INFLUENCE OF CORONAL MASS EJECTION ON GEOMAGNETIC ACTIVITY DURING 1988–1993

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Abstract. The most rapid and dramatic evolution in the solar corona occurs in events now known as Coronal Mass Ejections (CMEs). There have considerable importance for our understanding of the evolution of the mass and energy injected into the interplanetary medium. In this work, we have studied the relation of CMEs with geomagnetic activity for the period of 1988 to 1993. Not all CMEs are capable of producing geomagnetic disturbances. Our study indicates that the maximum chance of a geomagnetic disturbance occurs two to three days after a CME in association with B-type solar flares.

Keywords: Coronal mass ejections, geomagnetic activity, magnetic cloud, solar activity, solar flares, solar wind

1. Introduction

Coronal Mass Ejections (CMEs) propagate through interplanetary space and, on arrival at 1AU, can generate disturbances in the geomagnetic field. CMEs represent large-scale changes in the solar corona as up to 10^{12} kg of matter is expelled into the interplanetary medium. Such a huge amount of energy (10^{25} J) propagating into interplanetary space produces important perturbations in the density and magnetic structure of the solar wind.

For years it was thought that solar flares were responsible for major geomagnetic storms. However, recently we have seen a shift in our concept such that CMEs, after than flares, are considered the key causal link with solar activity. The CME data are not satellite data, as found on SOHO, SMM or SOL WIND, but ejections seen by observatories. These data were prepared by NASA in response to an IAU working group recommendation in 1979. However, recent observations of CME events provide further data to reinvestigate the influence of these events on the geomagnetic field. In a number of recent research works in the field of solar terrestrial physics, CMEs are investigated as one of the primary causes of geomagnetic disturbances (Kudela et al., 1995; Gosling, 1993). A significant relationship between CME events and geomagnetic disturbances is reported by a number of

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investigators (Gosling et al., 1992; Biber and Evanson, 1997; Shrivastava, 2001). In this paper a systematic study has been performed to understand the effect of CMEs on the geomagnetic field variation.

2. Data and Method of Analysis

Data for the CME events of this study have been taken from solar geophysical data book-prompt reports, the monthly publication of NOAA Boulder, Colorado, USA. We have selected only those CME events having a duration more than three hours, leaving 144 CME events for the period of 1988 to 1993. In this investigation Chree analysis of superposed epoch has been applied to find short-term effects. By this statistical technique one can detect the periodic or recurrent, and non-periodic variation. Chree analysis is a procedure for analysing one set of measurements during epochs selected on the basis of a specific type of feature in the second set of measurements.

The technique is a "Row × Column" array in which the response index values filling any row are data pertaining to a single key event. The number of rows is the sample size of such events. The columns line up to the index values in fixed time relative to the key times. The key times are called the zero epoch or zero day, and times following the zero day are labelled positive and times preceding the zero epoch are labelled negative.

Column averages than give the time variation of the parameter under study relative to the zero day. In recent years this technique has been used in several disciplines either for testing the relationship between two diverse phenomena or to search for periodicities in the data.

3. Results and Discussion

It is observed that most of the CMEs at 1 AU exhibit the large and coherent internal field rotation characteristics of a magnetic flux rope. For example, there are bi-directional electron flows related to magnetic flux rope structure associate with CME events. Magnetic cloud events in interplanetary space are also considered to be one of the signatures of interplanetary transients (Ihara et al., 2001). Kaushik and Shrivastava (1999) reported the bi-directional events (BDEs) and Magnetic Cloud Events (MCEs) as interplanetary phenomena, which significantly influence the Earth's magnetic field. Therefore, considering these mechanism, we have done the statistical analysis to determine the influence of CMEs on the geomagnetic field.

In the present work, we have done a Chree analysis of epoch superposition to determine the effect of CMEs on geomagnetic activity, in association with solar flares. Daily values of Ap index (geomagnetic disturbance index) have been taken as geomagnetic indices. In our analysis zero day corresponds to the starting day of occurrence of the CME at 1AU. We considered a one day window, which concides with the first appearance day of CME. We have considered only major solar flares which have optical importance ≥1 for all the three F, N and B categories. Further, to study the solar flare association of geomagnetic variation in association with CMEs, we have divided all the CME events into three categories: (i) Associated with N-type solar flares, (ii) associated with F-type solar flares, (iii) associated with B-type solar flares. The results of Chree analysis for −5 to 10 days have been plotted for the three different categories as shown in Figures 1–3 respectively.

The analysis has been done for each year from 1988 to 1993. The error bars shown in the figure establish the quantitative nature and significance of study. During each year from 1988 to 1993, significant increases in geomagnetic activity for CME events associated with B-type solar flares are evident. Ap-values are found to peak up to 2 to 3 days after the zero epoch day. Slight increase in Ap values for N-type solar flares in associated with CME events are noticed during 1988 to 1993. In contrast, it is difficult to draw any conclusion in F-type solar flares. Finally, we conclude that CMEs associated with B-type solar flares are more effective in producing disturbances in the geomagnetic field.

