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INVESTIGATION OF THE PROPERTIES OF GEO-EFFECTIVE CORONAL MASS EJECTIONS (CMES) DURING SUNSPOT CYCLE 23

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Abstract-In this presented work, we have studied the geo-effective characteristics of halo Coronal Mass Ejections (CMEs) and examined their distribution over three kinds (Intense, moderate and weak) of geo-effective properties. For this study, we have selected the halo CMEs that were observed during the solar cycle 23, i.e. from 1996 to 2007. We selected three properties of CMEs viz. speed, acceleration and transit time and constructed several ranges. From our analysis showed that 60% of CMEs occur in the 500–1500 km s−1 category of CME speed. Similarly, 55% of CMEs are distributed over the range of 25–75 hours, of transit time while 60% of CMEs occur in the 0–20 m/s2 category of positive acceleration and 78% of CMEs occur in the 0–20 m/s2 category of negative acceleration of CMEs. We also investigated the geomagnetic effects of the selected Coronal Mass Ejections (CMEs) by considering the geomagnetic storms caused by them. The geomagnetic storms were divided into mainly three categories on the basis of the peak Dst value, as weak ($Dst > -50$ nT), moderate (-100 nT $< Dst \leq -50$ nT) and intense ($Dst \leq -100$ nT). The highest numbers of intense storms were registered in the intermediate ranges of CME properties. Moreover, we have also found that decelerating CMEs produced significantly larger number of intense storms. Hence, more geo-magnetic storms occurred because of decelerating CMEs than the accelerating CMEs.

Keywords: Halo CMEs; geomagnetic storms; geo-effectiveness.

1. INTRODUCTION

Coronal mass ejections (CMEs) are found to correlate with the occurrence of strong, non-recurrent geo-magnetic activities [1]. After the study of CMEs and their interplanetary consequences from last two decades, however, has yet to answer a number of questions, such as, which CMEs are Geo-effective and which ones are not? It is likely that there may be considerable evolution of physical properties (speed, density, mass, and magnetic field) of CMEs on their way from the Sun to the Earth and the lack of information on CME propagation in the gap between manifestations near the Sun and in situ measurements is one of the major drawbacks in making progress in the better understanding of geo-effectiveness of them. As we know that, every CME launched from the Sun is not able to produce a geomagnetic storm. It can cause a disturbance in geomagnetic field if it is ejected in the direction of the Earth. Only one out of many CMEs is originally pointed in the Sun – Earth direction and hits the Earth [2]. The CMEs directed along the Sun–Earth line appear as halos around the occultor disk in the field of view of coronagraph, and are called halo CMEs. Hence, only halo CMEs are potential candidates to cause disturbances at geomagnetic field. It has been found that only 50% of total halo CMEs are geo-effective [3][4][5]. The most essential and important properties of a CME (near Earth) that determines its geo-effective character is the way the CME ejecta can cause the interplanetary magnetic field (IMF) to be oriented in southward direction. Therefore, the presence of a southward component of interplanetary magnetic field ($Bz < 0$), of sufficient magnitude and duration ahead and inside of an ICME, is a necessary condition for a CME to cause a geomagnetic storm. [6][7]. Therefore, geo-effectiveness of an ICME is often characterized by the nature of Bz component of interplanetary magnetic field. However, Burton et al. [1975] showed that the disturbance in geomagnetic field or Dst index, a measure of storm time ring current, is an integral value which includes not only Bz but a combination of velocity V and IMF Bz as

$$Dst \approx dT * Ey$$

Where dT is the duration of Ey, where

$$Ey = V \times Bz$$

In this regard several studies have investigated the correlation of velocity V and Interplanetary magnetic field component Bz with peak Dst index [6][8][9]. All such studies have concluded that the speed expansion of halo CME structures is highly correlated with the peak Dst of the storms they generate. Therefore, the speed of an ICME is a very important characteristic which determines the geo-effectiveness of CMEs. The majority of CMEs are observed in the range of 500–1500 km s^{-1}, which indicates that high speed CMEs are decelerating, while slow speed

CMEs are accelerating after initiation [10][11][12] the change in the speed of CMEs (acceleration/deceleration) is due to the exchange of energy between solar wind and the CME. Therefore, acceleration or deceleration determines how the speed of a CME changes as it travels through interplanetary medium. Therefore, acceleration/deceleration of CMEs has also been considered in earlier studies concerning CMEs geo-effectiveness. Similarly, Manoharan and Mujiber Rahman [2011] [11] suggested that the transit time of a CME can give some insight into the geo-effective character of a Coronal Mass Ejection. The transit time is the time taken by a CME to reach Earth after being released from the Sun. Therefore, it is an indicator of its average speed between coronagraph field of view and Earth. Usually, a CME takes about 2-3 days (45-60 hours) to reach Earth. The transit time is particularly important in geomagnetic storm forecasting.

