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On the role of cosmic rays in the atmospheric processes

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ABSTRACT

The role of charged particles in processes in the atmosphere is considered. It is shown that these particles play the important role in the global electric circuit provided the conductivity of air. The steady state equation describing ion production rate and their recombination is analyzed on the base of experimental data on cosmic ray fluxes and ions concentrations. These data were obtained at polar, middle and equatorial latitudes in the atmosphere from the ground level up to 30-35 km. The influence of charged particle fluxes on rainfall values during Forbush decrease and powerful solar proton events is demonstrated. Also, the mechanism of thunderstorm electricity production, separation of opposite sign charges, and lightning production is discussed.

INTRODUCTION

The main task of this paper is to attract considerable interest to charged particle fluxes participating in processes in the atmosphere. If one compares the flux of the solar electromagnetic radiation falling on the top of the Earth's atmosphere (~ 10^{10} erg/m^2 s) with the flux of energy of cosmic rays (~ 10^2 erg/m^{2}s for particles with energy E $\geq$ 0.1 GeV) the evident conclusion could be made: the influence of charged cosmic ray particles on the processes in the atmosphere is negligible in comparison with the electromagnetic radiation coming from the Sun. However, such conclusion is wrong. Let us imagine for a moment that cosmic rays stopped to intrude into the Earth's atmosphere. The ion production will be aborted and the global electric circuit will be destroyed. The production of thundercloud electricity and lightning will be over. The cloud area will be changed and precipitation level will decrease.

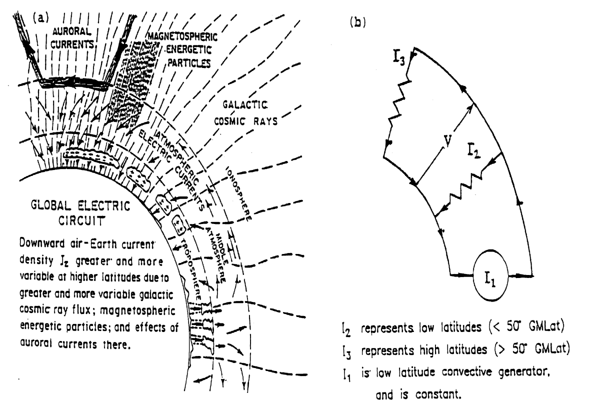

Figure 1. The sketch of global electric circuit taken from Tinsley (1996): **a)** a meridional section; **b)** simplified equivalent electric circuit.

The main part of total energy of cosmic ray (about 60%) falling on the top of the Earth's atmosphere belongs to the primaries in the energy range 0.1-1.5 GeV and these particles constitute about 95% of all cosmic rays. These particles undergoes the influence of the geomagnetic field in such way that the fluxes of cosmic rays at polar latitudes is higher than the ones at equatorial regions as much as ~ 30-35 times. Below some aspects of influence of charged particle fluxes on atmospheric processes are considered.

THE GLOBAL ELECTRIC CIRCUIT AND ION PRODUCTION

It is well known that the Earth has a negative charge about 6x10^5 C and the strength of electric field near its surface measured during fair-well weather equals E $\simeq$ -130 V/m (directed from the Earth's surface). The value of average current flowing between equalizing layer to be in the ionosphere at the altitude h $\simeq$ (55-80) km and the Earth's surface is I $\simeq$ 10^{-12} A/m^2 (Chalmers, 1967; Reiter, 1992). The light ions provide this current in the atmosphere. These ions are produced by cosmic charged particles (near the surface of the Earth radioactivity also gives ions). The lightning in thunderstorms and precipitation form another branch of the closed electric circuit providing electric current from the Earth to the equalizing layer. The sketch of global electric circuit taken from Tinsley (1996) is given in **Figure 1**.

