

## EFFECTS OF SOURCE POSITION ON THE DH-TYPE II CME PROPERTIES

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### ABSTRACT

The properties of SOHO/LASCO CMEs are subjected to projection effects. Their dependence on the source position is important to be studied. Our main aim is to study the dependence of CME properties on helio-longitude and latitude using the CMEs associated with type IIs observed by Wind/WAVES spacecraft (Deca-hecta metric type IIs - DH type IIs). These CMEs were identified as a separate population of geo-effective CMEs. We considered the CMEs associated with the Wind/WAVE type IIs observed during the period January 1997 - December 2005. The source locations of these CMEs were identified using their associated GOES X-ray flares and listed online. Using their locations and the cataloged properties of CMEs, we carried out a study on the dependence of CME properties on source location. We studied the above for three groups of CMEs: (i) all CMEs, (ii) halo and non-halo CMEs, and (iii) limb and non-limb CMEs. Major results from this study can be summarized as follows. (i) There is a clear dependence of speed on both the longitude and latitude; while there is an increasing trend with respect to longitude, it is opposite in the case of latitude. Our investigations show that the longitudinal dependence is caused by the projection effect and the latitudinal effect by the solar cycle effect. (ii) In the case of width, the disc centered events are observed with more width than those occurred at higher longitudes, and this result seems to be the same for latitude. (iii) The dependency of speed is confirmed on the angular distance between the sun-center and source location determined using both the longitude and latitude. (iv) There is no dependency found in the case of acceleration. (v) Among all the three groups of CMEs, the speeds of halo CMEs show more dependency on longitude. The speed of non-halo and non-limb CMEs show more dependency on latitude. The above results may be taken into account in correcting the projection effects of geo-effective CMEs.

*Key words :* Sun: coronal mass ejection

### I. INTRODUCTION

The coronal mass ejections (CMEs) are magnetized plasma ejected from the Sun. The subject of studying their properties and propagation is very important due to their effects on space and on the earth such as heliospheric and geomagnetic disturbances (e.g., Gosling, 1993). Since the launch of the Large Angle and Spectrometric Coronagraph (LASCO, Brueckner et al. 1995) on board the Solar and Heliospheric Observatory (SOHO) spacecraft in 1996, the CMEs have been identified and their properties are listed in an on-line catalog ([http://cdaw.gsfc.nasa.gov/CME\\_list](http://cdaw.gsfc.nasa.gov/CME_list)). Because the properties are derived from the sky-plane projected images of CMEs, the properties of CMEs are subjected to projection effect. Earlier, many authors (Burkepile et al. 2004; Michalek et al. 2005; Yeh Chin-Teh et al. 2005; Yayaun Wen et al. 2007) pointed out the projection effects by comparing the properties of

CMEs occurred close to the solar limb and far from the limb. Most of these studies considered the helio-longitude as the representative position of the CME. They provided strong evidence that projection effects systematically influence the deduced properties of CME events. However, some of the corrections suggested for projection effects gave unsatisfied results.

Burkepile et al. (2004) investigated a set of 111 limb events identified in Solar Maximum Mission (SMM) white light observations and found that these limb CMEs have greater average speeds ( $519 \pm 46$  km/sec) and masses ( $4.5 \pm .5 \times 10^{15}$  grams) than the average values obtained from all SMM CMEs. Hence they provided strong evidence that projection effects systematically influence the deduced properties of CME events. In addition, Gopalswamy et al. (2001) analyzed separately a subset of limb CMEs of the CMES associated with DH-type II radio bursts, and identified that the speed of the limb CMEs are more than the CMEs occurring far from the limb, because the limb events are not subjected to projection effects.

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Michalek et al. (2005) estimated the projection effect of CMEs from the onset time of the shock-associated type III radio burst observed Wind/WAVES spacecraft. The difference between the onset times of CMEs and radio bursts was correlated with the position of CMEs on the Sun and examined how much the projection effect can really affect CME measurements.

Recently, Howard et al. (2008) concluded that while using the plane-of-sky measurements may be suitable for studies of general trends in a large sample of events, correcting for projection effects is mandatory for those investigations which rely on a numerically precise determination of the properties of individual CMEs.

