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2013 J. Phys.: Conf. Ser. 409 012182

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doi:10.1088/1742-6596/409/1/012182

Precursors of Forbush decreases connected to western solar sources and geomagnetic storms

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Abstract. It is suggested in many studies that the pre-increases or pre-decreases of the cosmic ray intensity (known as precursors) which usually precede a Forbush decrease could serve as a useful tool for studying space weather effects. The events under consideration in this particular investigation were chosen based on two criteria. Firstly, the heliolongitude of the solar flare associated with each cosmic ray intensity decrease was in the 50° – 70° W sector and secondly, the values of geomagnetic activity index (Kp_{max}) were ≥ 5 . As a result only Forbush decreases connected to western solar flares and accompanied by a geomagnetic storm were selected. In total 25 events were gathered for the time period from 1967 to 2006. For the detailed analysis of the aforementioned cosmic ray intensity decreases data on solar flares, solar wind speed, geomagnetic indices (Kp and Dst) and interplanetary magnetic field were used. The asymptotic longitudinal cosmic ray distribution diagrams for all events were plotted using the "Ring of Stations" method. The results revealed clear signs of precursors in 60% of selected events.

1. Introduction

The study of the precursors (pre-decreases or pre-increases) in the cosmic ray intensity (CRI) usually preceding Forbush decreases, has served as the main subject for many investigations (e.g. [1-3]). Pre-decreases apparently result from a "loss cone" effect, in which the neutron monitor station is magnetically connected to the cosmic ray depleted region downstream of the shock [4] and [1], while pre-increases are caused by galactic cosmic ray acceleration at the front of the advancing disturbance, as the particles are being reflected from the approaching shock [4] and [3].

In recent investigations ([5-6]) it is mentioned that the enhanced equatorial component of the first harmonic of the cosmic ray anisotropy A_{xy} , observed for at least one hour before the shock arrival, could be considered as a satisfactory criterion for precursors. In this particular study the events under examination were chosen based on the heliolongitude of the solar flare associated with each CRI decrease $(50^{\circ}-70^{\circ} \text{ W})$ and the values of the geomagnetic index Kp (\geq 5). Thus, 25 events were selected, some of which are described in more details below. Although events related to western sources are not so big and well pronounced in the cosmic ray variations near Earth as those related to eastern or central sources, they were chosen to be studied because they are characterized by greater anisotropy before the shock arrival.

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doi:10.1088/1742-6596/409/1/012182

2. Data and Method

The asymptotic longitudinal cosmic ray distribution diagrams were plotted using the "Ring of Stations" (RS) method. This method uses hourly data of CRI variations recorded by the neutron monitor stations. In this study stations with cut-off rigidity $R_c < 4 \, \text{GV}$ and latitudes $< 70^\circ$ were used [4] and [7]. The asymptotic longitudinal cosmic ray distribution diagrams were obtained using data from 31 neutron monitors. A detailed list of the neutron monitor stations used by the RS method was included in [5]. The density and first harmonic of the anisotropy for cosmic rays of rigidity 10 GV, as calculated by the global survey method [8] and solar wind parameters and geomagnetic indices, as obtained from the OMNI database (http://omniweb.gsfc.nasa.gov), have been used for the analysis of each event.

3. Results

A certain correlation exists between the size of the Forbush effect (FE) and a precursor, though for the western sources this rule is often broken: it is possible to see a big precursor at small FE since the main part of solar wind disturbances goes to the west and is not visible at Earth.

In this particular work the events on October 28, 2000, August 24, 2005, May 26, 1990 and October 4, 1983 are being presented. Below follows a detailed description of the relevant interplanetary disturbances during the aforementioned decreases along with the longitude-time distribution of cosmic ray variation diagrams of these events.

One of the most interesting examples of the aforementioned events from western sources, with clear precursor and with the sudden storm commencement (SSC) registered at 9:54 UT, is the Forbush effect on October 28, 2000. The source of disturbance was the flare of class C4.0 which occurred at 8:45 UT on October 25, 2000 in AR9199 with coordinates N10W66. No big disturbances in cosmic rays or geomagnetic field prior to this event were observed. During this event the maximum IMF intensity was 18.8 nT and the maximum solar wind speed was 415km/sec. The CRI decrease was about 7.7% and the maximum anisotropy was 3.49%. The registered geomagnetic storm was moderate (Kp index was 6 and Dst index was -127 nT).

The asymptotic longitude distribution of cosmic rays variations by different stations is presented in Figs. 1-3. In these figures the vertical axis corresponds to the asymptotic longitude of the stations and the horizontal axis refers to time as DD.HH, UT. The CRI decreases, as measured by all neutron monitor stations used by the RS method, are depicted with red circles while yellow circles refer to CRI increases, relatively to a quiet fixed period. The size of the circles is proportional to the size of the variation. The vertical line denotes the time when the SSC was registered.

It is seen that the main phase of FE decrease of intensity at all stations started just after the shock arrival. But well in advance, about 24 hours prior to the shock, clear pre-decrease was observed at the stations with asymptotic directions near to 90°.

Concerning the event on August 24, 2005 the SSC was registered on August 24, 2005 at 6:13 UT. This event was the result of a combination of M2.6 flare registered on August 22 at 00:44 UT in active region 10798 with coordinates S11W54 and the coronal hole 183. During this event the maximum IMF intensity was 52.2 nT and the maximum solar wind speed was 720 km/sec. The CRI decrease was about 6.4% and the maximum anisotropy was 2.66%. Besides, a severe storm with Kp index 8.7 and Dst index -216 nT, was registered. As seen in Fig. 2 pre-decrease around 90°, was visible before the shock.

