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QUASIELECTROSTATIC MODEL OF ATMOSPHERE-THERMOSPHERE-IONOSPHERE COUPLING

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ABSTRACT

Multiple experimental evidences obtained recently convincingly show the strong influence of near ground atmospheric processes (volcano eruptions, sand storms, radioactive air pollution, earthquakes etc.) on the upper layers of thermosphere and ionosphere. The correspondent model explains the observed phenomena by the quasi-electrostatic field effects. The model consist of three parts: 1-electric field generation model, 2-electric field penetration at thermosphere-ionosphere heights, and 3-effects of electric field in the thermosphere-ionosphere. In the first part a model of ion kinetics in a near-ground layer of troposphere is considered. It explains the appearance of strong vertical electric field up to several kV/m. Second part with the help of existing model of atmosphere conductivity vertical distribution makes calculations of penetrated electric field at the heights from 90 up to 1000 km. It explains the horizontal electric field ~ 1 mV/m at the ionospheric heights as a result of original vertical electric field ~ 1 kV/m at the ground surface. The third part demonstrates the effects of electron concentration modification over the vertical electric field source. Self-consistence of the model is demonstrated by correspondence of the calculated parameters to the measured experimentally.

ION COMPOSITION AND ELECTRIC FIELD MODIFICATION AT THE GROUND LEVEL

One of the main factors of the presented model is the formation of some source of significant electric field variations at the ground level. For example, dust storms, thunderstorms, volcano eruptions, earthquakes and radioactive contamination could be such sources. At the time of the dust storm a maximum deviation of potential gradient made from + 15 kV/m up to -10 kV/m (Kamra, 1972). The movement of the dust in air influences on electrical field of atmosphere. A spatial electrical charge appears as a result of dispersion and friction of dust particles and attachment of small ions to them. Volcano activity can be the reason of variability of a electrical field too. In this case the huge quantity of ashes and other particles is thrown out into the atmosphere. Uncompensated charge of dust cloud can cause a thunderstorm (Kolokolov and Shalagina, 1978). Perturbations of the ground level electrostatic field in a range up to 1000 V/m are frequently observed before earthquakes in the regions of tectonic faults (Vershinin, 1997). In this case significant quantity of metal aerosols of the type Cu, Fe, Ni, Zn, Pb, Co, Cr and radon are emanated into the near ground layer of atmosphere (Boyarchuk, 1997). The special significance a dust acquires when it becomes radioactive, for example, as a result of failure on nuclear object, and renders strong influence to potential gradient of atmospheric electric field. So, for example, practically in all thicker ground layer of atmosphere (50 - 100 m) in 30-kilometers zone around Chernobyl NPP the ionisation rate was 10^5 - 10^6 cm^{-3} s^{-1}. Thus, all submitted processes effect on the level of ionization rate in the atmosphere. Therefore it is possible to consider, that the source of ionization is a generator of a local electric field. At the initial moment of time, the action of radiation generates a great number of O_2^+ ions in the atmosphere near the Earth's surface. This process occurs through both direct ionisation and the reaction of recharging involving primary N_2^+ ions, $N_2^+ + O_2 \rightarrow O_2^+ + N_2$ and electrons, which rapidly attach to oxygen in the three-body reaction, which is probable in dense lower atmospheric layers. If the molecule of oxygen absorbs electron directly, the excited ion can dissociate: $e + O_2 + O_2 \rightarrow O_2^- + O_2$; $e + O_2 \rightarrow O^- + O$. Free electrons also attach to metal atoms emanated from the tectonic faults. Such processes lead to the formation of negative ions. Thus, primary free electrons, as well as positive and negative elementary ions arise in the air at the ground level. Then the different ion-molecular reactions take place, which are typical for this layer. Action of these reactions during the time about 10^{-5} s results in the formation of stable

ion's content of the atmosphere near the Earth's surface (Boyarchuk, 1997; Boyarchuk, 1998): O^-, O_2^-, O_2^+, NO^+, CO_3^-, NO_2^-, NO_3^-, NH_4^+ and H_3O^+. The contents of other types of ions are negligible.
The huge quantity of molecules the water vapour ($\sim 10^{17}$ cm^{-3}), having substantial dipole moment p = 1.87 D, are contained in troposphere. Then hydration of elementary ions and formation ions' complexes of a type $NO_3^-{\cdot}(H_2O)_n$ and $H_3O^+{\cdot}(H_2O)_m$, with characteristic significance's n, m = 3 and more occurs rather quickly. Numerical analysis with the detailed account of the real contents of the extrinsic gases specifies an opportunity of formation in troposphere of more difficult structures of the type $NO_3^-{\cdot}(HNO_3)_n{\cdot}(H_2O)_m$, $HSO_4^-{\cdot}(H_2SO_4)_n{\cdot}(H_2O)_m$ (Kawamoto and Ogawa, 1986).

In hydrated ions cluster's sheath, consisting from 3 - 7 molecules of a water, has energy of connection about 5.4 eV (Kebarle *et al.* 1967), and it should not be destroyed from collisions at temperature below 1000 K. Naturally to assume, that such cluster's sheath can hinder recombination. It is known for electrolytic dissociation, that if the heat salvation surpasses the energy evolved at recombination of ions, the sheath around ions will detain recombination. Naturally, to assume, that it is not excluded and for a gas phase, i.e. when the energy hydration of ions surpasses energy, evolved at them recombination. The experimental supervision of slowing down of recombination processes of ions at the lower layers of troposphere are observed in work (Stozhkov *et al.*, 1997). A structure of ions is demonstrated on Figure 1. It is visible, that charge is completely shielded by hydrate sheath.

