Cosmic ray rigidity spectrum and anisotropy during GLE on 14 July 2000

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Abstract. Using the method of spectrographic global survey, rigidity spectrum and anisotropy of galactic cosmic rays during GLE on 14 July 2000 have been studied with the data from ground-based observations of cosmic rays (CR) at the world-wide network of stations. The CR rigidity spectrum observed during this period over the range 1 to ~ 20 GV is shown to be described not only by power function of particle rigidity: distribution of CRs in the earthward direction varies with time and depends on their energy.

1. Introduction
On 14 July 2000, an increase in the CR intensity (GLE) was recorded by high- and mid-latitude neutron monitors after 10:30 UT. This increase was associated with a solar flare (3B/X5.7) that occurred in active region 9077 (heliocoordinates N220, W070) at 10:30 UT. The increase in the CR intensity of 14 July was accompanied by the Forbush decrease that started on 13 July 2000. This event was studied by many authors [1–3] presenting time profiles of the CR intensity and anisotropy at the world-wide network of stations, as well as CR spectrum values, on the assumption that this spectrum is described by a power function, and the pitch-angular distribution of energy protons on the boundary of the Earth’s magnetosphere.

2. Data and technique
To approximate experimental values, we choose the CR rigidity spectrum in the Earth’s orbit [4], which describes well the data over a wide range of energies.

The paper rests on proton intensity observations from GOES-11 spacecraft over the energy ranges of 4–9, 9–15, 15–40, 40–80, 80–165 and 165–500 MeV [5]. At higher energies, we have exploited data on primary CR spectrum variations obtained by the method of spectrographic global survey (SGS) [6, 7]. Modulation amplitudes have been measured from the background level of 6 July 2000.

3. Results of analysis and conclusions
On 14 July 2000, an increase in the CR intensity was recorded by the ground-based network of high-latitude neutron monitors at 10:30 UT. There was no increase in the CR intensity at CR stations located at the points that have geomagnetic cutoff rigidities of more than ~3.5 GV (Figure 1a). Figure 1b presents calculated dynamics of amplitudes of primary CR variations having rigidities of 4 and 10 GV as well as amplitudes of the first (Figure 1c) and second (Figure 1d) spherical harmonics of pitch-angular anisotropy for particles having a rigidity of 4 GV. As the CR intensity near the Earth’s surface was going up, no noticeable increase in amplitude of the first harmonics was observed for the particles...
having a rigidity of 4 GV; at 11:00 – 12:00 UT, however, amplitude of the second harmonics of pitch-angular anisotropy for such particles went up to ~10% (i.e., bidirectional CR anisotropy was observed). This implies that the Earth was in the IMF loop-like structure during this period.

Figure 2 presents rigidity spectra of primary protons over the energy range 1–20 GV (solid lines) to which neutron monitors are most sensitive and which have been determined from GOES-11 measurement data and from world-wide network of neutron monitors, taking account of rigidity spectrum expression from [4] for different time moments when the CR intensity near the Earth’s orbit went up. Dashed curves on the plots indicate spectra under quiet conditions (6 July). One can see that the excess of intensity over the quiet level is observed for rigidities of up to ~4–5 GV, whereas at higher energies, the Forbush decrease that started on July 13 goes on. According to the figure, spectra are not described only by the power function of rigidity over the entire rigidity range. Spectra can be described by the power function of rigidity with value ~−2.4 only over the range 10 to 20 GV, from 10 to 24 UT on 14 July. Over the range 1–20 GV, the closest to the power function of rigidity are the spectra at 10 and 11 UT (γ = −2.3, −2.7, respectively). The spectrum observed later over the rigidity range 1 to ~2, 2.5 GV can also be described by the power function.

Figure 1. a) Amplitudes of variations in intensity of the CR neutron component observed at stations Apatity (R =0.6 GV), Novosibirsk (R =2.78 GV), Irkutsk (R =3.66 GV); b) amplitudes of primary CR variations; c), d) amplitudes of the first and second spherical harmonics of the CR anisotropy for particles having a rigidity of 4 and 10 GV.
Figure 2. CR spectra in the Earth’s orbit (solid line). Dashed line represents the CR spectra under undisturbed conditions on 6 July 2000. Triangles show observation data.

Table 1 lists values of the power function of particle rigidity when approximating the CR primary spectrum in the Earth’s orbit over these ranges. Over the rigidity range 1–2.5 GV, rigidity spectrum $\gamma$ is about $-9$, whereas the upper limit of this range lowers by the end of 14 July.

| Time, UT | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 20  | 22  | 24  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Rigidity range, GV | 1–2.5 | 1–2.5 | 1–2.5 | 1–2.5 | 1–2.5 | 1–2.5 | 1–2.5 | 1–2.5 | 1–2.0 | 1–1.8 |
| $\gamma$ | -8.8 | -9.3 | -8.5 | -8.6 | -8.6 | -8.7 | -8.8 | -8.8 | -8.6 | -8.8 |

Figure 3 demonstrates relative changes in the CR intensity (relative to 6 July 2000) having a rigidity of 2, 4 and 10 GV in the solar-ecliptic geocentric coordinate system for different moments of time at initial moments of GLE. Values of longitudinal angle are plotted on the abscissa; those of latitudinal angle, on the ordinate.
One can see complicated dynamics of intensity of CRs that have different energies, depending on arrival direction of particles. When an enhanced particle flux having a rigidity of 2 GV at 10:00 UT comes from the direction ~ 330°, ~30°, no bidirectional anisotropy is observed for these particles, whereas it is observed for particles having higher energies. At subsequent moments of time, we see the similar distribution topology of intensities of CRs that have different energies, depending on arrival direction of particles. An enhanced particle flux is observed both in the north and south; in the south, however, it is much less intense. At 12:00 UT, distribution of CRs depending on arrival direction of particles is similar to the distribution at 10:00 UT; at 12:00 UT, bidirectional anisotropy is observed for particles having a rigidity of 2 and 4 GV, and no bidirectional anisotropy is observed for particles having a rigidity of 10 GV.

From the above discussion we can draw a conclusion that the CR rigidity spectrum observed during GLE on 14 July 2000 over the range 1 to ~ 20 GV is described not only by power function of particle rigidity: distribution of CRs in the earthward direction varies with time and depends on their energy.

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References
[1] Bombardieri D J, Duldig M L , Michael K J and Humble J E 2006 Astrophys. J. 644 1 565
[2] Bieber J W, Gdroge W, Evenson P A, Pyle R, Ruffolo D, Pinsook U, Tooprakai P, Rujiwarodom M, Khumlumlert T and Mkrucker S 2002 Astrophys. J. 567 1 622
[3] Vashenyuk E V, Gvozdevsky B B, Phelkin V V, Usoskin I G, Mursula K and Kovaltsov G A 2001 Proc. 27th ICRC. 3383 (Hamburg)
[4] Kravtsova MV and Sdobnov V E 2011 Proc. 32th ICRC. 11 229 (Beijing)
[5] http://spidr.ngdc.gov/spidr/index.html
[6] Dvornikov V M, Sdobnov V E, Sergeev A V 1983 Proc. 18th ICRC. 3 249 (Bangalore. India)
[7] Dvornikov V M and Sdobnov V E 2002 Int. J. Geomagn. Aeron. 3 3 217