The event on May 26, 1990 is an example of a very peculiar precursor. The SSC was registered on May 26, 1990 at 20:37 UT. The source of the event was M8.7 flare, which occurred on May 23 at 4:01 UT in active region 6063 with coordinates N33W55. Even though there is no obvious CRI decrease, there is a good example of precursor. Almost 6 hours prior to the shock arrival a very characteristic CRI decrease at longitudes around 90° was recorded. This variation is expected to be precursor of a CRI decrease, which however was not registered by neutron monitors due to the GLE on May 26, nevertheless it was a precursor of geomagnetic storm started simultaneously with shock arrival. Cosmic rays were undergone this decrease in the interplanetary medium and brought this information

doi:10.1088/1742-6596/409/1/012182

at Earth. Thus, this event is unusual and has no analog. During this event the observable CRI decrease was about 0.8% but the maximum anisotropy was 2.61%. The registered geomagnetic storm was strong (Kp and Dst indices were 7.3 and -87 nT respectively). The asymptotic longitudinal cosmic ray distribution diagram for this event is presented in Fig. 3.

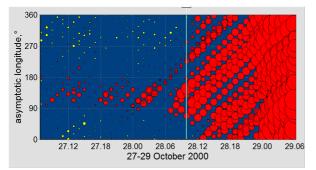


Figure 1. The event on October 28, 2000 presented as a longitude-time distribution.

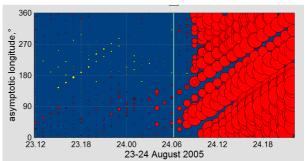


Figure 2. The event on August 24, 2005 presented as a longitude-time distribution.

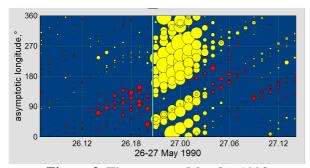


Figure 3. The event on May 26, 1990 presented as a longitude-time distribution.

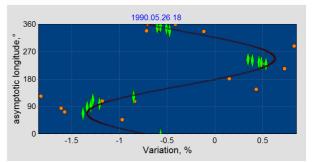


Figure 4. Dependence of cosmic rays variations on the asymptotic longitude of neutron monitors in the event on May 26, 1990.

In some previous studies, e.g., [9] it was shown that during precursors a specific angle distribution of the cosmic ray variations appears, when maximum and minimum are very close to each other and in this moment CRI changes sharply around definite longitudes. In Fig. 4 such an angle distribution of the CR variations is plotted for the event on May 26, 1990 at the moment (18:00 to 19:00 UT) – two hours before the shock arrival. The figure clearly manifests close position of the minimum and maximum of cosmic ray variations in the narrow strip of longitudes – around 90° . As it clearly seen, this distribution cannot be described by the simple harmonic of the first order.

In Figs. 4 and 5, orange dots are hourly cosmic ray variations, green diamonds depict cosmic ray variations averaged within the sector \pm 20° for Fig. 4 and \pm 10° for Fig. 5 and the curve is the fitted first harmonic of anisotropy (solar – diurnal variation) for data under consideration.

The event on October 4, 1983 demonstrates that such a characteristic precursor's distribution can last long enough. The SSC for this event was registered on October 4, 1983 at 5:41 UT. The source of the event was a M1.1 flare on October 2, 1983 at 6:12 UT in active region 4324 with coordinates S18W53. During this event the maximum IMF intensity was 23.6 nT and the maximum solar wind speed was 533km/sec. The CRI decrease was about 1.1% and the maximum anisotropy was 1.91%. The registered geomagnetic storm was moderate (Kp index was 6.7 and Dst index was -71 nT).

doi:10.1088/1742-6596/409/1/012182

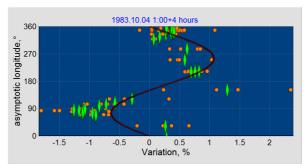


Figure 5. Dependence of cosmic ray variations on the asymptotic longitude of neutron monitors in the event on October 4, 1983.

In Fig. 5 data are plotted for four hours consecutively from $1:00 \ (1:00-4:00 \ \mathrm{UT})$ of October 4, 1983. It is seen that the first harmonic does not completely define a distribution of the variations. It is obviously expressed that similar variations are grouped at definite longitude: minimum is within the narrow strip of the longitudes – around 90° .

Conclusions

Twenty five Forbush decreases, which were associated to western solar flares and followed by geomagnetic activity, were chosen from a list of events for the time period 1967 – 2006. It is concluded from the analysis that before geomagnetic storms and FEs, which are caused by CMEs with a source in the western portion of the solar disk, precursors can be seen in galactic cosmic rays very often as CRI pre-increase and pre-decrease in certain longitudes. Growing amplitude of the first harmonic of cosmic ray anisotropy, which is determined in these periods by neutron monitor network data, is connected, as a rule, with the appearance of the precursor.

Sometimes the size of the precursor is so big and the CRI distribution is so unusual and specific, that this precursor may serve as a basis for prognosis of a significant interplanetary disturbance arriving to Earth, even in the absence of other data.

Acknowledgements: The authors thank all the providers of the NMDB stations. This work is partly supported by Russian FBR grants 11-02-01478, Program № 22 Basic Research of the Presidium RAS "Fundamental processes of research and development of the Solar System".

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