Characteristic features of coronal mass ejections and their effect on geomagnetosphere

A. P. Mishra and R. Tripathi

Department of Physics, A.P.S. University, Rewa – 486 003 (M.P.), India

Abstract. We present an overview of coronal mass ejections (CMEs) and their effect on the geomagnetosphere during current solar cycle 23. Large Angle and Spectrometric Coronagraph (LASCO) on board the Solar and Heliospheric Observatory (SOHO) mission has given high quality CME data over the past ten years. We have summarized here physical and statistical properties of CMEs and associated phenomena using SOHO. We found that (1) the average width of normal CMEs (20 < width < 120) increased during solar minimum to solar maximum; (2) CMEs were detected around the equatorial region during solar minimum while during solar maximum CMEs appear at all latitudes; (3) The average apparent speed increases during solar minimum to solar maximum. It is found that halo CMEs are the major cause to produce large geomagnetic storms. The results will be discussed in the light of earlier findings.

Index Terms. Coronal mass ejections, large geomagnetic storm, solar atmosphere.

---

1. Introduction

Coronal Mass Ejections (CMEs) were first detected in the 1970s by the Orbiting Solar Observatory (OSO–7) (Tousey, 1973). These solar phenomena are episodic ejections of mass and magnetic field from the solar corona, which involve large-scale reconfigurations of the corona and significant disturbances in the solar wind. Changes in the large–scale coronal structure caused by mass ejections typically occur on timescales ranging from several minutes to several hours and associated solar wind disturbances typically reach the orbit of Earth in 3 or 4 days (Hundhausen, Burkepile and St. Cyr, 1994). The initial detection of CMEs was followed by extensive observations available through various space borne coronagraphs. These coronagraphs are ATM coronagraph on board skylab, the solar wind coronagraph on board the P78–1 satellite, the coronagraph / polarimeter on board the solar Maximum Mission (SMM) and currently the Large Angle and Spectrometric Coronagraph, on board the Solar and Heliospheric observatory (SOHO) mission (MacQueen et al., 1974; 1980; Michels et al., 1980; Dimingo et al., 1995; Brueckner et al., 1995). The LASCO coronagraphs have tracked CMEs upto a heliocentric distance of ~ 32 radii of sun for the first time. The earliest activity observed on the sun was a prominence eruption observed in microwave emission from the southeast quadrant of the sun. The prominence eruption was also observed by the extreme-ultraviolet imaging telescope (EIT), on board SOHO. In running difference images, a faint depletion can be seen surrounding the prominences. There are two dimming regions (D), one on each side of the neutral line, that mark the pre-eruption location of the prominences. After the eruption a post eruption arcade forms (denoted by AF) with its individual loops roughly perpendicular to the neutral line. Dimming is a change in the physical condition (density and temperatures) of the emitting plasma, typically observed in X-rays, EUV and occasionally in microwaves (Hudson, 1999, Gopalswamy and Thompson, 2000, Gopalswamy, 2003). The white light CME first appears an hour later above the occulting disk of the Large Angle and Spectrometric Coronagraph (LASCO) in the same position angle as the eruptive prominences. The observation of large number of CMEs by LASCO has provided an unique opportunity to examine the characteristics features of these events. Coronal mass ejections are dynamic large scale events during which huge amounts of plasma expel from the sun's outer atmosphere. CMEs are the progenitors of interplanetary shocks, which result in geomagnetic storms upon reaching the magnetosphere. In this paper characteristic features of CME and their effect on the geomagnetosphere have been studied.

2. Selection criteria and data analysis

In the present study, we have analyzed in detail all CMEs occurred during current solar cycle 23. Nearly 9000 CMEs were observed from January 1996 to December 2004. The data of CMEs is obtained from the website http://cdaw.gsfc.nasa.gov/CME_list. This online CME catalogue gives the value of CME's (first order and second order) speed, apparent angular width and central position angle and measurement position angle. In the present study we have also analyzed large geomagnetic storms in relation to CMEs. Here, we have considered large geomagnetic storms observed during the period 1996-2005, where Disturbance storm time index (Dst) magnitude is less than –200nT. The geomagnetic data (Dst) is obtained from Solar Geophysical Data (Prompt and comprehensive) report of U.S. Department of Commerce, NOAA, USA.

