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Geo-effectiveness of CMEs

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Abstract. Coronal Mass Ejections (CMEs) are important phenomena in coronal dynamics causing interplanetary signatures (ICMEs). They eject large amounts of mass and magnetic fields into the heliosphere, causing major geomagnetic storms and interplanetary shocks. Geomagnetic storms are often characterized by abrupt increases in the northward component of the earth's field, called sudden commencements (SSC) followed by large decreases of the magnetic field and slow recovery to normal values. The SSCs are well correlated with IP shocks. Here a case study of 10–15 February 2000 and also the statistical study of CME events observed by IPS array, Rajkot, during the years 2000 to 2003 and Radio Astronomy Center, Ooty are described. The geomagnetic storm index Dst, which is a measure of geo-effectiveness, is shown to be well correlated with normalized scintillation index 'g', derived from Ooty Radio Telescope (ORT) observations.

Key words. Coronal mass ejection—interplanetary medium and normamalized scintillation index.

1. Introduction

Coronal Mass Ejections (CMEs) are the most energetic and the largest phenomena associated with the eruption of plasma and magnetic field from the Sun. These are transient expulsions of coronal plasma defying the gravitational field of the Sun. Each CME drains the solar mass in the range of 10^{11} to 10^{13} kg (Webb 1995). CMEs are the major solar drivers of space weather, including non-recurrent geomagnetic storms (Tsurtani *et al.* 1988) and solar energetic particle events (Tsurtani & Lin 1985). CMEs originating from close to the disk center significantly perturb earth's environment and they directly impact the earth (Gopalswamy 2006). Such earth-directed CMEs are the major cause for the severe geomagnetic storms. This paper reports typical geoeffective CMEs observed by IPS array at Rajkot and Ooty and also an important statistical analysis to determine effectiveness of interplanetary parameters for the modeling of geo-magnetic storms and their prediction.

2. Data and results

The interplanetary scintillation observations reported in this study have been obtained from the Rajkot IPS array and Ooty Radio Telescope (ORT) at 103 MHz and 327 MHz respectively. The details of these telescopes and data analysis procedures are given by Vats & Deshpande (2004) and Manoharan (2003) respectively. IPS is a technique for studying the propagation of the solar disturbances from ground-based observations of radio sources (Rickett 1975; Wantanabe & Kakinuma 1984). The scintillation is measured by a statistical index S_4, which is defined by Briggs & Parkin (1963) as the normalized root-mean-square deviation of signal intensity:

$$S_4 = \frac{\langle (1 - \langle I \rangle)^2 \rangle^{1/2}}{\langle I \rangle} \tag{1}$$

and the normalized scintillation index, g, is derived from long term observations of the interplanetary scintillation by IPS array at Rajkot and Ooty Radio Telescope.

During the years 2000–2003, IPS-Rajkot recorded 25 events, which produced enhancements in scintillation index associated with CME (Jadeja 2007). The interplanetary signatures of one of these, observed during 10–15 February, 2000 are clearly seen in Fig. 1. Here the arrival of the IP shock is characterized by a solar wind velocity increase from $\sim$ 400 km/s to $\sim$ 600 km/s; IMF Bz became negative (-10 nT); $\sim$ 8 fold increase in ram pressure (Pram) and 3-fold increase in density.

For the 10–15 February 2000 event, the IPS sources observed by ORT and IPS array at Rajkot showed enhancements in g-values. The variation of g in ORT and Rajkot data is shown in Fig. 2. Both the temporal variations clearly show the effect of the passage

