N90-28192

SOLAR ACTIVITY INFLUENCE ON COSMIC RAY PENETRATION IN THE MIDDLE ATMOSPHERE

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ABSTRACT

A new improved model for cosmic rays - middle atmosphere interaction is developed. The ionization q(h)-profile dependence on penetrating high energy particles composition (protons, alpha-particles and heavier nuclei) and energy spectra (solar activity modulation included) are investigated. A computer program, realizing the Gaussian algorithm for solving of multidimensional integrals is created. The corresponding electron density profiles N(h) at solar minimum and maximum are obtained, too.

INTRODUCTION

The galactic cosmic rays (GCR) flux is an important factor for the middle and low atmosphere ionization under day and night conditions. GCR form the independent CR- or C-layer at height from 50 to 80 km in the ionosphere, thus forming its base (VELLINOV et al., 1974). Here - at 50-60 km height a region characterized with anomalously high field values up to $-4 \div -6$ V/m (APSEN et al., 1988; KOCHEEV et al., 1976, MAYNARD et al., 1981) is registrated via rocket measurements of the atmospheric electric field E_h-profiles. Thus, GCR ionization proves important for the clarification of a number of problems concerning the middle atmosphere electrodynamics and middle atmosphere - ionosphere interaction. For that purpose, a new model for the GCR - middle atmosphere interaction will be developed that will contribute to the further precision and generalization of previous results (VELLINOV et al., 1974).

GCR IONIZATION IN THE MIDDLE ATMOSPHERE

The electron production rate ($cm^{-3}s^{-1}$) at height h (km) for the particles type i is

$$q_i(h) = \frac{1}{Q} \int_{E_i}^{\infty} \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\pi/2+\Delta\theta} D_i(E,h,\theta) \left(\frac{dE}{dh}\right)_i \sin\theta \, d\theta \, d\varphi \, dE \qquad (1)$$

where $Q=35$ eV is the energy necessary for one electron-ion pair formation, (dE/dh) - the particles ionization losses, D(E) - their differential spectra, φ - the azimuth, θ - the angle towards the vertical. As GCR penetrate isotropically from the upper hemisphere from (1) follows:

$$q(h) = \frac{2\pi}{Q} \int_{E_i}^{\infty} \int_{\theta=0}^{\pi/2+\Delta\theta} D_i(E,h,\theta) \left(\frac{dE}{dh}\right)_i \sin\theta \, d\theta \, dE \qquad (2)$$

where E_i is the energy (GeV/nucl) corresponding to the geomagnetic threshold R(GV), $\Delta\theta$ takes into account that at a given altitude the particles can penetrate from spatial angle $(0, 90^\circ + \Delta\theta)$ that is greater than the upper hemisphere angle - $(0, 90^\circ)$. For $\Delta\theta$ there is the following equation (VELLINOV, 1968):

$$\Delta\theta = 90^\circ - \arc\cos\left(2R_e h + h^2\right)^{1/2} / (R_e + h) \qquad (3)$$

where $R_e=6371$ km is the Earth radius. In the interval 30-100 km

θ changes from 6 to 10°.

For dE/dh we are going to use the dependency (DOBROTIN,1964; VELLINOV et al., 1974, p.202)

$$-\frac{1}{\rho}\frac{dE}{dh}=\begin{cases} 2 \quad MeV.g^{-1}.cm^2 \quad E=10^3\div 0.6\ GeV & \text{region 1} \quad (4)\\ \frac{1.37}{E^{3/4}} \quad MeV.g^{-1}.cm^2 \quad E=0.6\div 10^{-3}\ GeV & \text{region 2} \quad (5)\end{cases}$$

where ρ is the atmosphere density in $g.cm^{-3}$. In fact the particle energy fall law in region 1 (0,6–10 GeV) is

