Semi-Diurnal Variation of Galactic Cosmic Rays

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Abstract

Variations of the second angular distribution of galactic cosmic rays are analyzed by data from the world station network neutron monitors using the global survey method for the 1964 to 1999 period. In the high–energy particle region, the 11–year change of semidiurnal variation amplitude with a minimum during years of low solar activity has been determined. In the energy region of particles registered by neutron monitors, the 22–year variation of semi- diurnal anisotropy maximum time is observed. The influence of shearing flows in solar wind on anti–symmetric diurnal and semi–diurnal variations is shown.

1. Introduction

The second spherical harmonic in the cosmic ray distribution is formed by the solar wind shearing flow in the simplest case. It is known [1] that in the moving medium having a speed $\vec{u}$, the observed see the anisotropy with a maximum in the direction opposite to the speed and the magnitude $(\gamma+2)u/v$, where $\gamma = 2.5$ is an index of differential energy spectrum, $v \sim c$ is the velocity of cosmic ray particles. If the plane–parallel flow has a shift (gradient) of velocity, $\vec{g}$, whose direction is perpendicular to itself speed, then the anisotropy in directions is given by

$$\delta f/f_0 = (\gamma+2)\frac{g\lambda}{v}\cos\Theta\cos\alpha, \tag{1}$$

which is proportional to a mean free path λ and directrix cosines of particle movement relative to "axes" $\vec{u}$ and $\vec{g}$. In the spherical coordinate system with the polar axis, parallel to $\vec{g}$, and a longitudinal angle counted from the speed direction $\vec{u}$ will be

$$\delta f = \frac{(\gamma+2)}{2}\frac{g\lambda}{v}\sin 2\Theta\cos\varphi f_0. \tag{2}$$

If the Earth's rotation axis is parallel to $\vec{g}$, then in the case we will observe known as "antisymmetric" diurnal variation. In a sloping position relative to $\vec{g}$ the semi–diurnal variation appears. In reality, no speed field of solar wind, and the speed field of cosmic rays (which it is considered as a gas) is of importance. At each point

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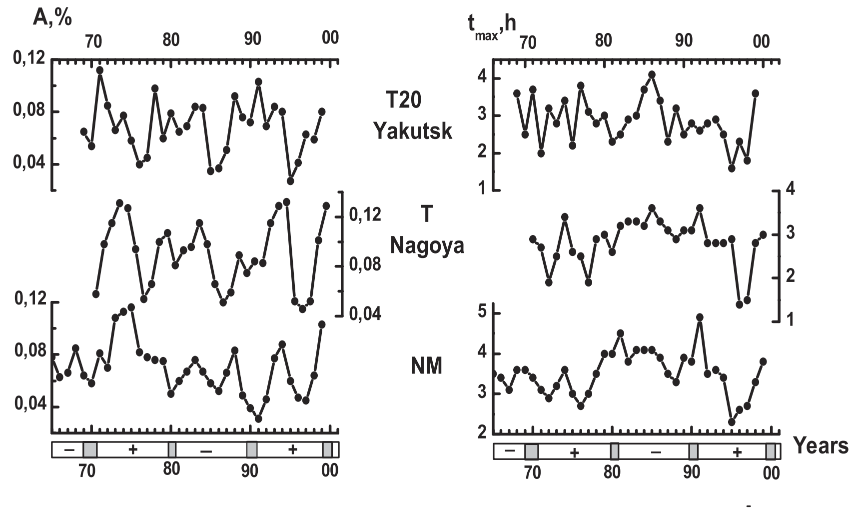

Fig. 1. Long-term changes of the amplitude and maximum time of the semi-diurnal anisotropy.

of space, such a frame of reference, moving at a velocity $\vec{w}$, can be determined, in going to which the directed movement of cosmic rays disappears. This value may be named as a current velocity of cosmic rays. It does not always coincide with the speed $\vec{u}$. Namely, a shift of speed must give rise to the second spherical harmonic. As calculations imply in the "base" model of cosmic ray heliospheric modulation, the positive polarity of a general magnetic field of the Sun is accompanied by the disappearance of the anisotropy at enough long distances from the neutral surface, and, consequently, there is a shift of the current velocity.

