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Variations of the Electric Fields and Currents in Low Ionosphere Produced by Air Conductivity Growth over Region of Forthcoming Earthquake

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Variations of electrical fields and currents in the lower ionosphere are considered. The variations appear due to air conductivity growth near the ground. Two models of conductivity perturbations are investigated: a) a flat layer with high conductivity, b) semispherical region above the future earthquake centre.

1. Introduction

There are some processes which lead to the air conductivity growth near the ground in periods of preparation and during earthquake (EQ). First of all, we have to mention radioactive gases (radon) emanation from the earth crust. It produces an additional ionisation which increases the air conductivity. Besides, additional charged microparticles appear in the air due to acceleration by the piezoelectric fields produced in the earth crust.

The air conductivity growth leads to variations of the current which flows between the Earth and ionosphere. In its turn, it produces influence on ionospheric processes. This mechanism was considered, in particular, in papers [1,2].

The aim of the present publication is to carry out some calculations which connect the air conductivity near the ground with measurable ionosphere parameters.

Point is that the growth of the air conductivity itself does not give rise to electrical fields and currents. However, it is necessary to take into account that the space between Earth surface and the ionosphere forms peculiar spherical capacitor. This capacitor is under the voltage about some hundreds kV. It is assumed that the capacitor is charged due to the global thunderstorm activity. Recently, another charging mechanism is also discussed in the literature. It is connected with the effect of unipolar induction which arises due to different velocities of the rotation of the Earth's core and plasmasphere [3].

Here, we are not interested in the nature of the capacitor charge. We proceed now simply from the experimental fact that there is an electric field in the gap between the Earth and the ionosphere. It is so called the electric field of fair weather and its intensity near the ground $E_0(0) \cong 10^2 V/m$.

The air conductivity near the ground is equal $\sigma_0 \cong 10^{-14} S/m$. Therefore, the current $J_0 \cong \sigma_0 E_0 \cong 10^{-12} A/m^2$ flows in the air near the ground.

2. The estimation of electric field and current variations in the model of a flat-layer medium

The air conductivity growth near the ground due to a radioactive emanation gives birth to variation of the current $\vec{J}$ and electric field $\vec{E}$ on the background of their unperturbed values $\vec{J}_0$ and $\vec{E}_0$. In order to obtain the proper estimates it is necessary to know the air conductivity $\sigma(z)$ at any heights (the conductivity of the ground is considered as infinite large). Generally speaking, the air conductivity depends not only on the height z but on the distance from the epicentre of the future EQ as well. But the vertical scale of the conductivity variations $H \cong 10^3 \div 10^4$ m is much less than horizontal scale $L \cong 10^4 \div 10^5$ m. It permits to consider the air as a flat-layer medium.

We shall use in calculations the model of exponentially growing conductivity which is often met in the literature:

$$\sigma(z) = \sigma_0 \exp(z/H). \qquad (1)$$

When considering electrical processes in atmosphere it is necessary to take into account not only conductivity of the air σ but its relative permittivity ε also. But difference ε from 1 is about 10^{-4}, and for frequencies ω_0 which satisfy inequality $\sigma_0/(\omega_0\varepsilon_0) >> 1$ ($\varepsilon_0 \cong 9 \cdot 10^{-12}$ F/m is electric space constant) the air may be considered as a conductor. It means that an approximation of a conductive medium is valid for electrical processes with characteristic time scale $T \cong 2\pi/\omega_0 >> 6 \cdot 10^3$ s. We will assume farther that this condition is fulfilled. The

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distribution of electric fields and currents is described by following set of equations:

$$div\vec{J} = 0,\ \vec{J} = \sigma\vec{E},\ rot\vec{E} = 0. \qquad (2)$$

The solution of these equations for the undisturbed field of fair weather and σ from (1) is

$$J \equiv J_z = J_0,\ E \equiv E_z = E_0 \exp\left(-\frac{z}{H}\right),$$

$$J_0 = \sigma_0 E_0. \qquad (3)$$

It is possible to consider the Earth potential as zero. Then at $z \to \infty$ the potential

$$U_0 = \int_0^\infty E_0 \exp(-z/H)dz = E_0 H.$$

The total resistivity of the infinite pillar of the air with unit cross-section is

$$R_0 = \int_0^\infty dz/\sigma(z) = H/\sigma_0.$$

Apparently, $J_0 = U_0 / R_0$.