If cosmic ray flux is changed atmospheric current is changed also because the density of ions is defined by cosmic ray fluxes. The equation describing the relation between ion production rate, q, and their recombination in the atmosphere under quasi-state conditions usually is taken in the form

$$\mathbf{q = a\ n^2,}$$

where n is ion concentration, α is recombination coefficient (Loeb, 1960). It is possible to test experimentally the validity of this equation using the data on cosmic ray fluxes and ion concentrations in the atmosphere. In **Fig. 2** and **3** the charged particle fluxes, I, and ion concentrations, n, measured at several latitudes are presented versus altitude [Ermakov et al., 1997]. It is easily to show that ion rate production, q, is proportional to charged particle flux: q=AI, where A is constant and depends on the characteristics of detector of charged particles. If there is the measurements of n and I performed at two different latitudes then, we can construct the following ratio:

$$\mathbf{(q_1/q_2) = (a\ n^2)_1/(a\ n^2)_2,}$$

where the signs 1 and 2 correspond to the latitudes with different geomagnetic cutoff rigidities R_{c1} and R_{c2}. Substituting AI instead of q and taking $A_1 = A_2$ and $a_1 \simeq a_2$ (these suggestions are fulfilled in the atmosphere) one can get that $\mathbf{(I_1/I_2)=(n_1/n_2)^2}$.

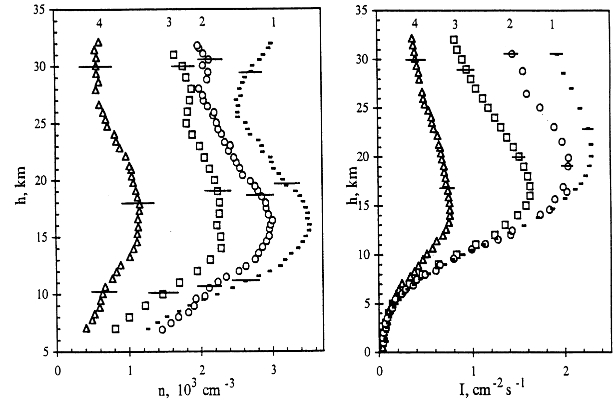

Figure 2. The charged particle fluxes vs. altitude.
Figure 3. The light ion concentrations vs. altitude measured at the latitudes with geomagnetic cutoff rigidities.

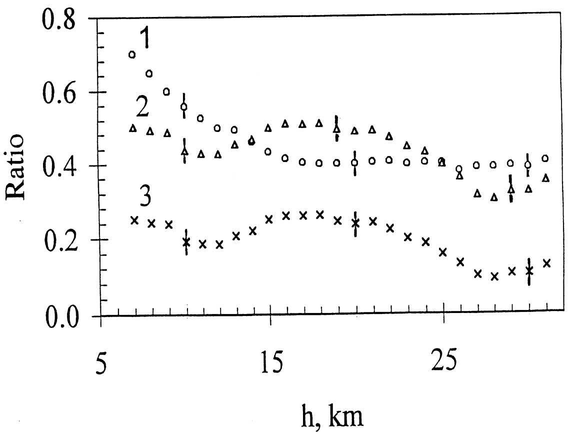

Figure 4. Ratios of charged particle fluxes, ion concentrations, and squared ion concentrations vs. altitude, h, for the equatorial and middle latitudes.

As an example in **Fig. 4** the ratios of charged particle fluxes (curve 1), ion concentrations (curve 2), and squared ion concentrations (curve 3) obtained from experimental data presented in Figs. 2 and 3 are given. The data obtained in equatorial (R_c = 17.3 GV) and middle (R_c = 3.3 GV) latitudes are used in this example. It is seen that the ratio of cosmic ray fluxes coincides with ion concentration one (curves 1 and 2 accordingly) and differs significantly with squared ion concentration ratio (curve 3). Everyone can find detail of such consideration in Ermakov et al., (1997).

Thus, the very important conclusion must be made that the ion balance in the atmosphere under quiet conditions is described by linear equation (not quadratic one)

$$\mathbf{q = b x n,}$$

where β is the linear recombination coefficient.

From the available experimental data on cosmic rays in the atmosphere and light ion concentrations linear coefficient of ion recombination, β, the rate of ion production, q, and electric conductivity of air can be calculated for any site of the Earth and any level of solar activity. Now this work is in progress.

