Depression in cosmic ray intensity influenced by interplanetary disturbances

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Abstract: Interplanetary manifestations of coronal mass ejections with specific plasma and field properties, called "interplanetary magnetic clouds," have been observed in the heliosphere since the mid-1960s. Depending on their associated features, a set of observed magnetic clouds identified at 1 AU were grouped in four different classes using data over four decades: (1) interplanetary magnetic clouds moving with the ambient solar wind (MC structure), (2) magnetic clouds moving faster than the ambient solar wind and forming a shock/sheath structure of compressed plasma and field ahead of it (SMC structure), (3) magnetic clouds "pushed" by the high-speed streams from behind, forming an interaction region between the two (MIH structure), and (4) shock-associated magnetic clouds followed by high-speed streams (SMH structure). A detailed analysis has been carried out in the present work to study the onset times of cosmic-ray decreases occurring during 2005-06 with respect to the arrival times of interplanetary shocks and magnetic clouds. The interplanetary magnetic field strength (B), north south component of interplanetary magnetic field (Bz), solar wind velocity (V), sunspot number (R) and disturbance storm time index (Dst) associated with these events have been studied in the present work. The data (neutron monitor count rate) of different cosmic ray neutron monitors have been used. It is noted that on the onset of magnetic cloud the cosmic ray intensity, Bz component of IMF, Disturbance storm time index Dst found to decrease for one day and then all the three components increases gradually, whereas interplanetary magnetic field B increases for one day and then decrease sharply. However the solar wind velocity found to remain constant and sunspot number (R) increases after one day of the onset of cloud with some depression. This southward turning of Bz produces large geomagnetic disturbances, which reflects in Dst value. Increase in Dst index, sunspot number (R) and Bz after the magnetic cloud event seems to be associated with cosmic ray intensity increase.

Keywords: cosmic ray, interplanetary magnetic field, solar wind, geomagnetic storm.

1 Introduction

The magnetic cloud (MC) is a large-scale interplanetary structure produced due to transient ejections in the ambient solar wind. Burlaga et al. [1] reported the characteristics of magnetic cloud. Peculiar type of interplanetary structure, named as magnetic cloud, has following properties. 1. The magnetic field direction rotates smoothly through a large angle during an interval of the order of one day. 2. The magnetic field strength is higher than average. 3. The temperature is lower than average.

All three of these criteria must be satisfied to identify any interplanetary event as a magnetic cloud. Several research investigations have been performed from time to time to derive effects of magnetic clouds on geomagnetic field as well as on cosmic ray modulation. Earlier reported an associated decrease in cosmic ray intensity. On the other hand, the absence of CR decrease during the passage of magnetic clouds. The relationship between MC and CR is very complex and hence needs detailed studies. In the present study, we have taken three magnetic cloud events of 1996, a low solar activity year to derive their effects on interplanetary parameters, geomagnetic field as well as on cosmic ray intensity variation. The period of minimum activity is specifically suitable because of the expected presence of a very few events of transient variations in cosmic ray intensity. Interplanetary magnetic clouds belong to one of the several classes of transient flows in the solar wind. Magnetic clouds as ideal force free objects (cylinders or spheres) are ejected near the sun and followed beyond the Earths orbit. It is found that the decrease in cosmic ray intensity, which are associated with magnetic cloud preceded by a shock, are very high and these decrease starts few days earlier than the arrival of cloud at Earth. From the study of the time profile of these decrease, it is found that the onset time of a forbush type decrease produced by a shock associated cloud starts nearly at the time of ar-rival of the shock front at the Earth (Duggal et al., 1983; Ba-druddin et al., 1986) and the recovery is al-most com-plete with in a week. Forbush decreases as-sociated with shock-associated cloud are caused by magnetic field variations associated with interplane-tary disturbances (Badruddin et al., 1986).

Badruddin et al. (1985) have reported a possible correla-tion between magnetic clouds and cosmic ray intensity decrease while Kudo et al (1985) have re-ported an in-creases in cosmic ray intensity that may be related to the geomagnetic Dst index and Iucci et al. (1985) have found short term increase in CR in-tensity occurring inside the Forbush decrease, that possible may be associated with magnetic clouds. Zhang and Burlaga (1988) infer that the cosmic rays are mainly modulated by fluctuation rather than by drifting in the strong smooth field in the magnet-ic cloud

Magnetic clouds are the interplanetary manifesta-tions of magnetized plasma ejected from the solar surface. The existence of unusual magnetized clouds of plasma emit-ted by the active sun was proposed by Morrison (1954) as a cause of the worldwide de-creases in cosmic ray intensity. Specific magnetic field structure with geometry consistent with mag-netic loop, called magnetic clouds, was identified in the solar wind by Zhang and Burlaga (1988). After the identification of magnetic clouds in the inter-planetary plasma and field data, detailed studies of relations between magnetic clouds and cosmic rays have been made (Badruddin et al., 1986; Cane, 2000; Kudela et al., 2000; Lockwood et al., 1991, Venkate-san and Badruddin, 1990; Zhang and Burlaga, 1988).

The various cosmic-ray intensity variations over different time-scales, the modulation of the intensity by the evolv-ing solar activity and the role of the electromagnetic state of the interplanetary medium (otherwise called helios-phere) can now be investigated as never before; these studies contribute immensely to our knowledge of the solar neighborhood. This article essentially deals with the studies of time and spatial variations of cosmic-ray inten-sity that have been conducted especially over the past two decades.