Though many authors reported that the speed of CMEs is affected by projection effects, how speed varies with respect to longitude is not understood clearly. The latitudinal dependence is not considered so far. Similarly the dependency of other physical properties of the CMEs such as, width and acceleration, with respect to the source position is not yet studied.

Gopalswamy et al. (2001) investigated the characteristics of CMES associated with DH-type II radio bursts using the CME and WAVE type II data during the period 1997 - 2000. They found interesting results that the CMEs associated with DH-type IIs are faster and wider than the any other CMEs. So they suggested that the detection of DH type II radio bursts may provide a useful tool in identifying the population of geo-effective CMEs. The average speed and width of the DH-CMEs were found to be nearly twice that of all CMEs (average speed =  $487 \text{ km s}^{-1}$  of all CMEs, and average width = 58 degree of all non-halo CMEs). In addition, the DH-CMEs were found to have a different average acceleration ( $-7 \text{ m s}^{-2}$ ) compared to metric-type II CMEs ( $-3 \text{ m s}^{-2}$ ) (Gopalswamy et al. 2005). A majority (60%) of the DH-CMEs were found to slow down within the C3 field of view (Gopalswamy et al. 2001). Shanmugaraju et al. (2003) studied the statistical characteristics of flares and CMEs associated with and without metric type IIs. In which, they also examined the flares and CMEs associated with DH-type IIs and found that they are more energetic than the metric-type II events.

Since the CMEs associated with DH-type IIs are energetic and form a separate population of geo-effective CMEs, and there are projection effects for these CMEs, we carry out a study on how the properties of these CMEs depend on the longitude and latitude.

In the next section, we describe the data analysis and results. Discussions of the results are given in Section 3. Finally, conclusions are presented in Section 4.

## II. DATA AND ANALYSIS

We considered all the 325 DH-type IIs, observed by the Wind/WAVE spacecraft in the frequency range of less than 14000 kHz, and listed in the web site ([http://cdaw.gsfc.nasa.gov/CME\\_list/radio/waves\\_type2.html](http://cdaw.gsfc.nasa.gov/CME_list/radio/waves_type2.html))

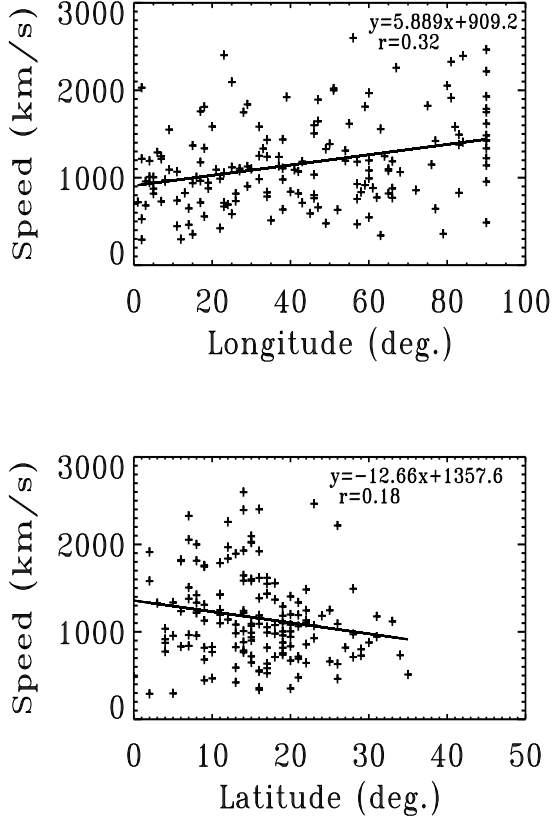
along with their associated flares and CMEs. Out of which, we have neglected some events for which (i) the starting and ending frequency was not identified, (ii) either the flare location or the flare class was not reported, (iii) there was data gap in LASCO, and (iv) acceleration was not measured using more than three data points. Finally, we have obtained a set of 210 CMEs for which their source location was identified from the corresponding flare location. These CMEs were observed by SOHO/LASCO during the period 1997 to 2005 and their properties are cataloged on the web site [http://cdaw.gsfc.nasa.gov/CME\\_list](http://cdaw.gsfc.nasa.gov/CME_list). We have utilized the cataloged values of CMEs' properties (speed, width and acceleration) and their source location for this study. The following three group of CMEs are analyzed individually: all CMEs(210); halo(112) and non-halo(67) CMEs; limb(37) and non-limb CMEs(173). Halo and non-halo CMEs were identified using the width, halo if the width is equal to 360 deg. Otherwise if the width is less than or equal to 200 deg., they are called non-halo. Limb CMEs were identified using the longitude; limb CMEs occurred beyond 75 degree, otherwise they are called non-limb CMEs. Note that more than 50% of the DH-CMEs are halo type.