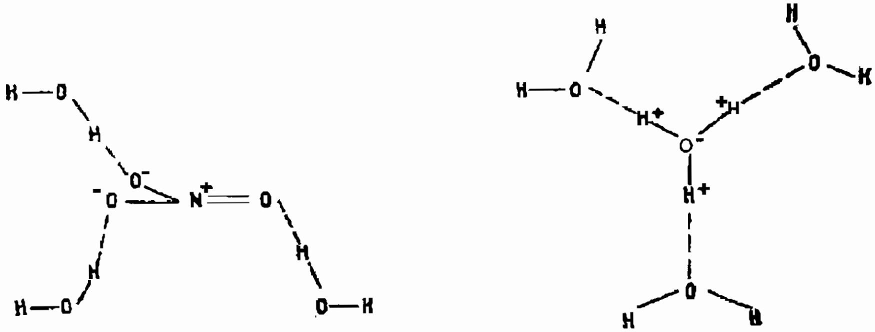

Fig.1. Structure of complex ions.

The ions can be captured by large particles forming charged aerosols. Aerosol particles can move in the atmosphere due to convective movements or under the effect of the Earth gravitation. During their movement through the atmosphere heavy aerosol particles may adsorb light ions, i. e., they may acquire electric charge several times larger than the elementary charge. A significant re-distribution of spatial charge in the atmosphere may result from this motion. For example, water drops in a cloud can play the role of heavy aerosol particles (Boyarchuk et al., 1998).

Foundation of the charge separation theory in a cloud was developed by (Wilson, 1929). Here we propose a double-scale model of kinetics of atmospheric aerosol. On the Figure 2 is demonstrated the pattern of such kinetics processes in atmosphere. We took into account the following processes: diffusion of all particles, drift of large and small charged particles in a local electric field, precipitation of large particles-drops, and transfer of small particles upwards with constant speed by convective flows. We also took into account interaction between particles: small charged particles recombine like elementary ions. A small charged particle attaches to large neutral or charged particle. Kinetic coefficients of these processes are different for different couples of interacting particles. Moreover, they depend on the local electric field E. Calculating the interaction of ions with large polarised water drops or aerosols we considered aerosols as a conducting sphere, located in given electric field. The dipole moment of a polarised sphere creates potential $\varphi = -\vec{E}\vec{r} + \vec{E}\dfrac{\vec{r}\cdot a^3}{r^3}$, where a – radius of a drop. Resolving a problem of relative movement of ions and polarised water

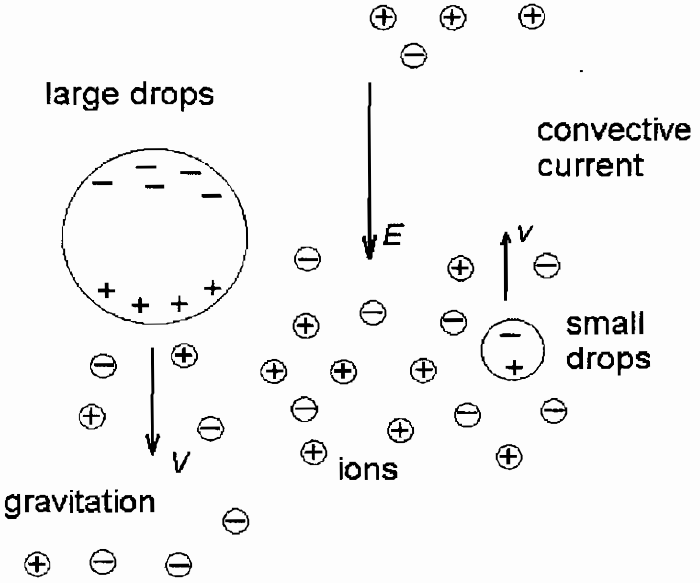

Fig.2. Sketch of ion adsorption process by large aerosols in troposphere.

aerosol in the given electric field with initial velocity, parallel to the vector $\vec{E}$. The attachment coefficient is proportional to cross-section of this interaction. For weak fields, such as $\frac{E\mu}{V} << 1$ (μ is mobility and V – precipitation speed) is executed, the dependence of an attachment coefficient on the electric field can be considered with good accuracy as a partially-linear dependence looking as:

$$\beta_{ij} = \beta_{ij}^{0}(1 \pm 4\frac{E\mu}{V}), \quad \text{under} \quad E > -\frac{V}{4\mu}; \text{and 0 under } E < -\frac{V}{4\mu} \ ,$$

where β_{ij}^{0} is the attachment coefficient without electric field (Hoppel, 1985). The sign in brackets is defined by polarity, (-) for negative ions, (+) for positive ones (if to consider as the positive field E, directed upwards from the Earth).