2. DATA COLLECTION

We have selected 324 halo CMEs events which were observed during solar cycle-23 i.e. 1996–2007, as listed in SOHO LASCO catalog; website http//cdaw.gsfc.nasa.gov. To study the geoeffective properties of halo CMEs as well as their distribution, we considered their main three properties viz. speed, acceleration and transit time. The values of speed and acceleration for selected CMEs were taken from the SOHO LASCO catalog database. The transit time was computed as the time taken by CME between the start time of CME on the Sun and the commencement of geomagnetic storm. We identified the geomagnetic storms that were caused by each of the selected CMEs. The selection of the geomagnetic storms, associated with the selected CMEs, was made on the basis of storm intensity index (Dst). The identified geomagnetic storms were then classified into three categories, on the basis of peak Dst index and were labeled as intense ($Dst \leq -100$ nT), moderate (-100 nT< $Dst \leq -50$ nT) and weak ($Dst > -50$ nT). The values of Dst index with 1 h resolution were obtained from World Data Center (WDC), Kyoto at website http//wdc.kugi.kyoto-u.ac.jp/ and https//cdaweb.sci.gsfc.nasa.gov/index.html/.

3. RESULTS AND DISCUSSION

In this presented work, we had constructed different intensity ranges for properties of CMEs and geomagnetic disturbances, we computed the number of events of CMEs and geomagnetic storms in each range of CME properties. We first examined the distribution of CMEs over the different ranges of their three important properties i.e speed, acceleration and transit time. The distribution of CMEs over different ranges of CME speed is shown in Fig. 3.1 for SC-23. We notice that the highest fraction (37.34%) of CMEs occur in the range of 500–1000 km s^{-1}, while 22.53% of CMEs fall in the range of 1000–1500 km s^{-1}. Therefore, about 60% of CMEs are distributed in the range of 500–1500 km s^{-1}. It can be clearly seen that very high speed CMEs are minor (only 8.32%). Similarly, low speed CMEs are only ~18%. It can be concluded that a larger number of CMEs occur in the intermediate speed range where as low and high speed CMEs are less in number.

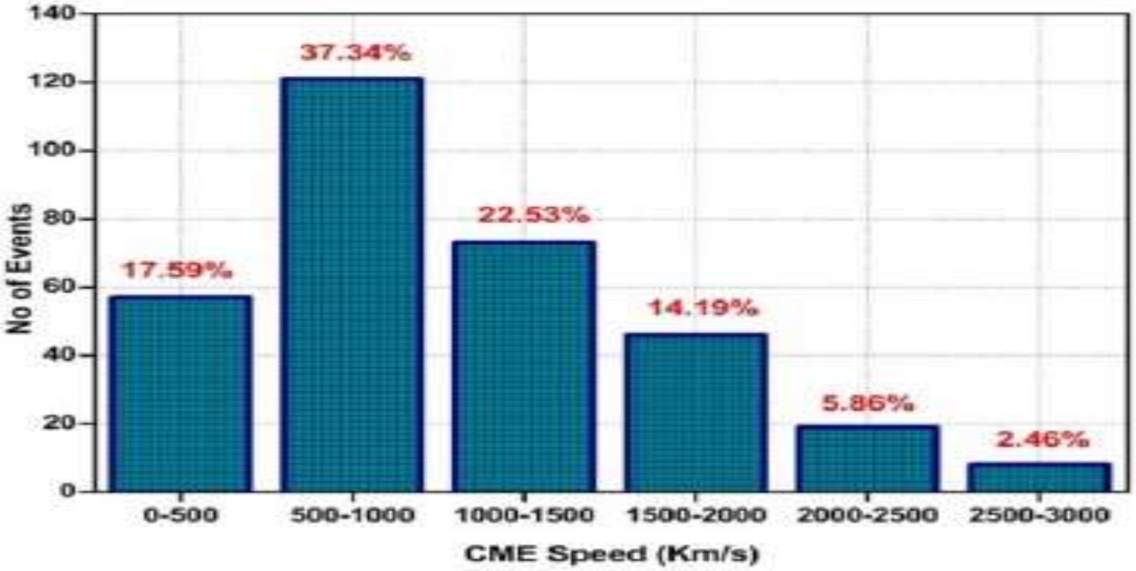

Fig. 3.1 The Distribution of Coronal Mass Ejection During Sunspot cycle 23 in Range of Speed