3. Properties of CMEs

3.1 Physical properties

The CMEs are expected to be observed at coronal temperature, however, the core of the CME can be quite cool (4000–8000 K). White light coronagraphs detect, just the mass irrespective of the temperature. The magnetic field of the CMEs near the sun and in the cavity is virtually unknown. The density in the inner corona is typically 10^{8-9} g cm^{-3} and is expected to be present in the frontal structure of CMEs close to the sun. Skylab data indicated that a single CME could account for a mass of ~ 4 x 10^{15} g (Gosling et al., 1974), which was confirmed by various investigators (Hildner, 1977; Howard et al., 1984). The mass of a CME is estimated by determining the CME volume and the number of electrons in the CME with the assumption that the CME is a fully ionized hydrogen plasma with 10% helium. It is found that the average kinetic energy of CMEs is 5 x 10^{30} erg while the average potential energy is 9.6 x 10^{30} erg.

3.2 Statistical properties

Apparent width

CME angular span (also referred to as CME width) is measured as the position angle extent in the sky plane. For CMEs originating from close to the limb, the measured width is likely to be the true width. For CMEs away from the limb, the measured width is likely to be overestimated. Fig. 1, shows distributions of the apparent angular width (W) of CMEs from January 1996 through December, 2004. The last bin with width greater than 180º include halo CMEs. During the solar minimum (1996–1997), the shape of the distributions is simple with a peak at W ~ 50º. During the starting of solar maximum (1999–2000), the distribution has two peaks at 20º and 70º. The distributions become simple with a peak at ~ 20º-40º during 2001–2004. In order to investigate the properties of CMEs with different angular width, we have simply grouped CMEs into 3 populations : narrow ($W \leq 20º$), normal ($20º < W \leq 120º$) and wide ($W > 120º$) CMEs. The CMEs with $W > 120º$ are called partial halo. It is found that the fraction of narrow CMEs increases towards solar maximum. Further, we have observed that the occurrence of normal CMEs increases during solar minimum to solar maximum.

Apparent position angle of CMEs

In order to study the position angle of CMEs, we have categorised CMEs into position angle 90º, 180º, 270º, 360º. Fig. 2, shows the distributions of apparent position angle of CMEs from 1996 through 2004. During the solar minimum (year 1996) most of the CMEs have occurred in position angle 180º–270º. This position angle corresponds to equator region. During the solar maximum, CMEs appeared at different position angle with similar probability. This is in