### (a) All CMEs

When all the CMEs are considered as a group, we found that there is certainly a dependence of speed on both longitude and latitude as shown in Figure 1. While the CMEs observed at higher longitudes near the limb have more speed than the CMEs observed at longitudes near disc center(Figure 1). On the other hand, CMEs are observed with less speed in higher latitudes. It can be seen that there is a weak correlation ( $r = 0.32$ ) between speed and longitude, where as,  $r = 0.18$  between speed and latitude. In the former case, 1-sigma uncertainty in the constants of linear fitting ( $y = mx + c$ ) are 29.73 and 0.59, and p-value of significance of the correlation coefficient is  $4.4\text{e-}5$ . Here p-value indicates a probability from random distribution. For example, if  $p = 0.05\%$ , then the statistical significance is 95%. Typically in case  $p < 0.05$ , the correlation coefficient is significant. For the second case of speed vs latitude, these values are 38.3, 2.24 and 0.024, respectively. It shows that the correlation is significant in this case also.

In addition, we have examined the dependency of other properties of CMEs, such as, acceleration and width. There is no clear dependency of acceleration on the longitude and latitude. On the other hand, a very weak correlation ( $r = 0.25$ ) is found between width and longitude, where as, it is only 0.17 for latitude.

In order to see a qualitative result in the dependency of speed, width and acceleration on both the longitude and latitude, we analyzed the group of all CMEs as follows. We separated the events having different longitude bins (0-15, 15-30, 30-45, 45-60, 60-75, 75-90 de-

