Long-term variations of the cosmic ray anisotropy by the data from neutron monitor network.

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Abstract— **The basic properties of the equatorial component of cosmic ray vector anisotropy were studied over two almost full magnetic solar cycles (1965-2003) by the hourly characteristics of cosmic ray of rigidity 10 GV derived by the Global Survey Method from the neutron monitor network data.**

Anisotropy in disturbed days has bigger amplitude and distinguishes by the phase from the anisotropy in the quiescent days, but these differences are much less than that in the solar wind parameters or in the geomagnetic activity indices. Except of an evident quasi 22 year recurrence there are numerous anomalies isolated, with characteristic time of several months, especially in the periods of low solar activity. It is shown that inhomogeneous phase distribution and amplitude-phase relation are the main properties of the anisotropy and exist for all long enough time intervals gradually changing within the solar cycles.

The performed research leads to a conclusion that even during the perturbed days the main properties and long term behavior of the cosmic ray anisotropy are determined mainly not by separate disturbances in the solar wind but by the long term recurrent changes on the Sun and in the heliosphere.

I. Introduction

Anisotropy is one of the basic peculiarities of the galactic cosmic rays (GCR) are observed by the ground methods, and it is sufficiently steady by the magnitude and direction. The existence and main properties of the GCR anisotropy are being well explained in the frame of convective-diffusion model, proposed in [1] and then improved by many authors, for example [2, 3, 4].

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The steadiness of anisotropy is conditioned by the existence of two definite directions in each point of the interplanetary space. The first one is the radial direction practically coincided with the vector of solar wind (SW) velocity. The second one is specified by the interplanetary magnetic field (IMF) direction. Although the IMF vector is much more variable than SW velocity, nevertheless, it has two predominant locations along the Archimedean spiral. These definite directions change weakly within the solar activity cycle and should not depend on the magnetic solar cycle. However, it is already known during the more than 50 years [5] that averaged characteristics of the vector GCR anisotropy vary with 11- and 22-year periodicity. By the beginning of 70-s after researches by [6, 7] it became clearly, that anisotropy variations in the magnetic cycle are defined by the hall component variations and caused by the transverse gradient of the CR density.

Long time variations of the CR anisotropy have been studied in many papers, for example, by [8, 9]. At these analysis more often data from separate ground level CR detectors have been used, from which solar diurnal variation of anisotropy have been isolated on the basis of daily mean values. In this paper we use hourly characteristics of the CR anisotropy derived from the worldwide neutron monitor network data. The aim of this work is to understand better long-term behavior of the CR anisotropy, revise some its peculiarities, and to obtain averaged by the time some characteristics of the CR anisotropy as well, which, in particular, is necessary for a calculation CRA (cosmic ray activity) [10] indices.

II. Data and Method

Data base, in this analysis used and created in IZMIRAN, is embedding parameters of the CR density and anisotropy and data on the solar wind, IMF, solar data and indices of geomagnetic activity as well [11-13]. Density and anisotropy for the CR of 10 GV rigidity were calculated by the global survey method (GSM) [14] for the period 1965-2003 by the hourly data from neutron monitor network. All data were divided by the relatively quiescent and disturbed periods.

The background, relatively quite condition and corresponding background anisotropy exist for each sufficiently extended period (for example, for each month).

The CR anisotropy is defined (as it follows from convective-diffusion model) by the gradient of CR density and by different SW characteristics: its velocity and the IMF intensity, direction and level of regularity. Selecting the background periods, in the first turn we have to exclude days with significant disturbances of the SW, when intensity of the IMF increases and its direction deflects from a normal and varies significantly. At the same time the CR density changes and CR gradient differs from a normal one by the magnitude and direction. All this should cause an anomalous CR anisotropy. The periods of significant geomagnetic disturbances seem to be also excluded: firstly, they are able to be an indicator of the interplanetary disturbances that is essentially useful when direct SW measurements are absent; secondly, geomagnetic disturbances lead to the changes of asymptotic directions for the particles by NM recorded, and thus, contribute to the anisotropy. These changes usually are not large, but geomagnetic disturbance in some manner destroys the homogeneity of time sets of the anisotropy characteristics.

