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Variations of Angular Distribution of Cosmic Rays during GLE Period on January 20, 2005

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Abstract: The variations of anisotropy of primary spectrum of cosmic rays (CR) during the period of CR intensity increasing on 20 January, 2005, have been obtained using the method of spectrographic global survey according to the data of ground-based observations of CR at the world-wide network of stations. It is shown that in the flare main phase a CR strong anisotropy and the particle flux to the south of the Sun were observed. At a later time, the anisotropy direction has periodically changed from north-southern to the opposite.

Introduction

A significant increase was registered of cosmic ray (CR) intensities associated with the solar flare of X7.1 importance that began at 06:36 UT in the 10720 area with coordinates N12W58, at the world-wide network of neutron monitors on January 20, 2005. Such a ground level event (GLE) of CR intensity is the most important one since February 23, 1956. It should be noted that the registered GLE occurred during the recovery phase of Forbush decrease, which began after the geomagnetic storm with a sudden commencement on January 17, 2005. A narrow relativistic neutron stream reached the Earth at ~ 06:50 UT. The maximum of CR intensity variation amplitudes within five minute intervals on January 20, 2005, at the southern polar stations run to several thousand percent, whereas at the northern polar stations, the increase was as much as several hundred percent [1], that means high degree of the CR anisotropy. In [2, 3] the CR anisotropy in the event has been studied by using a technique [4] under the assumption that the anisotropy results from the dependence of energetic particle intensity of solar origin on their pitch angle in the interplanetary magnetic field (IMF), i.e. the assumption that the propagation of the particles accelerated on the Sun occurs in external magnetic fields. The authors [5, 6] obtained the results pointing to the fact that polarization electric fields are generated as solar cosmic rays (SCR) propagate in inhomogeneous fields of the heliosphere. The polarization electric fields act on background particles of solar wind (SW) plasma and on galactic CR (GCR), transforming the energetic spectrum and the angular distribution of GCR. In this instance, anisotropy components orthogonal to IMF vector should also be taken into account along with the CR intensity dependence on the pitch angle of the particles in IMF.

Variations of the CR anisotropy in terms of the peculiarities mentioned above are studied in this paper.

Data and Technique

For the analysis, the data averaged over five minute intervals are used from the world network of neutron monitor stations, as well as the data corrected for pressure from the Sayan spectrographic complex. Amplitudes of the increase have been calculated from the intensity background level within an hour interval from 05:00 to 06:00 UT on January 20, 2005. The data of 35 neutron monitors have been employed. Fig. 1a shows time profiles of the intensity observed relative to increases at the world network stations: South Pole (R_c=0.09 GV), Tixie Bay (R_c=0.45 GV), Irkutsk 2000 m (R_c=3.56 GV) from 06:00 to 19:00 UT on January 20, 2005.

As evident from Fig. 1a, this event is characterized by distinction in time of the commencement of the CR intensity increase, as well as by different value of the increase amplitude at CR stations of southern and northern hemispheres. Thus, at South Pole station, the peak of intensity increase came at 06:55 UT, with the intensity increased more than 30 times. In Tixie Bay and Irkutsk, the peak of intensity increase came at 07:10 UT, while the intensity increased ~ 3 and ~1.2 times respectively. This testifies a significant anisotropy in angular distribution of primary particles.

Processing of the data of the world network of CR stations has been performed by the method of spectrographic global survey [5], which is based on the assumption that the anisotropy in distribution of CR along the line of coming is due to dependency of their intensity on a pitch angle in IMF, and due to a density gradient at the Larmor radius of particles. To describe the CR anisotropy, we employed three spherical harmonics, while for approximation of rigidity dependences, the sets in rigidity inverse degrees were restricted by three terms for the isotropic component and by two ones for each of anisotropy components.