$$E(h)=E-2.10^{-3}\tilde{h}Z^2\ Ch(\theta,h) \tag{6}$$

where $\tilde{h}=\int\rho(h)dh$ is the depth (g/cm^{-2}), Z is the particle charge, and $Ch(\theta,h)$ Chapman function taking into account the spherical form of the atmosphere. During particles penetration in the middle atmosphere their energy decreases while their ionization losses in the region 1 remain constant; in the region 2 they rise drastically according to (5): That effect was not taken into consideration in the previous investigations. After deducting (4,5) in (2) the total equation for the electron production rate is received:

$$q(h)=q_1(h)+q_2(h) \tag{7}$$

where q_1 from the region 1 practically coincides with the previous calculations (VELLINOV,1968). The ionization in the region 2 will be added to q_1

$$q_2(h)=1.8\times10^5\rho(h)\left[1.37\int_{10^{-3}}^{0.6}\int_{\theta_1}^{\pi/2+\Delta\theta}D(E)E^{-3/4}f_2(\theta)\sin\theta\ d\theta\ dE+\right. \tag{8}$$

$$\left.+D(>0.6)\int_{\theta_1}^{\pi/2+\Delta\theta}f_2(\theta)\sin\theta\ d\theta\right]$$

$$f_2(\theta)=\left(\frac{10^{-3}}{E_i+\Delta E}\right)^{3/2} \qquad \Delta E=2.10^{-3}(\tilde{h}-\tilde{h}_2) \tag{9}$$

$$\tilde{h}_2=\frac{172}{Ch(\theta,h)Z^2/A}+\frac{E_i-0.6}{2.10^{-3}Ch(\theta,h)Z^2/A}. \tag{10}$$

In fact, the function $f_2(\theta)$ normalizes the particles integral spectra in the regions 1 and 2. A is the particles atomic weight. The angle θ_1 is determined with the help of equation (10), when the proportion $\tilde{h}_2(\theta_1,h)=\tilde{h}(h)$ is fulfilled.

COMPUTER REALIZATION OF THE MODEL AND ANALYSIS OF THE RESULTS

The theoretical model thus presented is realized with the help of a computer. The Gaussian method is applied for the solution of multidimensional integrals (PRESS et al., 1987).It is characterized by high precision for the smooth integrant functions, that are well approximated with polinoms. That method is machine run-time efficient – it uses only 10 function values in the integral interval.

Having in mind, that Z/A=1 for the protons and about 0,5 for the heavier nuclei, as well as the actual GCR composition (DORMAN, 1963) $q_i(h)$ were calculated for all groups of nuclei: protons (Z=1), alpha-particles (Z=2), light (Z=3÷5), middle (Z=6÷9), heavy (Z=10÷21) and very heavy (Z > 22). In consequence the ionizations of the separate groups were summed up and the total ionization q(h) was received.

The calculations were conducted for two GCR spectra - in maximum and minimum solar activity, i.e. the 11-year GCR modulatiion from the solar wind is considered (DORMAN,1963). That modulation is expressed in the reverse solar activity changes and the GCR flux. A part of the results from the program model realization are presented on the Table: q(h) in the upper (80 km) and lower (50 km) part of the C-layer. The results from the previous calculations are given in brackets (VELLINOV et al., 1974). Hence, the contribution of q_z to the total q can be considerable. From the Table it is seen also that at geomagnetic latitudes over 55° q(h) is growing during the solar minimum period two times, compared to the solar maximum. At middle latitudes the 11-year variation is still considerable, while at low and equatorial latitudes the variation is weak.

C-LAYER ELECTRON DENSITY DURING MAXIMUM AMD MINIMUM SOLAR ACTIVITY

The equilibrium electron density (cm^{-3}) is obtained from equation

$$N(h) = \left[\frac{q(h)}{\alpha_e(h)(1+\lambda)} \right]^{1/2}$$

where $\lambda = N^-/N$ is the negative ions-electrons ratio and α_e is the effective recombination coeficient. Having in mind the α_e values from MITRA (1986)the C-layer electron density was calculated for typical day conditions for middle (41°) and high (55°) geomagnetic latitudes during solar minimum and maximum. The results are given on the Figure and are mean valued in relation to season dependency due to the unsufficient representativeness of the α_e seasonal variations. But, it can be said definitely, that in the C-layer (and below it) maximum in winter N is 30-40% greater than in summer. Over 80 km the season variation changes its sign.

