Rigidity Spectrum and Cosmic Ray Anisotropy during Sporadic Events in July 2000

M. V. Kravtsova and V. E. Sdobnov

Institute of Solar and Terrestrial Physics, Siberian Branch, Russian Academy of Sciences, Irkutsk, 664033 Russia
e-mail: sdobnov@iszf.irk.ru, rina@iszf.irk.ru

Abstract—A spectrographic global survey is performed to study the rigidity spectrum and anisotropy of galactic cosmic rays using spacecraft data and data obtained via ground-based observations of cosmic rays (CRs) by a worldwide network of stations during the GLE of July 14, 2000, and the strong magnetic storm related to the coronal mass ejection (CME) accompanying the solar flare. The CR rigidity spectrum observed over the range of 1 to ~20 GV during this period is shown to be described not only by the power function of particle rigidity; the distribution of CRs in the earthward direction varies over time and depends on their energy.

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INTRODUCTION

An increase in CR intensity (a GLE) was recorded by high- and mid-latitude neutron monitors on July 14, 2000, after 10:30 UT. This increase was related to the 3B/X5.7 solar flare that occurred in active region 9077 (heliocoordinates N22°, W07° at 10 : 30 UT). The increase in CR intensity of July 14 was accompanied by a Forbush decrease that started on July 13, 2000. A number of works have dealt with this event [1–3], providing time profiles of CR intensity and anisotropy from the worldwide network of stations and CR spectrum values (on the assumption that this spectrum is described by a power function) and the pitch-angular distribution of energy protons at the boundary of the Earth’s magnetosphere. On July 15, we recorded a strong magnetic storm and an increase in CR intensity, both associated [4] with the coronal mass ejection (CME) accompanying the solar flare. In that period, the speed and magnetic field modulus of the solar wind (SW) reached ~1000 km s^{-1} and 60 nT, respectively. The Dst index during the main phase of the geomagnetic storm was approximately −300 nT. The decline in the CR intensity observed by high-latitude neutron monitors was approximately −15%, while the decline observed by middle-latitude monitors was −10%.

DATA AND METHOD

To approximate experimental values, we chose the CR rigidity spectrum for Earth’s orbit in [5] since it provided a good description of the data over a wide range of energies.

Our work was based on the hourly observational data on proton intensities provided by the GOES-11 satellite over the energy ranges of 4–9, 9–15, 15–40, 40–80, 80–165, and 165–500 MeV [6]. For higher energies, we used data on primary CR spectrum variations obtained via a spectrographic global survey (SGS) [7, 8]. The background level of July 6, 2000 was used in calculating modulation amplitudes.

RESULTS AND DISCUSSION

On July 14, 2000 (10:30 UT), the ground-based network of high-latitude neutron monitors recorded an increase in CR intensity. No increase in CR intensity was observed at CR stations located at the points where geomagnetic cutoff rigidities were more than 3.5 GV (Fig. 1a). Figure 1b presents the dynamics of amplitudes of primary CR variations with rigidities of 4 and 10 GV, calculated via SGS, along with amplitudes of the first (Fig. 1c) and second (Fig. 1d) spherical harmonics of pitch-angular anisotropy for particles with a rigidities of 4 GV. As the CR intensity near Earth’s surface went up, no noticeable increase in amplitude of the first harmonics was observed for particles with rigidities of 4 GV; at 11–12 UT, however, the amplitude of the second harmonics of pitch-angular anisotropy for such particles went up to 10% (i.e., bidirectional CR anisotropy was observed), indicating that the Earth was in a loop-like structure of the interplanetary magnetic field (IMF) during this period.

Figure 2 shows the rigidity spectra of primary protons over the energy range of 1–20 GV (solid lines) to which neutron monitors are most sensitive, and which were derived from the measurement data provided by GOES-11 and worldwide network of neutron monitors, with due account taken of the expression for the rigidity spectrum from [5] for different moments in time as the CR intensity near Earth’s orbit rose. The dashed curves on the plots represent the spectra under
quiet conditions (July 6). We can see that the intensity is over the quiet level for rigidities of ~4–5 GV. At higher energies, the Forbush decrease that started on July 13 continues. According to the figure, the spectra are not described by one power function of rigidity over the range of rigidities. Spectra can be described by one power function of rigidity with a value of $\gamma \sim -2.4$ only over the range of ~10–20 GV, according to data obtained on July 14 (from 10:00 to 24:00 UT). The spectra observed at 10:00 and 11:00 UT are closest to the power function of rigidity over the range of 1–20 GV ($\gamma$ exponents $-2.3$ and $-2.7$, respectively). The spectrum later observed over the rigidity range of 1 to 2–2.5 GV can also be described by this power function.

The table lists values of the power function when approximating the CR primary spectrum in Earth’s orbit by the power function of particle rigidity over these ranges. Over the rigidity range of 1–2.5 GV, the rigidity spectrum $\gamma$ is approximately $-9$, and the upper limit of this range falls by the end of the day on July 14.

Figure 3 shows the relative changes in CR intensity (relative to July 6, 2000) with rigidities of 2, 4, and 10 GV in the solar–ecliptic geocentric coordinate system for different moments in time at the initial moments of GLEs.

We can see the complicated dynamics of the intensity of CRs that have different energies, depending on arrival direction of particles. When an enhanced particle flux with a rigidity of 2 GV at 10:00 UT comes from direction ~330°, ~30°, no bidirectional anisotropy is observed for these particles, but it is observed for particles with higher energies. At subsequent moments in time, we see a similar distribution topology for the intensities of CRs with different energies, depending on direction of particle arrival. An enhanced particle flux is observed in both the north and the south; in the south, however, it is much less intense. Depending on the direction of particle arrival at 12:00 UT, the CR distribution pattern is similar to the one at 10:00 UT; in this case, however, bidirectional anisotropy is observed for particles with rigidities of 2 and 4 GV, and no bidirectional anisotropy is observed for particles with rigidities of 10 GV.

During the Forbush decrease of July 15–16 associated with the coronal mass ejection accompanying the solar flare, the rigidity spectrum of variation amplitudes is not a power function of particle rigidity. Particle modulation is maximal over the range of rigidities from ~3 to 8 GV. At the stage of decrease development, the extremum shifts to lower rigidities; at the recovery stage, to higher rigidities.

The increased values for amplitudes of the first spherical harmonics and bidirectional CR anisotropy (see Fig. 1) indicate that Earth was in the region of

<table>
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<th>Time, UT</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
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<th>18</th>
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<td>R rigidity range, GV</td>
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<td>$-8.5$</td>
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