Long term variations of the amplitude-phase interrelation of the cosmic ray anisotropy first harmonic

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Abstract. There are some special directions in the interplanetary space, which are set by the solar wind velocity and position of the interplanetary magnetic field lines. Due to this a strongly inhomogeneous distribution of the phases and amplitude-phase interrelation appear in the first harmonic of the cosmic ray anisotropy. To study the long term variations of cosmic ray anisotropy the characteristics of its first harmonic defined for each hour by global survey method have been used throughout the period 1957-2010. For each year of this period longitudinal distribution of the cosmic ray vector anisotropy and its amplitude-phase relation were obtained. The results clearly demonstrate the dependence of cosmic ray anisotropy variations on the solar activity and solar magnetic cycles. Periods of specific behavior of the anisotropy are extracted and discussed. The results by this study obtained are consistent with the convection-diffusion model of the anisotropy.

1. Introduction

The anisotropy of galactic cosmic rays (GCR) is constantly observed in the solar wind near the Earth, and can be represented as a vector. The first spherical harmonic of the anisotropy (the magnitude and direction of its vector) is well described by the convection-diffusion model [1, 2]. One consequence of convection-diffusion model is the amplitude-phase interrelation of the first harmonic of anisotropy, which was predicted theoretically [3] and later confirmed experimentally [4, 5, 9].

In this paper, the first systematic study of long-term variations of amplitude-phase interdependence and phase distribution of the anisotropy was performed on the basis of data for 53 years (1957-2010 years) – five solar cycles.

2. Data and Method

We used a database of cosmic ray variations, which was created in IZMIRAN. This database contains various parameters of the interplanetary medium (the characteristics of the solar wind, interplanetary magnetic field, etc.), cosmic rays (density, anisotropy, etc.), as well as indexes of geomagnetic activity and solar parameters. Density and anisotropy for the CR of 10 GV rigidity were calculated by the global survey method (GSM) [6] by the hourly data from neutron monitor network. We did not use the periods when the ground level enhancements (GLE) are observed.

3. Results and Discussion

In figure 1, for the 1957-2010 years the phase (longitude) distribution of the first harmonic of the CR anisotropy and its amplitude-phase dependence are presented. To get the plotted points, longitudes

were divided into intervals of 10°. The maximum of the phase distribution (distribution of the number of hours with a fixed phase of the observable CR anisotropy over the whole period) is about 90°, i.e., in the direction from the east. Maximum of the anisotropy amplitude is very close to the phase maximum.
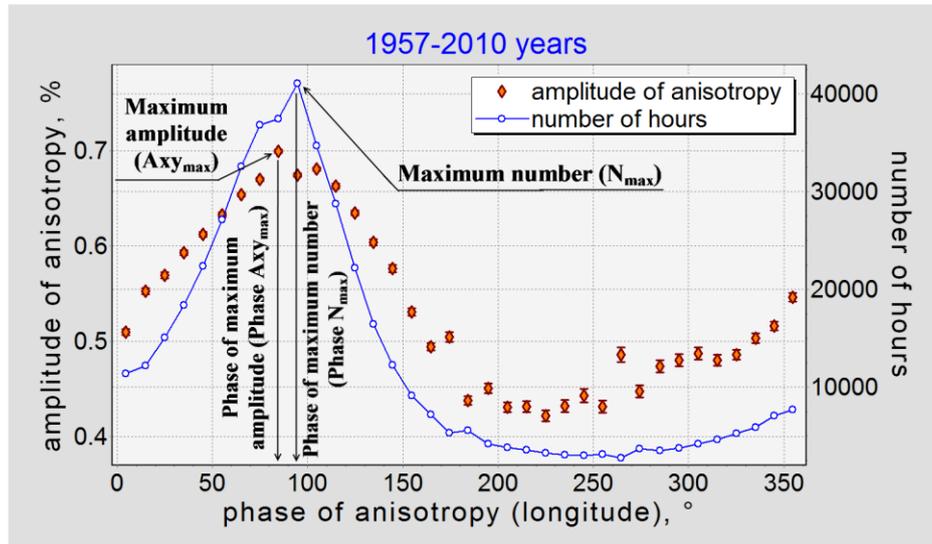

Figure 1. Amplitude-phase interrelation of solar-diurnal anisotropy and its phase distribution for 1957-2010 years

These smooth dependences are the result of averaging for a long period. In this figure data for 468313 hours are combined, which explains the small statistical errors. It is clear that results for some subsets of these data may be various, for example, depending on the magnetic cycle or solar activity cycle. The amplitude-phase dependences and phase distributions were obtained for each year separately.

