Proceedings of ICRC 2001: 3777 © Copernicus Gesellschaft 2001

ICRC 2001

Heliolatitude asymmetry of cosmic rays and general magnetic field of the Sun

G. F. Krymsky, P. A. Krivoshapkin, V. P. Mamrukova, and S. K. Gerasimova

Institute of Cosmophysical Research and Aeronomy 31, Lenin Ave., 677891 Yakutsk, Russia

Abstract. The annual variation in the periods of minimum solar activity caused by heliolatitude asymmetry of cosmic rays by neutron monitor world net data has been investigated. A sign of this asymmetry is related to the general magnetic field of the Sun in such a way that the cosmic ray intensity is higher in the positive magnetic field sectors. Possible reasons of this effect are discussed.

1 Introduction

Peculiarities of interaction of cosmic rays with the interplanetary magnetic field create the heliolatitudinal asymmetry of their distribution in the heliosphere. It can be manifested on the Earth in the form of the annual cosmic ray variation. According to neutron monitor data for three solar cycles (Krymsky et al., 1981), the clear relation of the reversal of annual variation phase of cosmic rays to the change of the polarity of the general magnetic field of the Sun has been established. The annual change of the cosmic ray intensity correlates positively with the annual change of the interplanetary magnetic field sector structure. The cosmic ray intensity is higher in the positive sector. In the present work we consider the heliolatitudinal distribution of cosmic ray intensity at different phases of solar magnetic cycle (1954,1965,1976,1987,1997) using data for 5 cycles. Those years are characterized by the minimum solar activity and the different polarity of the general magnetic field of the Sun.

2 Data and Analysis

We use the monthly average values of neutron monitors at Climax (1954, 1965, 1976, 1987, 1997) and Moscow (1965, 1976, 1987, 1997) stations. The long-term variation of the cosmic ray intensity has been excluded by the subtraction of the moving average for 13 months. The amplitude and phase of annual intensity changes by Climax and Moscow data calculated by means of the Fourier analysis are presented in Table 1.

Table 1. The amplitude and the phase of annual cosmic ray variations.

Year	Station	Amplitude, %	Phase, deg.
1954 $qA > 0$	Climax	0.289 ± 0.011	207.4 ± 2.2
1965	Climax	0.854 ± 0.011	35.4 ± 0.7
$qA < 0$	Moscow	0.861 ± 0.010	40.3 ± 0.7
1976	Climax	0.530 ± 0.011	266.8 ± 1.2
$qA > 0$	Moscow	0.262 ± 0.011	263.1 ± 2.4
1987	Climax	1.601 ± 0.011	63.2 ± 0.4
$qA < 0$	Moscow	1.631 ± 0.010	53.0 ± 0.4
1997	Climax	0.263 ± 0.011	175.0 ± 2.4
$qA > 0$	Moscow	0.311 ± 0.011	145.1 ± 2.0
Mean	Climax	0.361 ± 0.006	216.4 ± 1.0
$qA > 0$	Moscow	0.286 ± 0.008	203.5 ± 1.6
Mean	Climax	1.227 ± 0.008	49.3 ± 0.4
$qA < 0$	Moscow	1.246 ± 0.007	46.7 ± 0.3

It is seen from Table 1 that the data are in good agreement with each other. The amplitude of annual cosmic ray variation at the negative polarity of the solar magnetic field is larger by a factor of 3 than at the positive one. The maximum falls on September at the positive polarity and on March the negative polarity of the general magnetic field of the Sun. The heliolatitudinal development of annual changes of the cosmic ray density by Climax neutron monitor data depending on the solar magnetic dipole polarity is given in Fig.1.

Here the first harmonic of the annual variation is taken. From Fig.1 it is clearly seen that the heliolatitudinal asymmetry of the cosmic ray density changes its sign depending on the polarity of the general solar magnetic field. In the positive sectors the cosmic ray density is higher than in the negative ones without regard to the polarity of general solar magnetic field. The result obtained in the present work has

---

Correspondence to: G. F. Krymsky (krymsky@ikfia.ysn.ru) confirmed our conclusions by the data other stations for the shorter observation period (Krymsky et al., 1981).

3 Discussion

The asymmetrical cosmic ray gradient can be explained with the help of the cosmic ray modulation model taking into account their drift movement. Let's use the approximation of "the far zone", when the magnetic field is considered to be purely azimuthal one and therefore the field-aligned diffusion particles is not taken into account. In this case the cosmic ray distribution is given by the expressions:

$$f_- = -b \mid \psi \mid , \tag{1}$$

$$f_+ = b(\mid \psi \mid - \frac{1}{2k}(1 - e^{-2k|\psi|})) \tag{2}$$

Here it is assumed the heliolatitude ψ is small, k is the ratio of the particle path length to their giroradius, and a constant b depends on the wind speed u_0 and the intensity H_0 of the field radial component in the Earth's orbit r_o

$$b = (\gamma + 2) \cdot \frac{u_0}{c} \cdot \frac{eH_0 r_0}{pc} \tag{3}$$

Here c is the velocity of light, $\gamma = 2.5$ is the cosmic ray differential spectrum index, $p = 13$ GeV/c is the effective impulse of particles responsible for the neutron component at sea level. Assuming $u_0 = 4 \cdot 10^7$ cm/s, $H_0 = 3.5 \cdot 10^{-5}$ Gs, we obtain $b = 7.26 \cdot 10^{-2}$. The functions f_+ and f_- represent a varied part of the distribution functions taken as a unit and are determined in such a way so that $f_\pm = 0$ at $\psi = 0$. Besides of the difference in a sign, which shows that the heliolatitudinal gradient changes its direction at the reversal of the polarity of the general magnetic field of the Sun, the functions differ by the behavior near the point $\psi = 0$: at the positive polarity the gradient passes smoothly through a zero near this point, whereas at the negative polarity it undergoes an jump here.