2 Data Analysis

The temperature and pressure corrected hourly data (counts of neutrons) of cosmic ray intensity from Mos-cow neutron monitor (Latitude 55.47 N, Longitude 37.32 E, Altitude 200 m, Standard pres-sure 1000 mb, Geo-magnetic cut-off rigidity 2.43 GV) and Kiel Neutron Monitor (Latitude N 54.30, Longitude E 10.10, Elevation 54 m, Rigidity ⩾2.36 GV/c) have been used, where the long-term change from the data has been removed by the method of trend correction. The days of Forbush de-creases have also been removed from the analysis to avoid their influence in cosmic ray variation. Interplane-tary magnetic field and solar wind plasma data have been taken from the interplanetary medium data book..

3 Results and Discussion

Cosmic rays are broadly defined as massive, energetic particles that arrive at the earth from anywhere beyond its atmosphere. They carry information on the composi-tion of astrophysical sources in our immediate neighbor-hood as well as those farther out in our galaxy, and on acceleration processes operative therein. Cosmic rays can be of galactic origin, from outside our solar system, or originate in the solar corona, as a result of transient erup-tions. Galactic cosmic rays provide us with some of the few direct samples of matter from outside our solar sys-tem. They are mostly atomic nuclei which have had their electrons stripped during their their passage through the galaxy at relativistic speeds. The intervening turbulent magnetic fields “scramble” the directions of these charged particles, so that they are isotropic when de-tected at the earth. Most galactic cosmic rays are be-lieved to be accelerated by shock waves driven by super-nova explosions. However, there are several observations of very high energy cosmic rays (of the order of 1020 eV) for which this explanation is inadequate. It is often con-jectured that ultra-high energy cosmic rays could be coming from outside the galaxy, from gamma ray bursts and/or active galactic nuclei. They could also represent signatures of exotic mechanisms such as strongly inte-racting neutrinos, or topological defects in the structure of the universe. Questions such as these link cosmic ray physics to basic particle physics and the fundamental nature of the universe. Magnetic Clouds (henceforth referred to as MC) are large-scale disturbed structures in Interplanetary (IP) Space, which originate from the Sun, and encompass enhanced solar wind speeds and densities, but lowered plasma temperatures. They contain magnetic fields which remain enhanced over time-scales of tens of hours. Applying the methodology of Zhang and Burlaga (1988) we have identified three interplanetary mag-netic cloud events (5, February 2006, 13 April 2006 and 14 April 2006) during 2006 to study their influ-ence on interplanetary, solar wind plasma as well as on cosmic ray intensity.

It is observed form the plots (shown elsewhere) representing the magnetic cloud event of February 5, 2006. The onset time of magnetic cloud is 1910 Hr UT on day 036. In plots we have plotted daily average of hourly cosmic ray count rate (Moscow & Kiel neutron monitor) from January 25, 2006 to February 15, 2006 i.e. 11 days prior and 10 days after the onset of magnetic cloud event. The daily average of interplanetary magnet-ic field (B), north south component of interplanetary magnetic field (Bz), solar wind velocity, sunspot number (R) and disturbance storm time index (Dst) associated with this event is also plotted in different panels of the figure. As one can see from the plot that the cos-mic ray intensity is observed to increase 11 days prior to 2 days prior from the event and then remains constant upto onset of magnetic cloud and then in-creases statistically upto 10 days after the event with some depression on February 10, 2006.The inter-planetary magnetic field B is increas-es significantly from 6 days prior to 1 days after the event with some depression on February 4, 2006 then decrease significantly up to 4 days after the event. The systematic variations are seen in the Bz component of inter-planetary magnetic field 11 days prior to the event up to the onset of magnetic cloud and then decrease significantly after one day of the event and then in-crease significantly up to 2 day after the event and then systematic variations continued up to 10 days after the event. The solar wind velocity is seems to remain constant before and after 5 days of the onset of magnetic cloud. The sunspot number (R) significantly decreases 11 days prior to the event 6 days prior to the event and then significantly remains constant upto 1 day after the event. The abrupt change is observed in the sunspot numbers after 1 day of the onset of magnetic cloud. The disturbance time index, Dst is found to increase significantly 10 days prior to the event up to 5 days prior to the event and then decreases upto 1 day prior to the event. On the onset of magnetic cloud the Dst decreases significantly for 1 day and then increase upto 5 days after the event. It is noted that on the onset of magnetic cloud the cosmic ray intensity, Bz component of IMF, Disturbance storm time index Dst found to decrease for one day and then all the three components increases gradually, whereas interplanetary magnetic field B increases for one day and then decrease sharply. However the solar wind velocity found to remain constant and sunspot number (R) increases after one day of the onset of cloud with some depression.The Dst index has been taken as a level of geomagnetic disturbance. North south component of interplanetary magnetic field Bz turns southward immediately after the magnetic cloud event. This southward turning of Bz produces large geomagnetic disturbances, which reflects in Dst value. Increase in Dst index, sunspot number (R) and Bz after the magnetic cloud event seems to be associated with cosmic ray intensity increase. We have rigorously studied all the three magnetic clouds and found the similar trends in all the cases.

4 Conclusion

An inverse correlation between cosmic ray inten-sity and solar activity measured by sunspot numbers (Rz), as one would expect from Forbush's original analysis. The interplanetary magnetic field, B shows a weak negative correlation (-0.35) with cosmic rays for the solar cycle 20, whereas B shows a high anti-correlation for the solar cycles 21-23 (- 0.76, - 0.69). The interplanetary magnetic field strength (B) shows a good positive correlation with sunspot numbers for four different solar cycles.

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