Next we examined the distribution of geo-magnetic storms of different intensities over different ranges of CME speed. The distribution of weak, moderate and intense storms over the different ranges of CME speed is shown in Fig. 3.2. It can be clearly seen, from Fig. 3.2, that in the low speed range the weak storms dominate while in the high speed range (< 2000 km s^{-1}) intense and moderate storms prevail, the weak storms are either absent or lesser in number. Although, there is no considerable difference between the occurrences of weak, moderate and intense storms in the three intermediate ranges of CME speeds i.e 500–1000, 1000–1500 and 1500– 2000 km s^{-1}, but intense and moderate ones tend to dominate (excluding 1000–1500 band).

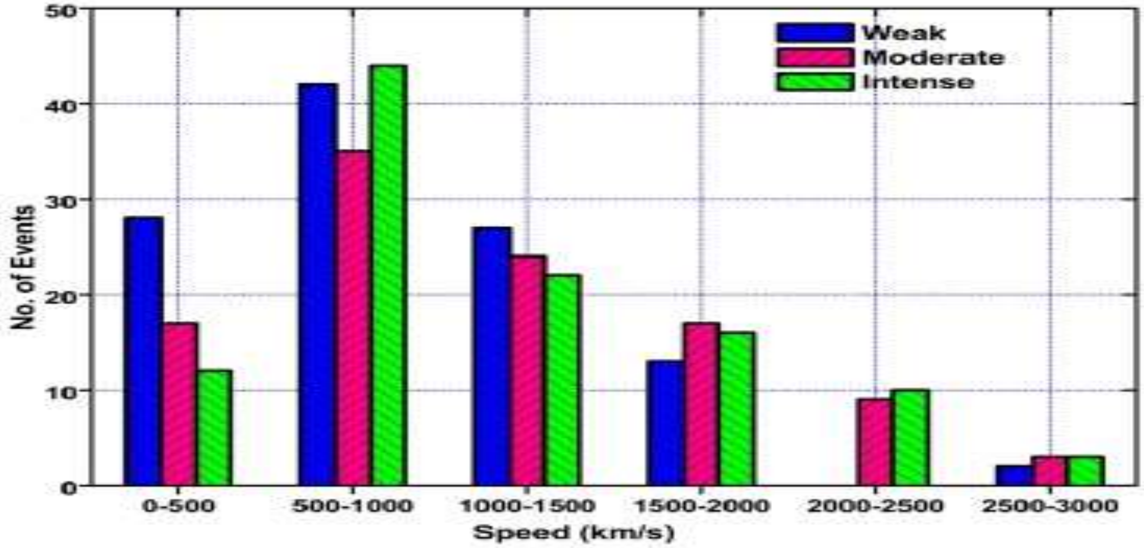

Fig. 3.2 Distribution of Weak, Moderate and Intense Storms Over Different Ranges of CME Speed Over the Period of 1996 to 2007

In solar cycle 23, the distribution of CMEs over different ranges of CME acceleration (positive and negative) is shown in Fig. 3.3. In general, we found that out of 324 events, 122 (37.65%) events have a positive acceleration i.e. these are accelerating while 199 events (61.41%) have a negative acceleration i.e. these are decelerating. It clearly shows that larger number of CMEs is ejected from the Sun with a speed greater than the speed they possess near Earth and lesser number of CMEs is released at slow speeds. In both types of accelerations, the maximum percentage of CMEs was found to be distributed over 0–10 ms^{-2} category. In positive acceleration category, we find that about 60% of CMEs lie in the range 0–10 ms^{-2} and about 80% of the CMEs accelerate below 20 ms^{-2}. Only a significantly less number of CMEs have more acceleration.

