# Variations of the cosmic ray cutoff rigidity in Irkutsk and Almaty during the extreme events in 2003

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***Abstract.*** **The ground-based measurements of cosmic ray intensity at the worldwide neutron monitor network, and the data of the GOES spacecraft are used to calculate variations of the cutoff rigidity in Irkutsk and Almaty for October–November 2003. The calculated cut-off rigidity variations are presented together with the $D_{st}$ variations of geomagnetic field. The obtained results are compared with calculations made on the basis of Tsyganenko's magnetospheric model.**

***Keywords*: Neutron Monitor, Cosmic Ray Variations, Geomagnetic Field**

## I. Introduction

Disturbances of the Earth's magnetic field during magnetic storms can change significantly the trajectories of charged particle in the magnetosphere; to such an extent, that the allowed trajectories may become prohibited and vice versa. In the ground-based observations, this effect produces (1) the change of effective cutoff thresholds, and (2) the change of the effective asymptotic directions of particle arrival, resulting in variation of the receiving coefficients for different stations. The magnetospheric effect related to variation of the cutoff rigidity may be sufficient enough to considerably change the behavior of the temporal dependence of the cosmic ray (CR) intensity variations observed at the mid- and low-latitude stations, as compared to that at high-latitude stations, where this effect is not seen.

Dramatic magnetospheric effects in CR are usually observed simultaneously with the profound modulation ones, resulting from the electromagnetic processes in interplanetary space, because both are due to the same cause. Firstly, the magnetospheric variations of CR intensity are of an interest from the physical standpoint, i.e., in terms of formation, development, and decay of magnetospheric current systems. Beside, the variation of the rigidities of geomagnetic cutoff threshold (GCR) obtained in a study of geomagnetic effects in CR may provide an additional information source for testing the one or another model of the Earth's magnetosphere. Secondly, magnetospheric effects are essential from the methodological standpoint, as they interfere with the extraterrestrial variations of cosmic ray, and should be eliminated from the experimental data, whenever possible.

Methodological questions of manifestation of the magnetospheric component in variations of the CR intensity, and determination of the GCR variations during different magnetic storms were discussed in [1], [2], [3]. Here we examine the variations of the GCR threshold during the strong sporadic phenomena in heliosphere which have been occurred in October–November 2003.

## II. Data and method

For our analysis we use the hourly averaged data about the proton intensities in the energy ranges of $4-9$, $9-15$, $15-40$, $40-80$, $80-165$, and $165-500$ MeV which have been measured aboard the GOES-11 satellite [4], and the intensity variation data on the CR of different rigidities obtained by the method of spectrographic global survey (SGS) [5], [6] from the ground-based measurements at the World Neutron Monitor Network (44 stations). Modulation amplitudes are measured starting from the quiet level of 12 October 2003. The SGS method is used to obtain information on variations in the angular and energy distribution of primary CR outside the Earth's magnetosphere, as well as on the hourly changes in the planetary system of geomagnetic cutoff rigidities.

In addition, the following system of nonlinear algebraic equations is solved:

$$\frac{\delta I_c^i}{I_c^i}(h_\lambda) = -\Delta R_c W_c^i(R_c, h_\lambda) \cdot (1 + \frac{\delta J}{J}(R_c)) \quad (1)$$
$$+ \int_{R_c}^{\infty} \frac{\delta J}{J}(R) W_c^i(R, h_\lambda) dR,$$

where $\frac{\delta I_c^i}{I_c^i}(h_\lambda)$ is the variation amplitude of the flux of secondary particles of type $i$ (relative to the background level $I_c^i$) as observed at the geographical point $c$ at the level $h_\lambda$ in the Earth's atmosphere; $R_c$ is the effective rigidity of geomagnetic cutoff; $W_c^i(R, h_\lambda)$ is the connection function between the primary and secondary variations in CR, and $\frac{\delta J}{J}$ are the variation amplitudes in the primary CR spectrum (the SGS method applies a formal mathematical approximation for $\frac{\delta J}{J}$). The dependence of the cutoff rigidity variation $\Delta R_c$ on the threshold rigidity is approximated as $\Delta R_c(R_c) = (b_1 R_c + b_2 R_c^2) e^{-\sqrt{R_c}}$. For cosmic ray stations being distributed non-uniformly over the globe, the longitude variation effect of the planetary CR geomagnetic cutoff remains beyond the account of our calculation.