The system of equations describing kinetics of this process could express as:

$$\begin{aligned}
&\frac{\partial n_1}{\partial t} = d_1\frac{\partial^2 n_1}{\partial z^2} - \mu_1\frac{\partial}{\partial z}(En_1) + q - \alpha n_1 n_2 - \beta_{10}Nn_1 - \beta_{11}N_2 n_1 - v\frac{\partial n_1}{\partial z}, \\
&\frac{\partial n_2}{\partial t} = d_2\frac{\partial^2 n_2}{\partial z^2} + \mu_2\frac{\partial}{\partial z}(En_2) + q - \alpha n_1 n_2 - \beta_{10}Nn_2 - \beta_{11}N_1 n_2 - v\frac{\partial n_2}{\partial z}, \\
&\frac{\partial N_1}{\partial t} = D_1\frac{\partial^2 N_1}{\partial z^2} - M_1\frac{\partial}{\partial z}(EN_1) + V\frac{\partial N_1}{\partial z} - \beta_{00}N_1 N_2 + \beta_{10}Nn_1 - \beta_{11}N_1 n_2, \qquad (1) \\
&\frac{\partial N_2}{\partial t} = D_2\frac{\partial^2 N_2}{\partial z^2} + M_2\frac{\partial}{\partial z}(EN_2) + V\frac{\partial N_2}{\partial z} - \beta_{00}N_1 N_2 + \beta_{10}Nn_2 - \beta_{11}N_2 n_1, \\
&\frac{\partial N}{\partial t} = \beta_{11}n_2 N_1 + \beta_{11}n_1 N_2 - \beta_{10}Nn_2 - \beta_{10}Nn_1 + \beta_{00}N_1 N_2 + Q - v\frac{\partial N}{\partial z}, \\
&\frac{\partial E}{\partial z} = 4\pi e(n_1 - n_2 + N_1 - N_2),
\end{aligned}$$

were n_1, n_2 — concentrations of positive and negative ions; v — velocity of small aerosols; q — ionisation rate; d_i and μ_i — diffusion and mobility of ions; α — factor of ion's recombination; N_1 and N_2 — concentrations of positive and negative charged particles; β_{ij} — attachment factor for small ions i-polarity to large particle of j-polarity. N — concentration of neutral aerosols particles. D_i and M_i — diffusion and mobility of large aerosols, V — speed of precipitation, Q — rate of drops condensation, E — electric field strength.

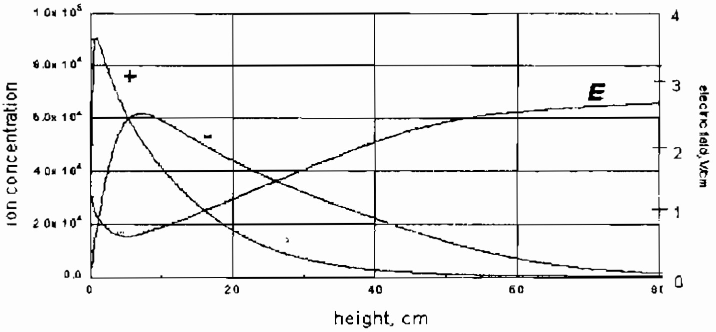

Fig.3. Distribution of positive (+) and negative (-) ions as a result of drift in an electrical field. Height distribution of electrostatic field magnitude E 50 seconds after the ionization commencement.

Figure 3 presents the results of simulations performed within the framework of the model described above, but without drops charges separation. In this case the main effect is the drift of ions in electric field. Such process can be realised due to the existence of mobile and long-life ions. Under the action of the natural near ground electric field the spatial distribution of charges can be formed at the surface: positive ions will drift to the Earth surface where they will recombine, but due to their low mobility, a spatial layer of positive ions forms at the surface. The negative ions will move vertically upwards (we do not consider electrons in this model since their concentration at the Earth surface is negligible). The presented plots clearly demonstrate the formation of a near-surface electrode layer. The electric field decreases in this layer and noticeably increases above it.

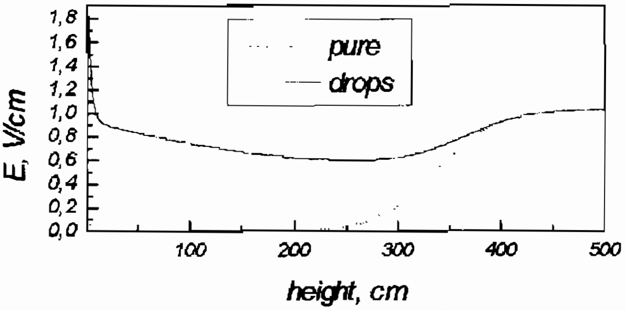

Fig.4. Change of an electrical fields by transfer of fog's drops the negative charge.

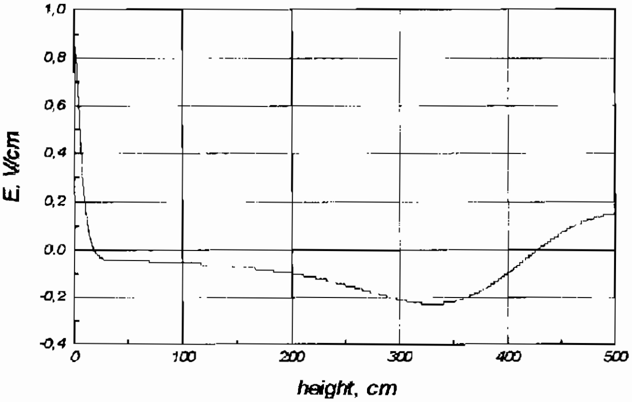

Fig.5. Change of an electrical field at presence of positive ions source.

