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THE THEORETICAL AND EXPERIMENTAL INVESTIGATION OF COSMIC RAY FORBUSH-EFFECTS

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ABSTRACT

The theoretical results of analysis of the expected spatial distributions of density, gradients and anisotropy of cosmic rays, obtained on the basis of the numerical solution of anisotropic diffusion equation in the presence of the disturbances of shock wave type in the interplanetary space are presented. The theoretical calculations on the definition of the energy spectrum and anisotropy of galactic cosmic rays during Forbush - effect are compared with the experimental data.

The theoretical model. Cosmic ray Forbush-effects have a complex structure and nature /I,2/. They differ from each other both by power and by energy spectrum indices et al. However, there exist the indications such as the recurrence and sporadicity of Forbush-effect origin, the character of shock wave development causing Forbush-effects, the change of energy spectrum index in time et al. by with the definite classification of Forbush-effects can be carried out /3-4/.

In this paper the study of cosmic ray Forbush-effects on the basis of the processes occurring in the interplanetary space in the presence of the disturbance passage limited by the heliolongitudes, but having no boundary in the radial direction is carried out i.e. the type of recurrent Forbush--effect is considered.

The anisotropic diffusion equation/5/ is taken as modeling of the electromagnetic conditions occurring in the interplanetary space under the following assumptions: a) solar wind velosity u and the diffusion coefficient $\varkappa$ of cosmic rays in the disturbed region changes nearly twice in comparison with the environment, b) the disturbed region is given in a cone form for which the helioequator is a symmetry plane, i.e. along the trajectory of the Earth the heliolatitudinal gradient $\partial n/\partial \theta = 0$, c) it is considered that, since the disturbed region across the heliolatitude is limited in the range of several a.u., and in the radial direction the process is stationary, the stationary approximation is quite true, i.e. $\partial n/\partial t = 0$. Hence, the anisotropic diffusion equation has the following form:

$$\nabla_i(\varkappa_{ik}\nabla_k n) - \nabla_i(n \cdot u_i) + \frac{1}{3R^2}\cdot\frac{\partial}{\partial R}(R^3 n)\cdot \nabla_i u_i = 0 \qquad (1)$$

where n and R -the density and the rigidity of cosmic ray particles, and u_i the solar wind velocity. Taking into account the above assumptions for solar wind velocity U and the diffusion coefficient $\varkappa$: $U=U_0(1+\alpha_1\tau)$ (see Fig. 1a) and $\varkappa=\varkappa_0(1-\alpha_2\tau)$ (see Fig.1b), where $\alpha_1=3,4$; $\alpha_2=1,75$; and $\tau=\frac{1}{\pi^2}[arctg(2(\varphi-30))-arctg((\varphi-70)/7)]$.

The equation (1) is solved by net method under the following boundary conditions:

$$\frac{\partial n}{\partial \tau}+\alpha n+\beta\frac{\partial n}{\partial R}\Big|_{\tau=0}=0,\quad n\Big|_{R=450}=1,\quad n\Big|_{\tau=\tau_0}=1,\quad n\Big|_{\varphi=0}=n\Big|_{\varphi=\pi},$$

where $\alpha=(3/2)d$, $\beta=d\cdot R/3$ and $d=U\tau_0/\varkappa$.

The expected change depending on the heliolongitude during Forbush-effect for two rigidities $R=10$ GV and $R=20$ GV is presented in Fig. 2, It is seen, that the change of solar wind velocity U and the diffusion coefficient $\varkappa$ (see Fig.1a,b) induce a gradual decrease and restoration of cosmic ray intensity that is characteristic of the recurrent Forbush-effects.

For the case, when the approximation is given by $\frac{\delta D}{D}(R)\sim R^{-\gamma}$, the energy spectrum index of Forbush-effect is equal $\gamma=1,06$.