As the stations in GCR range of $\sim 1-2$ GV have a low coupling coefficients near their rigidity threshold, the CR spectrum accuracy within this rigidity interval is low, and the values of GCR variations $\Delta R_c$ can not be well determined. To improve this accuracy for such stations, we use the spectrum derived from the GOES data over several energy ranges.

The differential rigidity spectrum of CR in a wide energy range can be written as [7]:

$$J(R) = A[\frac{\epsilon^2 - \epsilon_0^2}{(\epsilon + \Delta\epsilon)^2 - \epsilon_0^2}]^{3/2}\frac{\epsilon + \Delta\epsilon}{\epsilon} \quad (2)$$

$$\times[\frac{\sqrt{(\epsilon + \Delta\epsilon)^2 - \epsilon_0^2}}{\sqrt{(T_0 + \epsilon_0)^2 - \epsilon_0^2}}]^{-\gamma+1},$$

$\epsilon$, $\epsilon_0$, and $T_0$ being correspondingly the total particle's energy, its energy at rest, and the kinetic energy at which the intensity of CR of corresponding rigidity in the Galaxy is $A$; $\Delta\epsilon$ is the heliospheric particle energy variation as determined by the next expression:

$$\Delta\epsilon = \Delta\epsilon_{pt} + \epsilon - \sqrt{\beta(\epsilon^2 - \epsilon_0^2) + \epsilon_0^2} + \epsilon(1 - e^{\alpha/2}),$$

if $R < R_0$, and

$$\Delta\epsilon = \Delta\epsilon_{pt} - \epsilon R_0(1 - e^{\alpha/2}),$$

if otherwise.

Here $\Delta\epsilon_{pt} = ZeU$, $Ze$ is the particle's charge, and $U$ is a potential of the induced electric field $E$ in the heliosphere, $\mathbf{E} = -\frac{1}{c}\mathbf{u}\times\mathbf{B}$. Further on, $\mathbf{u}$ is the velocity of solar wind (SW); $\mathbf{B}$ — intensity of the interplanetary magnetic field (IMF); $\beta = B/B_0$, where $B_0$ and $B$ are respectively the background and the time-variant component of IMF; $\alpha = E_{pl}^2/B^2$; $E_{pl}$ is the intensity of the polarization electric field which arises in the heliosphere due to propagation of accelerated particles; $R_0$ is the rigidity of a particle whose Armor radius is equal to the size of the nonstationary electromagnetic field region, where the particles are accelerated.

The primary spectrum in form (2) was obtained with the use of a physical model of CR modulation owing to the change of their energy in the different regular electromagnetic fields of interplanetary medium. A GCR variation for the each CR station is calculated with regard to variation of the primary spectrum (2).

## III. Result of the analysis

The plots in Fig. 1 present the temporal dependencies in October-November, 2003, of the following parameters: the IMF module; the angles $\Psi$ and $\lambda$ describing orientation of the IMF vector in geocentric ecliptic coordinate system; the velocity of solar wind and the $D_{st}$ index [8]; and the variation of geomagnetic cutoff GRC ($\Delta R_c$) at the points with $R_c$=3.66 GV (Irkutsk) and $R_c = 6.61$ GV (Almaty), as obtained by SGS method in our analysis. Fig. 2 displays a more detailed plots of the $\Delta R_c$ variation in Irkutsk and Almaty for 29–31 October together with $D_{st}$ index. Fig. 3 shows the GCR variations $\Delta R_c$ in dependence on the $R_c$ threshold rigidities in some time instants of October and November 2003.

