Study of large Forbush decrease events of solar cycle 23rd

M. L. Chauhan *, Manjula Jain and S.K. Shrivastava
Dept. of Physics, Govt. Model Science College Jabalpur, M.P., India
* email: mlchauhan111@yahoo.com

Abstract: In the descending phase of 23rd solar cycle about 10 exceptionally large (with > 10 % magnitude) Forbush decrease (FD) events have been observed. Of these, selecting five FD events recorded by Moscow neutron monitor station, in the same year 2005 i.e. on 18 January, 15 May, 17 July, 24 August and 11 September of 2005, we have investigated their properties in terms of their origin (solar sources), temporal evolution and relation with interplanetary and geomagnetic parameters. The 7-day cosmic ray intensity (CRI) variation with the variation in solar wind velocity, total interplanetary magnetic field B, its southward component Bz, Dst and Kp indices have been analysed to see the changes taking place in the magnetosphere and geospace. The passage of interplanetary (IP) shock and arrival of storm sudden commencement (SSC) was also examined during the onset of FDs. The cause of sudden depression in CRI near the Earth was traced back by noting the activities of the Sun two–three days before the occurrence of FD. For this, the data of Sunspot number, Sunspot area, eruption of Coronal Mass Ejection (CME), associated solar flare and their location on solar disc, all are thoroughly studied. The presence of interplanetary counterpart of CME (ICME/magnetic cloud) is also looked for to get the exact reason of shielding of cosmic rays. It is concluded from this comprehensive study that - Large FDs are caused due to fast halo CMEs associated by intense solar flares, there is abrupt rise in interplanetary parameters before the main phase of FDs, and such events are always accompanied with major geomagnetic storms which can be used for space weather prediction.

Keywords: Forbush Decreases, CME, Interplanetary Shock, SSC.

1 Introduction

A fast decrease of CRI during 1-2 days with gradual recovery in 5-7 days is called Forbush decrease (Forbush, 1937). They are formed after the outstanding flares on the Sun and intensive solar coronal mass ejecta (Burlaga, 1995, Cane, 2000). These phenomena appear randomly in time sporadically without any regularity, increase their frequency in maxima of the solar activity. The CME-driven shock compresses plasma ahead of it. If it is assumed that the magnetic field is frozen into the plasma, it follows that the magnetic field strength is enhanced in the vicinity of the shock. As the shock passes the Earth, it acts as a shield of sorts against the ambient population of cosmic rays, since they cannot easily diffuse across the enhanced magnetic field in the vicinity of the shock. This leads to a decrease in the intensity of cosmic rays when the Earth is within the shock; this is manifested as part of the observed FD. This is an idealized description, in reality; the magnetic field has an ordered, as well as turbulent component.

Cosmic rays generally diffuse through the tangled, turbulent magnetic field, and this diffusion process in inhibited in the vicinity of the shock, which has a strong ordered magnetic field component. It is the inability of the cosmic ray particles to diffuse efficiently across the shock front that causes the observed FD (Subramanian et al. 2007).

Coronal mass ejections hurl huge volumes of magnetized plasma into interplanetary space often referred to as ICME or ejecta seen near 1 AU. The signatures of ejecta include depressed plasma proton temperatures, bidirectional particle flux and strong magnetic fields with dimensions 0.2-0.3 AU. ICMEs have many identifying characteristics, among them one is depressed energetic particle intensities known as Forbush decrease resulting from the increased magnetic field.

Interplanetary shocks can arise from a variety of sources. They can be driven by various forms of solar ejecta (magnetic clouds being one form) and by faster streams impinging on slower solar wind. Due to the interplanetary coronal mass ejection (ICME) impacting on slow solar wind there is a sheath upstream of the ICME led by a fast forward shock. The more energetic CMEs accompanied by flares, which when propagate towards the Earth at super Alfvénic speeds, drive shocks ahead of them (Reiner et al. 2007). The forward shocks
which are related to ejecta and/or magnetic clouds are very much effective in producing Forbush decrease (Cane 2000). Approximately 20 shock events of the year 2005 have been studied by Rathod et al. (2008), in which they found a definite relationship between the changes in the solar wind/IMF parameters, and the ground based geomagnetic indices Kp, Dst & CRNM (cosmic ray neutron monitor) count notably so after the onset of an IP shock.

2 Data Analysis:
The large FD events of 2005 are selected from Moscow neutron monitor and analyzed data related to solar flare, CME, solar wind velocity and geomagnetic index Dst with cosmic ray intensity. The changes in solar wind and IMF parameters reveal the effect of ICME driven shocks on the magnetosphere and on cosmic ray flux, therefore these parameters have been analyzed before, during and after all FD events. This helps in understanding the mechanism of Forbush decrease. The geomagnetic storm has a severe effect on space weather, so the correlation of FD with geomagnetic indices is simultaneously investigated. It can be utilized in prediction of storm and can save mankind from its hazardous effects.

