EFFECTS OF SOLAR MAGNETIC FIELD ON COSMIC RAYS

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The paper is devoted to some aspects of problem of galactic cosmic ray (gcr) propagation including inversion of solar total magnetic field (stmf) and to analysis of experimental facts related to heliomagnetic cycle.

It is known (Jokipii I.R.,et al.,1977, Krainev M.V.,1979,Erkhov V.I.,et al.,1983) that the global structure of solar total magnetic field (Parker's field) results in additional flux of gcr generated by curvature and gradient drifts. Velocity of charged particles drift is

$$\mathcal{D}_i = \frac{\partial \varkappa_{ij}^{(A)}}{\partial x_j} \qquad (1)$$

where $\varkappa_{ij}^{(A)}$ - antisymmetric part of diffusion tensor. It can be written for stmf in the form

$$\vec{\mathcal{D}} = \vec{\mathcal{D}}_1 + \delta(\theta - \pi/2)\vec{\mathcal{D}}_2 \qquad (2)$$

where $\vec{\mathcal{D}}_1$ is regular part and $\vec{\mathcal{D}}_2$ - singular part of velocity. Delta function is connected with the fact of existence of boudary between inward and outward lines of force of magnetic field of the Sun that is neutral current sheet.

The main equation including diffusion, convection, energy changes and drifts in heliocentric system of coordinate is of the form:

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\left(\varkappa_{rr}\frac{\partial n}{\partial r} - nu - n\mathcal{D}_r\right)\right] + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}\left[\sin\theta\left(\frac{\varkappa_{\theta\theta}}{r}\frac{\partial n}{\partial\theta} - n\mathcal{D}_\theta\right)\right] + \frac{2}{3}\frac{u}{r}\frac{\partial}{\partial\varepsilon}(\alpha\varepsilon n) = 0 \qquad (3)$$

where $\alpha = \frac{\varepsilon + 2m_0}{\varepsilon + m_0}$, n is density of galactic cosmic rays, ε - kinetic energy. To analyse effects related to redistribution of galactic cosmic rays due to drift motion let's consider the equation including only convection, diffusion along lines of force of magnetic field and drift. We obtain

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\left(\varkappa\frac{\partial n}{\partial r} - nu - n\mathcal{D}_r\right)\right] - \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}\left[\sin\theta\, n\,\mathcal{D}_\theta\right] = 0 \qquad (4)$$

Integration of equation (4) over θ within the limits of $\pi/2 - \varepsilon$ and $\pi/2 + \varepsilon$ and approaching ε to zero gives following condition:

$$n(r, \varepsilon, \theta = \pi/2) = n_0(\varepsilon) \qquad (5)$$

where $n_0(\varepsilon)$-density of galactic cosmic rays out of modulation region that is for $r \geqslant r_0$.

It shoud be noted that on the basis of general mathematical considerations (Mors F.M., Feshbach G., 1958) condition(5) has sense only for odd cycles of solar activity. In order to solve parabolic equation (4) we used traditional boundary conditions for this kind of the problems (Ashirov R.R. et al., 1979, Krylov V.I., et al., 1977)

$$n(z=z_0,\varepsilon,\theta)=n_0(\varepsilon)\,; \quad \left[\sigma n+(1-\sigma)\frac{\partial n}{\partial z}\right]\Big|_{z=0}=0 \qquad (6)$$

where σ - parameter.

The set of boundary conditions (5) and (6) allows to solve equation (4) correctly. Grid technique and Crank Nicholson schemes (Krylov V.I., Bobkov V.V., Monastyrsky V.I., 1977) were employed for solution. Equation (4) was solved for the energy range ε>1GeV. Figure 1 shows radial variation of n/n_0 at the heliolatitude -7 for energies 1 and 10 GeV. Figure 2 illustrates latitudinal variations of n/n_0 for the energies. Following values of latitudinal gradient of gcr were obtained at the orbit of the Earth:

$$\frac{1}{n}\frac{\partial n}{\partial \theta}(\varepsilon=1\,GeV)=1.9\%/a.u \qquad \frac{1}{n}\frac{\partial n}{\partial \theta}(\varepsilon=10\,GeV)=0.16\%/a.u$$

Hence including in the equation of gcr propagation the term describing drift of particles results in redistribution of density ,appearance of latitudinal gradient and reduction of modulation depth.