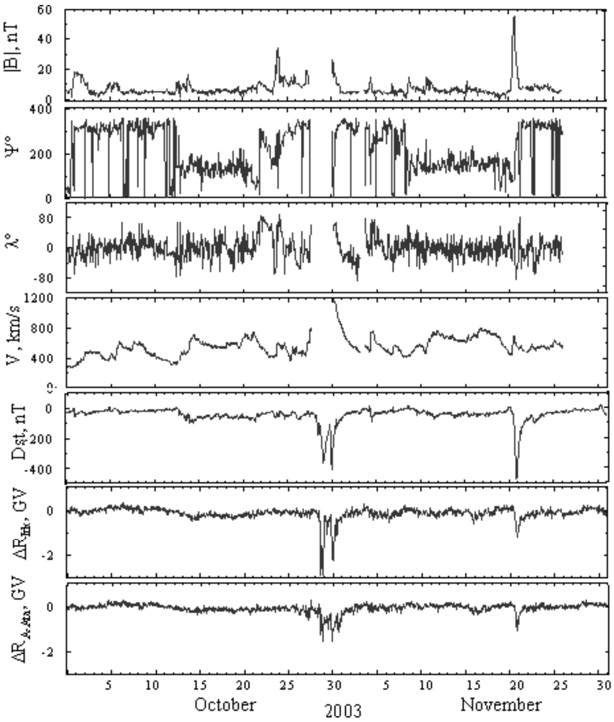


Fig. 1. Parameters of the interplanetary medium: the IMF module, angles $\Psi$ and $\lambda$ of the IMF vector orientation; the SW velocity; the $D_{st}$ index; temporal profiles of GCR variations in Irkutsk and Almaty.

## IV. Discussion and conclusions

In the plots $\Delta R_{Irk}$ and $\Delta R_{Ata}$ it is seen, that the GCR variations in magnetic storm of 29-31 October greatly differ between each other, in correspondence with the latitude difference of both stations. In Irkutsk, the most significant decreases in the threshold rigidity GCR were observed in the moments of 15:00 UT ($\Delta R_{Irk} \sim -2.9$ GV, $D_{st} = -126$ nT), and 21:00 UT ($\Delta R_{Irk} \sim -2.9$ GV, $D_{st} = -286$ nT) on 29 October, which decreases do not coincide in time with the local minima of $D_{st}$ index. At the same time, the dependence of $\Delta R_{Irk}$ on 30 October matches the temporal behavior of $D_{st}$ index. Our attention engages a considerable difference in $\Delta R_{Irk}$ values by approximately identical values of the $D_{st}$ index on 30 October. So, for instance, at 00.00–01.00 UT on 30 October $\Delta R_{Irk} = -0.5$ GV, $D_{st} = -363$ nT, whereas at 22.00–23.00 UT on 30 October $\Delta R_{Irk} = -1.9$ GV, $D_{st} = -342$ nT.

As it is seen in the plot of $\Delta R_{Ata}$ in Fig. 1, at the Almaty station the threshold rigidity decreases by $\Delta R_{Ata} \sim -1.2$ and $\Delta R_{Ata} \sim -1.5$ GV in the moments of the first two considerable decreases in GCR. The maximum decrease occurs during the main phase of the magnetic storm of 30 October ($\Delta R_c \sim -1.6$ GV, $D_{st} = -342$ nT), an hour before the highest decrease in the $D_{st}$ index ($-401$ nT); i.e., at 22:00 UT. During the event of 20 November, the maximum GCR decrease ($\Delta R_c \sim -1.2$ GV) in Irkutsk took place at $D_{st} = -472$ nT in the main phase of magnetic storm at 20:00 UT, while the decrease in Almaty ($\Delta R_c \sim$