There are two approaches to a selection of the disturbed days: 1) to take only the SW characteristics, since the local perturbations in the SW define both geomagnetic disturbance and local variations of the CR; 2) instead of the SW parameters to involve parameters of geomagnetic activity and CR density variations. The second approach turned out to be more preferable because of the large gaps in the SW data. Criterion of the disturbed day selection embedded additionally: Ap-index >19, i. e. practically all days with magnetic storms. Also the days with the big CR density variations (>1.5%) were considered as disturbed ones.

III. Results and Discussion

Data for 341856 hours were available in the study performed. To avoid the effect from GLE the 40 short periods were excluded from the analysis, which is in total 542 hours (0.16% from the whole volume). The rest 341314 hours were divided on the quiet and disturbed accordingly to the method above described. In Table 1 the number of hours, averaged evaluations of the CR anisotropy (Ax, Ay, Axy), geomagnetic parameters (Ap, Ae) and parameters of the interplanetary space (Vsw, Bimf) are entered for quiet and disturbed conditions.

TABLE 1.
PARAMETERS OF ANISOTROPY AND SOLAR WIND IN THE WHOLE, QUIET AND DISTURBED PERIODS.

	Whole amount	quiet	disturbed
Number of hours	341314	231456	109858
Ax	0.08±0.0007	0.06±0.0007	0.12±0.0015
Ay	0.40±0.0008	0.38±0.0009	0.44±0.0017
Axy	0.62±0.0007	0.57±0.0007	0.72±0.0015
Ae	0.41±0.0011	0.39±0.0012	0.46±0.0024
Ap	26.74±0.09	8.48±0.01	26.74±0.09
Vsw		416.2±0.2	495.0±0.4
Bimf		5.59±0.005	8.91±0.02

One can see that anisotropy in disturbed days has a bigger amplitude and differs by the phase from that in the quiet days, but these distinctions are not big and they are much less than in the parameters of solar wind and geomagnetic activity indices.

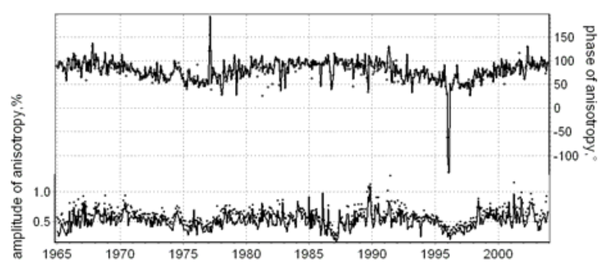

Fig. 1. Monthly values of the amplitude and phase of the CR solar diurnal anisotropy for the quiet (solid lines) and disturbed (points) periods derived by the hourly data through the 1965-2003.

In Fig.1 in the long term behavior of monthly means of the CR anisotropy amplitude and phase derived by the hourly data, first of all, the 22-year recurrence of the phase and 11-year recurrence of amplitude are notable. On this background the numerous fluctuations and anomalies are seen, certainly not of statistic origin since the statistic errors are very small here. Especially big deflections in the phase behavior revealed in 1976 and 1996- in the minima of the solar cycles. It is pertinent to note that analogous behavior was observed also in 1954 [15 and references there].

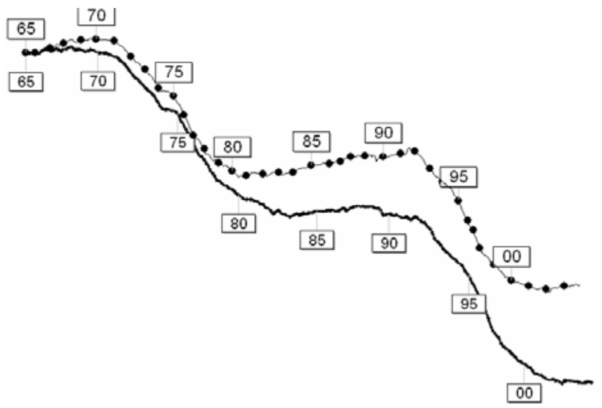

Fig. 2. Vector diagram of solar-diurnal anisotropy for the period 1965-2003: points are for the quiescent and tick solid line –for the disturbed days.