The expected change of socmic ray anisotropy before, during and after the cosmic ray Forbush-effect duration for the rigidity $R=10$ GV is presented in Fig. 3. It is seen that after strong disturbances of anisotropy vectors near the minimum of Forbush-effect the monotone restoration to the initial position is observed.

The experimental data. The change of intensity of cosmic ray neutron (1) and muon component at a level 0 and 7 m.w.e. (2) and (3) in Tbilisi station for the period February I4-I7,I978 is presented in Fig.4a. The change of the energy spectrum of this Forbush-effect in time has been studied by two independent methods. The first one is a well-known spectrographic method /5/ and the second one - the method of the coupling coefficients, presented by the Japanese authors /6/. The analysis by the spectrographic method has been carried out by the intensity of cosmic ray neutron and hard μ-meson components at Tbilisi station and by method of the coupling coefficients - by the data of Tbilisi station and the world network. The changes of the energy spectrum index γ , obtained by the spectrographic method (the dashed curve) and by the coupling coefficients (the solid curve) are presented in Fig. 4b. It is seen that the results obtained by both methods show the same temporal changes, however, the values of the energy spectrum index obtained by the spectrographic method are systematically higher than the values obtained by the method of the coupling coefficients. In the Fig.4c the changes of DSt variation of the Earth's magnetic field (dashed) and the cutoff rigidity threshold ΔR_c (solid) are presented.

Discussion and Conclusion. The obtained result is explained easily. The fact is that the change of the cutoff rigidity threshold ΔR is not taken into account in the process of calculating the energy spectrum index by the me-