On the assumption that "the heliolatitude" ψ is counted not from the solar equator plane but from the neutral surface which is shifted southward on the average then the asymmetrical gradient $G_\pm$ will appear. The deviation of the force tubes of the interplanetary field southward was supposed earlier on the basis of the analysis of solar cosmic ray increases (see, for example, Krymsky and Kuzmin, 1964). Let the neutral surface is shifted to the south by no less than 7°. Then the measured heliolatitudinal gradient will be completely asymmetrical and at the negative polarity of the general solar magnetic field its value will be equal to $G_- = -b$, that in the recount per one degree of latitude it gives $G_- = -0.127$ $\%/deg$. The value observed $G_- = -0.179$ $\%/deg$ on the average shows that the wind speed and the magnetic field intensity for the considered periods is somewhat greater than the values accepted by us. As to the general solar magnetic field positive polarity, the gradient is of the opposite sign and its mean value should be smaller, because it completely disappears at $\psi = 0$. As seen from the expression for f_+, the mean value of the gradient with the account of the shift $\Delta\psi$

$$\overline{G_+} = \frac{f_+(7° - \Delta\psi) - f_+(-7° - \Delta\psi)}{14°} \tag{4}$$

depends on k parameter. At the shift by in heliolatitude $\Delta\psi = -7°$ the mean value of the gradient depending on the parameter k is given in Table 2.

Table 2. Calculated values of the asymmetrical cosmic ray gradient for the different parameters k.

k	2	3	5
Gradient,$\%/deg$.	0.051	0.067	0.088

It is seen that the gradient value is considerably lower that at the negative polarity. The value observed $G_+ = 0.052$ $\%/deg$ corresponds to $k \approx 2$.

4 Conclusions

The conformity of the observed asymmetrical cosmic ray gradient to their calculated values points to the reality of the diffusion -drift model of cosmic ray modulation and the asymmetry of the solar wind and magnetic field, which are preserved during 5 solar cycles.

Acknowledgements. The work has been carried out at the support of Russian Foundation for Basic Research (grant N 00-02-17961 and N 01-02-06381 and grant of Leading Scientific School N 00-15-96669) and the Integration Project SO RAN N 56.

References

Krymsky, G.F., Krivoshapkin, P.A., Mamrukova, V.P., Skripin, G.V., The Interaction Effects of the Heliosphere with the Galactic Field in Cosmic Rays, Geomagnetism and Aeronomy, 5, 923–925, 1981.(in Russian)

Krymsky, G.F., Kuzmin A.I., Solar Cosmic Rays and Interplanetary Magnetic Field, Izv.AN USSR. Ser. Fiz., 12, 2005–2006, 1964.(in Russian)

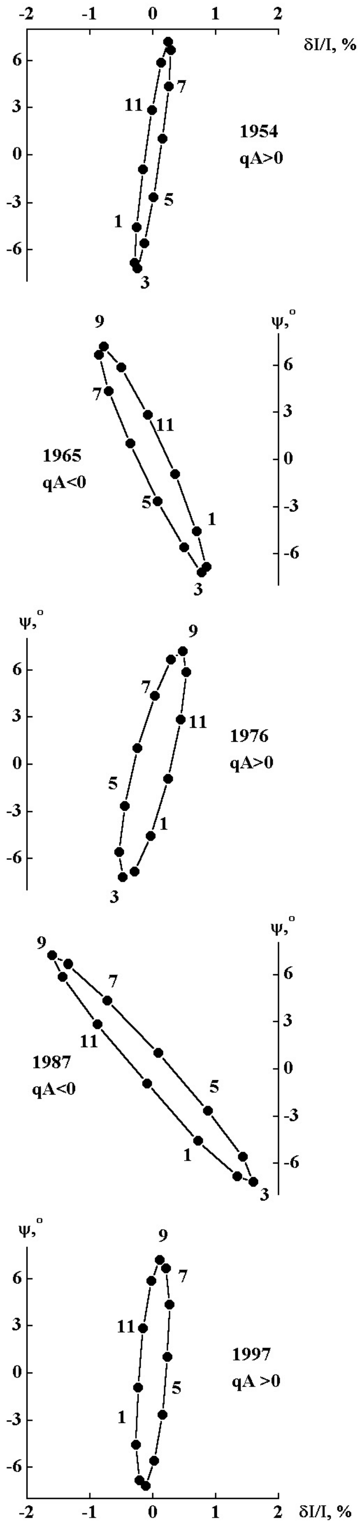

Fig. 1. The cosmic ray intensity versus the Earth’s heliolatitude.