Let's consider and analyse experimental data connected with heliomagnetic cycle. As follows from abovementioned facts latitudinal gradient results in N-S asymmetry (Kolomeets E.V., et al., 1977) . Let's consider asymmetry of cosmic rays and solar activity. Figure 3 shows amplitude of north-south asymmetry in the stratosphere data of Mirny and Murmansk at the depths of 20 g/sm^2 (a) and 480 g/sm^2 (b). One can see that amplutude of the effect grows with the depth in the atmosphere, this fact demonstrates rigid energy spectrum of the effect.

The investigation of solar activity during the last magnetic cycle reveals pronounced N-S asymmetry at all heliolatitudes. Figure 4 shows north-south asymmetry for the ranges of heliolatitudes (20-30) (a); (30-40) (b); (40-50) (c). One can see 22-year wave in N-S asymmetry. The change of the sign of north-south asymmetry occurs during the periods of inversion of solar total magnetic field. Periods of inversion are shaded.

In order to study nature of 22-year variation of neutron component of cosmic rays we analysed continuous set of the data of neutron monitors of the worldwide network for the last magnetic cycle. The wave averaged over two eleven-year cycles was substructed from original data to exclude 11-year variation. Figure 5(a) shows obtained 22-year variation for Deep River station.

Taking into account 22-year wave in solar activity we

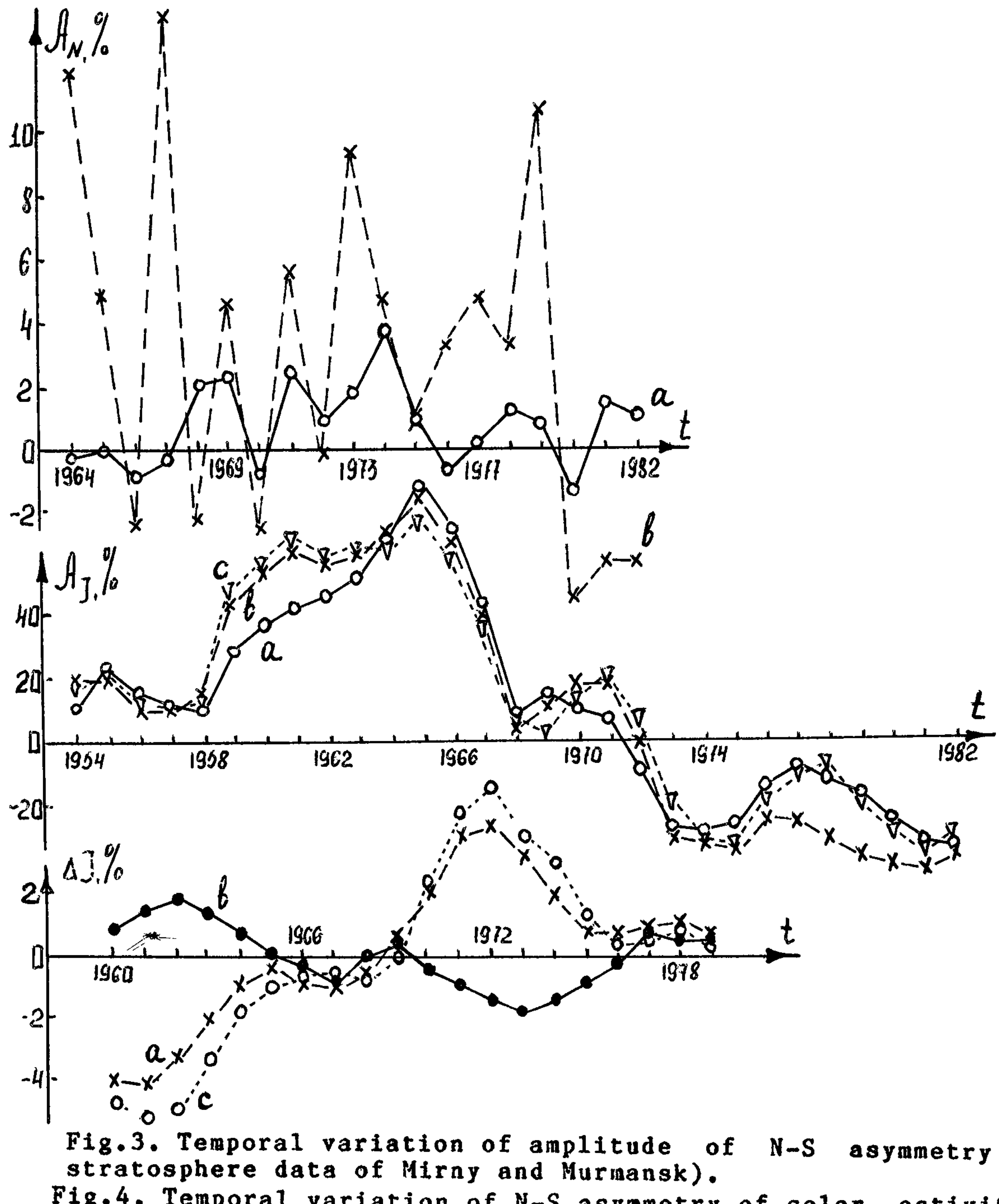