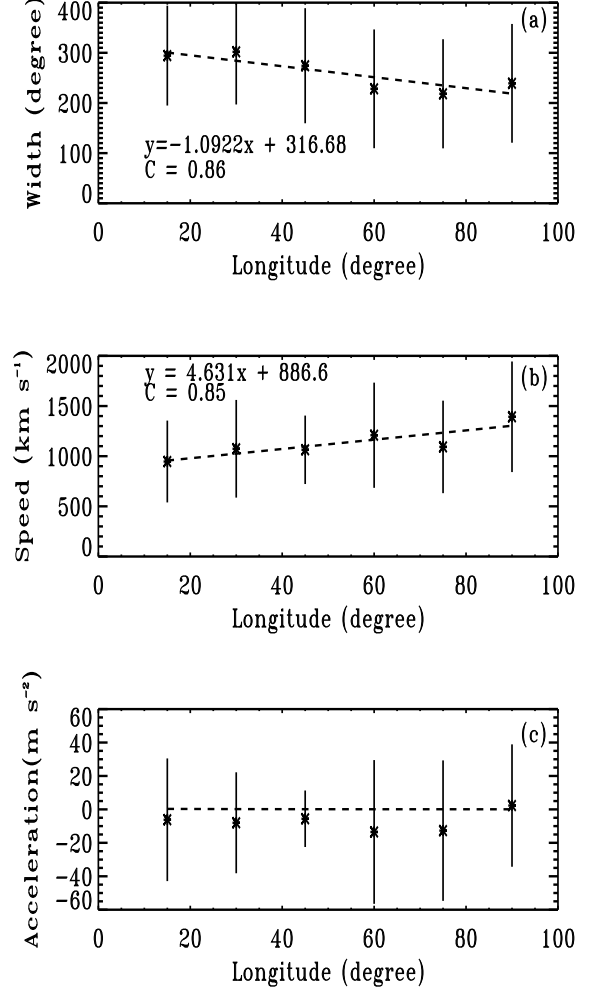


**Fig. 1.**— Dependence of speed of all CMEs on (top) longitude and (bottom) latitude. Solid line shows the linear fit.

gree), and calculated the average and standard deviation in speed, width and acceleration. As shown in Fig.2a and b, we can see the dependency in speed and width clearly with respect to longitude with a correlation  $r = 0.85$ . But, there is no trend seen in the case of acceleration (see Fig.2c). In the same way, the events are separated according to different latitude bins (0-5, 5-10, 10-15, 15-20, 20-25, 25-30, >30 degree), and the values are again determined as shown in Fig.3. Here also, one can see the clear trend in speed and width with respect to latitude. However, there is no dependence seen in the case of acceleration. These figures (2 and 3) give a conclusive evidence for the dependency on the longitude and latitude.

#### (b) Halo and Non-Halo CMEs

As illustrated above, we have analyzed the dependency for another set of CMEs such as, halo and non-halo CMEs. Since the properties of these groups of CMEs are different, we examined them separately. As shown in Figure 4, the trend of observation of faster CMEs towards the solar limb has become more clear



**Fig. 2.**— Dependency of (a) width, (b) speed and (c) acceleration of all CMEs with respect to longitude. The dashed line shows the linear fit. The vertical bar denotes the RMS value at each point.

( $r \sim 0.5$ ). The 1-sigma uncertainty in the constants of linear fitting ( $y = mx + c$ ) are, 74.8 and 1.6 (halo), 101.1 and 1.9 (non-halo). The correlation coefficient is found significant in both cases.

There is only a poor correlation in the case of width (figure not shown). Similarly, we found no dependency of acceleration on the source position.

Similarly, the dependency of speed on the source position can be easily seen (Figure 4) in the case of non-halo CMEs (67 events). Here, the latitudinal dependency is also seen with a weak correlation. In this case, the 1-sigma uncertainty in the constants of linear fitting are, 118.4 and 7.2 (halo), 99.8 and 4.9 (non-halo). The correlation coefficient is found significant for non-halo CMEs but not to halo CMEs. For this group of CMEs,

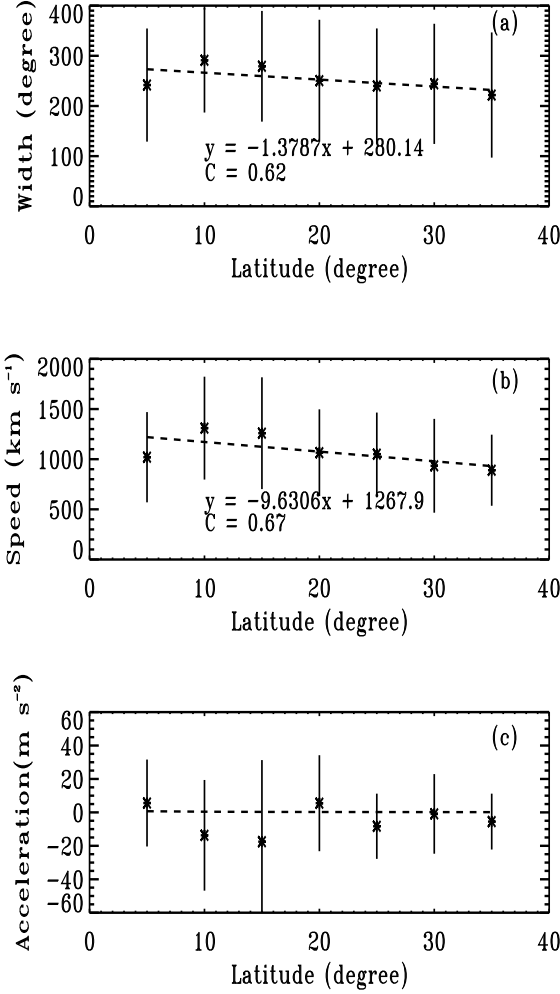


Fig. 3.— Similar to the Fig.4, but for latitude.

the distributions of acceleration and width with respect to longitude and latitude have poor correlations in the cases of acceleration - longitude, and, width - latitude (figure not shown).