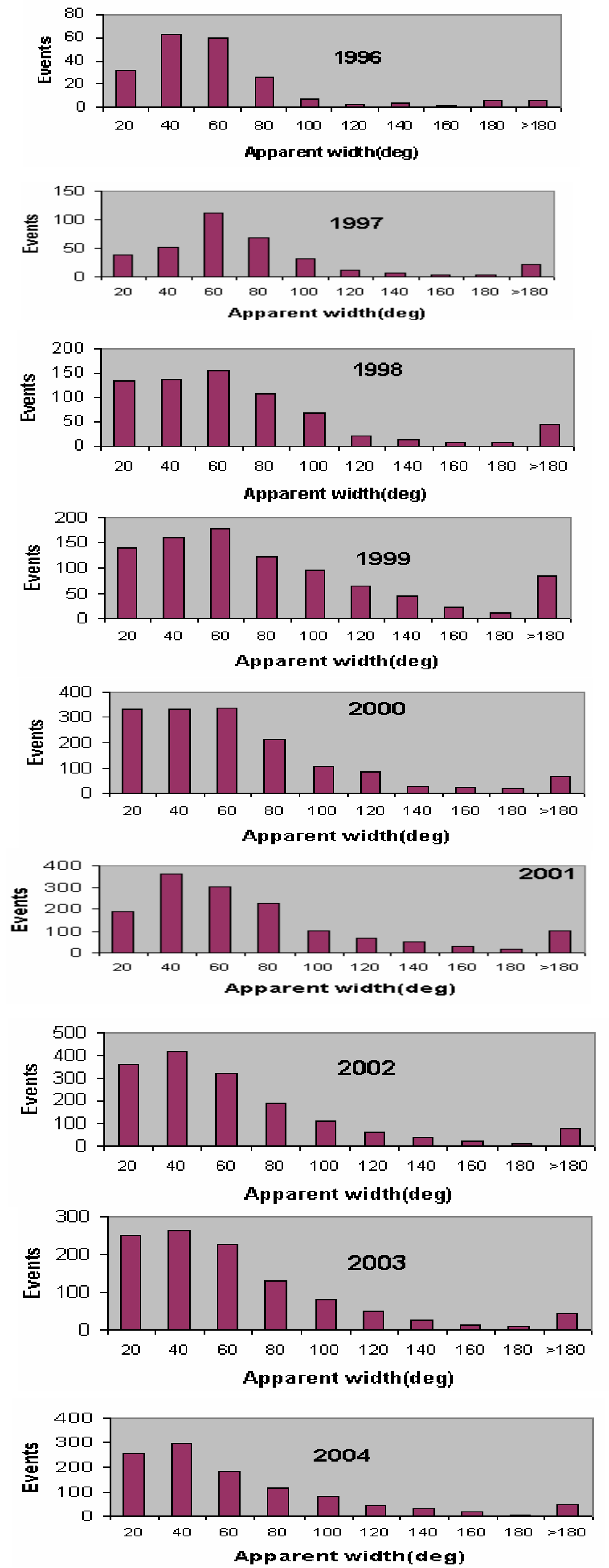

Fig. 1. Histogram of apparent width (deg) of CMEs.

agreement with the results from solwind (Howard et al., 1985) and SMM (Hundhausen et al., 1983).

Apparent speeds of CMEs

The CME speed is determined when at least two height measurement are available. Data gaps resulted inability to measure the speeds of about 4% of the CMEs. Fig. 3, shows the apparent speed distributions of CMEs for each calendar year. We have used linear fit speed from the SOHO / LASCO CME catalogue. It is found that in year 1996, most of the CMEs speed are in the order of 500 km/s. During the solar maximum the speed of CMEs ranged from ≈ 500 km/s to 3000 km/s.

Table 1. List of Large Geomagnetic Storm Associated with CMEs

Sr	Date	Max. Mag. of event (nT)	CME association	Type of CME
01	04 May 1998	-216	CME (871 Km/s)	Halo CME
02	25 Sept. 1998	-233	No CME	X class flare
03	22 Oct. 1999	-231	CME (739 Km/s)	Partial Halo
04	7 April 2000	-312	CME (1927 Km/s)	Halo
05	15 July 2000	-300	CME (1147 Km/s)	Halo CME
06	12 Aug 2000	-237	CME (999 Km/s)	Halo CME
07	31 Mar 2001	-358	CME (1147 Km/s)	Halo CME
08	11 Apr 2001	-256	CME (2975 Km/s)	Halo CME
09	06 Nov 2001	-277	CME (1691 Km/s)	Halo CME
10	24 Nov 2001	-212	CME (1409 Km/s)	Halo CME
11	30 Oct. 2003	-401	CME (1519 Km/s)	Halo CME
12	20 Nov 2003	-472	CME (1656 Km/s)	Halo CME
13	8 Nov 2004	-373	CME (1759 Km/s)	Halo CME
14	10 Now 2004	-289	CME (2000 Km/s)	Halo CME
15	15 May 2005	-256	CME (1689 Km/s)	Halo CME
16	24 Aug. 2005	-219	CME (1250 Km/s)	Halo CME

Table 1 shows the severe geomagnetic storms with Dst magnitude $\leq$ -200 nT associated with Halo Coronal Mass Ejection, which clearly indicates that the Halo CME is the main cause to produce severe geomagnetic storms (Tripathi *et al.*, 2005).

4. Conclusion

Based on the analysis discussed as above, following conclusions are drawn:

(1) The angular width distribution has two categories, one narrow ($W \leq 20^o$) and the other normal ($W > 20^o$) CMEs. Almost similar number of events have been observed with apparent width in the range 0º–20º, 21º–40º, 41º–60º during the year 1998–2000 (early phase of solar maximum).

(2) The average width of normal CMEs ($20^o < W \leq 120^o$) increases from 50º (during solar minimum) to 70º (during solar maximum).

