Rigidity spectrum of cosmic ray variations over the periods of large Forbush decreases during solar cycles 22 and 23

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Abstract. The paper presents findings of rigidity spectrum of cosmic ray (CR) variations during certain Forbush decreases recorded at the worldwide network of neutron monitors over the period 1991–2005. In the majority of events under consideration, rigidity spectrum of primary CR variations is not described by the power function of rigidity over the energy range to which neutron monitors are most sensitive.

1. Introduction

It is commonly supposed [1, 2] that rigidity spectrum of cosmic ray (CR) intensity variations is described by the power law over a wide energy range, with a slight variation of inclination (a kink that is sometimes referred to as a knee) 

\[ \frac{\Delta J}{J}(R) \sim R^{-\gamma} \]

where \( R \) is the particle rigidity; \( \gamma \) is the spectral index. Behaviour of the spectral index over the periods of Forbush decreases (FDs) during different solar cycles [3] and at different FD phases [4] has been examined, taking into account this assumption about rigidity spectrum of variations. The examination has revealed that spectral index values are over the range ~ 0.8 to ~ 1.

The paper presents findings of rigidity spectrum of CR variations obtained using the method of spectrographic global survey [5, 6] during certain FDs recorded at the worldwide network of neutron monitors over the period 1991–2005 and accompanied by strong geomagnetic disturbances. Table 1 presents summary of helio- and geophysical conditions for each event under study (including data on solar flares and geomagnetic disturbances).

For the analysis, we used data from the worldwide network of neutron monitors, corrected for pressure and averaged over hourly intervals. The undisturbed period was selected for each event before the FD initiation.

2. Discussion of results and conclusions

Figure 1 presents variations in the isotropic component of primary CR intensity with rigidity of 4 GV for all FDs under consideration.
Table 1. Helio- and geophysical conditions during the events under consideration

| date           | Data on solar flares | date and Dst-index of geomagnetic storm |
|---------------|----------------------|---------------------------------------|
|               | date | class | active region | helio- coordinates |                     |                        |
| 23–25/03.1991 | 22.03.1991 | 3B    | 6555        | 26°S 28°E         | 24.03.1991 (Dst = –300 nT) |
| 12–14/06.1991 | 11.06.1991 | 2B    | 6659        | 32°N 15°W         | 13.06.1991 (Dst = –114 nT) |
| 29–31/10.2003 | 28.10.2003 | X17.2/4B | 0486      | 16°S 08°E         | 30.10.2003 (Dst = –401 nT) |
| 20–22/11.2003 | 18.11.2003 | M3    | 10501       | 00°N 18°W         | 20.11.2003 (Dst = –465 nT) |
| 10–11/11.2004 | 10.11.2004 | X2.5/3B | 10696      | 09°N 49°W         | 10.11.2004 (Dst = –289 nT) |
| 24–25/08.2005 | 22.08.2005 | M5.6  | 10798       | 11°S 62°W         | 24.08.2005 (Dst = –216 nT) |

Figure 1. Time dependence of variation amplitudes of the isotropic component of primary CRs with rigidity of 4 GV.
Figure 2 presents rigidity spectra of variation amplitudes of primary CRs at certain moments of FD development. According to Figure 2, rigidity spectra of variation amplitudes can not be described by the power function of rigidity over the rigidity range ~2 to 50 GV. Approximation of rigidity spectrum by the power function of particle rigidity can be made only when rigidity values exceed ~ 10 GV. The maximum CR modulation is observed over the rigidity range ~3 to 7 GV for all events under consideration. The extremum location in this rigidity range is different for each event. Of particular interest are the events of 20–22 November 2003 (at all development stages) and 24–25 August 2005 (at the maximum development stage). It is evident that rigidity spectrum of variations during the events under consideration can be described by the power function of rigidity over a wide energy range. Distinction between the events of 20–22 November 2003 and 24–25 August 2005 and other events is that no increase in amplitude of the second pitch-angular harmonics (bidirectional) anisotropy is observed during the first two events. No increase in amplitude of bidirectional anisotropy can be explained by the fact that no loop-like structure of the interplanetary magnetic field (IMF) has been formed in interplanetary space. According to D. Sc. Victor V. Grechev (private communication), an unusual IMF configuration – in the form of a compact magnetic cloud unrelated to the Sun was observed in November 2003. As spectrum forms of the events of 20–22 November 2003 and 24–25 August 2005 differ from those of other FDs considered, and no bidirectional anisotropy is observed in particle distribution, we can speak of different IMF spatial structures that have caused these effects.
Table 2 lists values of the spectral index of rigidity spectrum of CR variation amplitudes over the range 10 to 50 GV at different development stages of FDs under study (at decrease, at the moment of maximum modulation, and at the stage of the CR intensity recovery).

**Table 2.** Values of the spectral index of rigidity spectrum of CR variation amplitudes over the range 10 to 50 GV

| Date of event       | FD development stage |
|---------------------|----------------------|
|                     | decrease | maximum | recovery |
| 23–25/03.1991       | -0.93     | -0.83    | -0.79    |
| 12–14/06.1991       | -0.96     | -0.82    | -0.86    |
| 29–31/10.2003       | -0.92     | -0.90    | -0.86    |
| 20–22/11.2003       | -1.06     | -1.39    | -0.95    |
| 10–11/11.2004       | -0.80     | -0.90    | -0.86    |
| 24–25/08.2005       | -0.96     | -1.42    | -0.81    |

According to Table 2, a soft spectrum [4] with gradual hardening at the recovery stage is observed at the decrease stage of most FDs under consideration. Of particular interest are the events of 20 – 22 November 2003 and 24–25 August 2005: we observe the soft spectrum with significant values of the spectral index \( \gamma \) at the moment of maximum modulation of the CR intensity (\( \gamma = -1.39 \) and \( \gamma = -1.42 \), respectively).

We can draw the conclusions that, during FDs:

1. Rigidity spectrum of primary CR variations is not described by the power function of rigidity over a wide energy range.
2. Rigidity spectrum of primary CR variations can be described by the power function of rigidity when particle energy is more than \( \sim 10–15 \) GeV.
3. Obviously, a softer rigidity spectrum of primary CR variations is observed when the Earth is in magnetic formations of the solar wind (e.g., magnetic clouds unrelated to the Sun).

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**References**

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