In Fig.2 long term changes of the anisotropy vector are shown during the whole period under consideration for the quiescent and disturbed days. These monthly values are obtained by the hourly parameters of CR anisotropy derived from the neutron monitor network data by the GSM method. The most noticeable changes of the anisotropy phase have occurred after the reverse of the solar magnetic field in 1970-1972 and 1991-1992. However, well pronounced changes are also seen as before so after the reverse, in the solar activity minimum, when the abrupt decrease of the anisotropy amplitude is also indicated.

A. Phase distribution and amplitude-phase relation of anisotropy

The phase distribution looks apparently the same for the quiescent and disturbed days (Fig. 3). In both these periods the anisotropy maximum was found within 72-96°, i.e. close to co-rotation direction.

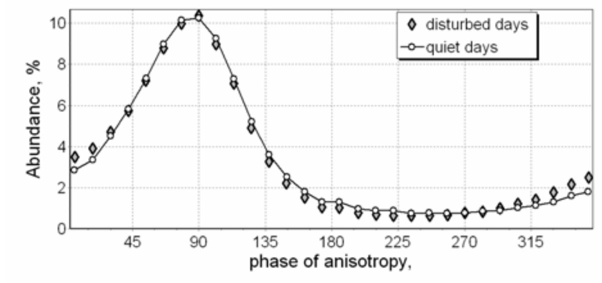

Fig.3. Frequency – phase distribution of the solar-diurnal anisotropy for the quiet and disturbed days.

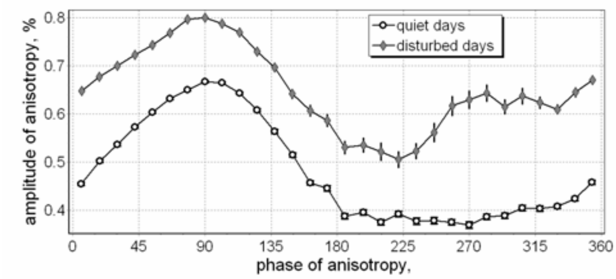

Fig. 4. Amplitude-phase distribution of the CR anisotropy over the period 1965-2003 for the quiet and disturbed days.

From the wide sector 190-320°, corresponding to the forbidden directions [4], the CR flux ranks in order below than from around the mode. Maximum and minimum frequencies calculated for 12-grad sectors differ in 13.5 for the quiet days and in 16.5 for disturbed ones.

Similarity of the amplitude-phase relation for the quiet and disturbed days is also evident (Fig. 4). Mentioned above an increase of amplitude in the disturbed days exists over all the phases. However, the area of the lowest amplitudes in disturbed days (180-240°) is significantly narrower than that in the quiet days, and the biggest distinguishes are observed in the interval (260 -360°).

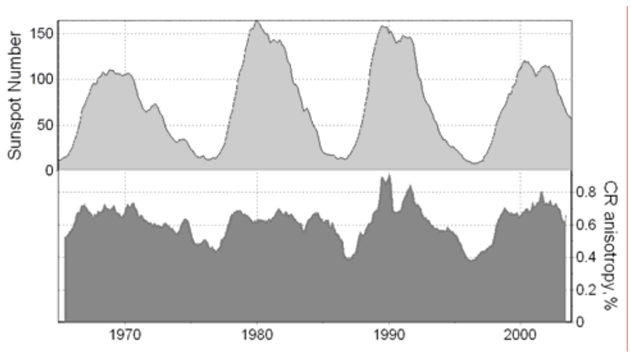

Figure 5. Correlation of the anisotropy amplitude with the sunspot number

In Fig. 5 and 6 a correlation is clearly seen between CR anisotropy amplitude and 11-year solar cycle (Fig.5), and between anisotropy phase and magnetic solar cycle, which is present here by means of the polar magnetic solar field [16] (Fig. 6).

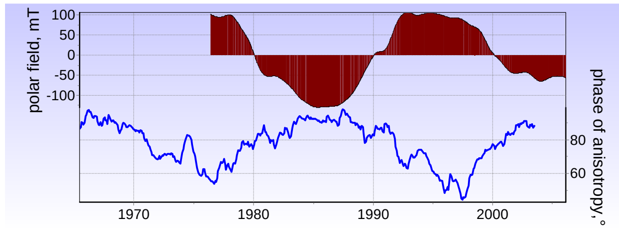

Figure 6. Correlation of the anisotropy phase and polar magnetic solar field

B. Dependence on the Solar Wind velocity

Solar wind speed is the only experimentally measuring characteristic, which is introduced in theoretical formula for the anisotropy calculations. In Fig. 7 the amplitude of anisotropy indicates practically independence on the SW velocity and its phase weakly depends on the SW velocity. In a whole, some growing of the phase is observed (or, its closing to the co-rotation direction) along the velocity increase.