Figure 4 demonstrates the case when mechanism of drops charge separation exist near the Earth's surface in the morning fog. The major mechanism for charge separation here is the process of transfer of a negative charge downwards by falling drops. It is visible from a Figure 4, that the negative charge transferred by drops of the fog on the Earth's surface compensates the electrode effect, which is shown on a Figure 4. In this case the field decreases slowly. However, if there is a significant source of positive ions above the surface, the situation will strongly change - the field within the electrode layer can change its sign. For example, there are experimental observations of fluxes of Fe^{3+} ions through the ocean water on an ocean surface in seismic activity regions before the strong earthquakes or volcano eruptions (Hata *et al.*, 1998). It is known, that ion's production rate does not exceeds value of 3 $cm^{-3}s^{-1}$ above a water surface in ordinary conditions. Therefore even at an insignificant flow of positive ions from a surface of water, the positive ions will not have time to recombine with negative ions, since concentration of negative ions is not enough for neutralisation of positive ions. As a result at water surface a positive charge layer will be formed, which can make essential effect on intensity of local electrical field at a surface. The last case is presented on Figure 5.

The strongest effect of a given mechanism of charge space separation is reached in cloud, especially if into it attend a constant source of ions. For example, there is radioactive blow-up cloud. The given phenomenon is discussed Boyarchuk *et al.*, 1998. Thus, the phenomena considered by us prove an opportunity of existence strong variations of a local electrical field at the Earth's surface.

IONOSPHERIC EFFECTS

The problem of electric field penetration into the ionosphere and related effects have been considered in many publication. In particular, in (Farley, 1959; Park and Dejnakarintra, 1973) the problem of electric field penetration from the E-region into the F-region and from the troposphere into the ionosphere, respectively, have been studied. Let us calculate the penetration of a vertical electrostatic field into the ionosphere for the case considered. We choose a cylindrical reference frame (r, φ, z). Let the distribution of the vertical electrostatic field strength E_z on a fixed base plane z_0 = const above the Earth's surface be Gaussian-like $E_z = E_0 \exp\{-d(r/a)^2\}$, where E_0 is the maximum value of E_z; $d = 4\ln(10)$; a is the characteristic size of the field localization region, specifically, the diameter of the enhanced ionization region. To determine the field at ionospheric altitudes, we shall use the approach developed by (Park and Dejnakarintra, 1973). Assuming a horizontal stratification of the medium and a vertical geomagnetic field, it is easy to deduce the following equation for electric potential ϕ from the continuity equation:

$$\frac{\partial^2}{\partial r^2}\phi + \frac{1}{r}\frac{\partial}{\partial r}\phi + \frac{1}{\sigma_1}\frac{\partial}{\partial z}\left(\sigma_0 \frac{\partial}{\partial z}\phi\right) = 0\,, \tag{2}$$

Here σ_1 is the Pedersen conductivity, and σ_0 is the conductivity along the geomagnetic field. The distribution of the conductivities with altitude can be given as follows: $\sigma_0 = \sigma_1 = b\cdot\exp\{z/h\}$ for $0 \le z \le z_1$, $\sigma_{0,1} = b_1\cdot\exp\{(z-z_1)/h_{0,1}\}$ for $z_1 \le z \le z_2$, where $z_2 = 90$ km, $z_1 =$ 50 and 65 km for day and night conditions, respectively; $h = 6.5$ km ; $h_0 = 3$ km; $h_1 = 4.5$ km; $b = 2\times10^{-13}$ Mo/m; $b_1 = b\cdot\exp\{z_1/h\}$. Such a distribution of $\sigma_{0,1}$ roughly corresponds to the empirical model for conductivity (Cole and Pierce, 1965). In this case the general solution to the equation for the electric potential ϕ can be represented in the form:

$$\phi(0 \le z \le z_1) = \int_0^\infty J_0(kr) \cdot \{A_1(k)\exp(c_1 z) + B_1(k)\exp(c_2 z)\} dk,$$
$$\phi(z_1 \le z \le z_2) = \int_0^\infty J_0(kr) \cdot \{A_2(k)I_\nu(kf) + B_2(k)K_\nu(kf)\} f^\nu dk, \tag{3}$$

where

$$c_1 = -\frac{1}{2h} - \left(\frac{1}{4h^2} + k^2\right)^{1/2}; c_2 = -\frac{1}{2h} + \left(\frac{1}{4h^2} + k^2\right)^{1/2}; \nu = \frac{h_1}{h_1 - h_0}; f = \frac{2h_1 h_0}{h_1 - h_0} \exp\left\{-\frac{h_1 - h_0}{2h_1 h_0}(z - z_1)\right\}$$

Here J_0 is the Bessel function of zero order; I_ν and K_ν are the modified Bessel functions of the first and second kind, respectively, and A_1, B_1, A_2, B_2 are numerical coefficients. Above the altitude $z = z_2 = 90$ km the force lines can be considered equipotential, so the distribution of ϕ for $z \ge z_2$ is the same as at $z = z_2$. From here we obtain that the electric field of the source of the localized field in ionosphere at altitudes $z \ge 90$ km is determined by the relation

$$E_r = -\frac{\partial}{\partial r}\phi|_{z=z_2} = \int_0^\infty J_1(kr)\left\{A_2(k)I_\nu(kf|_{z=z_2}) + B_2(k)K_\nu(kf|_{z=z_2})\right\} f^\nu |_{z=z_2} kdk \tag{4}$$

where J_1 is the Bessel function of the first order, and the coefficients A_1, B_1, A_2, B_2 can be found from the boundary conditions to the problem:

a) $-\frac{\partial}{\partial r}\phi|_{z=0} = E_0 \exp\{-d(r/a)^2\}$; b) ϕ is continuous at $z = z_1$; c) $\frac{\partial}{\partial z}\phi|_{z=z_2} = 0$.

