Indian Journal of Radio & Space Physics
Vol. 39, October 2010, pp. 265-269

Characteristic features of ICMEs associated with big storms in geomagnetic activity and large Forbush decreases in cosmic ray intensity

V Gupta, Y P Singh & Badruddin[$]
Department of Physics, Aligarh Muslim University, Aligarh 202 002
E-mail: [$]badr_phys@yahoo.co.in

Received 28 July 2010; accepted 18 August 2010

The solar sources and features of interplanetary structures associated with big geomagnetic storm (GS) and/or large Forbush decrease (FD) events have been investigated. The hourly data of geomagnetic activity, cosmic ray (CR) intensity, and solar wind plasma/field has been utilized during the passage of ICMEs and associated structures (e.g. shock/seath, interaction region/high speed stream). The geo-effectiveness and CR-effectiveness of ICMEs, similarities and distinctions between them together with variations/fluctuations in interplanetary plasma/field parameters is utilized in order to identify distinct feature(s) of ICMEs and physical mechanism(s) playing important role in the development of GS and FD.

Keywords: Coronal mass ejection, Geomagnetic storm, Cosmic ray, Forbush decrease, Interplanetary magnetic field

PACS Nos: 96.60.*ph*; 96.50.Bh; 92.60.Qx

1 Introduction

The strength of geomagnetic storms (GS) is generally expressed by Dst index indicating the amount of solar wind energy penetrating the earth's ionosphere. The time sequence of a geomagnetic storm consists of three phases, viz, initial phase, main phase and recovery phase[1]. The large decrease in Dst during GS characterizes its main phase. Forbush decrease (FD) is characterized by sudden decrease in cosmic ray intensity (CRI) within a few hours followed by a slow recovery lasting several days[2]. During the recovery, both GS and FD phenomena have been studied extensively to understand solar/interplanetary causes and physical mechanism playing important role in their occurrence[3-11].

During extreme solar eruptions, a solar-terrestrial event chain is formed including flares, energetic particles, earth-directed CMEs and their interplanetary counterparts, FDs as well as strong GS[12]. Intense GS probably have the most dangerous influences on human life and technological systems[13]. FDs and GS are likely to be closely correlated partly due to their common causes from solar and interplanetary disturbances. However, the investigation of CRI decrease events and simultaneous Dst variations suggests that the relation between CRI decrease and geomagnetic activity is complicated[14]. Interplanetary manifestations of coronal mass ejections (ICMEs) have been suggested to generate big/moderate storms in geomagnetic activity as well as transient decreases/depressions in cosmic ray intensity. However, the magnitude, duration and time profiles of both phenomena (GS and FD) are related to the interplanetary structures and their associated features. Further, all the ICMEs, passing the earth, are neither substantially nor equally geo-effective and CR-effective. Thus, in view of their space weather implications[15] and to understand the physics of GS and FD, it is important to: (a) identify the structures and the relative importance of different features of ICMEs; (b) isolate interplanetary plasma and field parameters of crucial importance for GS and FD; and (c) understand physical mechanism(s) playing important role in the development of GS and FD.

In the present work, the solar sources and interplanetary structures associated with big GS and large FD have been investigated. The study on 'geo-effectiveness' and 'CR-effectiveness' of ICMEs, similarities and distinctions between 'geo-effective' and 'CR-effective' interplanetary structures has been attempted. Attempt has also been made to identify interplanetary plasma/field parameters and physical mechanism(s) playing important role in the development of GS and FD.

2 Observations and Discussion

A number of events of FD and GS that occurred during 2001-2003 have been identified and some of them have been selected for detailed study. The hourly data of geomagnetic index Dst, cosmic ray intensity as observed at Oulu neutron monitor, interplanetary plasma parameters (plasma speed V, temperature T, density n), interplanetary field parameters (magnetic field B, its north-south component Bz, root mean square standard deviation of field Sigma-B), electric field Ey (-Bz V) and E (BV) have been used. The parameters V, B, Bz and Ey have been selected as one or more of them are likely to play important role in generation and/or intensification of GS. The parameters B, V, Sigma-B and/or BV have been suggested in previous studies to be significantly important parameters for transient modulation of cosmic ray intensity. The enhancement in plasma parameters, N and T, together with V and B provide useful information about nature and strength of interplanetary structure reaching at the detector during an event. Figure 1 shows the variations in cosmic ray counts at Oulu neutron monitor, Dst geomagnetic index together with solar plasma and field parameters during the period 01-30 October 2001. During this period, a number of GS and FD events have been observed.