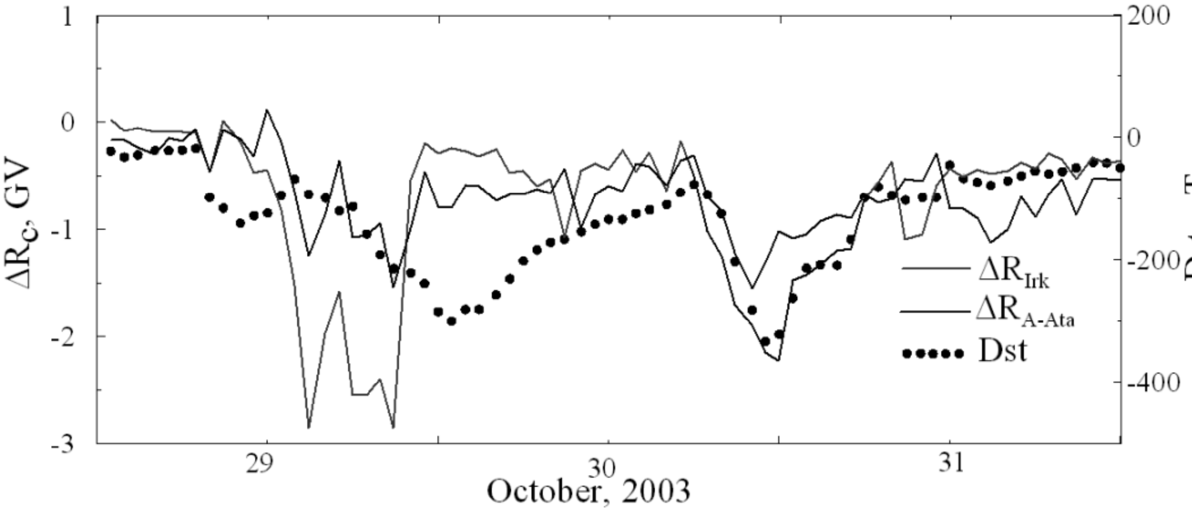


Fig. 2. GCR variations in Irkutsk and Almaty (solid lines), and $D_{st}$ index (dots) during the geomagnetic disturbances on 29-31 October 2003.

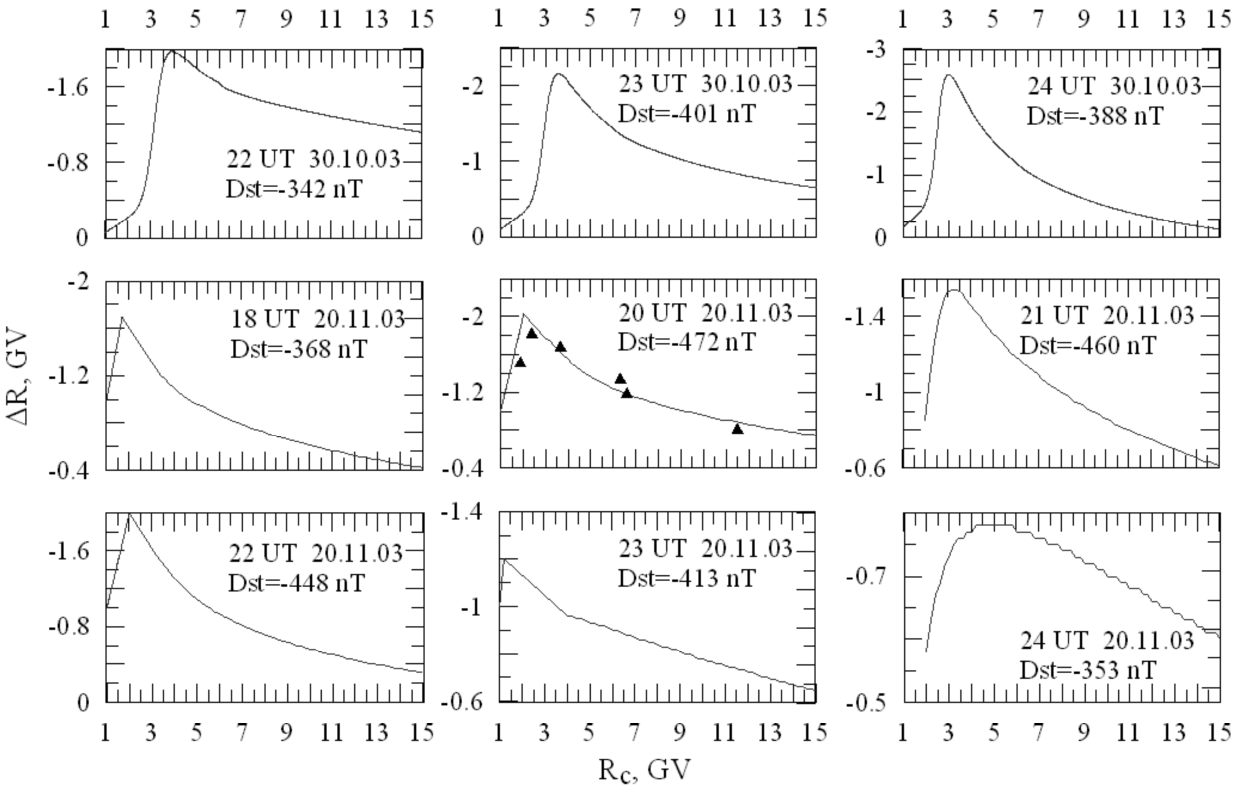


Fig. 3. Dependence of the GCR variation $\Delta R_c$ on the threshold rigidities $R_c$ in some isolated instants of the disturbed period in October-November 2003.

