Study of intensity fluctuations in cosmic rays during Forbush-decreases

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Abstract: A fast decreases of GCR intensity during one-two days and then it's gradually recovery in 5–7 days are called the Forbush decreases (FDs). They are formed after the outstanding flares on the Sun and intensive solar coronal mass ejecta. These phenomena appear randomly in time, sporadically without any regularity, increasing its frequency in maxima of the solar activity. The strong shocks propagating in the interplanetary medium sweep out energetic cosmic rays and this effect is known as Forbush decrease of the cosmic ray intensity. Studying the cosmic ray spectrum during the times of Forbush decreases would provide a tool for probing large scale interplanetary irregularities. The present study dealt with the relationship between Interplanetary Coronal Mass Ejections (ICMEs) and the count rate decrease detected by the muon detector/neutron monitor. The emphasis is given on the analysis of the solar event, studying data from the Interplanetary medium to identify the interplanetary structure responsible for the intense geomagnetic storm occurred during these period, where the Dst index peaked to its highest negative values. Using the muon count rate observed by Muon Detectors, we will be able to observe, in the future, the direction in which a given ICME moves and we will be able to calculate the angle, which they reach the Earth. The decreases observed in the count rates during magnetic storms may occur due to intense magnetic field of magnetic cloud like structure within the ICMEs, or within the turbulent magnetic field between shock and the magnetic field known as sheath field. The interplanetary disturbances associated with Forbush decreases appear to merge and contribute to the long-term solar-cycle modulation of cosmic-ray intensity.

Keywords: cosmic ray, forbush decrease, coronal mass ejections.

1 Introduction

The Forbush decreases of cosmic ray flux occur prevailingly together with geomagnetic storms, because these phenomena have a similar origin in solar/interplanetary processes. Sudden decreases in cosmic ray intensity following large flares were first reported by Forbush [1], from ionization chamber records. Typically a Forbush decrease exhibits a reduction in intensity occurring over a few hours, and a gradual recovery to about its original level in a few days. A study of the relative magnitudes of the decrease with detectors of different energy thresholds enables the determination of the rigidity dependence of the modulating process. The differences in the on-set times of the decreases recorded at various stations reveal the nature of the prevailing anisotropy during the period.

Gold [2] and Parker [3] have suggested that ex-territed regions of enhanced magnetic field, associated with solar flares, cause the sudden decrease in cosmic ray intensity by inhibiting the entry of energetic particles in the regions. The network of neutron monitors with high counting rates, and cosmic ray detectors on board satellites have extended to lower rigidities, the investigations of the rigidity dependence of this modulating mechanism.

Using data from Explorer VI, obtained by a detector with threshold energies of 75 MeV for protons and 13 MeV for electrons, Fan'et al. (1960a) have re-reported that the Forbush decrease in cosmic ray intensity in interplanetary space is nearly twice that recorded by the climax neutron monitor which has a rigidity cut off of 3.06 By. Fan'et al. (1960b) have also reported a ratio of 1.3 for the relative decreases, by a comparison of data from an identical instrument on board Pioneer V, with ground based data. Using data from Explorer XII detector, measuring protons of energy > 600 MeV, and comparing with the data from the Deep River neutron monitor, Bryant et al. (1962) obtained a ratio of 1.7 ± 0.3 for the relative decreases. Lockwood and Webber (1969) reported a ratio of 1.7 for the Forbush decrease of January 26-27, 1968,
from a comparison of the intensities of protons of energy above 14 and 60 MeV registered by a detector on board Pioneer 8, and that- recorded by the Durham neutron monitor (cut off rigidity X 1.44 Bv). Thus from the above mentioned studies, there seems to be a general agreement among various research workers that the Forbush decrease in inter-planetary space is about twice that registered by a ground based neutron monitor. Balasubrahmanyan et al. [6] have described in de-tail the IMP III detectors. The omnidirectional IMP-III Geiger counter, from which data is used for the present study, responds to protons of energy > 50 MeV and to electrons of energy > 3 MeV. The con-tribution of the electron component has not been ob-served in the past studies of large Forbush decreases. The differential effect of en-hanced magnetic field on this low energy low rigidity electron component is revealed in the present study of small Forbush de-creases. We wish to report an example of this kind.

Forbush decreases are short-term depressions in the cosmic ray flux reaching the Earth, and they are caused by the effects of the interplanetary counter-parts of coronal mass ejections (CMEs) from the Sun (and the shocks they drive) and also the corotating interaction regions originating from the Sun. They have been studied closely since their initial discovery in the 1930s [7-8]. With the recent upsurge of inter-est in space weather effects due to solar transients, the complementary information provided by the cosmic ray signatures of these effects has assumed increased significance.

Geomagnetic storms and Forbush decreases of the galactic cosmic ray flux belong to components of the space weather, which affect the Earth’s atmos-phere. Geomagnetic storms are probably the most important phenomenon among space weather phenomena. They produce large disturbances in the ionosphere, but they affect also the neutral atmos-phere including the middle atmosphere and tropo-sphere [9].