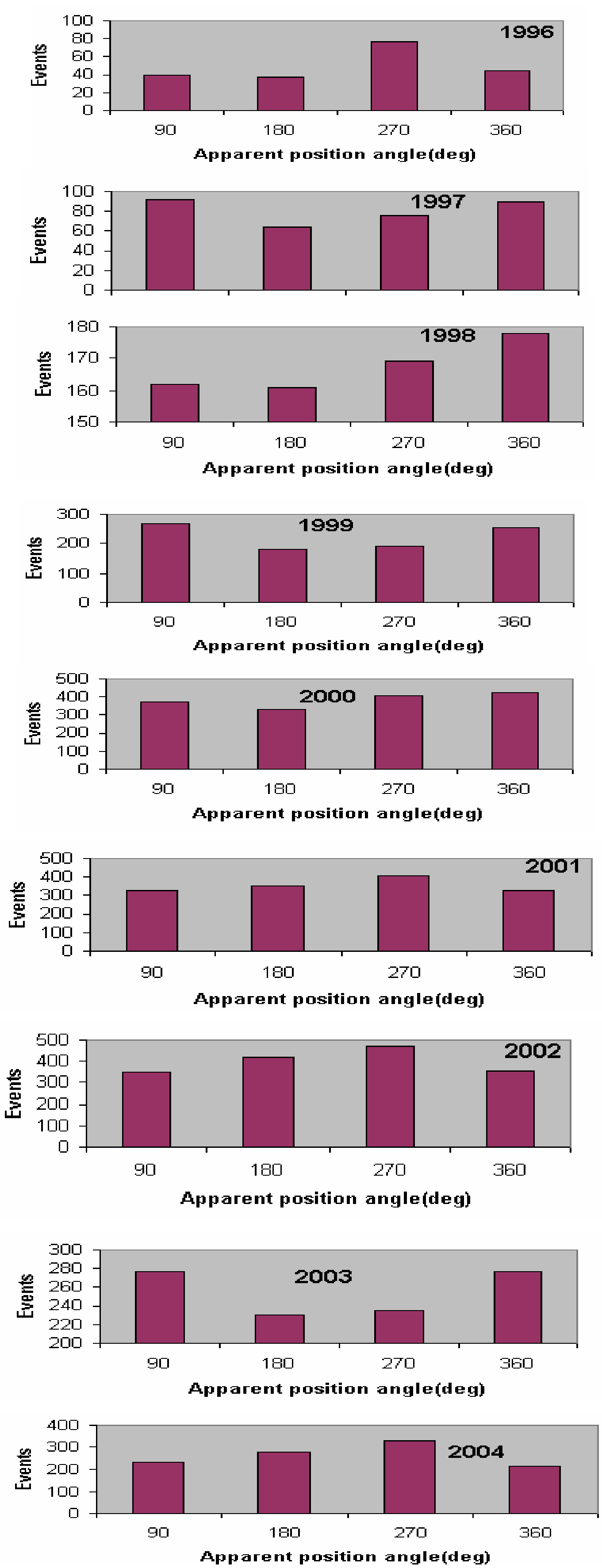

Fig. 2. Histogram of apparent position angle (deg) of CMEs.