### (c) Limb and Non-Limb CMEs

We considered the events occurred beyond a longitude of 75 degree as limb CMEs and the others are non-limb CMEs. On the one hand, the dependency is very poor (18%) for all the limb CMEs (including the CMEs at 90 degree) may be due to the absence of projection effects for these events. The latitudinal dependency is absent for limb CMEs. Similarly, we found no dependency for acceleration and width of limb CMEs, except a weak correlation ( $r = 0.3$ ) between width and longitude.

In the case of non-limb CMEs, there was a very weak to moderate dependency of speed and width (figure not

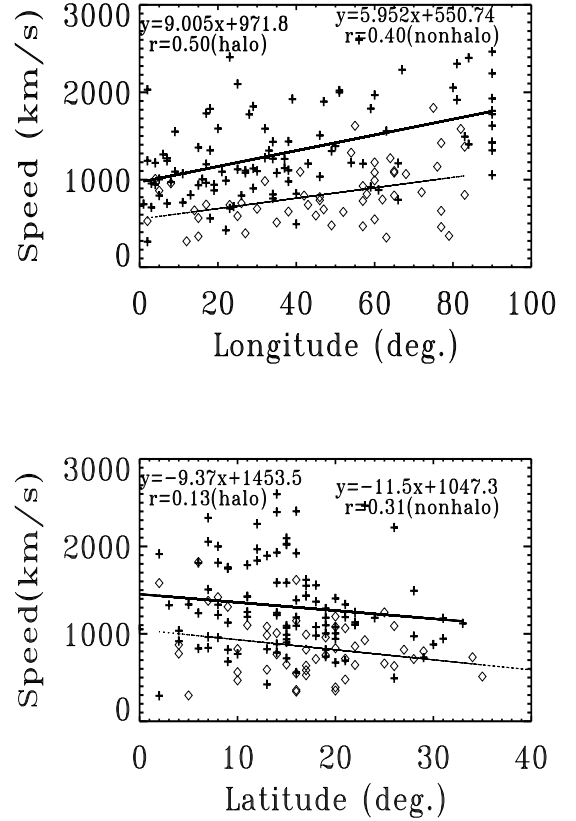
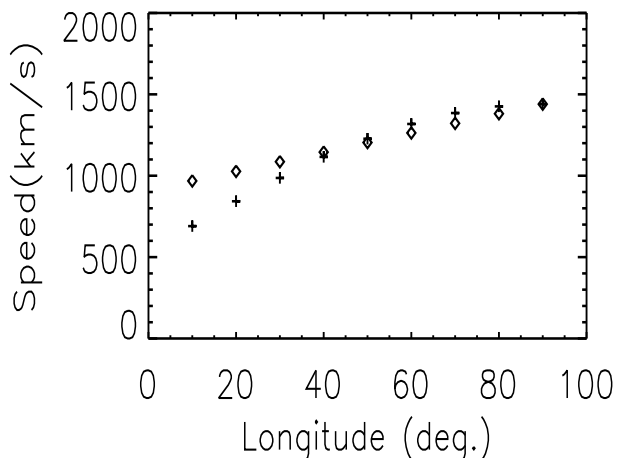


Fig. 4.— Dependence of speed of halo and non-halo CMEs on (top) longitude and (bottom) latitude.

shown here) with respect to both longitude and latitude.

### III. DISCUSSION

Vrsnak et al.(2007) examined several non-halo CMEs and found a correlation between plane-of-sky velocity and distance of the CME from the disc center. That is, CMEs with lower longitudes have lower speeds than the CMEs near limb. They found that the corrected speeds of non-halo limb CMEs are 1.5-2 times greater than the non-halo CMEs launched from regions close to the disc center. Similarly, in the present study in the case of all CMEs, while the events at the zero degree longitude have a speed of  $\sim 900$  km/s, the limb events have a speed of  $\sim 1400$  km/s. That is, the limb CMEs have roughly 1.6 times the speed of disc centered events. On the other hand, the CMEs with zero deg. latitude have a speed of  $\sim 1300$  km/s, the CMEs occurred at a latitude of 35 degree have lesser speed of the order of 900 km/s. This ratio comes to be 1.4. But in the case of halo CMEs, the speed of limb CMEs is 2 times of that of disc centered events.