Figure 2 shows the time dependence of the anisotropy parameters, marked on figure 1.
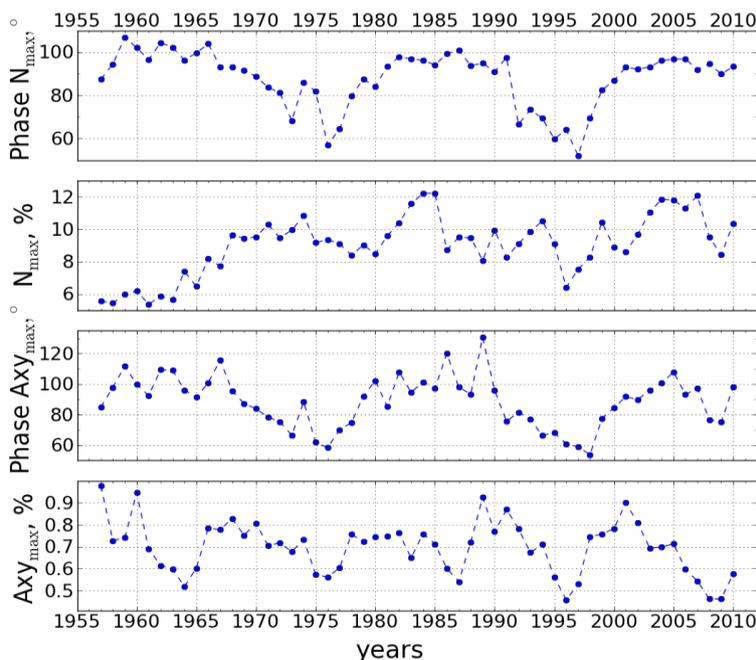

Figure 2. Time dependence of the anisotropy parameters: distribution of the maximum phase (PhaseN_{max}), portion of hours with the maximum distribution (N_{max}), the maximum amplitude (Axy_{max}) and phase (Phase Axy_{max}) of the diurnal component of CR anisotropy.

A position of maximum in a phase distribution is presented in the top panel; the second panel shows the portion of hours which falls on the maximum of distribution. At the two lower panels (figures 2) are similar dependences for maximum magnitude and phase of maximum amplitude of the anisotropy. In the presented figure we can see the 11-year variations in the behaviour of the maximum amplitude of anisotropy and frequency of appearance of a particular phase (the mode of phase distribution). The 22-year variations in change of the phase of maximums are clearly pronounced for both parameters. Thus these parameters behave like the amplitude and phase of the first harmonic of the anisotropy [4, 6-10].

The dependence of the phase of the anisotropy on the magnetic cycle reveals well near the minimum of solar activity that can be clearly seen in figures 3 and 4. To obtain these figures, we chose the hours in which the Ap-index was less than 10nT, the number of sunspots was <50, for the periods of negative and positive polarity of the general solar magnetic field, respectively.
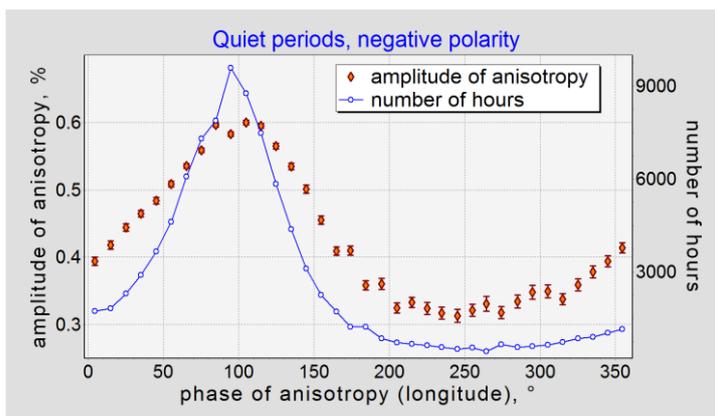