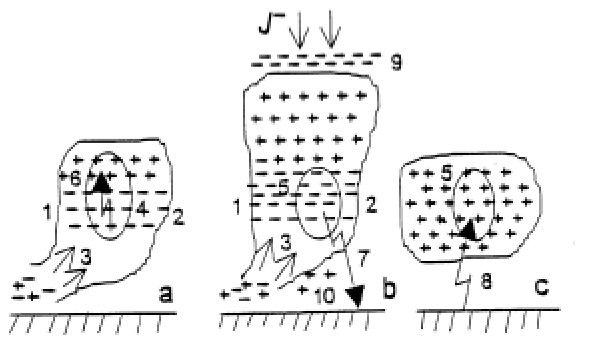

Figure 5. Schematic drawing of the stages of thundercloud formation: **a**-generation; **b**-maturity; **c**-degradation. **1**- warm front; **2**- cold front; **3**-ascending fluxes of wet ionized air; **4** and **5**-extensive air showers produced by primaries; **6**-discharges inside the cloud; **7**-descending strikes; **8**-the current of negative ions, running from the ionosphere to the top of a cloud; **9**-negative screen layer; **10**-positive charge in the cloud base.

COSMIC RAYS, THUNDERCLOUD ELECTRICITY AND LIGHTNING PRODUCTION

In 1920 Wilson put forward fascinating idea suggesting that thunderstorms act as a global generator of current maintaining the Earth's electric charge [Wilson,1922]. Since experimental evidences supporting this hypothesis were obtained [see references in Reiter, 1992]. However, the mechanisms of thunderstorm electricity production (separation of negative and positive charges in thunderclouds) and lightning generation are not clear completely till present time in spite of that there are a number of hypotheses [Willams, 1989]. Secondary charged particle fluxes generated in the atmosphere by primary cosmic rays are the only source of ion production and in such way positive and negative charges are produced throughout in the atmosphere. The problem consists in the spatial separation of negative and positive charges in the process of thundercloud production. The thunderclouds are formed from ascending wet air mass at the front of cold air. This mass always contains heavy ions (charged aerosols) because light ions produced by cosmic rays adhere to neutral heavy particles. As is known from the observations the concentration of aerosols has a maximum in the low atmosphere near the Earth's surface and its value is ~ 2 10^4 cm^{-3}.

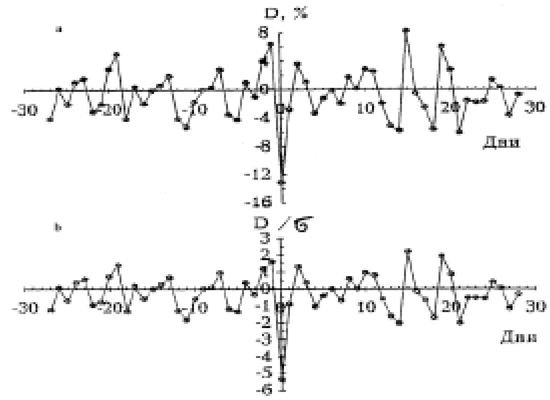

Figure 6. a) Relative changes of precipitation value D (days) on the Russian territory before and after forbush-decreases (for altitudes >20 km). **b)** The ratio of D to their standard deviations..

The half of these particles carries out the positive or negative electrical charge [Tverscoi, 1962]. These aerosols are picked up by ascending air mass. During ascending air mass is cooled and processes of condensation and coagulation of water molecules on charged aerosols take place. The rate of condensation essentially depends on the sign of charge. Namely, negative charged aerosols grow faster then positive ones as much as ~10^4 times [Rusanov and Kusmin, 1977; Rusanov, 1978]. The fast growth of aerosols with negative charge makes them heavy and their ascending with rising air mass is stopped at the low altitudes. At the same time aerosols with positive charge continue to rise with ascending wet air mass and stop their rising at higher altitudes than negatively charged aerosols. Such way the natural spatial separation of electric charges inside the cloud occurs [in detail see Ermakov and Stozhkov, 1998].

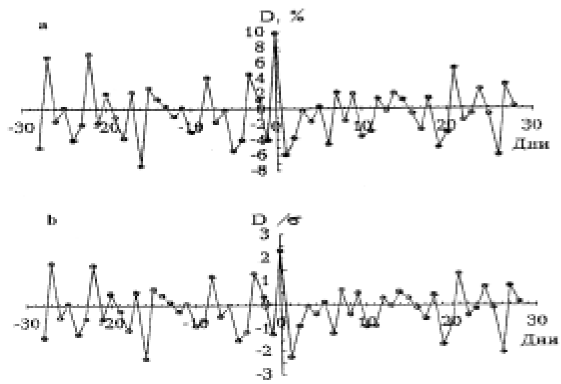

Figure 7. a) Relative changes of precipitation value D on the Russian territory before, during (0-day) and after solar proton flux invasion into the atmosphere (detected by neutron monitors on the ground). **b)** The ratio of D to their standard deviations.