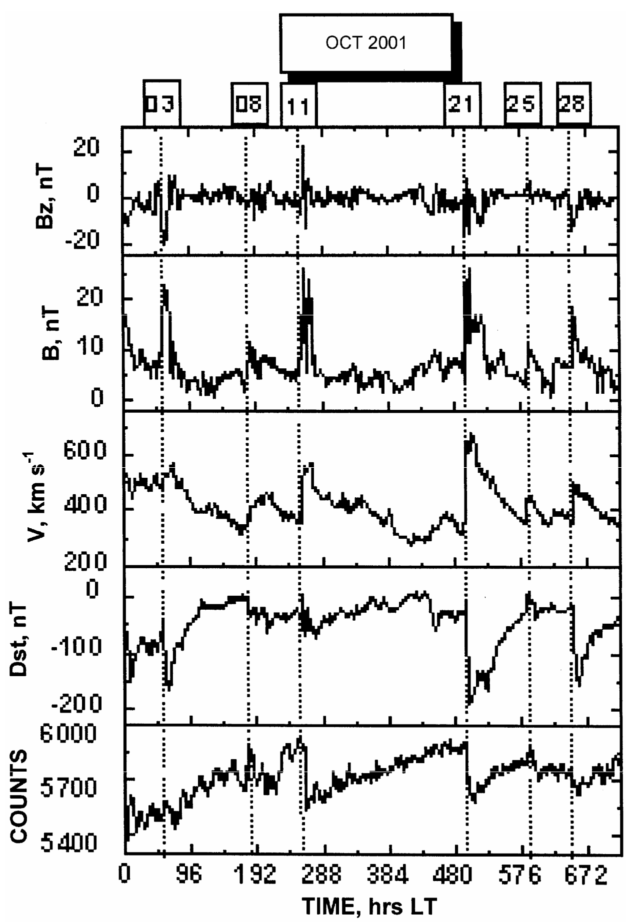

Fig. 1(a) — Hourly data showing variations in CRI (counts), Dst index, solar plasma velocity, IMF strength and its north-south component during 01-30 October 2001

(a) Event on 03 October 2001

On 03 October 2001, a big geomagnetic storm (Dst~ -165 nT) was observed but neutron monitor observations show only a small depression in CR intensity. The north-south component of the IMF Bz was negative (-20 nT) for long duration (~12 h). Plasma temperature and density was not much enhanced and shock appeared weak. There was no high speed stream following ICME responsible for this storm. The recovery of both CRI and Dst was fast. The responsible interplanetary structure was a shock associated CME, but shock appeared weak.

(b) Event on 08 October 2001

During this event, there has been slow depression in CRI but recovery was fast. A moderate geomagnetic storm (Dst~ -60 nT) was the consequence of this event. No big jump in interplanetary parameters was observed and plasma speed increased slowly. This event appeared due to co-rotating interaction region.