2. Analysis and Results

Fig.1 presents annual values of the amplitude and phase of the primary semi–diurnal anisotropy of cosmic rays by an underground azimuth telescope at Yakutsk at the depth of 20 m w.e.(N–S; $R_m = 120$ GV) for 1969-2001, a ground telescope at Nagoya (N–S; $R_m = 65$ GV) for 1970–2000 and neutron monitor world network data obtained by the global survey method for 1964–1999. The primary vectors of semi–diurnal anisotropy are obtained by means of the "receiving vector" method with the use of the energy spectrum $A_2^2(E) = E^1$ at $E_0 > E$; $A_2^2(E) = E^{-2}$ at $E_0 \leq E$, where $E_0 = 40$ GeV. The average amplitude of semi–diurnal variation by telescope data at Yakutsk is equal to $0.064 \pm 0.002\%$ with the maximum time $t_{max} = 2.9$ h, at Nagoya: $0.090 \pm 0.001\%$, $t_{max} = 2.8$ h and for the neutron component: $0.070 \pm 0.001\%$, $t_{max} = 3.5$ h. Average characteristics of the semi–diurnal anisotropy obtained in the region of high energies are

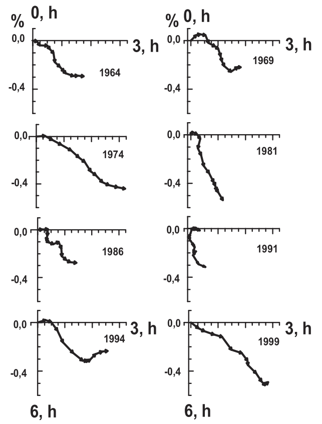

Fig. 2. Seasonal change of $\vec{r}_2^2$.

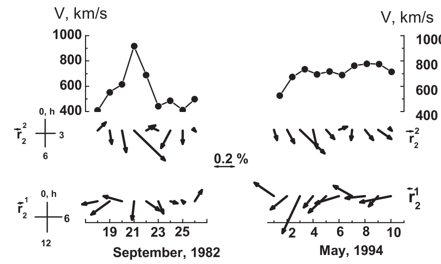

Fig. 3. Solar wind speed, antisymmetric diurnal variation$\vec{r}_1^2$ and semi-diurnal anisotropy $\vec{r}_2^2$.

satisfactory described by a screening mechanism of cosmic rays by the magnetic field [2], according to with the semi–diurnal vector is oriented perpendicular to the regular component of IMF. Variation of the semi–diurnal wave amplitude with the $\sim$ 11–year period in the energy region of cosmic rays registered with the telescopes at Nagoya and Yakutsk are traced. The amplitude of semi–diurnal variation decreases in the years of low solar activity: 1964, 1976, 1986, 1995. In neutron monitor data the 11-year changes are not found. The small decrease in amplitude is also seen in the years close to a sign–change of general magnetic field of the Sun (GMFS). In the energy region controlled by neutron monitors and the Nagoya telescope, the 22–year changes of the semi–diurnal anisotropy in phase are observed. The maximum time of the second harmonic for the epoch of GMFS positive sign (70's and 90's years) is the earlier time than for the epoch of negative sign (60's and 80's years). In the region of higher energies (telescope at the 20 m w.e. depth, Yakutsk) the 22–year variation in phase is not detected. The change of the semi–diurnal phase in the period of a sign–change of GMFS depending on the energy was also noted in [3].

The anisotropy of cosmic ray neutron component calculated by the global survey method for 1964–1999 allows to trace the dynamics of semi–diurnal anisotropy vector from day to day. The events of the duration from several days to $\sim$ 1 month with the direction of semi–diurnal anisotropy vector to $\sim$ 6h LT are revealed which are most often appeared at high heliolatitudes ($\pm 7°$) [4]. The appearance of the stable 6-hour component is also observed in the annual change of semi–diurnal anisotropy vectors. Fig.2 shows the diagrams of month average vectors of semi-diurnal anisotropy r_2^2 in years close to the solar activity minimum in 1964, 1974, 1986, 1994 and years of a sign-change (1969, 1981, 1991, 1999).From Fig.2 it follows that during several months the semi–diurnal vectors have large 6–hour component. In some months they make a sharp turn to $\sim$ 6 h. Fig. 3 shows the behavior of antisymmetrical diurnal variation and semi–diurnal anisotropy in high–speed solar wind streams for the periods on September 18–26, 1982 and on May 1–10, 1994. It is seen that the entry of the Earth into the high-speed stream leads to the increase of the 12-hour component of antisymmetrical diurnal and 6-hour component of semi–diurnal variations.

3. Conclusion

Among with the stable maximum of semidiurnal variation at 3h, in the region of low energy there exist the deviation of this time. Seasonal changes in the components of the second spherical harmonic vectors and direct their comparisons with the speed of solar wind high–speed streams testify about the influence of shearing flows on the cosmic ray distribution which lead to the appearance of 12–hour component in antisymmetrical diurnal variation and semi–diurnal 6-hour anisotropy.

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4. References

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