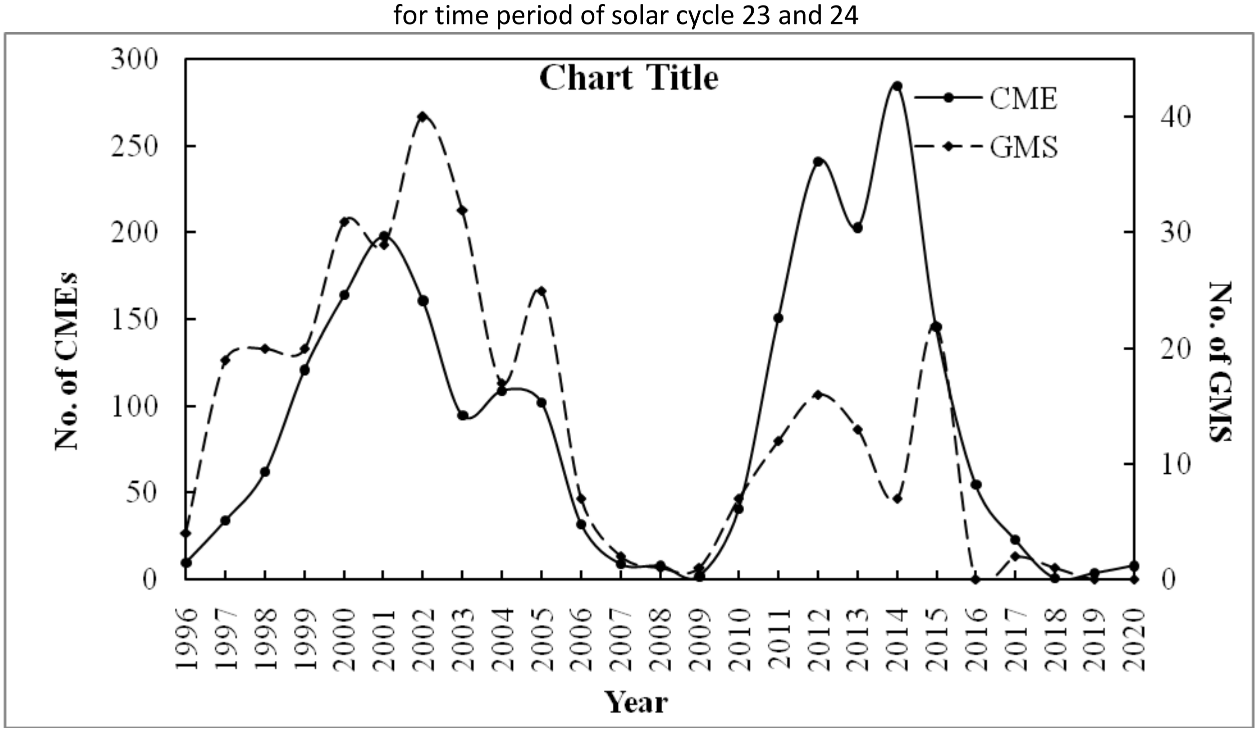

Figure:2 A graph between the total no. of CMEs and total no. of geomagnetic storms per year during 1996 2020