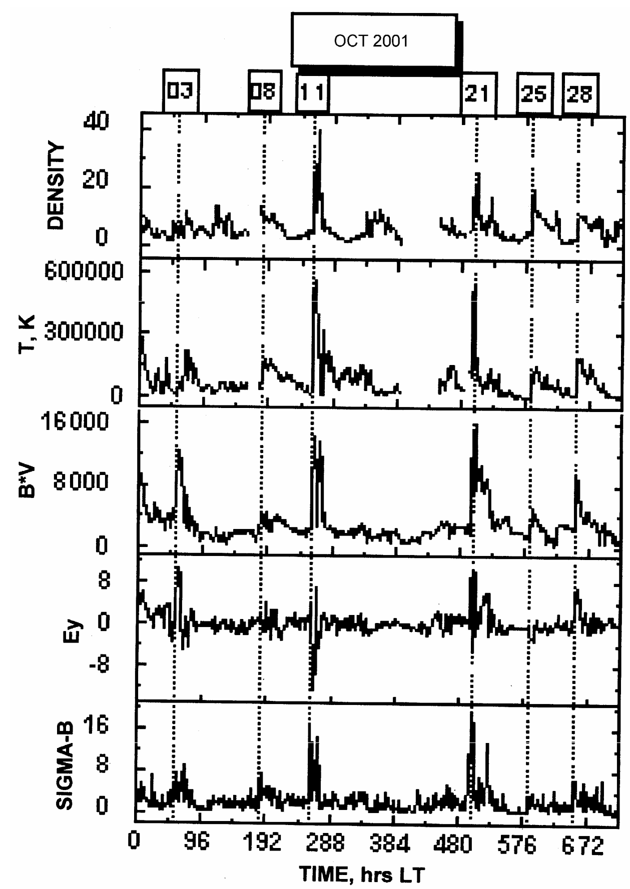

Fig. 1(b) — Variations in field variance (sigma-B), electric field (E_y), the product B.V, plasma temperature (T) and density during 01-30 October 2001

(c) Event on 11 October 2001

A typical big FD (~7 %) with slow recovery, lasting about 10 days, was observed. However, the GS is only of moderate intensity (Dst~ -65 nT). There are large jumps in plasma and field parameters but Bz is positive in the beginning of interplanetary event. Sigma-B is large (an indication of turbulent field) during passage of sheath region. The FD recovery appears to be influenced by slowly decreasing solar wind speed. The responsible interplanetary event is a shock-associated CME.

(d) Events on 21, 25 and 28 October 2001

A large FD (5.6%) and a big GS (Dst~ -185 nT) was observed on 21 October 2001. However, the event on 25 October is responsible for a moderate FD (~ 2.5%) and a small disturbance in geomagnetic activity (Dst~ -40 nT). On 28 October, FD had been of moderate amplitude (2.2%) but the GS was a big storm (Dst~ -160 nT). The recovery of FD on 25 October has been very slow, probably due to the arrival of a high field, low temperature and low density region at a time. Bz was negative for an extended duration during events on 21 and 28 October (~ 15 hours) but not during 25 Octobe event. Sigma-B is highest at the onset of first (21 October) event. All three events are associated with shock/ sheath/ CME.

(e) Event on 05 November 2001

This event (Fig. 2) produces a large two-step FD (~ 11%) and big GS (Dst ~ -300 nT). It is interesting to note that FD starts about 9 h later than GS start time. Onset of FD almost coincides with large enhancement in B and sigma-B, but GS commences later coincident with large negative Bz.

(f) Events on 19, 22 and 24 November 2001

First two events (on 19 and 22 October) produce FDs of moderate amplitude (2.5 and 1.5%, respectively). There has been a small disturbance in geomagnetic activity during 19 October event but there was no change in geomagnetic activity during 21 October event. On the other hand, 24 October

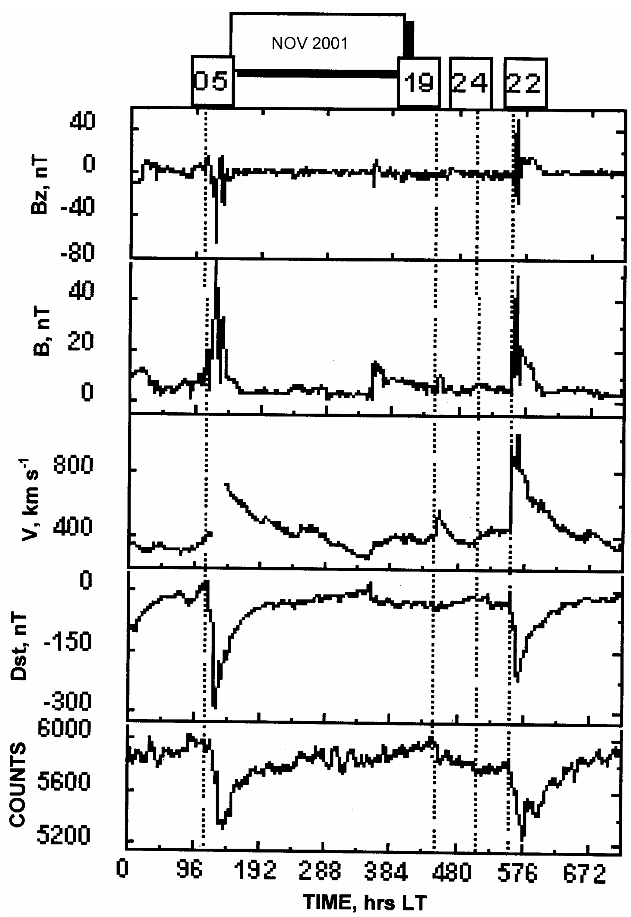

Fig. 2(a) — Hourly data showing variations in CRI (counts), Dst index, solar plasma velocity, IMF strength and its north-south component during 01-30 November 2001