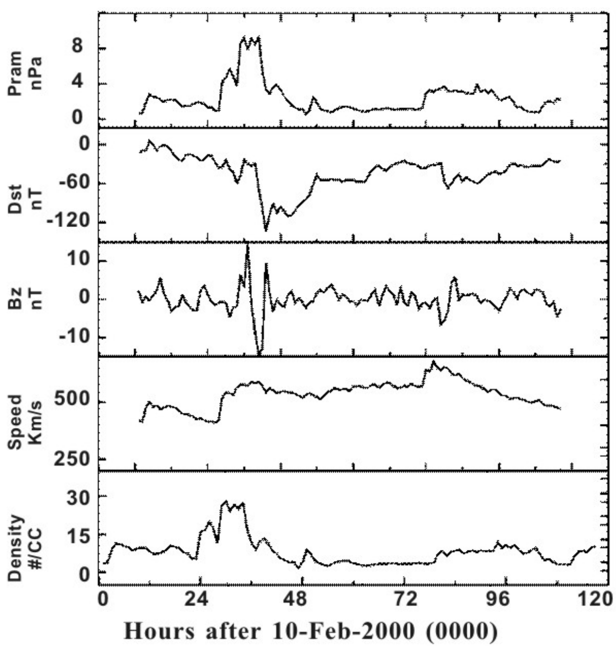

Figure 1. Variation of solar wind and geo-magnetic parameters during 10–15 February 2000.

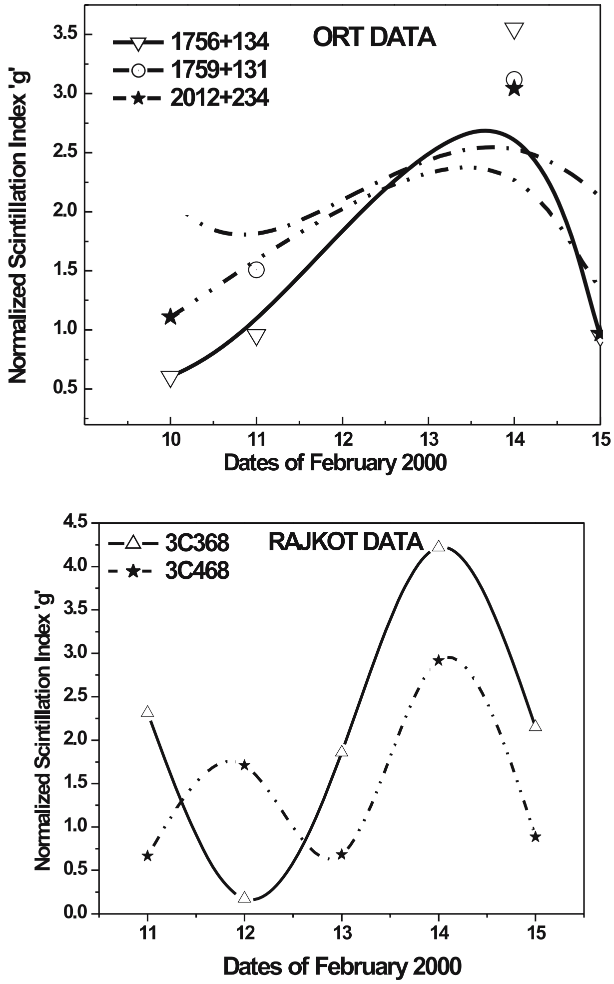

Figure 2. Variation in '*g*' observed by ORT during February 10–15, 2000 (top) and by IPS Rajkot during February 11–15, 2000 (bottom).

of the CME plasma cloud or interplanetary shock through the IPM. Three radio sources observed by ORT showed increased *g* values in the range of 2–2.5 (Fig. 2, top), while two radio sources at Rajkot recorded even higher values of *g* (2.5 and 4) during this event (Fig. 2, bottom).

Jadeja (2007) reported the statistics of 25 enhanced events in scintillation index observed at Rajkot, of these 2 were associated with severe geomagnetic storms (Dst_{min} between −200 nT and −350 nT); another 2 were associated with strong storms (Dst_{min} between −100 nT and −200 nT); 7 were associated with moderate storms (Dst_{min} between −50 nT and −100 nT) and 10 were associated with weak storms (Dst_{min} between −30 nT and −50 nT). There were 4 events which showed no apparent relation to any storm conditions.

In order to investigate key interplanetary parameters which might be responsible for producing geomagnetic storms, we have selected 30 large CMEs (angular