2 Data Analysis

We selected all strong geomagnetic storms (Dst <- 200 nT) over the period 1982–2002 accompanied by only marginal decrease or no change of the galactic cosmic ray flux at Lomnicky Stitl. Altogether seven such events were found. In some cases, these events were geomag-netic storms without Forbush decreases. For other events, measurements at Oulu (northern Finland) displayed the Forbush decrease, which was compensated for by a change of the verti-cal cutoff rigidity at Lomnicky Stitl. Four events occurred in the non-winter part of the year, storms of March 30, 2001, June 1991, May 1998 and August 2000. They did not display any consistent, system-atic effect of geomagnetic storms along latitudinal circles of 50 N and 60 N, as expected.

Three other events of Novembers 1982, 1989 and 2001 occurred in the winter part of the year, but in its very early phase. All three events fulfill the condi-tion of high solar activity. The first event was ob-served under the W- phase of the QBO conditions, while the second and the third one fulfilled the E-max condition. No systematic, consistent effect was observed in November 1982 and at 60 N for the other two events, as expected.

The event of November 1989 was accompanied only by a “mini-Forbush” at Oulu and, therefore, only oscillations of quasi-random character were ob-served at 50 N. This was storm without the Forbush decrease, and also without an effect similar to that caused by strong geomag-netic storms in winter under the E-max conditions.

Thus the event of November 1989 supports the idea of the Forbush decrease origin of the observed

3 Results and Discussion

A Forbush decrease is a rapid decrease in the observed galactic cosmic ray intensity following a coronal mass ejection (CME). It occurs due to the magnetic field of the plasma solar wind sweeping some of the galactic cosmic rays away from earth. The term Forbush decrease was named after the American physicist Scott E. Forbush, who studied cosmic rays in the 1930s and 1940s. The Forbush decrease is usually observed by particle detectors on Earth within a few days after the CME, and the decrease takes place over the following several days, the solar cosmic ray intensity returns to normal. Forbush decreases have also been observed by humans on Mir and the International Space Station (ISS) and by instruments onboard Pioneer 10 and 11 and Voyager 1 and 2, even past the orbit of Neptune.

The daily average cosmic-ray intensity indicates that the amplitude of the Forbush decrease of these se-lected events is 4.6% and 3.9%, respectively, which is about a fifth of the complete solar cycle variations. Here, Forbush decrease amplitude (%) is calculated as 100 (No − NF)/No, where No is the daily count-ing rate of the detector. We observed unusually long recovery phase of the Forbush decrease of at the Earth. Observation of a high depression of the cosmic-ray particles at low cut-off rigidities (<0.6 GV) during the recovery phase has been previously re-port[10-13]. However, no attempts have been made to identify the interplanetary conditions that caused the unusually long recovery of the FD.

The sheath region is sufficiently turbulent as indi-cated by the large variations in both the field strength and direc-tion in the region. The sheath has a high speed of about 400 km/s, which is much larger than the ambient speed of about 300 km/s, was most probably produced by the shock, and is conceivably hot (105 K) and dense (10 cm−3) though there is a data gap in solar wind density and temperature in the region. Therefore, the large IMF variations in the shocked plasma scatter the galactic cosmic rays, and thus swept away the cosmic-ray particles. When the IMF variations in the sheath become too feeble, i.e. in the lull region, the scattering of the galactic cosmic rays ceases; the scattering resumes, i.e. onset of second decrease, when the IMF variations in the sheath resume. Thus the event of November 1989 supports the idea of the Forbush decrease origin of the observed
field strength and rotation signature of the magnetic cloud; the magnitude of the magnetic field is up to about 10 nT, which is much larger than the ambient field of about 5 nT.

Sufficiently strong and statistically significant effects of geomagnetic storms and the Forbush de-creases of the galactic cosmic ray flux appear to oc-cur in the total ozone at the northern higher middle latitudes only for strong events (Ap>60 for storms), in winter, and under the E-max conditions. They oc-cur around 50 N, but not around 40 N and 60 N.

4 Conclusion

The Forbush decreases seem to play a very impor-tant, likely rather decisive role in the effects of geo-magnetic storms. The interplanetary conditions for these FDs ap-pear to indicate that the outward propa-gating interplanetary shock waves which were asso-ciated with the CSWSs, swept away the galactic cosmic-rays, causing the delay in the FD recovery at 1 AU, and, hence, the unusually long recovery of the two-step FD at 1 AU. The additional depressions by the interplanetary shocks associated with the CSWSs, which were superposed on the recovery phase of the FD, were shown to be larger on the lower energy galactic cosmic ray particles, and there-fore the duration of the recovery phase would be much longer in the lower energy region than in the high energy region, an expectation which is consis-tent with the observations.

5 References

[11] Lockwood, J. A., J. A. Lezniak, and W. R. Webber, Change in the 11- year modulation at the time of the June