Fig.3. Temporal variation of amplitude of N-S asymmetry stratosphere data of Mirny and Murmansk).

Fig.4. Temporal variation of N-S asymmetry of solar activity at various heliolatitude regions.

Fig 5. 22-year variation of cosmic ray intensity, observed at Deep River. (a) -22-year wave in cosmic rays expected due to corresponding variation of solar activity. (b)- variation of cosmic ray intensity due to drift effects.

determined contribution of the wave to cosmic ray intensity. 22-year wave in cosmic rays expected due to 22-year variation of solar activity was found on the basis of empirical relation between solar activity and cosmic ray intensity. The result is given in figure 5 (b). One can see that obtained change in cosmic rays due to solar activity is in opposite phase with the observed variation of cosmic rays. Substructing from obtained 22-year wave wave expected due to corresponding variation of solar activity we obtained variation of cosmic ray intensity produced by other mechanisms and among them drift of particles in solar total magnetic field. So corresponding variation of solar activity, inversion of solar total magnetic field, drift effects and other space distributions contribute to the observed 22-year variation.

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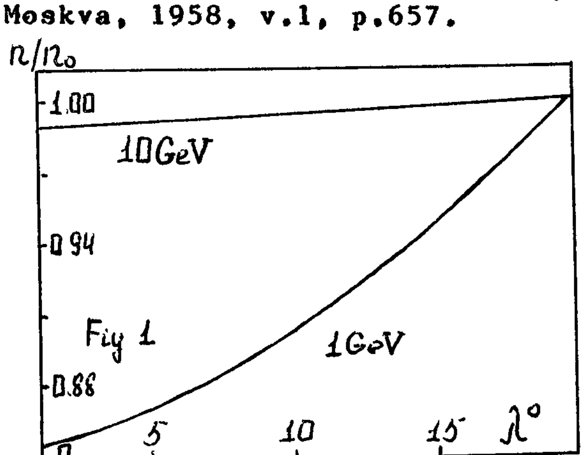

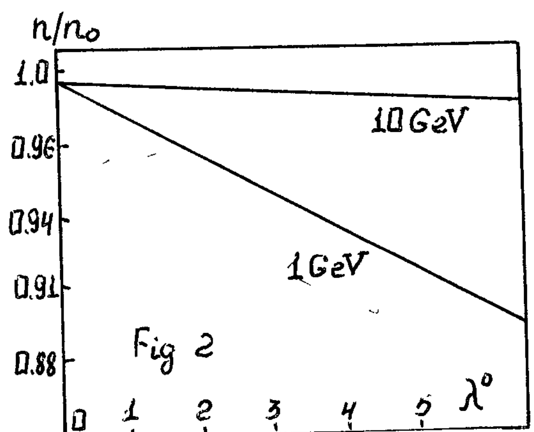

Fig.1. Radial dependence of gcr density at heliolatitude at energy 1 and 10 GeV.
Fig.2. Latitudinal dependence of gcr density at energies 1 and 10 GeV.