CONCLUSION

The present work consideres new aspects of the C-layer which together with the total GCR ionization in the middle and low atmosphere is of major importance for the global atmospheric-electric circuit in the system of the solar-terrestrial relationships and biorelationships.

The results obtained so far are not final and are an object of further specification. For example under significant Θ the particles pass greater quantity of substance connected with the drastic growth of the Ch function. In that case an object of consideration are not only the electromagnetic interactions of GCR (4,5) but the nuclear as well. And those secondary cosmic rays will probably increase still more the obtained herewith electron production rates.

Under high solar activity the importance of the solar cosmic rays in ionization will grow, and hence - in the conductivity, currents, the electric fields and energetic processes in the middle atmosphere (VELLINOV and MATEEV, 1989).

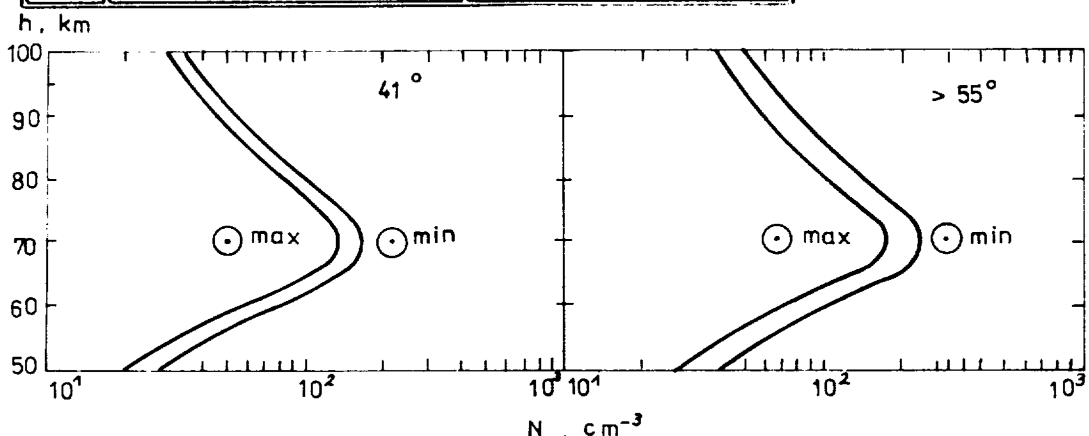
C-Layer Electron Production Rate $q.cm^{-3}\,s^{-1}$ Table

HIGH LATTITUDES - ABOVE 55°, R=1.5 GV

h, km	SOLAR MINIMUM		SOLAR MAXIMUM	
	SUMMER	WINTER	SUMMER	WINTER
80	$7.5\ 10^{-3}$	$3.7\ 10^{-3}$	$4\ 10^{-3}$	$2\ 10^{-3}$
	[$5\ 10^{-3}$	$2.5\ 10^{-3}$	$2.6\ 10^{-3}$	$1.3\ 10^{-3}$]
50	$4.8\ 10^{-1}$	$2.8\ 10^{-1}$	$2.5\ 10^{-1}$	$1.3\ 10^{-1}$
	[$2.5\ 10^{-1}$	$1.5\ 10^{-1}$	$1.3\ 10^{-1}$	$7\ 10^{-1}$]

MIDDLE LATITUDES 41° R=5 GV

80	$3.6\ 10^{-3}$	$1.8\ 10^{-3}$	$2.7.10^{-3}$	$1.5.10^{-3}$
	[$2.4\ 10^{-3}$	$1.2\ 10^{-3}$	$1.8.10^{-3}$	10^{-3}]
50	$2.3\ 10^{-1}$	$1.3\ 10^{-1}$	$1.7.10^{-1}$	10^{-1}
	[$1.2\ 10^{-1}$	$7\ 10^{-1}$	9.10^{-1}	$5.5.10^{-1}$]



C-layer electron density profiles for middle (41) and high (55) latitudes during maximum and minimum solar activity.

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