The results of calculations of the ionospheric distribution for the horizontal field strength E_r normalized by E_0 for various sizes of the field localization region E_z during the day and night are shown in Figure 6. It is seen that during the day the degree of field penetration into the ionosphere is much smaller than during the night. The field strength therewith critically depends on the characteristic size a. For example, at $a = 100$ km the maximal field strength E_r^{max} is more than an order of magnitude larger than E_r^{max} at $a = 20$ km and nearly three times smaller than E_r^{max} at $a = 200$ km, both for day and night conditions. The dependence of E_r on r is characterized by a fast initial increase and slow decrease after reaching maximum. The absolute value of E_r^{max} even for $a = 200$ km at night is only 0.07 mV/m for $E_0 = 100$ V/m, i.e. the efficiency of electric field penetration into the ionosphere is low.

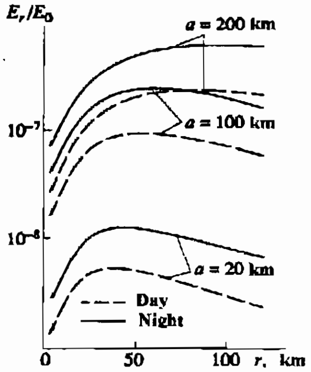

Fig. 6. Electric field strength E_r normalized by E_0 in the ionosphere at the altitude $z = 90$ km as a function of radial distance r from the electric field's source center.

Thus, the electric field strength produced by an atmospheric source at ionospheric altitudes is noticeable only when the region of horizontal localization of the field E_z near the Earth's surface is sufficiently wide ($a \ge 100$ km) and $E_0 \ge 500$ - 1000 V/m. Our model presented in the previous section confirms the possibility of existence of such a source.

Ionospheric Effect in the E-Region

Figure 7 shows the calculated electron concentrations N_e as function of distance r for three altitudes $z = 115$, 125, and 135 km. For a positive direction of E_z near the Earth's surface N_e decreases above the localization region of E_z (Figure 7a) and the

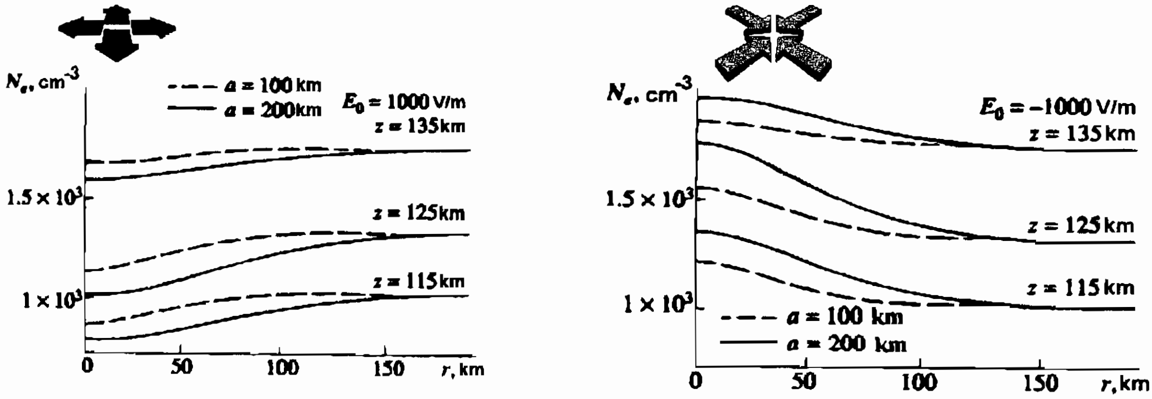

Fig. 7. Electron density modification in the E-region: (a) electric field at the ground surface is directed up, (b) electric field at the ground surface is directed down.

minimum value occurs at $r = 0$. With $E_z < 0$, i.e. when the field near the surface of the Earth is directed downward, the electron concentration above the localization area increases reaching a maximum at $r = 0$ (Figure 7b). Thus, the effect of the electrostatic field is most pronounced in the middle part of the nocturnal E-region.

Metallic Ion Layer Formation

The calculation of the ionospheric effect in the previous case was carried out without taking metallic ions M^+ into account. However, ionospheric plasma in the E-region can have such ions as an additive (Kim *et al.*, 1993). Let us consider the effect of the electric field E_r in this case, i.e. assuming that, in addition to molecular ions NO^+, N_2^+, and O_2^+ which are ordinarily the main ions in the E-region, the ionospheric plasma may also contain metallic ions M^+ with a mean mass close to that of molecular ions. Let us consider the case when the vertical electrostatic field E_z is directed downward onto the base plane. With such a directed field E_z the radial field component E_r at ionospheric levels and correspondingly the Pedersen ion drift are directed towards the z-axis, which provides the condition of ionospheric plasma storage above the electrostatic field generation region.

The results of calculations for E_0 = -1000 V/m and a = 200 km are shown in Figure 8. Before the moment of 'turning-on' the electric field, as well as at the boundary r = 1500 km, the molecular and metallic ion concentrations are determined using a photochemical approximation. As seen from the figure, 2 h after the beginning of the action of the electric field the metallic ion concentration above the field generation region becomes higher than for molecular ions in the altitude range 112 ± 134 km, and after 4 h the metallic ions dominate at altitudes of 107 - 146 km. Then at altitudes near z = 120 km a maximum of the metallic ion concentration occurs reaching 2.5×10^4 cm^{-3} within 4 h, which is approximately 60 times as high as the corresponding initial unperturbed value $N(M^+)$. In contrast, the molecular ion concentration at the same altitudes decreases, and by the moment of 'switching-off' the field a deep minimum of $N(XY^+)$ forms there with a value of 1.0×10^2 cm^{-3}, i.e., $N(XY^+)$ drops by an order of magnitude relative to its initial level.