Inside thundercloud the strength of electric field ranges up to E $\simeq$ 3 kV/cm and the distance between positive and negative separated charges is roughly estimated as Δh ~3-4 km. The high value of E is observed under thundercloud also. At the altitudes where thunderclouds are observed (h ~3 km) the value of puncture voltage is 15-30 kV/cm [Mick and Craggs, 1960]. In 1993 Ermakov put forward the idea that in such electric fields the discharges (lightning) are produced by extensive air showers arising from high energy cosmic ray particles with $\varepsilon \simeq 10^{14}$-$10^{15}$ eV. These high energy cosmic rays interact with nuclei of ambient air and give rise to many thousands of charged secondaries. Along ionized tracks of these particles in a strong electric field avalanches develop and propagate. The intensity of cosmic ray particles is enough to explain the number of lightning observed. As cosmic rays hit the Earth's atmosphere accidentally in all directions the lightning arise by chance also. In **Fig. 5** the processes of thundercloud electricity and lightning production are shown schematically [Ermakov and Stozhkov, 1998]. Thus, cosmic rays are responsible for the thundercloud electricity and lightning production.

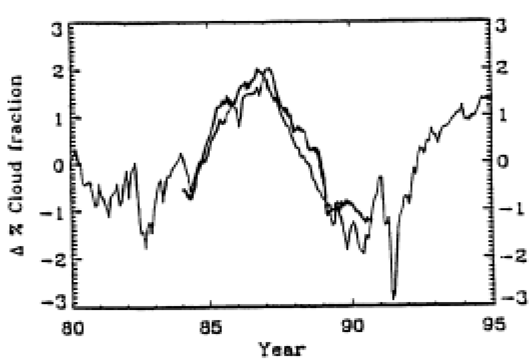

Figure 8. Cloud cover changes (12 month running average, thick curve) and monthly mean counting rate of Climax neutron monitor) in 11^{th} solar activity cycle. The data obtained by geostationary satellites correspond to the area over oceans [Svensmark and Friis-Christensen, 1997].

THE RELATIONSHIP BETWEEN COSMIC RAYS AND OTHER ATMOSPHERIC PHENOMENA

There are several publications in which the changes of cosmic ray fluxes are considered to be responsible for some processes in the atmosphere. Some of such phenomena are listed by Tinsley [1996]. Here we should like to analyze the following relationship: cosmic ray fluxes-cloudiness and cosmic ray fluxes-precipitation. The influence of charged particle fluxes on cloudiness was found by Veretenenko and Pudovkin [1994]. They found that the value of cloudiness reduces when cosmic ray fluxes in the the atmosphere decrease during so-called Forbush-effects of cosmic rays. As was shown by Stozhkov et al. [1995, 1996] during Forbush-effects the value of precipitation decreases also. In contrast, when high energy solar protons generated in powerful solar flare invade atmosphere and increase ionization value in it precipitation grow. These results were obtained at the examination of the data on precipitation at numerous meteorological stations located on the territories of Brazil and Former Soviet Union for more than two hundred Forbush-effects and several tens of solar flare events. In this analyses the superposed epoch method was applied. As example **Figs. 6** and **7** demonstrate the changes of precipitation in the cases of decreases and increases of cosmic ray fluxes in the atmosphere in Russia [Stozhkov et al., 1996]. Very interesting result were obtained by Svensmark and Friis-Christensen [1997] concerning the link in cosmic ray intensity and global cloud coverage. Their results demonstrate the strong relationship between charged particle fluxes on the Earth's surface and cloudiness during 11th solar activity cycle. This effect is given in **Fig. 8** [Svesmark and Friis-Christensen, 1997].