The Analysis Results

In Fig. 2b, the time profiles of variations of the CR primary intensity with 4 and 6 GV rigidities are presented. The CR intensity increase with these rigidities began at 06:55 UT and peaked at 07:00 UT on January 20, 2005. The maximal increase of the CR intensity was ~ 1000% for the particles with rigidity 4 GV and ~700% for the particles with rigidity 6 GV. Intensity decrease of different energy particles occurred with different rate. Thus, for example, the CR intensity with rigidity 6 GV decreased ~20 times for ~2 hours, while the CR intensity with rigidity 4 GV decreased for ~6 hours.

Fig. 1c, d presents the time profiles of the amplitudes of the first and second spherical harmonics of the anisotropy for the particles with rigidity 4 GV. The highest degree of anisotropy can be observed in the initial stage of the flare. The amplitude of the first spherical harmonic begins increasing at 06:45 UT and peaks (about 100%) within 06:55–07:05 UT; then it falls and keeps a level of 10–20 % during the whole considered period. The amplitude of the second spherical harmonic starts increasing at 06:50 UT and peaks (about 100 %) within 06:55–07:05 UT, then, at 07:20 UT, it goes to zero except some five minute periods, in which its value runs to several percent. Fig. 2 shows relative variations of the CR intensity with R = 4 GV depending on asymptotic directions in the solar ecliptic geocentric coordinate system for different moments on January 20, 2005. The crosses indicate hour values of IMF direction measured at spacecraft.

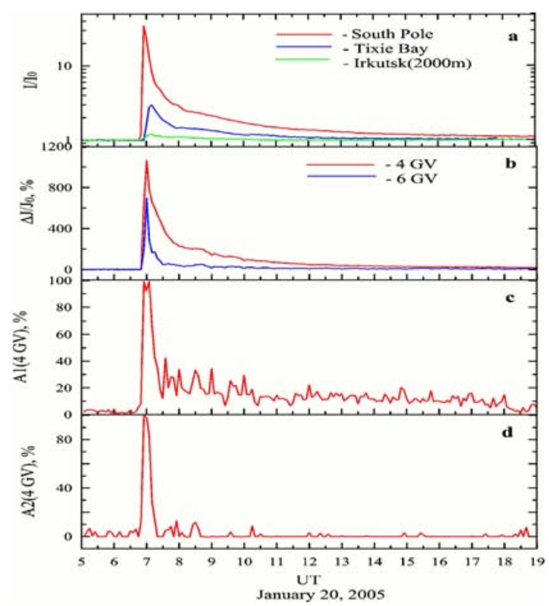

Figure 1: The time profiles of the relative variations of the CR intensity at different stations of the world network (a); the time profiles of the CR intensity variation amplitudes with rigidity 4 and 6 GV (b); the time profile of amplitudes of the first and second spherical harmonics for the particles with rigidity 4 GV (c, d) respectively.

The analysis of the distribution of the particles with rigidity R = 4 GV along the line of coming testifies relatively stable behaviour of the CR anisotropy during the period of its maximal values. Thus, in the initial phase of GLE at 06:55 UT, an increased particle flux came from the direction about 100°, –75° (5100 %), at 07:00 UT – from the direction ~ 60°, –65° (7500%). At 07:05 and 07:15 UT, it came from the direction ~15°, –60° (2300% and 850%, respectively). During the whole period, particle coming was from the directions orthogonal to IMF vector. Later on, the increased particle flux came from ~120° - 170°, ~0° - –30° directions coinciding with the IMF direction.

Discussion and Conclusions

As evident from the given results, the CR anisotropy in the investigated event is not described by the simplest dependence of the intensity on a pitch angle of particles in IMF. When observing anisotropy maximal values, its components orthogonal to the IMF vector are dominant. If it is suggested that such anisotropy behaviour is due to the particle density gradient at the Larmor radius, then, when observing IMF orientation, the particle density gradient should be directed towards the Sun both in the phase of particle intensity increase and in the phase of its decrease (see Fig. 1b). From this it follows that the observable time profile of the CR intensity is caused not by the passage of a bunch of particles with energy of few GeV by the Earth, but by time variations of their intensity as result of acceleration of background CR by polarization electric fields, originated when propagating SCR through inhomogeneous fields of the heliosphere.