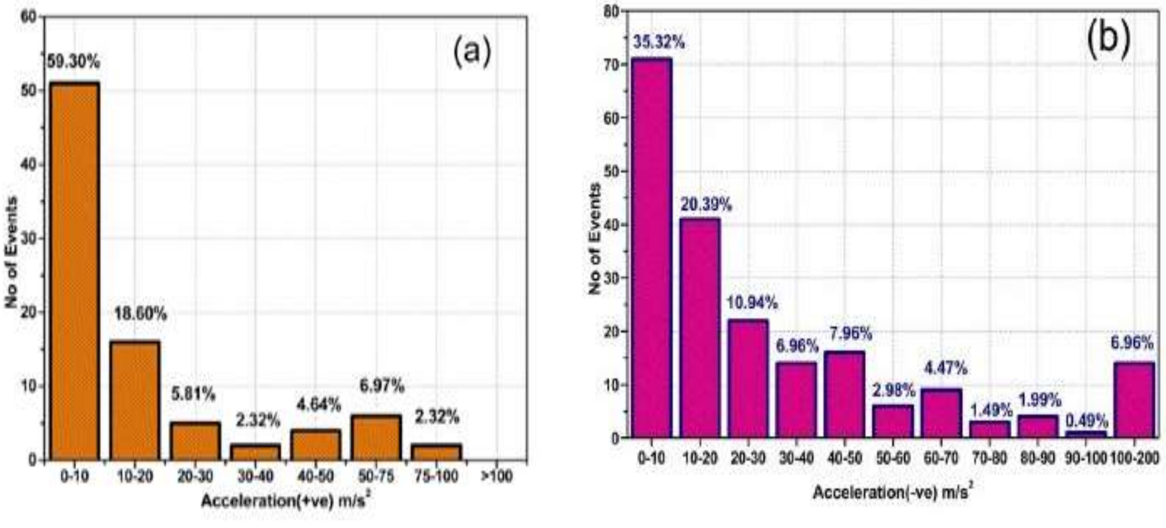

Fig. 3.3 Distribution of CME Events Over Different Ranges of Positive and Negative CME Acceleration

Similarly, investigation of negative acceleration category, we find about 35% of events occur in the speed range of 0 -10 ms^{-2} while about 60% of the events occur below 20 ms^{-2}. A significantly lesser number of CMEs decelerate more. Therefore, it can be concluded that most of the CMEs observed with the acceleration of 0 to ±10 ms^{-2} . Next we studied the distribution of geomagnetic storms (in all three range weak, moderate and intense) over CME acceleration, and is shown in Fig. 3.4. From Fig. 3.4, we can notice that, in the range of 0 to ±10 the intense geo magnetic storms occur more often than weak and moderate storms. However, in higher acceleration ranges, particularly in negative acceleration category, the weak storms prevail. Moreover, it can be observe that highest fraction of intense storms is associated with decelerating CMEs. Therefore, decelerating CMEs are more geo-effective.

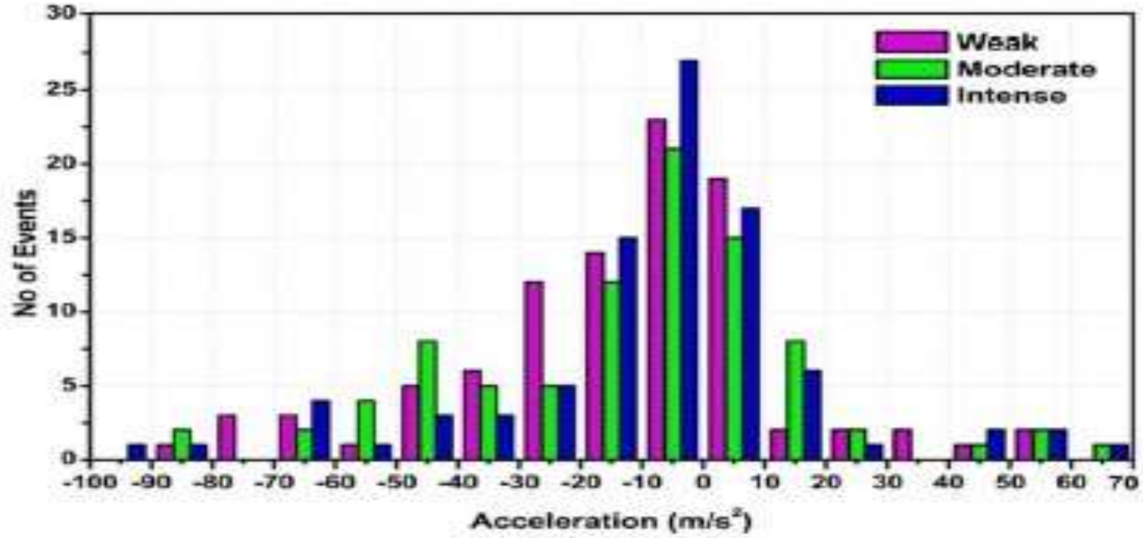

Fig. 3.4 Distribution of Weak, Moderate and Intense Storms Over Various Acceleration Ranges