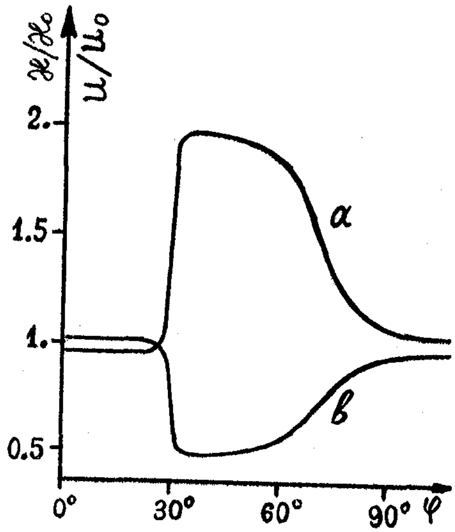

Fig. I

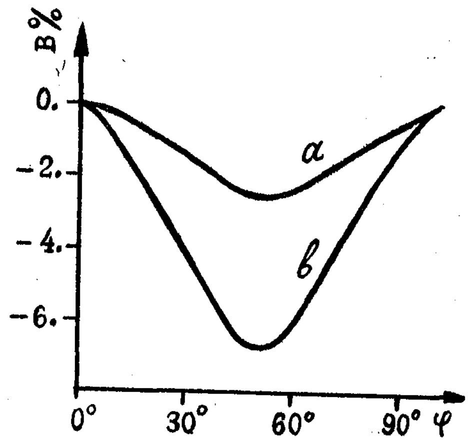

Fig. 2

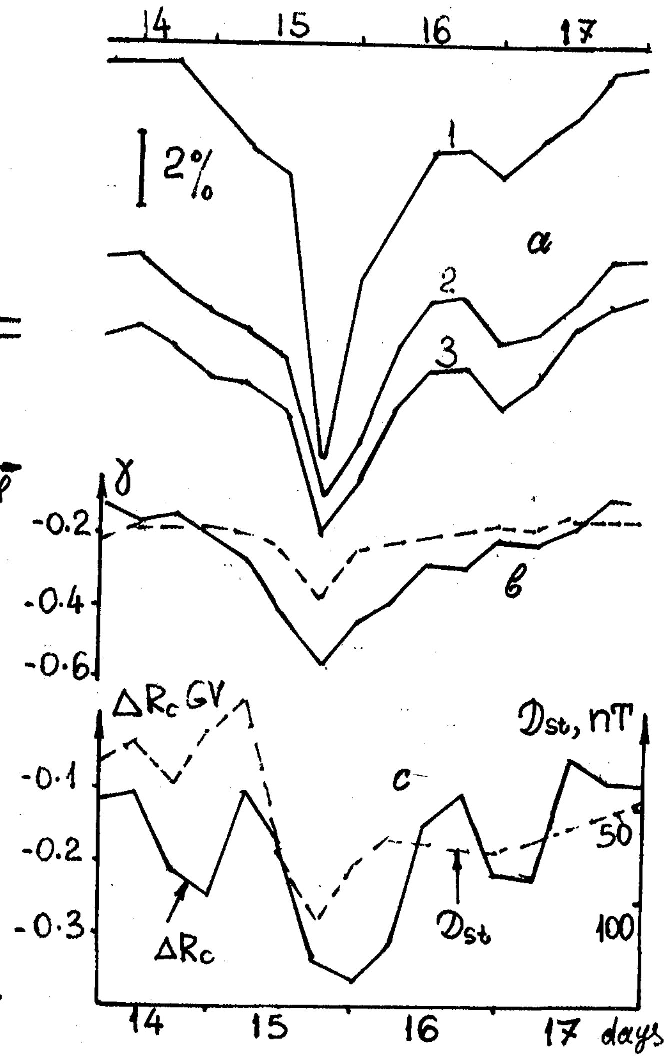

Fig. 4

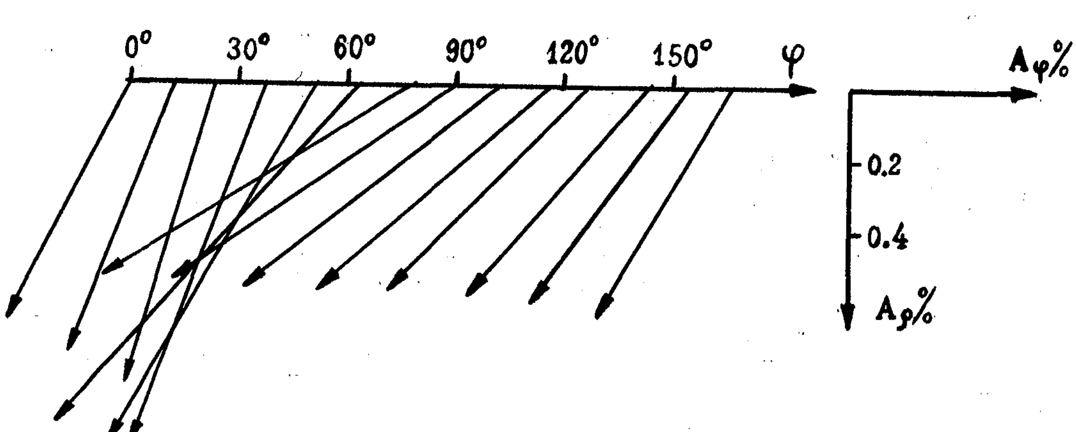

Fig. 3

thod of the coupling coefficients /6/, and is taken into account in the spectrographic method.

For the period considered the change of ΔR_c is observed, in particular, its decrease and therefore the amplitude absolute value of cosmic ray intensity decrease is diminished, i.e. the energy spectrum calculated by the coupling coefficients method will be more rigid, that is really observed.

The rigid energy spectrum before reaching the minimum of Forbush-effect must be connected with the predominant carring out of cosmic ray particles of relatively low energies with the high-velocity flux of the chromospheric flare /8/. In addition, the energy spectrum of magnetic inhomogeneity power of the medium frequencies which can induce cosmic ray particle modulation predominantly of relatively low energies can be increased in front of the magnetic cushion of the shock wave and in the cushion itself. Apparently, the geometric factor, the size of the compressed cavity in the front part of the shock wave plays an important role.

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