$-1.1$ GV at $D_{st} = -451$ nT) has occurred an hour before the storm.

In Fig. 3, a decrease in GCR variations at high threshold rigidities, and a maximum shift in the GCR variation to the lower GCRs values were observed in the dependence of $\Delta R_c$ on the threshold rigidities on 30 October from 22:00 up to 24:00 UT.

In the latitude dependence of $\Delta R_c$ for the event of 20 November 2003, the maximum decrease of GCR $R_c \sim 2$ GV occurred in the initial phase at 20:00 UT; then, at 24:00 UT, this maximum shifted to $R_c \sim 5$ GV. Fig. 3 presents the latitude dependence of $\Delta R_c$ for the moment 20:00 UT, 20 November 2003. By the triangles are shown the calculation results [9] which were made according to the Tsyganenko magnetospheric model [10]. Analysis given here allows to make the following conclusion:

(1) There exists considerable difference between the temporal profiles of GCR variations in Irkutsk and Almaty.

(2) During the magnetic storms on 29 October 2003 were observed the abrupt GCR variations which may be

related to the magnetopause currents, since the GOES-10 data show, that in this period the magnetopause has been displaced up to 6.6 Earth's radii [4].

(3) There exists none unique connection between the temporal profiles of GCR variations and the $D_{st}$ index.

(4) Results of a calculation held according to the Tsyganenko magnetospheric model agree well with the data derived from the ground-based observations at the global network of cosmic ray stations.

(5) This results may be used to test the different models of magnetospheric current system and its dynamics during the geomagnetic disturbances.

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## REFERENCES

[1] V.M.Dvornikov, V.E.Sdobnov. *A spectrografic global survey techique for studing cosmic ray distribution function and the planetary system of geomagnetic cutoff rigidities*, Proc. 23-rd ICRC Calgary, v.3, p.797-800, 1993.
[2] L.M.Baisultanova, A.V.Belov, L.I.Dorman *et al.* . *Magnitospheric effects in cosmic rays during Forbush-decreases*, Proc. 20th ICRC, Moscow, v.4, p.231-234, 1987.
[3] http://kosmofizika.ru/buri/buri.htm
[4] http://spidr.ngdc.noaa.gov/spidr/
[5] V.M.Dvornikov, V.E.Sdobnov. *Analyzing the solar proton event of October 22, 1989 using the method of spectrographic global survey*, Solar Phys, v.178(2), p. 405-422, 1998.
[6] V.M.Dvornikov, V.E.Sdobnov. *Variations in the rigidity spectrum and anisotropy of cosmic rays in the period of Forbush effect of 12-25 July 1982*, IJGA, v.3, 3, p.217-228, 2002.
[7] V.M.Dvornikov, M.V.Kravtsova, A.A.Lukovnikova *et al. Variations of the parameters of rigidity spectrum of cosmic rays during the events of January, 2005* Proc. 30th ICRC, Merida, v.1, p.127-130, 2007.
[8] ftp://nssdcftp.gsfc.nasa.gov/spacecraft_data/omni/omni2_2003.dat
[9] M.I.Tyasto M.I., O.A.Danilova, L.I.Dorman L.I. *et al.* , *On the possibility to check the magnetosphere's model by CR: the strong geomagnetic storm in November 2003*, Advances in Space Research, v.42, 9, p.1556-1563, 2008.
[10] N.A.Tsyganenko, H.J.Singer, J.C.Kasper *Storm-time distortion of the inner magnetosphere: How severe can it get?* J.Geophys.Res., 108(A5), p.1209, doi:10.1029/2002JA009808, 2003.