CONCLUSIONS

The results presented above testify that cosmic ray particle fluxes play important role in many atmospheric processes and only now this role begins to be elucidated. The thundercloud electricity and lightning production, cloud production, influence on the value of global cloudiness and precipitation on the short (days) and long (11th solar activity cycle) time scale, influence on processes of vortex production (VAI-index), operation of global electric circuit and long scale global climate changes depend on the values of cosmic ray fluxes. Future research help to understand in detail physical mechanisms of the link between atmospheric processes and fluxes of charged particles.

REFERENCES

Ramos, A.C.B., 1993, Three Dimensional AVO Analysis and Anisotropic Modeling Applied to Fracture Characterization in Coalbed Methane Reservoirs: PhD Thesis, Colorado School of Mines.

Rutherford, S.R., and Williams, R.H., 1989, Amplitudeversus-offet variations in gas sands: Geophyics, 54, 680688.

Ursin, B. and Tjaland, E., 1993, The Accuracy of Linearized Elastic Parameter Estimation, Journal of Seismic Exploration 2, 349-363.

Chalmers, J.Alan, Atmospheric Electricity, Pergamon press, 1967

Ermakov, V.I., Molnii-sledy chastiz sverchvysokich energii, Nayka I zhizn, Moskva, Prosveshenie, 1993, 92-98 (in Russian)

Ermakov, V.I., Bazilevskaya, G.A., Pokrevsky, P.E., and Stozhkov Y.I., Ion balance equation in the atmosphere, Journ. Geoph. Res., 1997, v. 102, No. D19, pp. 23,413-23,419

Ermakov, V.I.and Stozhkov Y.I., New mechanism of thundercloud electricity and lightning production, submitted to Journ. Geophys. Res., 1998

Loeb, L.B., Basic Processes of Gaseous electronics, New-York, 1960

Meek, J.M., and Craggs, J., Electrical Breakdown of Gases, Oxford, the Claredon Press, 1953

Reiter, R., Phenomena in Atmosphere and Environmental Electricity, Amsterdam, Elsevier, 1992

Rusanov, A.I. and Kusmin, V.L., On the influence of electric field on the surface tension of the polar liquid, Kolloidnyi Journal, 39, vypusk .2, 388-390, 1977 (in Russian)

Rusanov, A.I., To thermodynamics of nucleation on charged centers, Doklady Academii Nauk, USSR, 238, ? 4, 831-834, 1978 (in Russian)

Stozhkov, Yu.I., J. Zullo, Jr., I.M. Martin, G.Q. Pellegrino, H.S. Pinto, P.C. Bezerra, G.A. Bazilevskaya, V.S. Machmutov, N.S. Svirzevskii, A. Turtelli, Jr., Rainfalls during great forbush-decreases, Nuovo Cimento, 1995, v. 18 C, No. 3, pp. 335-341

Stozhkov, Yu.I., P.E. Pokrevsky, J. Zullo, Jr., I.M. Martin,V.P. Ohlopkov, G.Q. Pellegrino, H.S. Pinto, P.C. Bezerra, Turtelli, Jr., Influence of charged particle fluxes on precipitation, Geomagn. and Aeronomy, 1996, v. 36, No. 4, ppâ(in Russian)

Svensmark, H. and Friis-Christensen, E., Variation of cosmic ray flux and global coverage- a missing link in solar-climate relationships, Journ. Atmospheric and Solar-Terrst. Physics, 1997, v. 59, N0. 11, pp. 1225-1232

Tinsley, Brain A., Correlations of atmospheric dynamics with solar wind-induced changes of air-earth current density into cloud tops, Journ. Geophys. Res., 1996, v. 101, No. D23, pp. 29,701-29,714

Tverscoi, P.N., Course of meteorology, Leningrad, Gidrometeoizdat, 1962 (in Russian)

Veretenenko, S.V. and Pudovkin, M.I., Effects of forbush-decreases in cloudiness variations, Geomagn. and Aeronomy, 1994, v. 34, No. 4, pp. 38-44 (in Russian)

Sixth International Congress of the Brazilian Geophysical Society

Williams, E.R., Electricity of thunderclouds, Scientific American, 1989, No. 1, pp. 34-44,

Wilson, C.T., The maintenance of the Earth's electric charge, Observatory, 1922, v. 45.