Figure 3. Amplitude-phase interrelation of solar-diurnal anisotropy and its phase distribution in the quiet periods at the negative polarity of the general solar magnetic field (1960-1969, 1982-1989, 2001-2010 years).
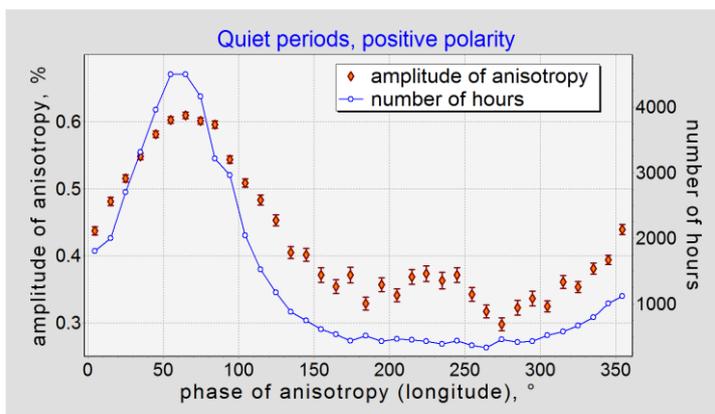

Figure 4. Amplitude-phase interrelation of solar-diurnal anisotropy and its phase distribution in the quiet periods at the positive polarity of the general solar magnetic field (1971-1978, 1992-1999 years).
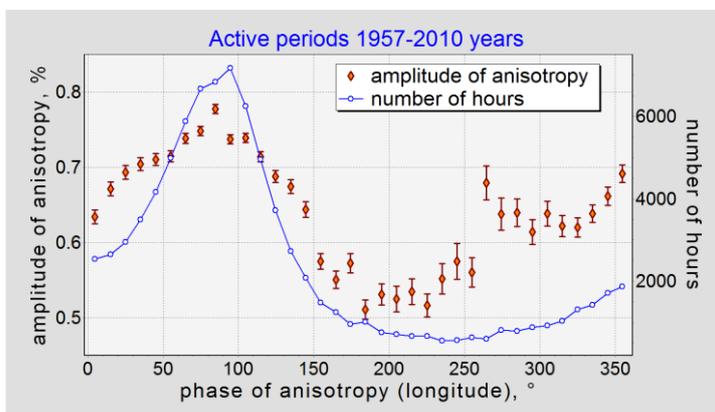

Figure 5. Amplitude-phase interrelation of solar-diurnal anisotropy and its phase distribution in the active periods during the 1957-2010.

During the negative polarity of the general solar magnetic field (figure 3) the maximum of phase distribution is about 95°, the maximum of the anisotropy amplitude is about 100°. For positive polarity (figure 4) the maximum of phase distribution is about 55°-65°, the maximum of the anisotropy amplitude – approximately 50°-70°. However, in figure 4 for the positive polarity of the general solar magnetic field is seen the second peak for the amplitude of the anisotropy – around 200°-260°. This may be due to the anomalous 1996 year and similar periods when the amplitude of the anisotropy did not have a pronounced maximum because of very small magnitude.

To study the active periods we selected hours with Ap-index > 20, independently of the number of sunspots and polarity. For active periods (figure 5) the maximum of phase distribution is about 85°, the maximum of the anisotropy amplitude is about 95°. But about 260°-270° there is another increase of the anisotropy amplitude. Apparently, this is evidence that during a disturbance anomalously large values of the CR transverse gradient are occurred together with the preferred direction of the IMF. This combination can create a large anisotropy in the direction opposite to normal.

4. Conclusions

The change of the phase distribution and the amplitude-phase dependences of the solar-diurnal anisotropy, considered for a long time interval (1957-2010), obey main the basic solar cycles.

Essentially inhomogeneous phase distribution and a significant the amplitude-phase dependence exist almost constantly, but in some periods can be greatly reduced. It occurs in disturbed periods and in certain periods of low solar activity during the positive polarity of the general solar magnetic field.

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