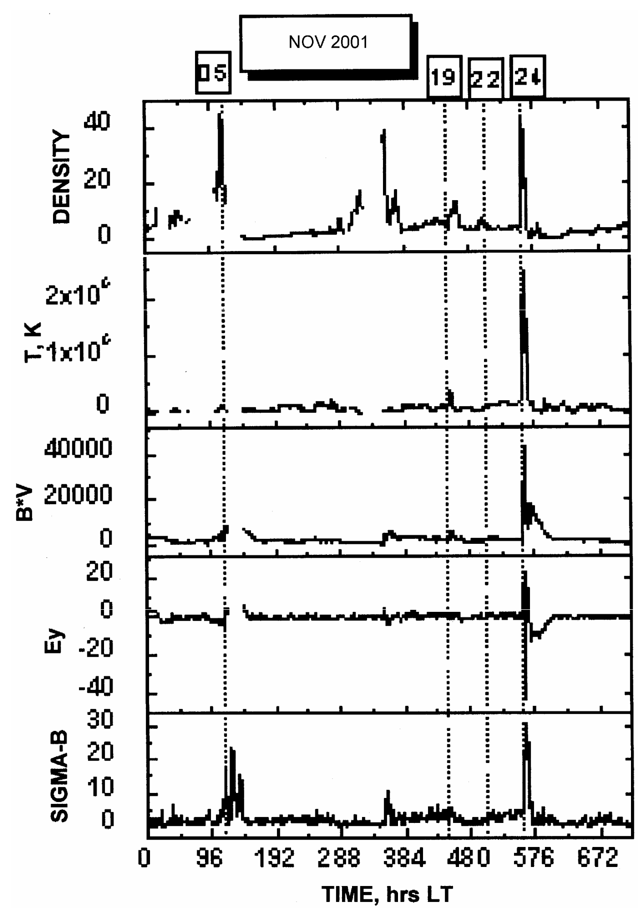

Fig. 2(b) — Variations in field variance (sigma-B), electric field (E_y), the product B.V, plasma temperature (T) and density during 01-30 November 2001

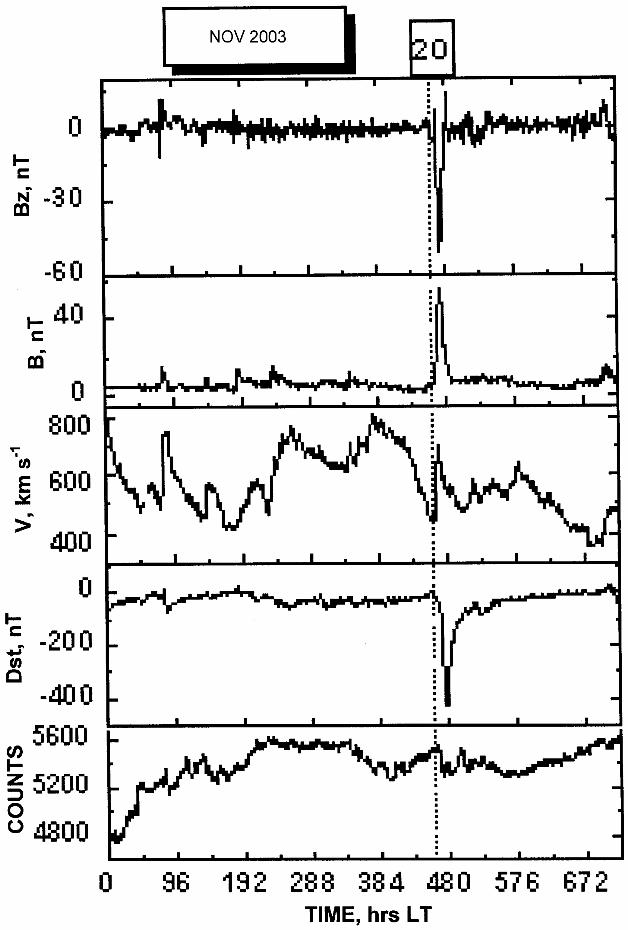

Fig. 3(a) — Hourly data showing variations in CRI (counts), Dst index, solar plasma velocity, IMF strength and its north-south component during 01-30 November 2003