Out of 144 CME events 66 are associated with high speed solar wind streams. We have considered events of high speed solar wind streams which satisfy the following two conditions: (i) The solar wind speed should persist at high values for at least three days after it begins to increase; and (ii) the solar wind speed should increase by at least 500 km s^{-1}. We have selected the events of high speed solar wind streams using the plots of hourly values of interplanetary parameters (King and Papitasheshi, 1994). In an earlier investigation, high speed solar wind streams with solar flare origin were found to be one of the responsible factors in geomagnetic disturbances (Mavromichalki et al., 1988; Shrivastava and Shukla, 1993, 1995). Now CMEs associated with slow and weak solar flares do not produce large geomagnetic disturbances because they lack the strong fields and high speeds necessary to stimulate significant activity in the earth's magnetosphere. Bright solar flares and CME driven solar wind disturbances are thus the long-sought link between solar activity and geomagnetic activity. It is also expected that major B-type solar flares near the central meridian of the Sun (as viewed from Earth) associated with CMEs generate an interplanetary shock. The solar flares and CMEs do not drive one another, but are the result of the same activity in the corona. Harrison (1994) reported that the solar flares and CME do not drive one another, but are the result of activity in the solar corona. The magnetic activity which leads to a flare event in one part of magnetic structure leads to an eruption of a larger scale component of structure. Flares do not show preferred association with CMEs and the relative locations and timing of the two phenomena show no systematic ordering. Our results suggest that perhaps CMEs associated with weaker flares do not produce large geomagnetic responses because they are associated with weaker magnetic fields of the Sun; they do not generate the strong fields and high

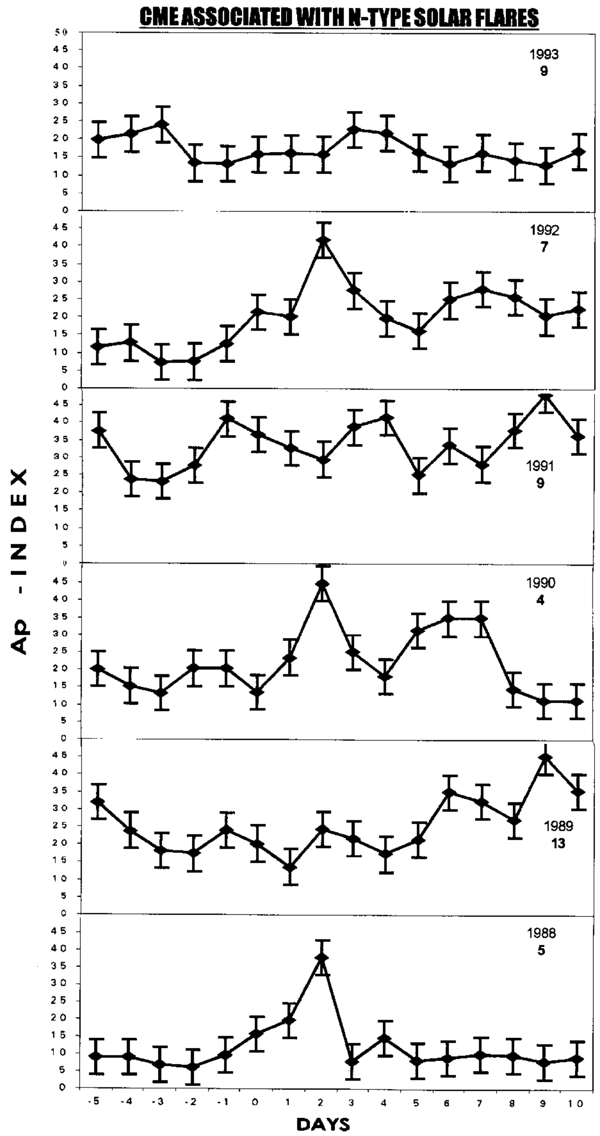

Figure 1. The result of chree analysis for −5 to 10 days with respect to zero epoch days. The variations of mean Ap values are shown in the figure. CMEs events associated with N-type solar flares are considered. Zero day correspond to the starting day of occurrence of CME events. Error bars are drawn in each point for all the years.