The third characteristic of the CMEs considered, in this study, is the transit time i.e. time taken by a CME to reach the Earth after being launched from the Sun. In Fig. 3.5 we notice that about 60% of CMEs have a transit time of 25–75 hours i.e. they take approximately 1–3 days and about 75% of CMEs take less than 4 days (100 hours) to reach Earth. Similarly, about 11.72% of the CMEs are found to be having transit time of 100 to 125 hours (4-5 days). Only about 6% of CMEs have more arrival times. Therefore, it can be concluded that the majority of CMEs travel for 50 hours (2 days) to arrive at Earth after leaving the Sun.

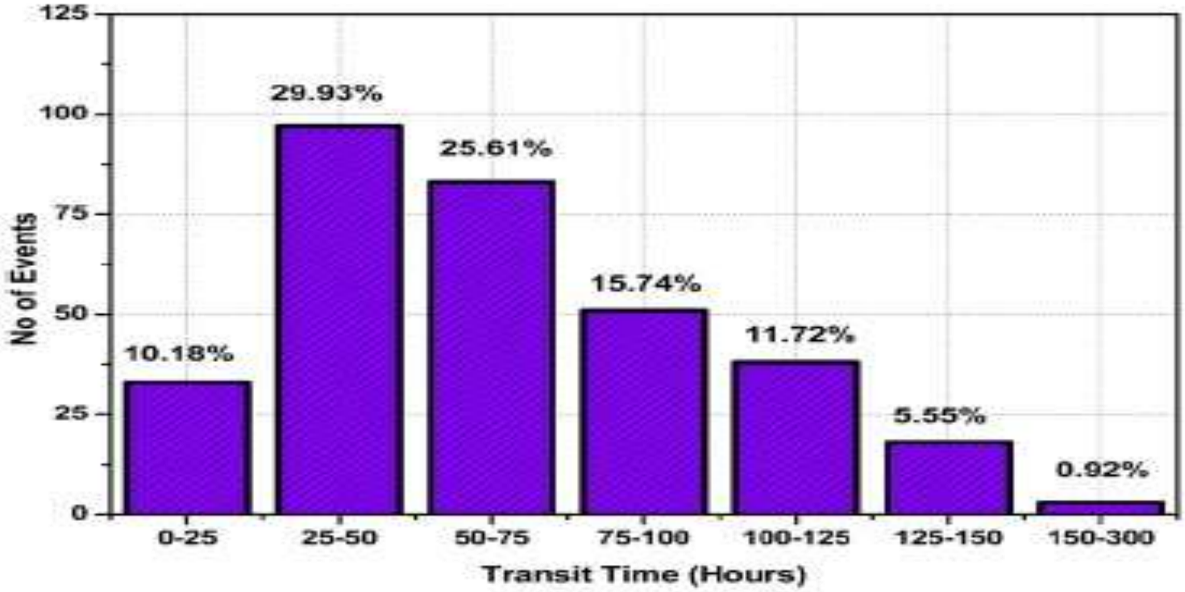

Fig. 3.5 Distribution of CMEs Over the Transit Time

We also investigated the distribution of different kinds of geomagnetic activity over the transit time, it is shown below in Fig. 3.6. From Fig. 3.5 we notice that the highest number of intense storms lie in the 25–50 interval. In other intervals (> 25−50) the number of weak and moderate storms is greater. Therefore, it can be concluded that CMEs which take about 50 hours to reach geo-space are potential candidate to produce geomagnetic storms of greater intensity, hence are more geo-effective.