event produced a big two step FD (~10.5%) and a big GS (Dst ~ -200 nT). This event has been due to a shock-associated magnetic cloud. The first step in FD is associated with shock and sheath region and the second step appears related to magnetic cloud.

(g) Event on 20 November 2003

As shown in Fig. 3, FD of about 4% but a severe storm of Dst ~ -425 nT was generated by the interplanetary disturbances on 20 November 2003. The north-south component of the IMF was large and negative (Bz~ -45 nT) for a duration of ~ 8 h. The Dst recovered quickly in a short time, but CRI remained depressed for a long time (about 10 days), probably due to enhanced speed of plasma ($\geq$ 600 km s^{-1}) for a long time. The event on 20 November is associated with a shock-associated magnetic cloud.

The correlation of Dst with a number of interplanetary plasma and field parameters and their

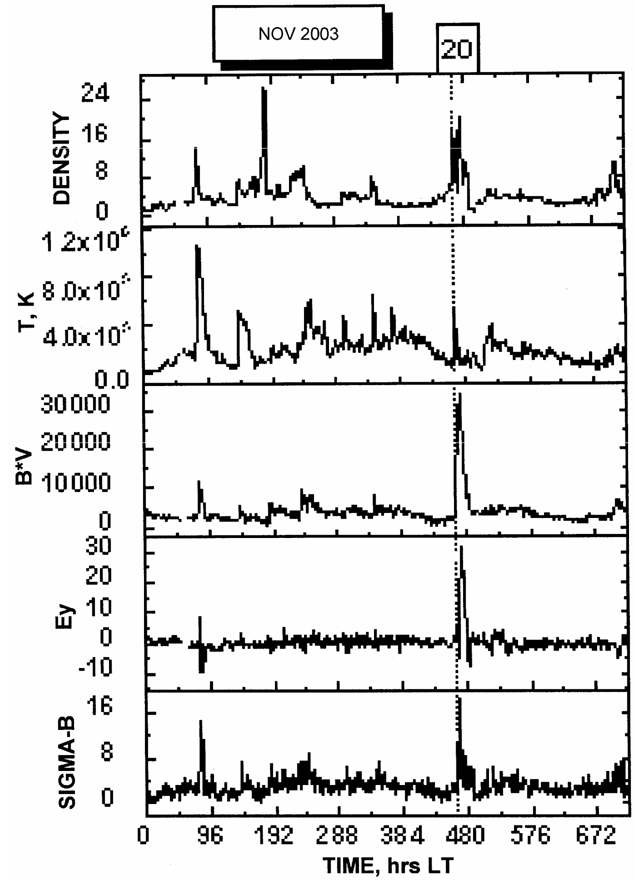

Fig. 3(b) — Variations in field variance (sigma-B), electric field (E_y), the product B.V, plasma temperature (T) and density during 01-30 November 2003

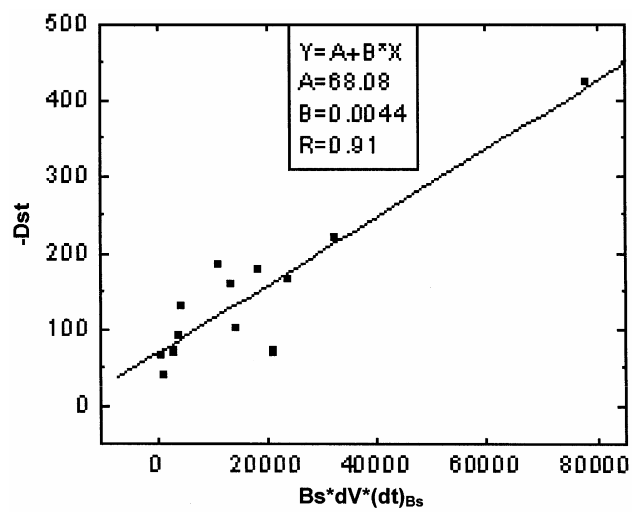

Fig. 4 — Dependence of Dst index on a combination of solar wind parameters during magnetic storms

various combinations have also been studied. The best correlation (Fig. 4) with Dst (R = 0.91) is found with (Bs.dV.dtBs). The best fit linear equation is:

Dst = 68.08 + 0.0044*{Bs*dV*(dt)Bs}

where, Bs, is the amplitude of the southward field during the event; dV, the change in V from ambient to maximum; and dt, the duration (at half maximum) for which Bz is negative.