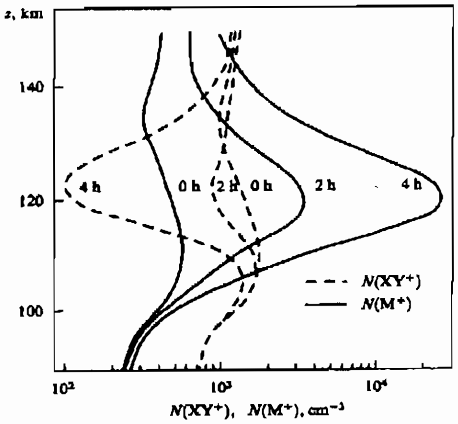

Fig. 8. Calculated altitude profiles of the molecular (dashed lines) and metallic (solid lines) ion concentrations above the electric field's source center (r = 0) at t = 0, 2 and 4 h after 'turning-on' the electrostatic field.

It should be noted that commonly, thin layers of metallic ions are formed in the mid-latitude E region due to the wind shear mechanism proposed by Whitehead, 1961. However, the metallic ion layers of such a kind are predominantly located at altitudes of 100 – 105 km and their typical thickness is 1 – 3 km, whereas in our case the layer thickness is more than 20 km.

Ionospheric Effect in the F2-Region

As a result of the electrodynamic drift induced by the electric field, plasma at F2-region altitudes will move along quasi-circular trajectories around the geomagnetic force line z' crossing the z-axis at z = 90 km, which is a line of zero electric field. In Figures 9 (a and b), the isolines of constant N_e at altitudes z = 250 and 500 km are shown at the moment 2 h after

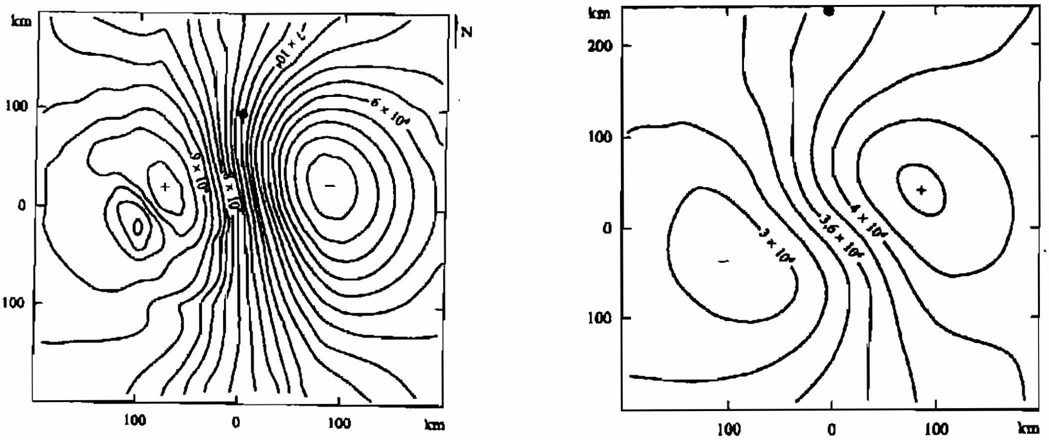

Fig. 9. Calculated electron density contours at the horizontal plane z = 250 km (a) and z = 500 km (b) in two hours after 'turning-on' the electric field. The coordinate system (x,y) is centered at the point where the geomagnetic line z' intersects the plane (z' is a line of zero electric field). The x-axis points to the equator and the y-axis points eastward. The black circle indicates the vertical projection of the electric field's source center onto the plane.

'turning-on' the field. The black circle marks the vertical projection of the electric field's source center on the corresponding ionospheric level. As seen from these figures, under the action of the field the horizontal distribution of ionospheric plasma over the F2-region above the field localization region on the base plane becomes essentially nonuniform. The characteristic size of the perturbed region exceeds 400 km. The maximum change in plasma concentration relative to the unperturbed level is about 30% at z = 250 km and 20% at z = 500 km.