**Fig. 5.**— Dependence of speed of CMEs on longitude (plus symbol - obtained from the equations(1,2) of Moon et al.(2002), square symbol - obtained from the regression equation in Fig.2b.) Please see the text for more details.

Regarding the longitudinal dependence, the trend that the CMEs occurring near the disc center are observed with less speed is similar to the results reported by many authors (Gopalswamy et al. 2001; Burkepile et al. 2004; Michalek et al. 2005; Vrsnak et al. 2007). One can simply justify the fact that the longitudinal dependence is caused by the projection effect, which may be expressed by some formulae (e.g., the appendix of Leblanc et al. 2001, also equations 1, 2 in Moon et al. 2002). Figure 5 shows a comparison between the regression in Fig. 2b and the equation (1) of Moon et al.(2002) when we take a half angular width=36 degree (an average of common CMEs), latitude=0 degree, and the radial velocity is 1400 km/s. As seen in the figure, both are very similar to each other except for small values of longitudes. Since our sample of CMEs are much wider than the common CMEs, the comparison would be better. Such a consistency strongly support that main reason of the longitudinal dependence should be the projection effect.

As for the latitudinal dependence, the trend of less speed for CMEs occurring at higher latitudes is seen in the present study. One can think over why the latitudinal dependence is different from the longitudinal one. If the projection effect is major one, then the latitudinal dependence should be positive. One possible explanation is solar cycle effect. We have considered the latitudinal dependence of CMEs throughout the study period. During the solar maximum, most of the sunspots are located near 10-20 degree in latitude but during the solar minimum they are near the equator or 30 degree. During the solar minimum, solar active regions producing CMEs are less active and CME speeds are lower.

We have divided the CMEs into three groups like : 1997-1998, 1999-2001, 2002-2005. Then plotted the

latitudinal dependence for each sub-group to check this explanation. We obtained the following several implications from this analysis: 1) very large speed of CMEs (speed  $> 2000$  km/s) are mostly located at low latitudes lower than 30 deg. 2) In relatively large latitudes (e.g.,  $> 30$  degree in latitude), the CMEs are observed with lower speeds (97-98:  $< 1000$  km/s, 99-01 :  $< 1600$  km/s, 02-05 :  $< 1500$  km/s). 3) At the solar maximum period, there are more number of large speed CMEs. So the combination of solar cycle effect and the butterfly diagram can produce a possible weak negative correlation between CME speed and latitude.

In addition, we have examined the dependency of other properties of CMEs, such as, acceleration and width. In the case of width, the disc centered CMEs are observed with more width. But in the case of acceleration, the dependency is not seen.

We have confirmed the dependence of speed in another way as follows. The dependency of speed on the angular distance between the sun center and source location by combining both the longitude and latitude (Leblanc et al. 2001; Moon et al. 2002). The result of this analysis also provided a dependency of speed on this angular distance ( $r = 0.31$ ). Among the three groups of CMEs, we found that the dependency of speed on the angular distance is more for halo CMEs. This may be ascribed to the fact that the disc-centered CMEs are mostly observed as halos and their speed measured from the two-dimensional images are less from their original value.

#### IV. CONCLUSION

From the above analysis, the following results are obtained: (i) A clear dependency is seen in the case of speed and width with respect to both longitude and latitude. This is not seen in the case of acceleration.

(ii) While the limb CMEs are seen with higher speeds (1.5 - 2 times) than that of disc centered events with respect to longitude, it is opposite with respect to latitude. That is, events occurred at higher latitudes have lower speeds.

(iii) In the case of width, the disc centered events are observed with more width than those occurred at higher longitudes. This result seems to be the same for latitude.

(iv) The dependency of speed on the angular distance between sun-center and the source location also shows confirming evidence.

(v) Among all the three groups of CMEs, the speed of halo CMEs show more dependency on longitude. The speed of non-halo and non-limb CMEs show more dependency on latitude.

While the longitudinal dependence can be explained due to the projection effect, the latitudinal dependence may be explained due to the solar cycle effect. These results may be taken into account in correcting the projection effects of CMEs.

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