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Abstract

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THE INFLUENCE OF FORBUSH EFFECTS ON THE STATE OF THE COSMIC LAYER IN THE LOWER IONOSPHERE

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It has been established that galactic cosmic rays create, at altitudes of 50–80 km in the lower ionosphere, an independent cosmic layer with an electron density of the order of 10^2 cm^{-3} ([1,2]). Up to now, variations of the cosmic layer associated with large changes in the cosmic-ray flux have been experimentally detected: 11-year variations ([3]) and effects of solar cosmic rays ([4]). In the present work the influence of Forbush effects on the cosmic layer is investigated.

In formulating the problem of the experimental detection of the influence of Forbush effects on the cosmic layer, it must be taken into account that, besides cosmic rays, X-ray and ultraviolet solar radiation act in the lower ionosphere. Therefore it is necessary to choose such an interval of observation when the relative influence of changes in galactic cosmic rays on the lower ionosphere is strongest. For this purpose the most suitable conditions are nighttime conditions, and it is expedient to carry out observations by means of long radio waves, which make it possible to obtain information even about comparatively small deviations of the cosmic layer from its normal state. These conditions are best met at the ionospheric observatory in Sofia by observations at a frequency of 155 kHz along the radio path Brașov (Romania)–Sofia, 370 km long.

In accordance with the considerations given above, data on the absorption of radio waves, variations of cosmic rays, and geomagnetic activity were analyzed for the period from 25 IV to 12 V 1960, characterized by a number of interesting solar and geophysical phenomena ([5]). This analysis showed that, despite the decrease in the intensity of cosmic rays during Forbush effects, the absorption and, consequently, the ionization increase. In order to clarify the possible reasons for this somewhat unexpected result, let us consider the equation for the variation of the rate of electron production at altitude h in the cosmic layer ([6])

$$\frac{\delta q(h)}{q(h)} = \frac{\delta \rho(h)}{\rho(h)} - \delta R_c W_q(R_c) + \int_{R_c}^{\infty} \frac{\delta D(R)}{D(R)} (W_q R)\, dR. \quad (1)$$

Here $\delta q(h)/q(h)$, $\delta\rho(h)/\rho(h)$, and $\delta D(R)/D(R)$ are the relative variations, respectively, of the rate of electron production at the level with pressure h, of the atmospheric density, and of the differential spectrum of primary cosmic rays in rigidity R; δR_c is the change in the geomagnetic cutoff rigidity R_c of cosmic rays (caused by the strengthening and change of the current systems of the Earth' s magnetosphere during periods of magnetic storms ([5])); W_q is the coupling coefficient for the rate of electron production by cosmic rays.

If nuclear interactions and absorption of primary cosmic rays at the altitude of the ionospheric D-region are neglected, then according to ([6]), in the first approximation,

$$W_q(R) = (\gamma - 1)/R. \tag{2}$$

(here $\gamma \approx 2.5$ is the exponent in the average differential spectrum of primary cosmic rays). Let us assume that $\delta\rho/\rho$ changes little during periods of magnetic storms, and that the spectrum of variations of primary cosmic rays can be approximated by the function

$$\delta D(R)/D(R) = -aR^{-n}, \tag{3}$$

where $a = 0.3 \div 1$ and $n = 0.5 \div 1$. Substituting (2) and (3) into (1), we find

$$\frac{\delta q}{q} = 1.5\frac{\delta R_c}{R_c} - 1.5\frac{a}{n}R_c^{-n} = 1.5\left[\frac{\delta R_c}{R_c} + \frac{1}{n}\frac{\delta D(R_c)}{D(R_c)}\right]. \tag{4}$$

It is seen that the variation of the electron production rate in the cosmic layer is determined by the balance between the simultaneous action of the geomagnetic variation (the term $\delta R_c/R_c$) and the extraterrestrial variation of galactic cosmic rays (the term $\delta D(R_c)/D(R_c)$).

In the case of strong magnetic storms accompanied by weak Forbush decreases, the condition

$$\frac{\delta R_c}{R_c} > \frac{a}{n}R_c^{-n}, \tag{5}$$

is satisfied, and then, despite the decrease in the flux of galactic cosmic rays outside the Earth, the ionization of the cosmic layer increases owing to the decrease in the geomagnetic threshold. In the case

$$\frac{\delta R_c}{R_c} \approx \frac{a}{n}R_c^{-n} \tag{6}$$

no effect should be observed in the ionosphere. In weak magnetic storms and strong Forbush decreases the electron production rate decreases, since

$$\frac{\delta R_c}{R_c} < \frac{a}{n} R_c^{-n}. \tag{7}$$

The variation $\delta q/q$ in equation (4) can be determined from measurements of the variation of nondeviating absorption of radio waves, $\delta L/L$, passing through the nighttime cosmic layer and reflected from the overlying layer E [7]:

$$\frac{\delta q}{q} = \frac{\delta L}{L} \left(2 + \frac{\delta L}{L} \right). \tag{8}$$

It should be emphasized that the result obtained can be used to solve another important problem as well. The point is that separating variations of geomagnetic and extraterrestrial origin encounters considerable difficulties. On the other hand, $\delta D/D$ is easily determined either from measurements of variations of secondary components of cosmic radiation by the method of coupling coefficients [8], or from measurements of the differential spectrum of primary cosmic rays on balloons and satellites. Thus, from equation (4) one can determine the change in the geomagnetic threshold during a Forbush decrease:

$$\frac{\delta R_c}{R_c} = \frac{a}{n} R_c^{-n} - \frac{\delta q}{1.5q}. \tag{9}$$

It is important to emphasize that expression (9) can be used to test the theory of geomagnetic storms and magnetospheric current systems. Indeed, numerous studies of the behavior of cosmic rays in a disturbed geomagnetic field have made it possible to calculate in detail the expected changes in the rigidity of the geomagnetic cutoff for various models of current systems of magnetic storms (circular equatorial

current; a current distributed over the shell of magnetic field lines; volumetric current systems responsible for the main phase of a magnetic storm; current systems responsible for the compression of the magnetosphere on the dayside and its elongation on the nightside, etc.).

Determination, by means of (9), of the latitude-longitude distribution $\delta R_c/R_c$ provides the information necessary for determining the spatial distribution of extramagnetospheric current systems and, in particular, their asymmetry as it changes with time.

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Note: Figure translations are in progress. See original paper for figures.