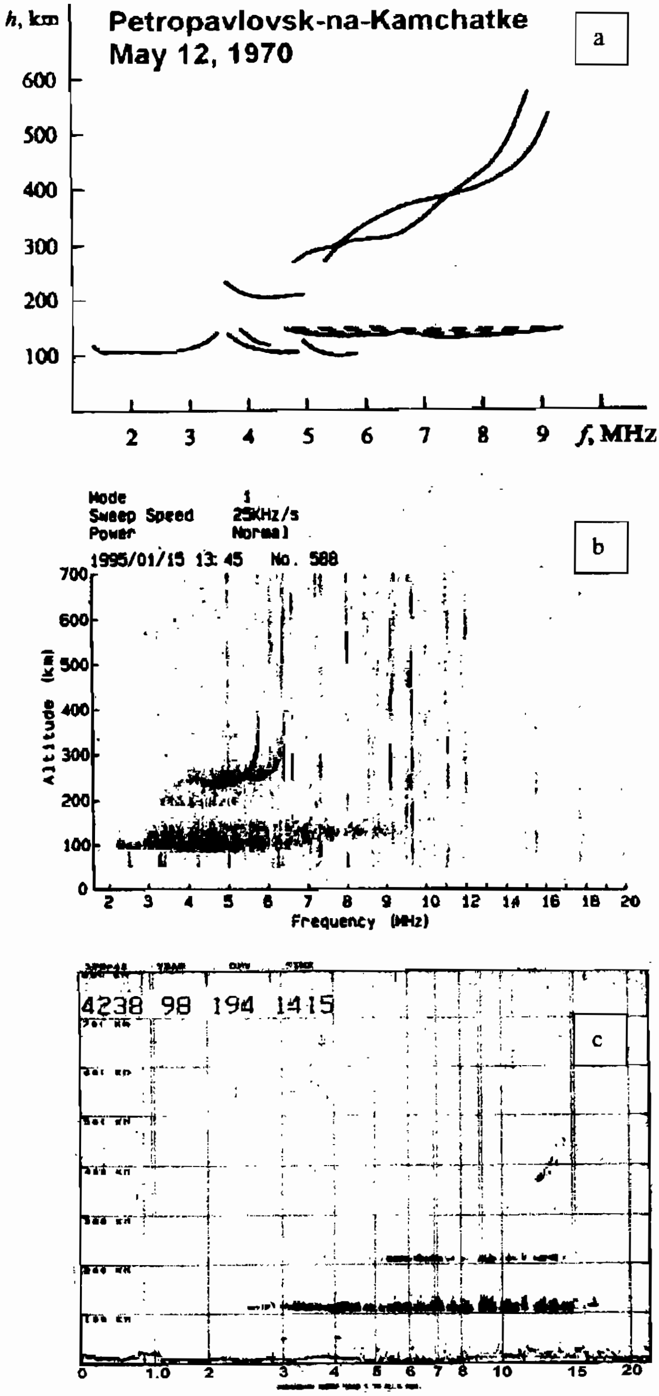

Fig. 10. Vertical sounding ionograms demonstrating formation of the sporadic E-layer at altitude of about 120 km: a) after Karymskii volcano (Kamchatka) eruption, 12.05.70, b) before the Kobe (Japan) earthquake, 16.01.95 c) before the Chia-I (Taiwan) earthquake, 17.07.98. For all cases the distance from ionospheric station to epicenter ≤ 200 km.

The picture of the horizontal distribution of the ionospheric plasma concentration is characterized by two sharp foci of positive and negative perturbations of N_e. With altitude, the perturbation region of the ionospheric plasma concentration shifts as a whole from the center of the vertical field localization region on the base plane (z_0 = 0) towards the equator. In this way in the bottom part of the F2 ionospheric region, the plasma concentration west and east of the magnetic meridian going through the electric field's source center increases and decreases, respectively, while in the upper part of the F2-region and at altitudes near the main ionospheric maximum the situation is the opposite: the focus of the positive perturbation of N_e lies east of the geomagnetic meridian, and west for the negative perturbation.

DISCUSSION OF EXPERIMENTAL RESULTS OBTAINED FROM GROUND-BASED AND SATELLITE STUDIES OF THE IONOSPHERE

Ionospheric changes are usually thought to be short-term (≤ 4 h) variations of electron density and other ionospheric parameters, which arise in quiet conditions without a visible external cause, i.e. in the absence of geomagnetic and other perturbations. The suggested mechanism of influence of atmospheric electricity on the ionosphere allows us (at least partially) to explain this phenomenon. In particular, seismic activity alone strongly affects the ionosphere: variations in the ionosphere of the order of 10 - 30% start emerging ~ 5 days before an earthquake with magnitude > 5. On average, ~ 300 thousand earthquakes occur on the Earth each year, ~ 100 - 120 of them with magnitude ≥ 5 in different regions of the world. Thus, the Earth's ionosphere turns out to be under the steady influence of seismic activity.

In (Pulinets *et al.*, 1997) the comparison was made of the radon concentration variations measured in a well near the epicenter of a forthcoming earthquake (Nazarbek, 12 December 1980, M = 4.7) and the changes of the critical frequency foF2 measured at an ionospheric station (Tashkent). The strong anticorrelation was shown between the electron concentration in F2-region of the ionosphere and radon concentration in seismoactive region, what confirms the feasibility of the mechanism proposed by us for electric field generation in the presence of an ionization source affecting the ionosphere.

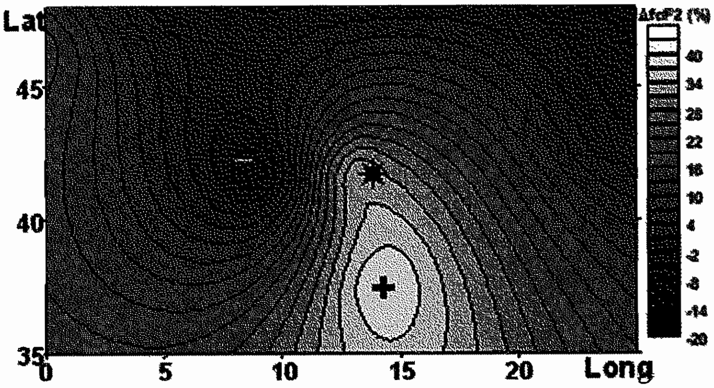

Fig.11 Critical frequency deviation distribution 5 days before the strong earthquake in Central Italy (Abruzzo, 07.05.84, M-5.8) by the data of European ground-based ionospheric stations network.