Acknowledgements

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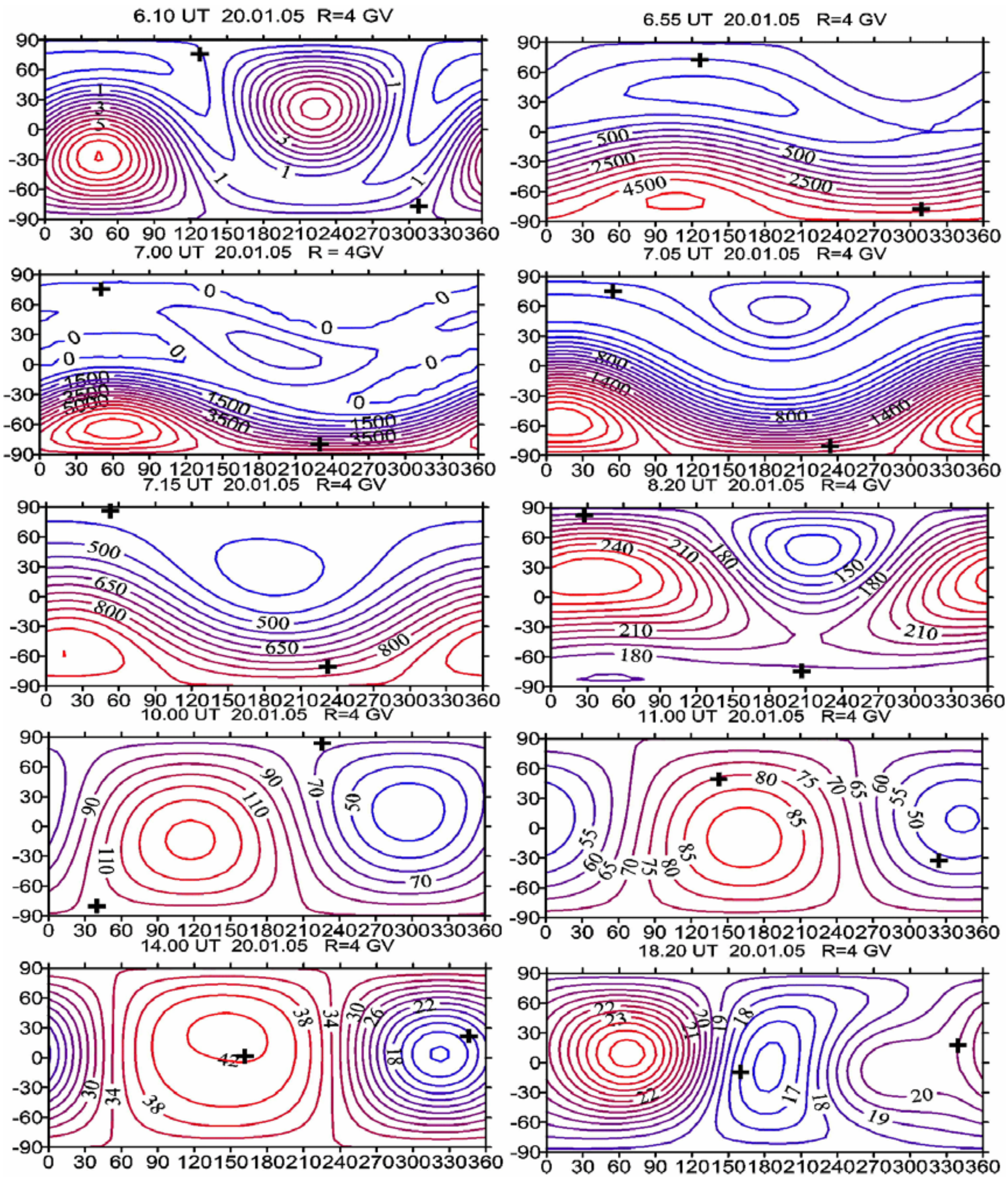

Figure 2: Relative variations of the CR intensity with R=4 GV depending on asymptotic directions in the GSE-coordinate system for different moments. The crosses indicate the directions, which are parallel and antiparallel to the magnetic field.