

Relationship of interplanetary coronal mass ejections with geomagnetic activity

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The signatures of Coronal Mass Ejection (CME) associated interplanetary disturbances are called as Interplanetary Coronal Mass Ejections (ICMEs). In the present study, 69 events of ICMEs have been utilized to derive their relationship with the geomagnetic activity for the period of 1996-2002. A significant positive correlation between Ap-index and ICME speed has been observed. Results of present analysis suggest that ICMEs can produce geomagnetic activity with an increase in geomagnetic Ap-index and decrease in Dst-index.

Keywords: Interplanetary coronal mass ejection, Coronal mass ejection, Geomagnetic activity, Solar activity

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1 Introduction

Coronal Mass Ejections (CMEs) are described as the mass ejection of matter from the coronal region of the Sun^{1,2}. These CME events generally occur in large numbers during the period of high solar activity, carry large amount of plasma ($\approx 10^{25}$ J and 10^{13} kg) into interplanetary medium³. The fast (> 500 km⁻¹) CMEs coming from the sun into interplanetary medium are the solar coronal features that contain high magnetic fields. These high magnetic fields are expected to be capable in producing interplanetary disturbances.

The CMEs have emerged as the main solar/interplanetary factors that produce geomagnetic field variation⁴⁻⁸. Gonzalez *et al.*⁹ have reported fast CME as the cause of intense magnetic storms (Dst < -100 nt). They consider the effects of interplanetary shock event on the sheath plasma. Examination of profiles of very intense storms from 1957 to the present, indicate that double and some times triple IMF Bs events are important causes of such events. They also discuss evidence that magnetic clouds with very intense core magnetic fields tend to have large velocities, thus implying large amplitude interplanetary (IP) electric fields that can drive very intense storms. However, it was pointed out by Cane¹⁰ that IP shocks are not always followed by

interplanetary CMEs (ICMEs), which are responsible for geomagnetic storms.

In a related study, Tsurutani¹¹ indicates the equal importance of both the sheath fields or draped fields and the driver gas fields for the generation of major geomagnetic storms. Tsurutani *et al.*¹² also reported the co-rotating stream/ (HCS) plasma sheath interaction region as a cause of moderate storms. The initial phases of these co-rotating stream related storms are caused by the increased ram pressure associated with the HCS plasma sheet and the further density enhancement from the stream-stream compression. The complex family of CMEs, sometimes with their leading shock waves has been called interplanetary Coronal Mass Ejections (ICMEs) during their heliospheric propagation. The ICMEs can be verified by various solar wind signatures including magnetic clouds and bi-directional electron fluxes. Dryer¹³ first time introduced the term ICME in his study of slow transient flow interaction. However, he has never examined the physical characteristics of ICMEs in his study. Recently, Wang *et al.*¹⁴ reported a list of 69 ICME events for the period 1996-2002, along with their transit time of average speeds in interplanetary medium.

In this paper, the characteristics of these ICMEs are examined and their influence on the geomagnetic activity for the period 1996-2002 is studied, which represent the ascending and high phases of the recent solar cycle 23.

2 Data analysis

Observations of CMEs are taken from the LASCO/SOHO, EIT/SOHO and GOES satellites. First these satellites are used to identify the front-side halo CMEs. Those CMEs, which have span angle larger than 100° are known as halo CMEs. On the other hand, ICMEs are the interplanetary counterparts of CMEs, which are observed from the ACE and wind space craft¹¹. Here, in the present analysis, the Wang *et al.*¹⁴ sample of ICME events is used. In their list, transit times of ICME and speeds are also given along with occurrence of front-side halo CMEs. All the 69 events of ICMEs have been taken for the period 1996-2002 in this analysis. In order to evaluate the atmospheric response to ICME disturbances, the daily values of geomagnetic planetary index Ap and Dst index are taken from solar geophysical data books/internet web sites. The Dst index is representative of the magnetic effect of low latitudes and Ap index shows the effect at mid-latitudes. The present study investigates by means of superposed epoch analysis the changes in geomagnetic activity on a longer time scale (5 days before and 10 days after 1 CME onset).