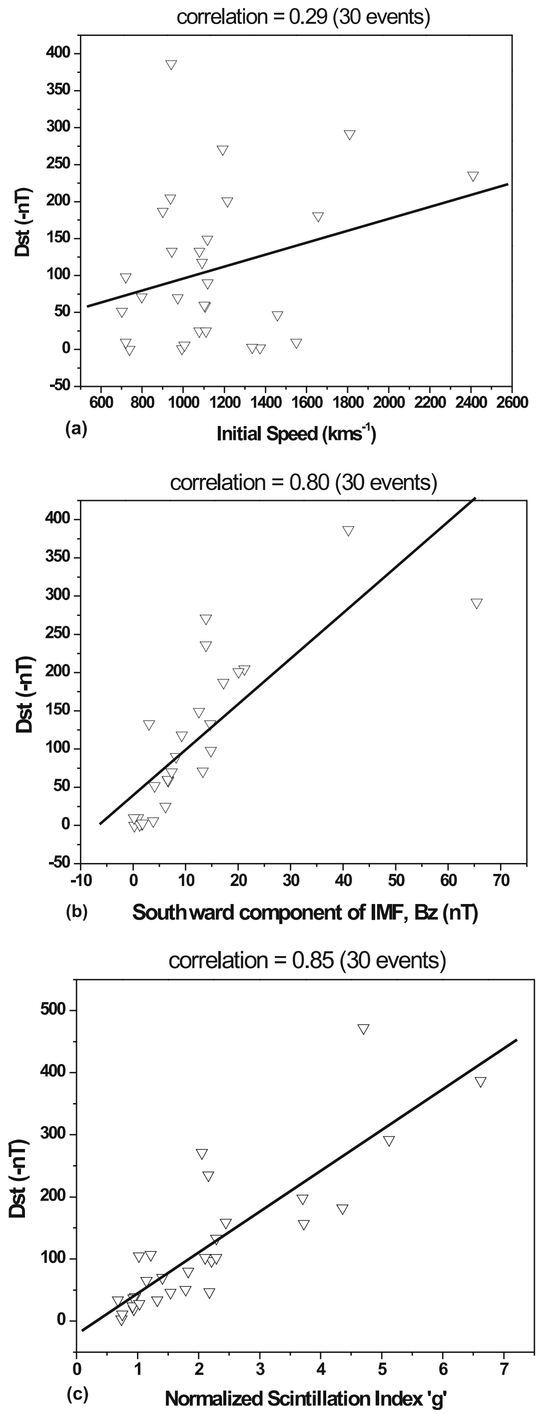

Figure 3. Correlation plots of geo-magnetic index Dst and 3 interplanetary parameters, namely: **(a)** initial speed of CME (km s^{-1}) measured by LASCO observations, **(b)** southward component of IMF, B_z (nT) measured by ACE satellite and **(c)** normalized scintillation index 'g measured by the IPS observations of radio sources at Ooty.

width $> 150°$) during the period 2000 to 2003. We have used the Dst index to represent the strength of the associated geomagnetic storm (geo-effectiveness) and studied its correlation with 3 IP parameters namely initial CME speed, Bz and g. These are shown in Fig. 3.

Figure 3(a) and (b) respectively show the correlation of Dst with the initial speed of CME as derived from LASCO observations and southward interplanetary magnetic field component Bz measured at 1 AU by ACE satellite. Correlation of Dst with normalized scintillation index 'g' (which is obtained from Ooty Radio Telescope) is shown in Fig. 3(c). These results indicate that the correlation of Dst with the initial speed of CME, Bz and g are 0.29, 0.80 and 0.85 respectively. From this it is apparent that initial speed of CME has a very poor role in producing geomagnetic storms, whereas g has the highest correlation with Dst, indicating that this parameter is most useful in predicting geomagnetic storms.

3. Discussion and conclusions

Even though Jadeja (2007) found that there are some enhancements in scintillation measurements which do not have a direct relation to the planetary magnetic index, however, the case study shown in Fig. 2 shows quite a large enhancement in g values of both the datasets (ORT and Rajkot). There are few cases of CMEs where moderate to severe deceleration process happens before their arrival at 1 AU, this may result into no apparent effect on the geomagnetic field and its indices. The case study and the statistical results reported here are in good agreement with earlier findings (Lindsay *et al.* 1999; Gopalswamy *et al.* 2000; Manoharan *et al.* 2004) which showed that most of the CMEs having an initial speed greater than ambient solar wind are decelerated. However, few cases of acceleration even when the initial speed is higher than ambient solar wind speed may be due to CME–CME interaction and/or by the energy gained at the time of CME onset and stored within the CME (Manaoharan 2006). The IPS measurement in the form of g appears to be a better interplanetary parameter for modeling and prediction of geo-magnetic storms.

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