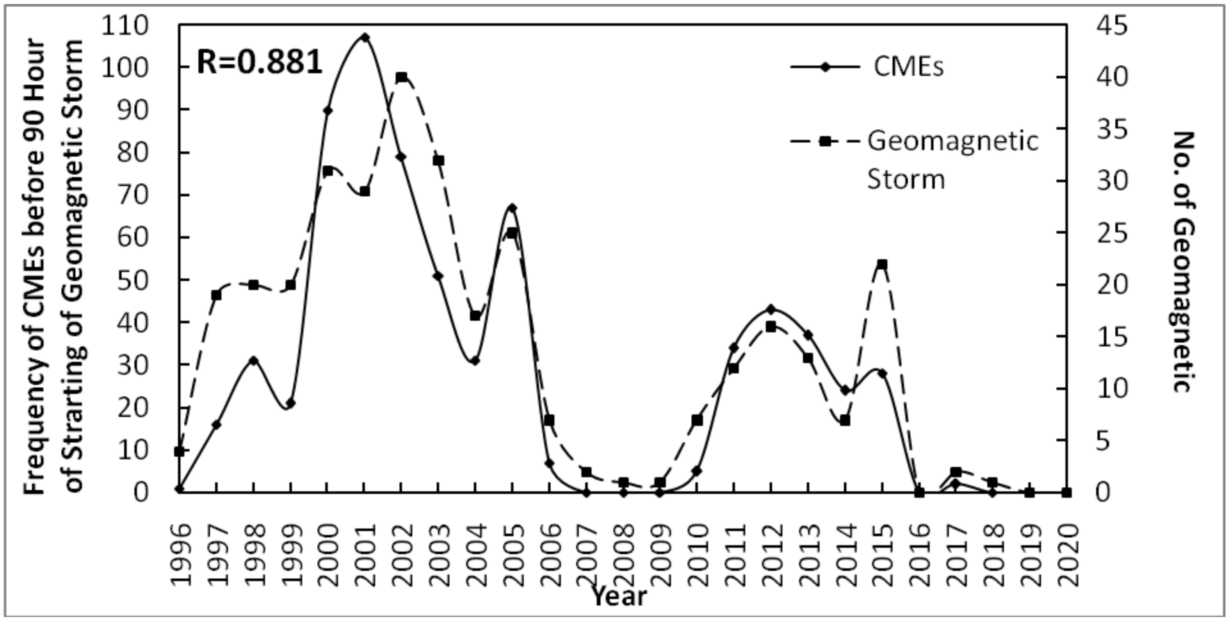

Figure:3 showing the correlation between frequency of occurrence of CMEs before 90 hours of starting of geomagnetic storm and total no of geomagnetic storms during 1996 to 2020.

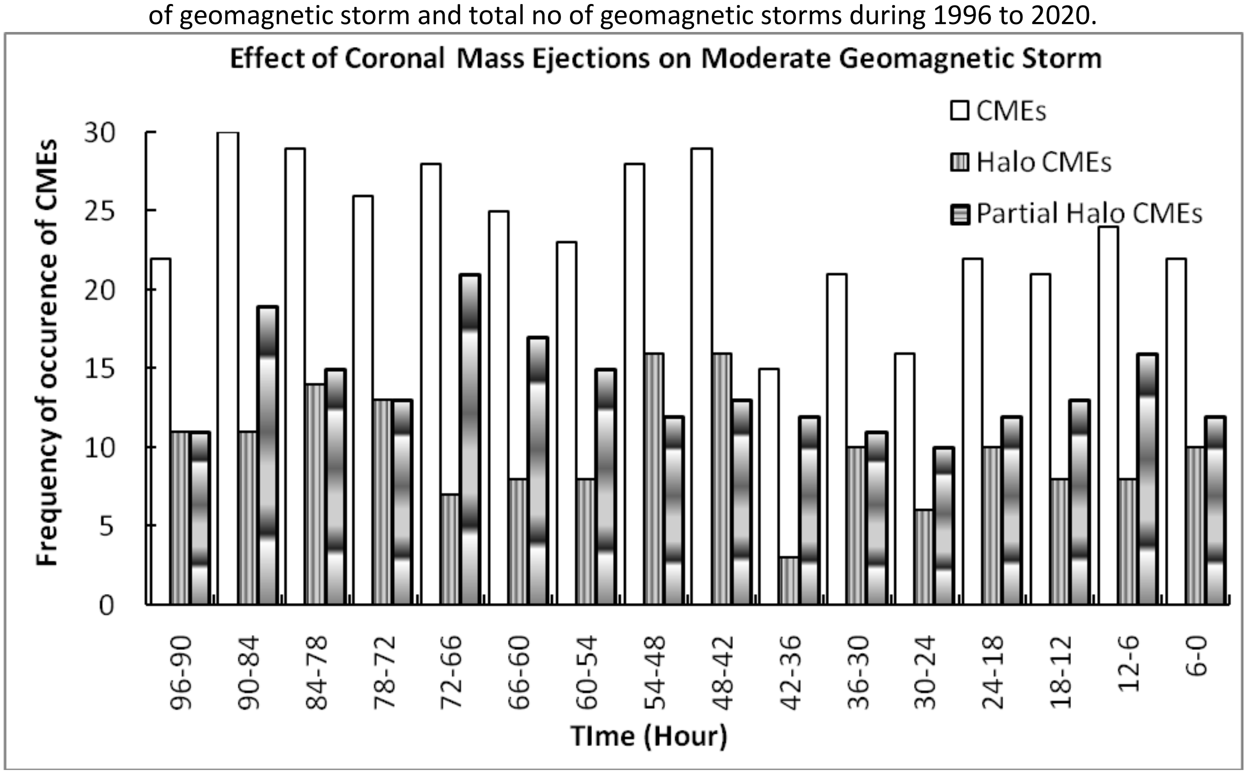

Figure: 4 represents the frequency of occurrence of CMEs before 96 hours of onset of moderate geomagnetic storm for time interval of 6 hours.