3. Result and discussion:
FD event of 15 May 2005 is one of the largest events (~11%) of the declining phase of 23rd solar cycle that was in response to the high solar instability. The Sun became very active in May 2005 as SSN became 100 on 13th May and sunspot area measured 1280 msh. Sunspot 10758 (N12E11) unleashed a strong M8.0 class solar flare at 1613UT on 13th May 2005.

The graphs in figure 1 (from the top) show rise in IMF |B| in the upper most panel, a large southward Bz in second panel, sudden rise in solar wind proton speed in third panel, high Kp values in fourth panel, a big dip in Dst in fifth panel respectively and a sudden decrease in CR in the lowest panel on 15 May 2005. These graphs help us to evaluate the overall affect of solar events at 1AU on Earth’s magnetosphere as well as cosmic rays reaching at ground. One notes that large FDs are caused by high IMF structures (compared to the size of Earth) convected by the solar wind past the Earth, the interplanetary remnants of the fast coronal mass ejection (ICMEs). The amplitude of an FD is largest when the Earth is located deep inside an ICME where GCR density is lower (Ahluwalia et al., 2007). It is concluded that the major FD event of 15 May 2005 is caused by CME associated with strong flare. Moreover, solar wind velocity is found to be increased before the onset of FD (Jain et al., 2007).

The last major event (13% magnitude) of present study occurred on 11 September 2005 shown in fig. 2. The active Sunspot 10808 (S12E67) generated a strong solar flare (X6.2) on 9 September 2003 at 1913UT. It hurled halo CME at 1948 UT; the speed of CME was very fast ~2257 km/s. An ICME was observed at 0114 UT without any magnetic cloud. It generated a large shock at 0100 on 11 September at Earth. The compressed plasma and turbulent field region (shock/sheath) driven by ICME produced the decrease in cosmic ray flux due to scattering of particles and a Forbush depression of about 13% amplitude started at 0049 UT on September 11, 2003. The shock arrived at the time approximately same as the onset of FD after 29 hours of CME lift off.

From the time profile of B, Bz, Vsw, Kp, Dst and cosmic ray intensity as shown in figure, it is observed that the interplanetary magnetic field raised to a high value, |B| ~ 18nT and Bz decreased to ~8nT. This is contributed to the high jump in solar wind speed that had increased to 1000 km/s, so the effect of solar wind velocity is found to be more significant than IMF strength particularly in case of large FDs. The onset of FD was at 0049UT, coinciding approximately with arrival of shock. The influence on the Earth’s magnetic field was also intense (Dst ~ -150nT) with max Kp = 9 (G3) and A= 105. Above analyses is in agreement with Belov et al. (2001). They concluded that the geomagnetic activity and CR modulation rise with increasing IMF intensity and SW velocity and the greatest FDs (with magnitude > 5%) without an associated storm are rare phenomenon. Thus FD might be used to forecast the geomagnetic storm.

On comparing the data corresponding to these events the following inferences can be drawn: All the active regions responsible for large FDs were located close to the disk center, however, distributed in all the four quadrants of the Sun. The magnitude of FD does not depend on SSN though the Sun spot area is above the median value for all events. The linear speed of associated CMEs is more than 1300 km/s with maximum value of 2459 km/s. FD with large magnitude are caused by very fast CMEs. For producing large FDs, CME should be Earth directed and should be able to drive shocks. Since all events are associated with fast halo CMEs and intense solar flares, fast CMEs accompanied by strong solar flares are the main cause of these events.

All FDs discussed have fast forward shocks ahead of ICMEs associated with them, which imply that interplanetary shocks are necessary to scatter GCR away from the Earth. The generation of shocks upstream of fast ICMEs which may be important accelerators of energetic particles, produce short-term (Forbush) decreases in the GCR intensity (Richardson et al. 2007). The appearance of SSC after FD is observed for all events. This shows that SSC is an indicator of major FD event and vice versa. The association of major storms and large FDs show that they have common origin. The CR variation observed during above FD events have similar pattern to that of Dst with a time lag of few hours which can yield a information for a storm in advance.

4. Conclusions:
The main source of reduction in galactic cosmic ray flux is fast halo coronal mass ejection associated with strong solar flare. The magnitude of Forbush decrease has good correlation with linear speed of CME (~0.6). Since halo CMEs are fast and wide and associated with flares of greater X-ray importance, they are the main
cause of FD. The CME and flares erupted within ± 20° latitude of the solar disk are more effective in causing FD. The major cause of FD on Earth is found to be the shock preceded by an ICME.

5 Acknowledgements:

The authors are grateful to the research teams working in Moscow neutron monitor station, ACE/Wind, OMNI, and NOAA data centers for providing the related data.

References:

Fig. 1 shows the events of 15th May 2005

Fig. 2 shows the events of 11th September 2005

Vol. 10, 263