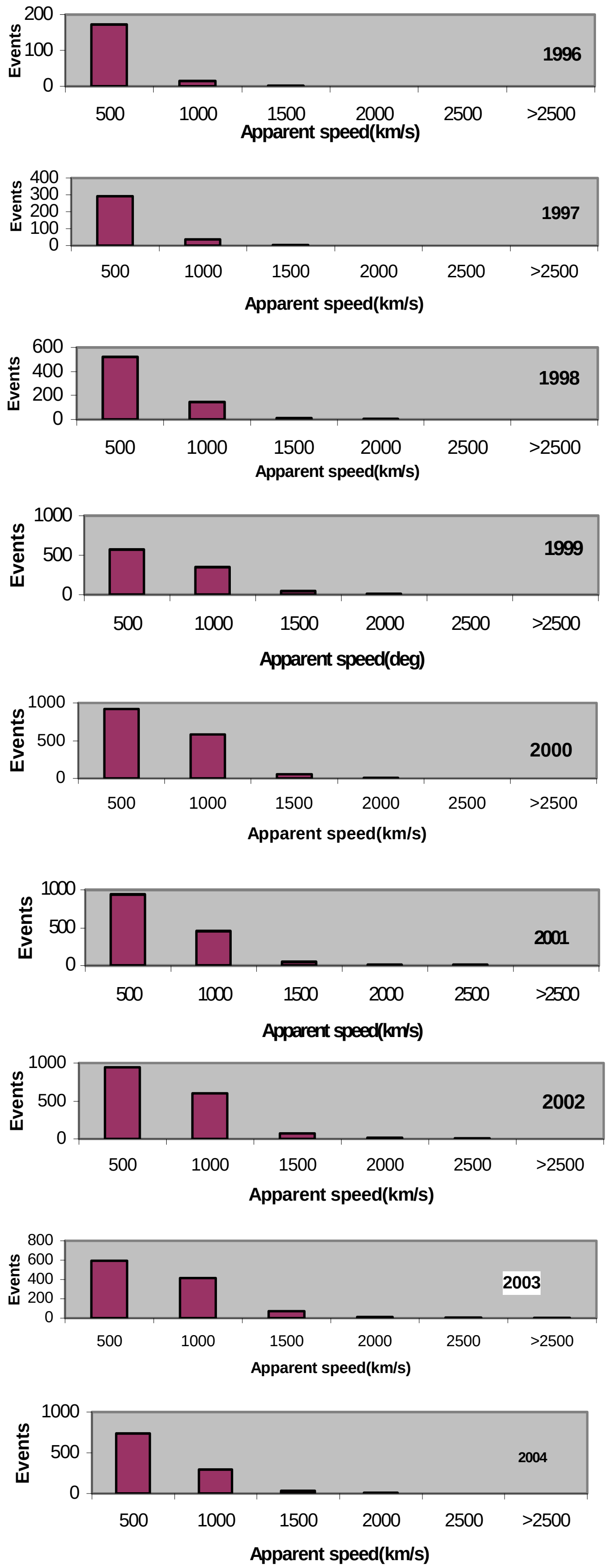

Fig. 3. Histogram of apparent speed (km/s) of CMEs.

(3) CMEs have generally occurred in equatorial region during solar minimum whereas it appears at all latitudes during solar maximum.

(4) Most of large geomagnetic storms (Dst $\leq$ -200 nT) are associated with Halo CMEs, which clearly indicates that they are main cause to produce large geomagnetic storms.

Acknowledgments. The authors are thankful to Dr. N. Gopalswamy for helpful discussion and suggestions during 29th International Cosmic Ray Conference held at Pune from 3–10 August, 2005.

References

G. E. Brueckner *et al.*, "The Large Angle Spectroscopic Coronaraph (LASCO)", *Solar Phys.*, vol. 162, pp. 357-402, 1995.

V. Domingo, B-Fleck and A. I. Poland, "The SOHO Mission: An overview", *Sol. Phys.*, vol. 162, pp. 1-37, 1995.

N. Gopalswamy, *Adv. Space Res*., vol. 31, p. 869, 2003.

N. Gopalswamy and B. J. Thompson, *J. Atmos. Sol. Terr. Phys.*, vol. 62, p. 145, 2000.

J. T Gosling, E. Hildner, R. M. MacQueen, R. H. Munro, A. I. Poland and C. L. Ross, *J. Geophys. Res.*, vol. 79, p. 4581, 1974.

E. Hildner, *Study of Travelling Intrplanetary Phenomena*, vol. 71, M.A. Shea, D. F. Smart and S. T. Wu, Eds. ASSL, 1977, p. 3.

R. A. Howard, D. Michels, N. R. Sheeley and M. J. Koomen, *J. Geophys. Res.* vol. 96, p. 8173, 1985.

R. A. Howard, N. R. Sheeley Jr., D. J. Michels and M. J. Koomen, *Adv. Space Res.*, vol. 4, p. 307, 1984.

H. Hudson, *NRU Report No. 479*, T.S. Bastian, N. Gopalswamy and K. Shibasaki, Eds. 1999, p. 15.

A. J. Hundhausen, *J. Geophys. Res.*, vol. 98, p. 13177, 1993.

A. J. Hundhausen, J. T. Burkepile and O. C. St. Cyr, *J. Geophys. Res.*, vol. 99, p. 6543, 1994.

R. M MacQueen, A. Csocke-Poeckh, E. Hildner, L. House, R. Reynolds, A. Stanger, H. Jepoel and W. Wagner, "The High Altitude Observatory Coronagraph / Polarimeter an the solar maximum mission", *Solar Phys.*, vol. 65, pp. 91-107, 1980.

R. M. MacQueen, J. A. Eddy, J. T. Gosling, E. Hildner, R. H. Munro, G. A. Newkirk, A. I. Poland and C. L. Ross, "The outer solar corona as observed from skylab: Preliminary results", *Astrophys. J.*, vol. 187, pp. L85–L88, 1974.

D. J. Michels, R. A. Howard, M. J. Koomen and N. R. Sheeley Jr., "Satellite observations of the outer corona near sunspot maximum", in *Radio Physics of the Sun*, M. R. Kundo and T. E. Gergely, Eds. D. Reidel, Hinghann, M. A., 1980, pp. 439-442.

R. Tousey, "The solar corona", in *Space Research XIII*, M.J. Rycroft and S.K. Runcom, Eds. Akademic –Verlag, Berlin, 1973, p. 713.

R. Tripathi and A. P. Mishra, "Properties of Halo CME in relation to large geomagnetic storms", in *29th International Cosmic Ray Conference*, Pune, 2005. pp. 101-104.