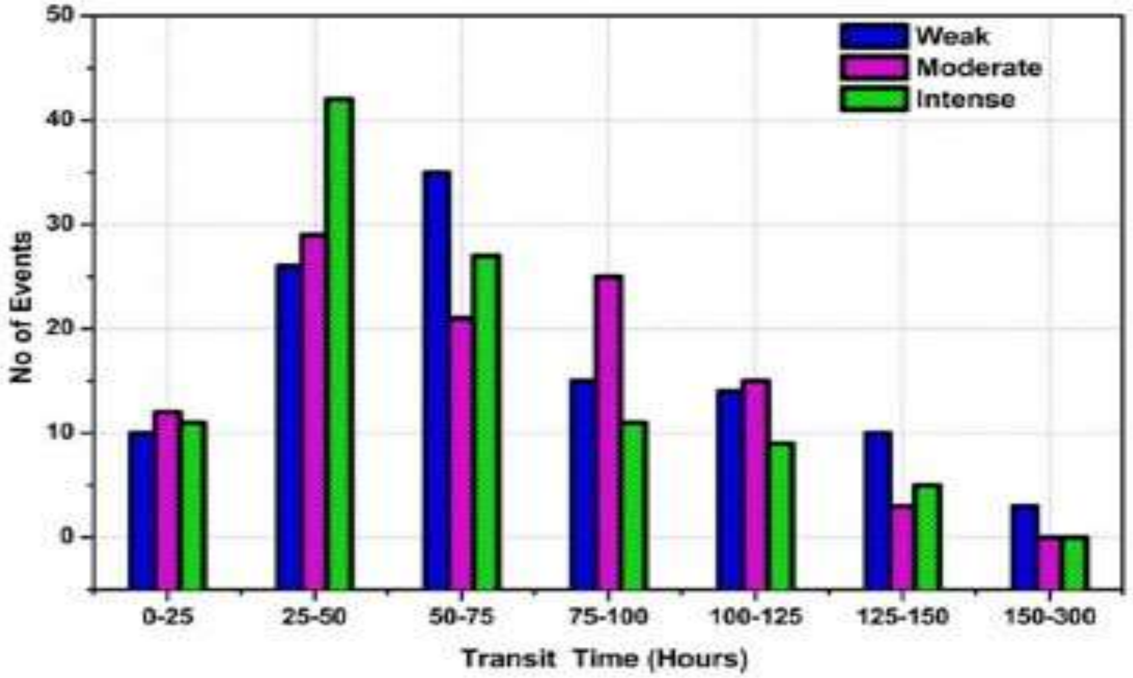

Fig. 3.6 Distribution of Weak, Moderate and Intense Storms Over CME Transit Time

We found that CMEs are distributed with three important characteristics. Yet the majority of CMEs occur with a specified and particular set of properties. Even if CMEs are released from the Sun with properties in other ranges they interact with solar wind and interplanetary medium and adjust their properties to their range. The more interesting result obtained is that the significantly larger fraction of intense geomagnetic storms is found to be caused by CMEs with this particular range of properties. Hence, such CMEs are more geo-effective than the CMEs with properties in other range of properties.

CONCLUSIONS

We have studied the relation between coronal mass ejection (CME) and geo-magnetic storms during the 23rd solar cycle. According to above study the following results have been obtained and conclusions can be summarized as follows:

- Significant fraction of CMEs occurs in the intermediate speed range while as high and low speed CMEs are less in number. In the duration of solar cycle 23, from 1996 to 2007; 60% of CMEs are distributed in the range of speed 500–1500 km/sec, 8.32% in the very high speed range above than 1500 km/sec and ~18% in low speed range below than 500km/sec.
- The occurrences of weak storms are large in numbers in low speed range of Coronal Mass Ejections, while in high speed range the occurrences of intense and moderate storms are more often.
- We found that 62% CMEs possess negative acceleration, where as only 38% have positive acceleration i.e. decelerating CMEs are more frequent during sunspot cycle 23.
- Under positive acceleration category we found that approximately 60% of CMEs are in the 0-10 ms^{-2} range and about 80% of the CMEs suffer an acceleration of greater than 20 ms^{-2}. Similarly, under the negative acceleration category, 35% of the CMEs occur in the range of 0 -10 ms^{-2} while about 60% of the events occur below 20 ms^{-2}.
- Therefore, it is concluded that CMEs usually experience an acceleration of 0 to ± 20 ms^{-2}. The number of intense storms in the acceleration interval 0 ± 10 ms^{-2} is larger than the number of weak and moderate storms, while in intervals with higher acceleration range, particularly in negative acceleration category, the occurrences of weak geo-magnetic storms are usually occur more often. It was also found that the highest percentage of intense storms is created by decelerating CMEs.
- We found that about ~60% of CMEs have a arrival/transit time of 25–75 hours i.e. take 1–3 days and about 75% of CMEs take less than 100 hours (about 4 days) to reach geo-space. The highest number of intense storms lies in the 25–50 interval of transit time. In other intervals (> 25−50) of transit time, the number of weak and moderate storms is greater in numbers.

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