3 Results and discussion

In earlier studies, it has been examined that the speed of CMEs are also an effective parameter that controls the geo-effectiveness of very fast halo CMEs. Solar flare generated CMEs generally showed higher speeds and smaller accelerations¹⁸⁻¹⁹. Recently, it has been also reported that large solar flares were likely to be associated with CME events¹⁷. In earlier studies on the basis of solar wind speeds, various investigators reported that the flare generated high-speed solar wind streams are related to significant increases in level of geomagnetic activity^{15,16}. One of the currently unknown factor is the behaviour of ICMEs in inner heliosphere and their effects on earth's magnetic field. In this paper an attempt has been made to examine the physical characteristics of ICMEs and find out their relationship with geomagnetic activity.

Figure 1 shows the distribution of transient speed of 69 ICMEs in interplanetary medium at 1 AU for

the interval 1996-2002. It can be seen in Fig. 1 that the speeds are scattered in a range from 500 km⁻¹ to 700 km⁻¹. To observe the relationship of ICME speed with geomagnetic activity, the ICME speeds have been correlated with Ap values, as shown in Fig. 2. Scatter of points in Fig. 2 shows a significant positive correlation ($r \approx 0.58$) between these two solar and geomagnetic parameters. It is now inferred from the analysis that the speed of ICME is an important parameter that controls the CME geo-effectiveness. Further, the analysis has been extended on short-term basis to draw the combined effect of these ICMEs on geomagnetic field, on adopting the Chree analysis of super epoch method. To observe the average behaviour of geomagnetic disturbances during the period of ICMEs, the Chree analysis as shown in Fig. 3 has been done for this study.

A significant increase in Ap values on zero day (arrival date of CME at 1 AU) is seen for almost each year, starting from 1996 to 2002. However, maximum

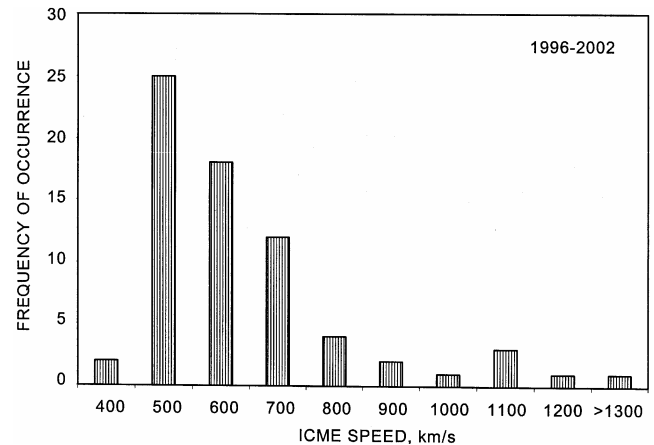


Fig. 1—Shows the frequency histogram of average ICME speed (km⁻¹) for the period 1996-2002

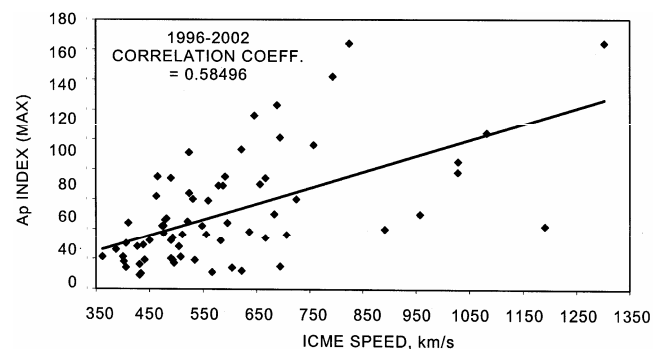


Fig. 2—Cross plot between the Ap-index and average ICME speed for the period 1996-2002