3 Conclusions

Shock-associated CMEs can produce both large FDs and big GS. However, some of the individual ICMEs are neither equally nor substantially geo-effective and CR-effective. In some cases, high speed stream and possible interaction region following ICMEs might influence the recovery (and hence the total duration) of GS and FD. Amplitude (of -Bz and its duration) is important parameter for occurrence and magnitude of GS. An empirical relation between Dst and a combination of interplanetary parameters has been obtained. Reconnection between interplanetary and terrestrial fields is important for the generation of GS. Field parameters B and sigma-B appear to play more important role in FD. Thus scattering of CR particles by high field turbulent region (in sheath) appears important mechanism for FD.

References

1 Gonzalez W D, Joselyn J A, Kamide Y, Kroehl H W, Rostoker G, Tsurutani B T & Vasyliunas V M, What is a geomagnetic storm? *J Geophys Res (USA),* 99 (1994) 5771.

2 Lockwood J A, Forbush decreases in cosmic radiation, *Space Sci Rev (Netherlands),* 12 (1971) 658.

3 Agrawal S P, Ananth A G, Bemalkhedkar M M, Kargatha L V & Rao U R, High energy cosmic ray intensity increase of non-solar origin and the unusual Forbush decrease of August 1972, *J Geophys Res (USA),* 79 (1974) 2269.

4 Badruddin, Interplanetary shocks, magnetic clouds, stream interfaces and resulting geomagnetic disturbances, *Planet Space Sci (UK)*, 46 (1998) 1015.

5 Badruddin, Shock orientations, magnetic turbulence and Forbush decreases, *Sol Phys (Netherlands),* 209 (2002) 195.

6 Venkatesan D & Badruddin, Cosmic ray intensity variations in the 3-dimentional heliosphere, *Space Sci Rev (Netherlands),* 52 (1990) 121.

7 Singh Y P & Badruddin, Effects of interplanetary magnetic clouds, interaction regions and high-speed streams on the transient modulation of galactic cosmic rays, *J Geophys Res (USA),* 112 (2007) A02101.

8 Gopalswamy N, Yashiro Y, Michalek G, Xie H, Lepping R P & Howard R A, Solar sources of largest geomagnetic storms of solar cycle 23, *Geophys Res Lett (USA),* 32 (2005) L12S09.

9 Cane H V, Coronal mass ejections and Forbush decreases, *Space Sci Rev (Netherlands),* 93 (2000) 55.

10 Kane R P, Solar terrestrial effects of two distinct types, *Adv Space Res* (UK), 39 (2007) 1890.

11 Zhang J, Richardson I G, Webb D F, Gopalswamy N, Huttunen E, Kasper J, Nitta N V, Poomvises W, Thompson B J, Wu C -C, Yashiro S & Zhukov A N, Solar and interplanetary sources of major geomagnetic storms (Dst ≤ 100 nT) during 1996-2005, *J Geophy Res (USA),* 112 (2007) A10102.

12 Wang R, Large geomagnetic storms of extreme solar event periods in solar cycle 23, *Adv Space Res (UK)*, 40 (2007) 1835.

13 Bothmer V & Zhukov A, The Sun as the prime source of space weather, in *Space Weather Physics and Effects* (Springer, Berlin), 2007, pp 31-102.

14 Kudela K & Brenkus R, Cosmic ray decreases and geomagnetic activity, *J Atmos Sol-Terr Phys (UK),* 66 (2004) 1121.

15 Badruddin, Transient perturbations and their effects in the heliosphere, the geo-magnetosphere, and the earth's atmosphere: Space weather perspective, *J Astrophys Astron (India)*, 27 (2006) 209.