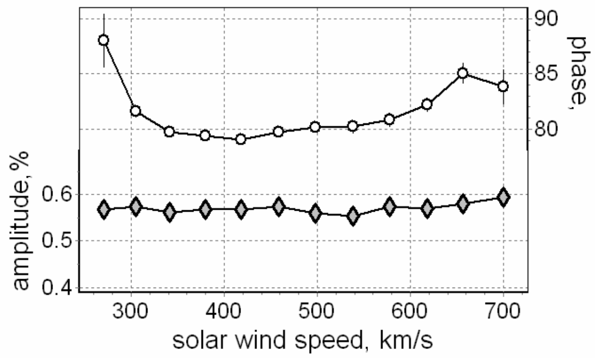

Figure 7. The anisotropy amplitude and phase versus the solar wind velocity in the quiet days.

However, around the small speeds (<300 km/s) the reverse dependence is revealed. The mean phase under velocity <300 km/s is close to the co-rotation direction likely as under the high velocities (>650 km/s).

If the high velocity (in this case of the quiescent days) is attributed to the high speed streams from the coronal holes, then low speeds appear nearly the heliospheric current sheet. In these specific conditions not only velocity but also CR gradient will be rather anomalous.

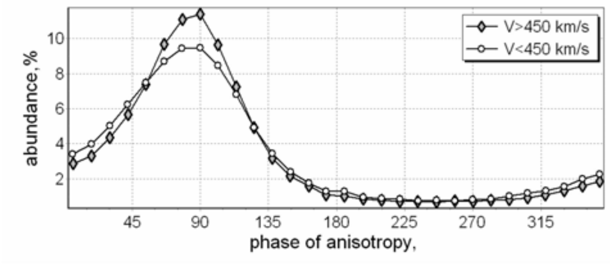

Fig. 8. Frequency- phase distribution of the solar diurnal anisotropy under different speeds of the solar wind.

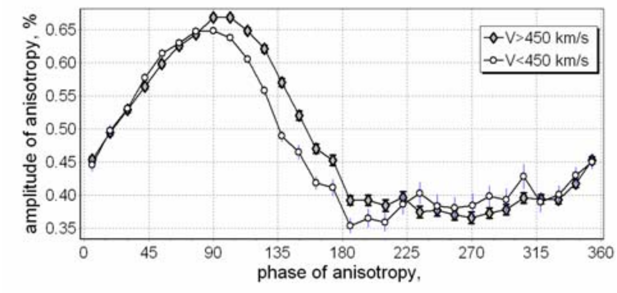

Fig. 9. Amplitude-phase interrelation of the solar diurnal anisotropy under different speeds of the solar wind.

The frequency-phase and amplitude-phase distributions of the CR anisotropy were also found separately for SW velocity >450 km/s and < 450 km/s. These dependences are present in Fig. 8 and Fig.9.

IV. Conclusion

Many years observations by the neutron monitor network show that long term behavior of the equatorial component of CR anisotropy regularly and sufficiently well reflect the solar recurrence. The mean value of anisotropy is determined by the phase of solar cycle, and its mean direction- by the phase of solar magnetic cycle. It is true not only for quiescent days but for disturbed days also. Characteristic and rather inhomogeneous phase distribution and amplitude-phase interrelation are the main properties of the anisotropy which exists for all long enough intervals gradually changing within the solar cycles. Besides of the gradual and regular changes the significant anomalies (deflection from normal direction) with characteristic time of several months are inherent to CR anisotropy behavior, which are more noticeable under the low solar activity. A performed study allows the conclusion that even within disturbed periods the main properties and long term behavior of the CR anisotropy are defined not by separate disturbances of the solar wind, but long term recurrent changes on the Sun and in the heliospere.

Acknowledgment

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