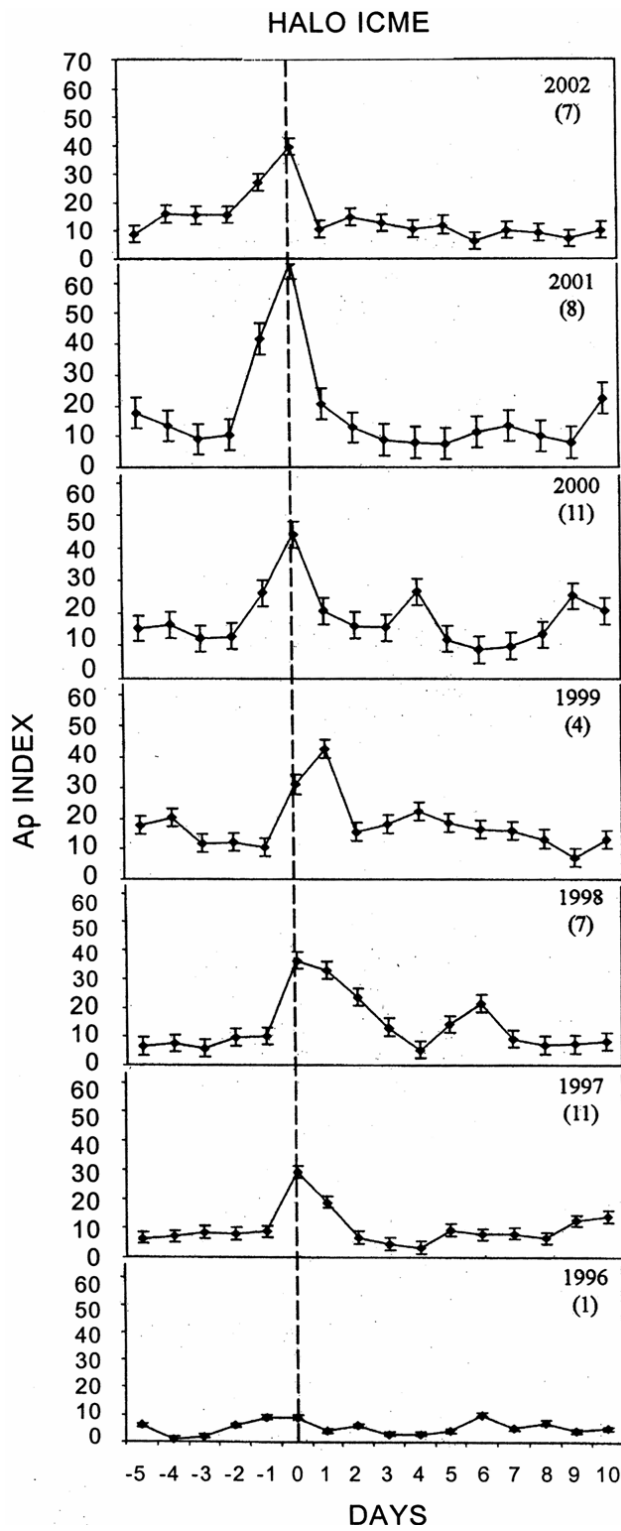


Fig. 3—The results of chree analysis for 5 to 10 days with respect to zero epoch days (The variation of Ap values are shown in the figure. Zero day correspond to the starting day of occurrence of ICME events. Error bars are drawn in each point for all the years.)

