Radial and Latitudinal Gradients of Cosmic Rays

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Abstract

Radial and latitudinal gradients of galactic cosmic rays are studied by using the muon telescope and ionization chamber ASK-1 data in Yakutsk. The radial gradient undergoes the 11-year variation. Its maximum value is in the solar activity maximum. The latitudinal gradient is of the 22-year wave. Thereby, in the positive orientation epoch of the solar magnetic dipole it is directed from the south to the north perpendicular to the ecliptic, and in the negative orientation epoch its direction is changed by 180°. Values of both gradients decrease as the particle energy increases.

1. Introduction

Cosmic ray gradients in the energy region up to 200 GeV by ground-based measurements were investigated in the number of works (Ahluwalia,1994; Munakata et al.,1997; Bieber and Chen,1991; Hall et al.,1993). Average values of radial and latitudinal gradients and their variability from year to year have been estimated. For this purpose some authors (Krymsky,1969; Ahluwalia and Dorman,1997) proceed from theoretical conceptions on the convection - diffusion origin of the anisotropy and other authors (Jokipii,1979) took into account the particle drift effect in the interplanetary magnetic field. To define the initial anisotropy Ahluwalia (1994) and Munakata et al. (1997) used the rigidity spectrum of a form A(R)=const at $R < R_c$ and A(R) = 0 at R>Rc. Bieber and Chen (1991) and Hall et al.(1993) used the spectrum A(R) =$R^{-\gamma}$. However, according to Krymsky (1969), from the convection-diffusion mechanism (CDM) it follows: A(E)=$b/(E+b)$ where b is a constant parameter. Among cosmic ray stations Yakutsk (ASK-1) and Deep River (NM) are especially characterized by the high accuracy, duration and continuity of measurements. The continuous measurements of the muon component with the crossed telescopes at four energetic levels were started in 1969.

2. Data Analysis and Discussion

From conceptions (Krymsky,1969; Ahluwalia and Dorman, 1997) on CDM it follows that the product of the longitudinal path length of particles ($\lambda_{\parallel}$) into the

radial gradient (G_r) depends on the Compton-Getting effect, values of radial (A_{12}) and longitudinal (A_{18}) anisotropies and the IMF spiral angle. The product of the Larmor's radius r_c into the latitudinal gradient G_θ depends on the azimuth component of anisotropy A_{18}, the radial gradient G_r, the IMF spiral angle ψ and the parameter $\alpha = \lambda_\perp / \lambda_{||}$, where $\lambda_\perp$ is the cross path length of particles. We assumed $\alpha = 0.1$. The parameter P taking into account the polarity sign of the general magnetic field of the Sun is also taken into consideration: it is assumed that P= +1 when qA>0 and P=-1 when qA<0. The Larmor's radius $r_c = 0.01632 \cdot E_{eff} / H(a.u.)$ where E_{eff} is the effective energy of particles calculated taking into account the coupling coefficients for each installation and the energy spectrum of anisotropy from the CDM (Krymsky,1969). The transport path length of particles along the IMF is equal to $\lambda_{||} = 3k_0 E_{eff} \cdot H / VH$ (a.u.), where k_0 is the diffusion coefficient equal to $6.6 \cdot 10^{22} cm^2/s$ (Ahluwalia & Dorman,1995), $\overline{H}$=6 nT is the mean intensity of the IMF on the Earth's orbit. For calculations we used solar wind parameters (the speed of wind, the intensity and the spiral angle of the IMF) (King). For absent data for 1955-1965 we used average values $\overline{V}$=450 km/s, $\overline{\psi}$=45°, $\overline{H}$=6 nT.

Annual values of the solar-diurnal variation of the neutron component (NM, Deep River) for 1955-1995 and the muon component by the Yakutsk installation complex data: the ionization chamber ASK-1 for 1953-1998, azimuthal telescopes (s-n) at the levels of 0 m w.e. (1969-1998), 7 m w.e. (1969-1998), 20 m w.e. (1969-1998), 60 m w.e. (1969-1998),60 m w.e. (vertical) (1969-1998). The observed solar-diurnal variation by ASK-1 temperature corrected data is of A_t=0.07 % and t_{max}= 4.4h (Skripin,1973). All vectors of the diurnal variation are corrected by the Compton-Getting effect caused by the the Earth's rotation around the Sun.

For each year we found the parameter b of energy spectrum (Krymsky,1969) by comparing the ratios of observed solar-diurnal variation amplitudes A_{NM}/A_{ASK}, $A_{NM}/A0_{(S-N)}$, $A_{NM}/A7_{(S-N)}$, $A_{NM}/A20_{(S-N)}$, $A_{NM}/A60_{(S-N)}$, $A_{NM}/A60_{(vert)}$ with corresponding theoretical predictions. The average value b=50.1±5.0 GeV. Besides, b undergoes the 11 - year variation. By using obtained values of b we calculated A_{12} and A_{18} of the initial anisotropy and modulation parameters G_r and G_θ.