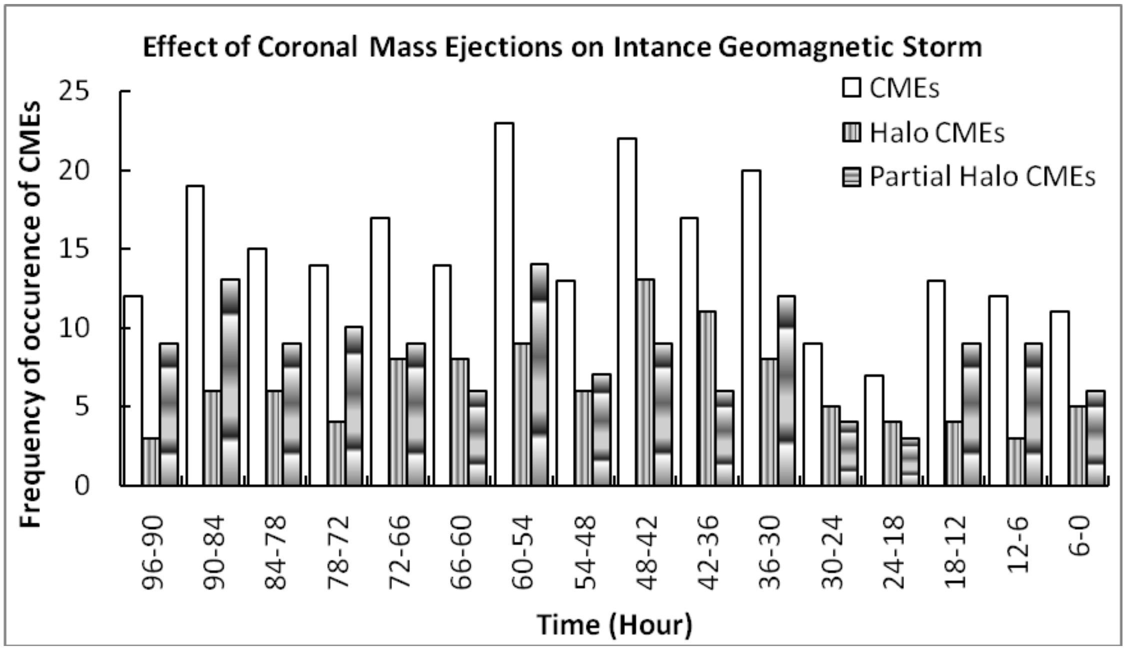

Figure: 5 represents the frequency of occurrence of CMEs before 96 hours of onset of intense geomagnetic storm for time interval of 6 hours.

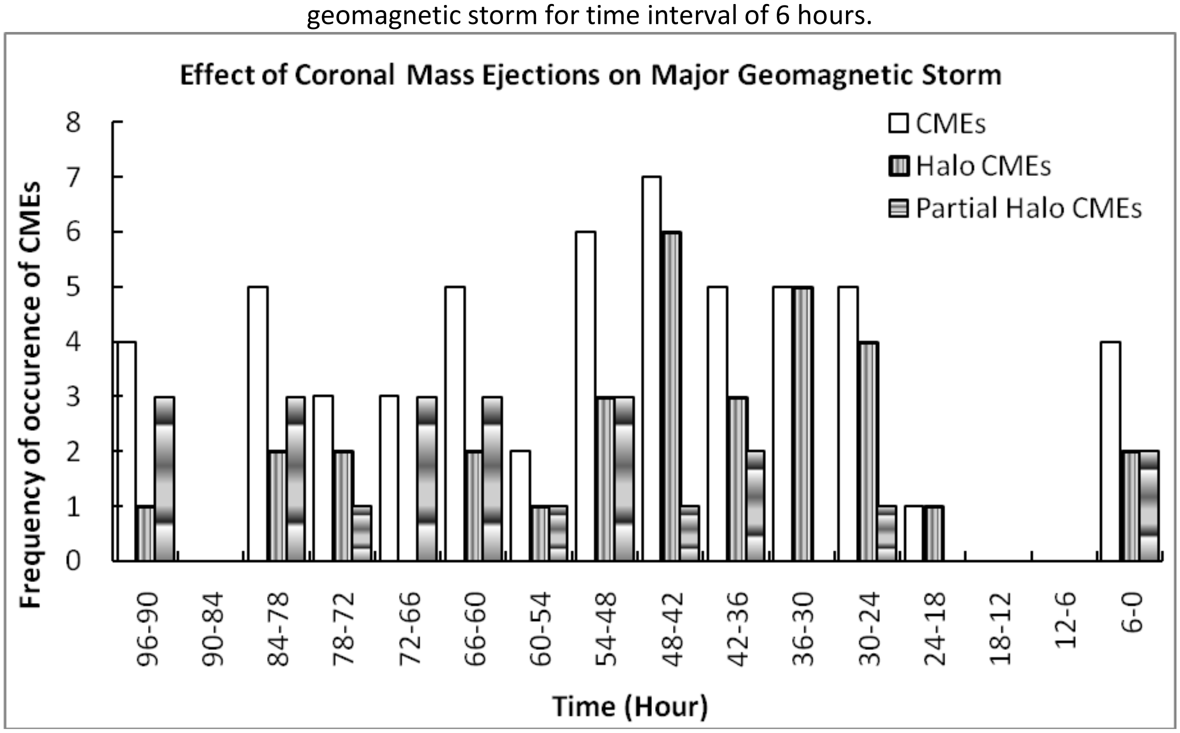

Figure: 6 represents the frequency of occurrence of CMEs before 96 hours of onset of major geomagnetic storm for time interval of 6 hours.