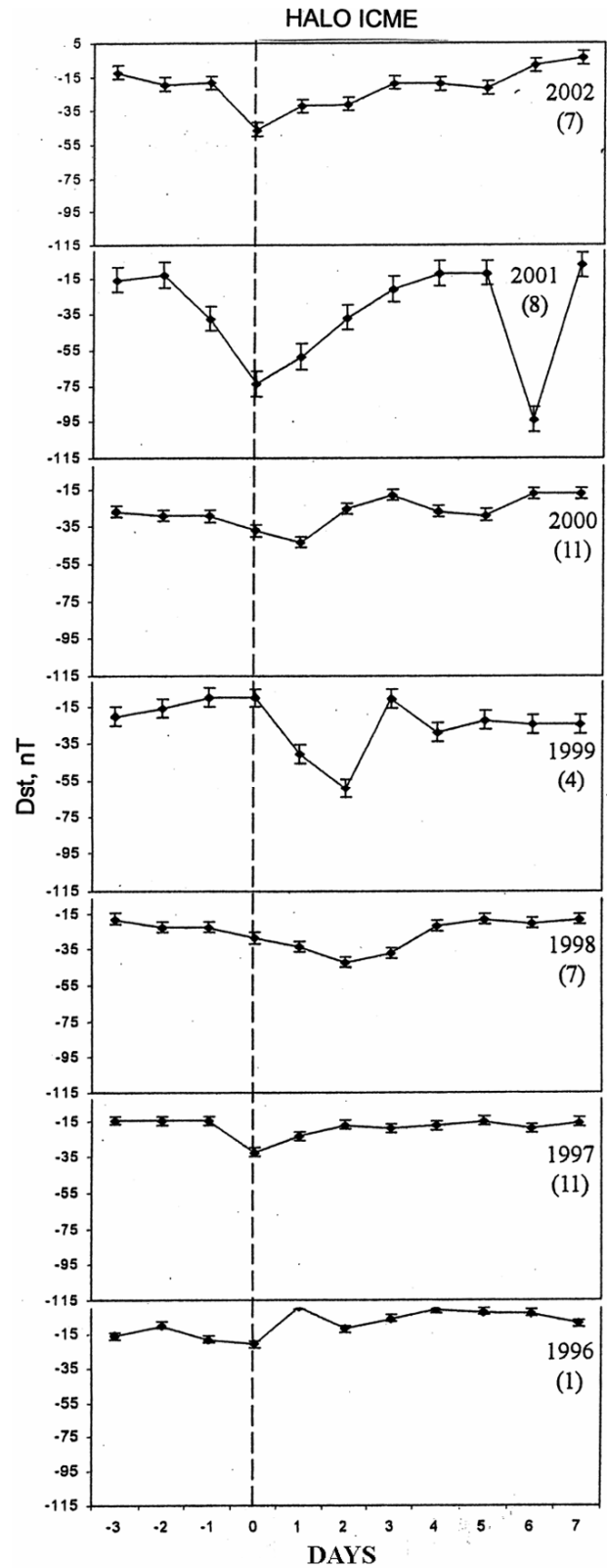


Fig. 4—Superposed epoch analysis plots of Dst values associated with ICMEs

of Ap values in 1999 deviates for one day from zero day. It may be expected due to some specific disturbances in interplanetary medium and needs a separate and detailed study. Second peaks are observed in 1998 and 2000 and depicted in Fig. 3, which may occur due to the complex behaviour of interplanetary medium during these two years. Similar analysis has been done for Dst values. The Dst index measures the effect of ring current in the magnetic field. It is based on hourly averages of the horizontal component recorded at four low-latitude observatories, subtracting the average solar quiet variation and permanent magnetic field from the disturbed one²⁰.

A geomagnetic storm is initiated when enhanced energy transfer from the solar wind and interplanetary magnetic field (IMF) leads to an intensification of earth ring current. The strength of geomagnetic storm is affected by two physical processes. First, solar wind ram pressure near the magnetopause given by $(\rho v^2)_{sw}$, where ρ is the main density and v the vertical speed of solar wind. Second is the direction of the Z-component of the interplanetary magnetic field (IMF). When the component is directed southward for a long duration, magnetic reconnection occurs between the IMF and geomagnetic field. This allows solar wind plasma particles to be injected into earth ring current. Brien *et al.*²² derived a modified dynamical equation nearly identical to the Burbon equation. They showed that the ring current decay lifetime varies with VBs, but not with Dst. The relationship between SW and the magnetic storm has been reported by many workers.

Fenrich and Luhmann²² reported increase in geoeffectiveness, N-S polarity clouds due to both an increase in solar wind dynamic pressure and a compressed southward field associated with a fast solar wind stream. Figure 4 depicts the superposed epoch analysis plots of the Dst geomagnetic index for ICME events each year separately, from 1996 to 2002. In general, Dst index decreased near the time of arrival of ICME and increased latter. In 1998 and 1999, maximum decreases occurred after two days from the zero epoch days, which slightly differ from the results obtained from Ap values.

Figure 4 shows delay of one or two days for the years 1999 and 2000 between Dst minimum and arrival time of the ICME. One expects that magnetic storm would ensue on the same day as an ICME and shock ahead of hits magnetosphere. The delay in one

to two days indicates the occurrence of some other interplanetary phenomena, which affect the geomagnetic activity. The Dst index gives the average depression of horizontal component in units of nT, which is proportional to the total kinetic energy of symmetrically distributed particles injected and trapped in the Van Allen belt. It is now expected that the shock disturbances in which the ICMEs driving the shock highly effective in stimulating geomagnetic disturbances. When a CME is accompanied by a shock, the compressed region between the shock and the driving CME, which is also known as shock sheath produces large geomagnetic disturbances, whenever it contains a southward magnetic field component.

4 Conclusions

From the above discussion of results, the following conclusions can be drawn:

- (i) It is found that the average speed of ICME shows a maximum around 400-700 km/s.
- (ii) Significant positive correlation has been found between ICME speed and geomagnetic Ap index.
- (iii) The ICMEs are found responsible for producing geomagnetic disturbances.

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