Table

	NM	0(s-n)	ASK-1	7(s-n)	20(s-n)	60 vert	60(s-n)
G_r,%/a.u.	0.4	0.12	0.12	0.10	0.06	0.03	0.03
G_θ,%/a.u	2.50	0.70	0.65	0.60	0.45	0.15	0.05
E_{eff}, GeV	21	64	68	70	114	215	224

From Table it follows that G_r and G_θ decrease as the effective energy of regestered particles increases. Besides the value of the radial gradient is significantly less than the latitudinal gradient value.
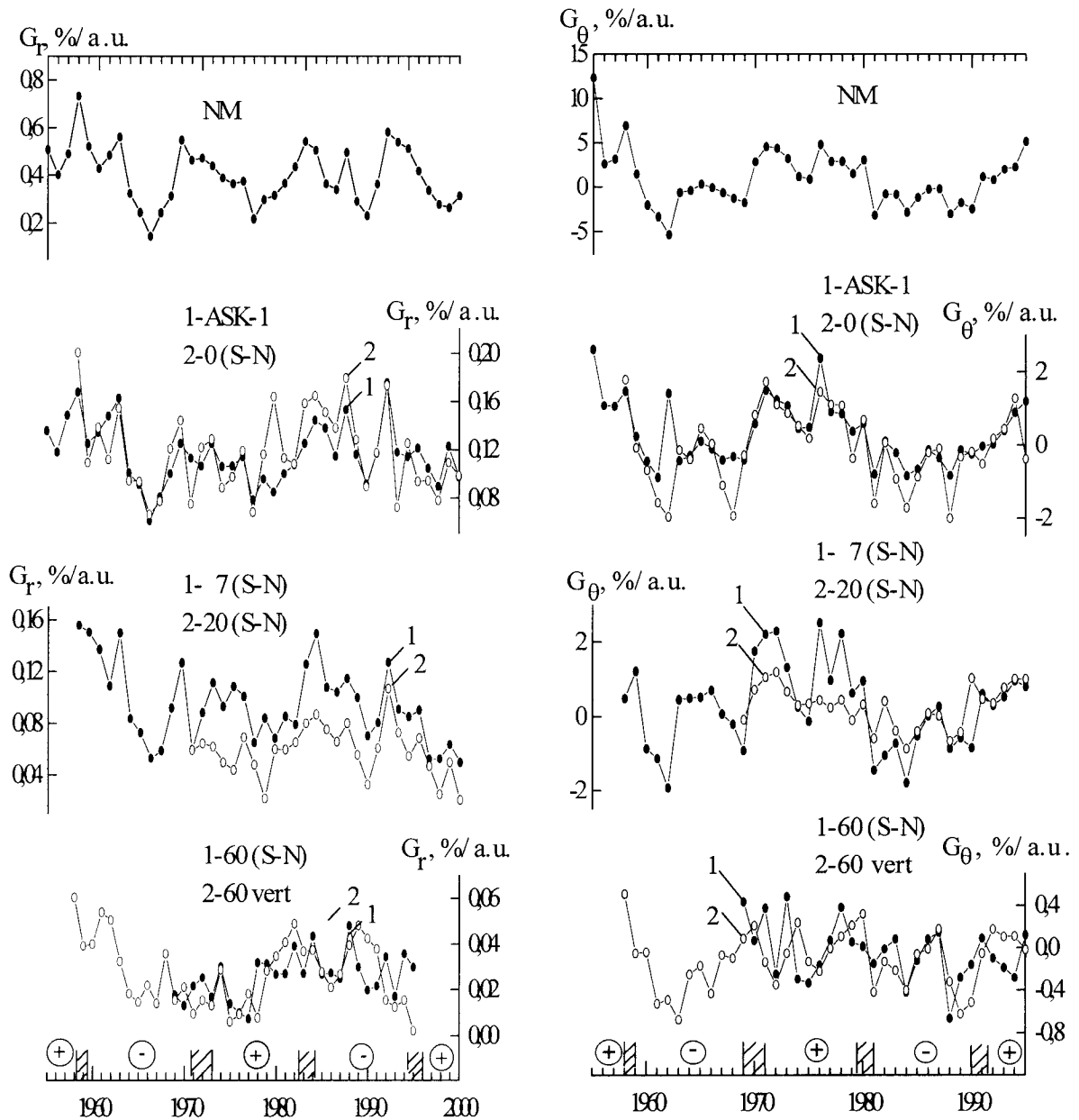

Figure: Radial (G_r) and latitudinal (G_θ) gradients of cosmic rays by
          NM (Deep River) and muon installation complex (Yakutsk) data

Figure shows that the radial gradient undergoes the 11-year variation and its maximum value is in the solar activity maximum. During the solar activity minimum it is ~0.2%/a.u. for the effective energy 21 GeV and it decreases to 0.04 %/ a.u. at E = 114 GeV (20m w.e., s-n). At E=220 GeV it is negligible.

The latitudinal gradient G_θ undergoes the 22-year periodicity. The absolute value of G_θ changes from 2.5%/a.u. at E=21 GeV to 0.15%/a.u. at E $\geq$ 220 GeV. A sign of the latitudinal gradient depends on the magnetic moment polarity of the heliosphere: the positive G_θ is (G_θ is directed from the south to the north) at qA>0 and the negative G_θ is at qA<0. This result is consistent with results obtained by annual variations of galactic cosmic rays in solar activity minima (Krymsky et al.,1981) where the excess of particles is observed at the positive IMF polarity.

Conclusion

Cosmic ray radial and latitudinal gradients are observed at all energy registration levels. The value of the latitudinal gradient is significantly larger than the radial gradient value. The radial gradient undergoes the 11-year variation: it is a maximum in solar activity maxima. The latitudinal gradient changes with the solar magnetic cycle, thereby, in the positive orientation epoch of the general magnetic field of the Sun it is directed from the south to the north perpendicular to the ecliptic, and in the negative orientation epoch its direction is changed by 180°.

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