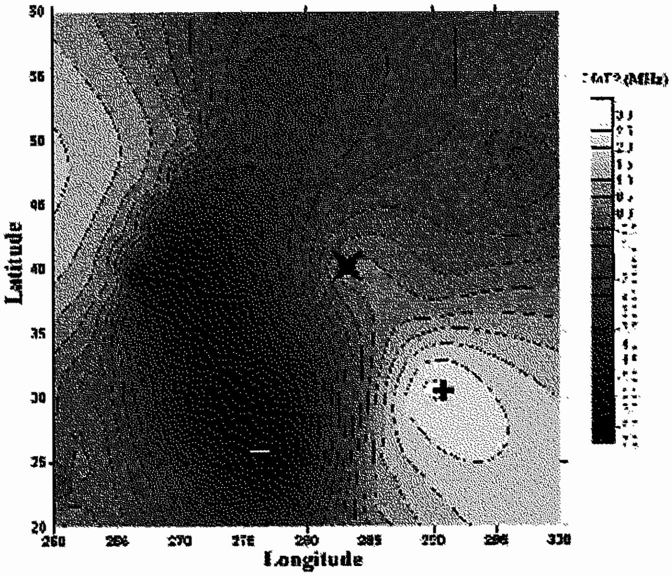

Fig.12 Critical frequency deviation distribution over the region of Three-mile Island atomic power station accident by the data of Intercosmos-19 topside sounder.

Experimental evidence is also available for electric field effects at different ionospheric levels. Figure 10a demonstrates a sporadic layer formed at an altitude of ~ 120 km due to the eruption of the Karymskii volcano (Kamchatka) on May 12, 1970 (Kolokolov and Shalagina, 1978), which exactly corresponds to the model calculations presented in subsection Metallic Ion Layer Formation. The same effects could be observed before the strong earthquakes due to anomalous electric field. On Figure 10 b and c are presented the sporadic E-layers observed before the Kobe (Japan, 17.05.95) earthquake (Ondoh, 1998) and before the Chia-I (Taiwan, 17.07.98) earthquake (Pulinets and Liu, 1998) respectively.

Even more compelling support for the approach considered is the comparison of ionospheric plasma density distributions obtained experimentally with the model calculations presented in subsection Ionospheric Effect in the F2-Region. These distributions were found by different methods (ground-based and space probing of the ionosphere) and for different physical phenomena (earthquakes and a nuclear power station accident). Figure 11 shows the deviation of the critical frequency foF2 (foF2 ~ $\sqrt{N_e}$) obtained with a ground-based network of ionospheric stations 5 days before a strong earthquake in Abruzzo (central Italy) on 07.05.84 with a magnitude of 5.8. A two-foci structure has been discovered which, as in the calculations, is shifted to south relative to the epicenter of the forthcoming earthquake. Similar structures are found when probing ionospheric regions above the areas of the forthcoming earthquake by topside sounding from onboard artificial satellites (Pulinets *et al.*, 1997; Pulinets, 1998a).

The calculations show that a radioactive injection into the atmosphere strengthens the atmospheric electric field more than above an earthquake region and the efficiency of the electric field penetration is higher, since the radioactive cloud is formed at altitudes of 1 - 2 km and not on the surface, as prior to an earthquake. In Figure 12, the distribution of the critical frequency change in the F2 ionospheric layer is shown a few hours after the accident at the "Three Mile Island" nuclear power station in the USA, obtained from the IK-19 satellite.

The experimental data presented confirm the results of theoretical predictions and permit us to conclude that the atmospheric electric field is a very important source of ionospheric variations.

CONCLUSIONS

The sources of the tropospheric electric fields are atmospheric events (thunderstorms, typhoons, atmospheric fronts, etc.), dust and sand storms, large active tectonic faults, volcanoes, ejections of radioactive material into the atmosphere during atomic power plant accidents, atmospheric contaminants above big industrial cities, etc. A self-consistent model is constructed for the electrodynamic interaction between the lower atmosphere and the ionosphere. Specifically, the following results were obtained: The anomalous electric field generation on the Earth's surface and in the atmosphere was calculated. It was shown that the additional flux of metallic aerosols leads to anomalous field strengthening. The penetration into the ionosphere of an electric field generated in a local region inside the near-surface atmospheric layer was evaluated. The efficiency of field penetration during the night is found to be higher than during day time and to strongly depend on the size of the vertical field E_z localization region. The electric field strength at ionospheric altitudes is significant only for large-scale sources on the condition that the maximum. E_z is about 1000 V/m. The effect of the electric field on the background ionosphere of E and F-regions was studied. The character of ionospheric perturbations is determined by the direction of E_z. A dense layer of metallic ions can be formed under the action of the field above its localization area in the middle part of the nocturnal E-region, which differs from the ordinary middle-latitude sporadic layer E_s by its thickness which is about three times greater than the mean thickness of the E-layer. Two regions with enhanced and decreased concentration are formed in horizontal distribution of the perturbed plasma concentration at altitudes of F2 ionospheric layer over anomalous electric field source on the ground. These regions are shifted towards the equator relative to the localization zone center of the vertical field E_z on the base plane.

We can state that at least the tectonically active regions (earthquake, volcanoes, active tectonic faults) make essential contribution to the global electric circuit (Bering III *et al.*, 1998) and to the day-today ionosphere variability (Pulinets, 1998b). It is supported by the revealed dependence of the seismo-ionospheric phenomena on the local time (Pulinets *et al.*, 1998). The relation between the global electricity LT variations and seismo-ionospheric phenomena LT dependencies and their interrelations would be the subject of further studies.

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