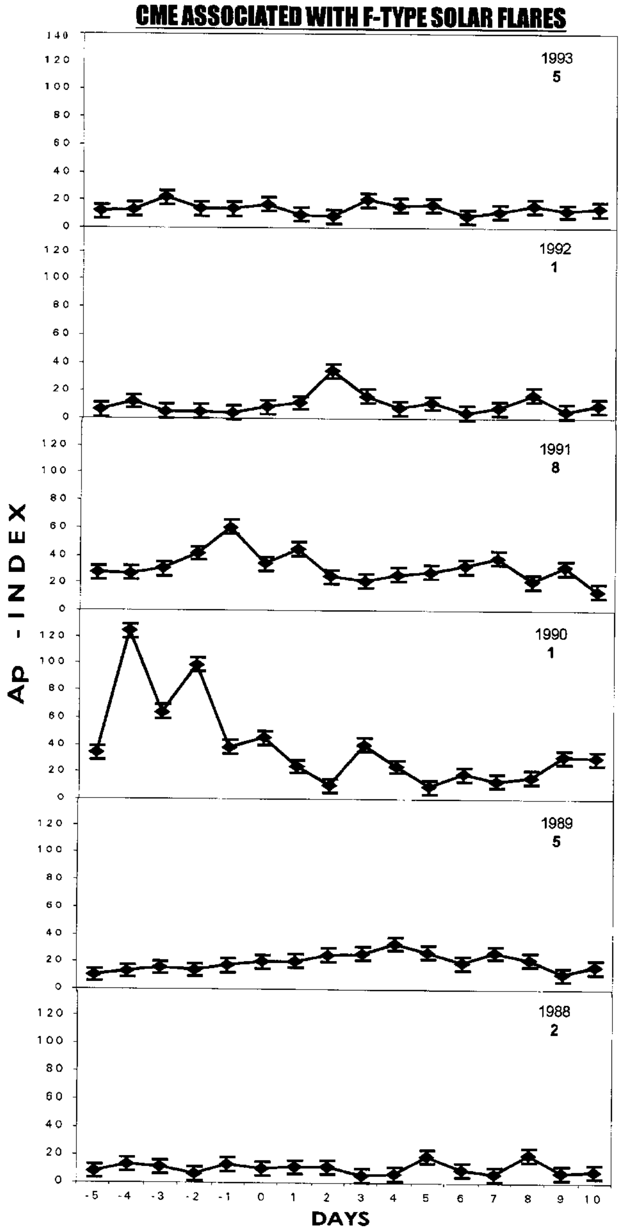

Figure 2. Same as Figure 1 but for CMEs events associated with F-type solar flares.

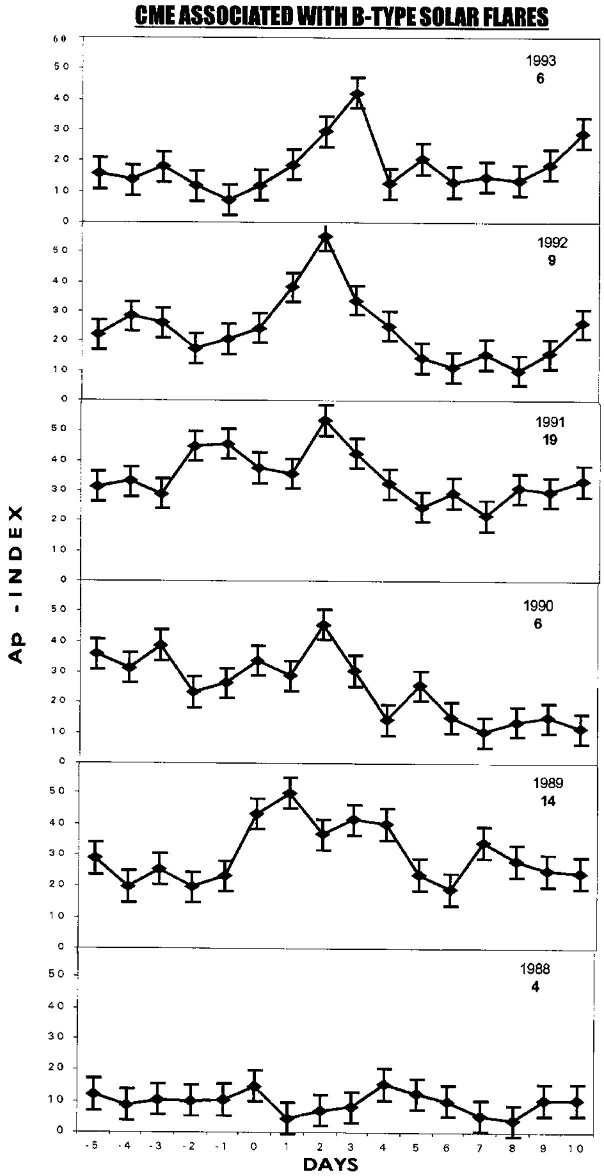

Figure 3. Same as Figure 1 but for CMEs events associated with B-type solar flares.

speeds necessary to stimulate significant activity in the Earth's magnetosphere. The magnetic activity which leads to a flare event is one part of the magnetic structure, leading to an eruption of a larger scale component of the structure. If the magnetic field embedded in the solar plasma contains a significant "southward" component, the interaction with the Earth's magnetic field results in a large enhancement in geomagnetic activity.

Since both the solar wind velocity **V** and the interplanetary magnetic field **B** tend to be high within the leading portions of interplanetary disturbances driven by the fast CMEs, so too does the convective electric field.

4. Conclusions

It is concluded from the present analysis that:

1. All CMEs arriving in the vicinity of the Earth, in the period 1988–1993, do not produce geomagnetic effects.
2. CMEs associated with B-class solar flares have the greatest chance of driving significant geomagnetic disturbances.
3. CMEs associated with N-class solar flares also show a significant chance of asociated geomagnetic activity.
4. CMEs associated with F-class solar flares do not show a strong association with geomagnetic activity.

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