It is not difficult to find what happens if conductivity of the air layer with thickness h would grow from σ_0 to $\sigma_1 >> \sigma_0$. The total resistivity of the infinite pillar of the air will be equal $R_1 = R_0(\exp(-h/H) + h\sigma_0/(H\sigma_1))$, and the current

$$J_1 = U_0 / R_1 =$$
$$= U_0 / [R_0(\exp(-h/H) + h\sigma_0/(H\sigma_1))].$$

If we shall use the optimistic values (in the sense of the effective influence of resistivity growth on electric fields and currents), it is possible to put $h \sim H$ and $\sigma_1 \sim 10\sigma_0$. Then $J_1 \sim 2J_0$ and in the same way electric field will grow at any height $z>h$ $E_1(z) = J_1/\sigma(z) \sim 2E_0(z)$.

But near the ground ($z<h$) the field intensity will decrease. Really,

$$E_1(z<h) = J_1/\sigma_1 = E_0(\exp(-h/H) +$$
$$+ h\sigma_0/(H\sigma_1))^{-1}\sigma_0/\sigma_1 \sim 0{,}2E_0.$$

It means that the decrease of the fair weather field at low heights may be considered as EQ-precursor in the cases when EQ-preparation is followed by radioactive gas emanation. But if fair weather field variations are produced by the electric charges in the bowels of the Earth then increase or decrease of E depends on the charge sign.

The abovetaken values of σ_1 and h are in reality uncertain enough. Nevertheless, it is possible to assume that up to heights $z \cong 60 \div 70$ km the intensity of electric field $E_1(z)$ will be noticeable larger than undisturbed fair weather field.

But we have not taken into account very important circumstance, namely the definite dimensions L of the area of resistivity perturbation. Inequality which was spoken about ($L>>H$) justifies the flat layer approximations only for altitudes $z \le L$, where it is possible to neglect border effects. The condition $z \le L$ may be not valid for the ionosphere and the estimations carried out above ought to be reconsidered.

The influence of finite dimensions of the area where air conductivity increases will be accounted by simple model of $\sigma(z,x)$ perturbations (x - is a horizontal coordinate).

3. The semispherical domain of the air conductivity perturbations

We will assume that the region with high conductivity $\sigma_1 = const$ is restricted by semisphere with radius R above the centre of a future EQ (Fig. 1). If radius R is not too large ($R < H \sim 10^4$ km) it is possible to consider the surrounding medium as almost homogeneous with $\sigma \cong \sigma_0$ and $J = J_0 = const$. Under such assumption we can obtain the necessary data by well known analogy between set (2) and electrostatic equations for dielectric medium: $div\vec{D} = 0$, $\vec{D} = \varepsilon\vec{E}$, $rot\vec{E} = 0$. Obviously, these equations coincide with (2) if we change ε to σ and $\vec{D}$ to $\vec{J}$.

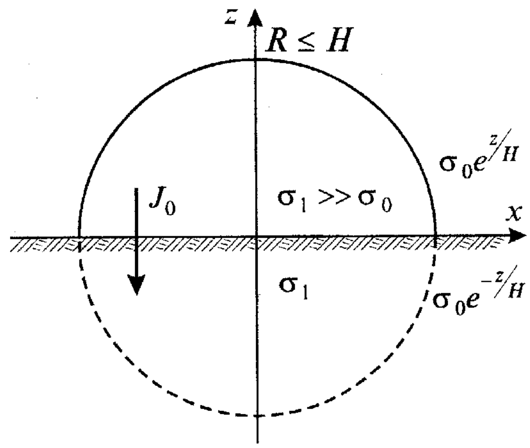

Fig. 1.

Let us consider the polarization of a sphere with permittivity ε_1 which is immersed in the medium with permittivity ε_0 and homogeneous electric field $\vec{E}_0$. It is known that homogeneous field $\vec{E}_1$ parallel $\vec{E}_0$ arises inside the sphere. The electric induction $D_1 = 3\varepsilon_1 D_0/(2\varepsilon_0 + \varepsilon_1)$, where $D_0 = \varepsilon_0 E_0$. As far as the electric field outside of the sphere is concerned, this field coincides with the field produced by dipole $p = D_0 R^3(\varepsilon_1 - \varepsilon_0)/[\varepsilon_0(2\varepsilon_0 + \varepsilon_1)]$ in the centre of the sphere with orientation parallel $\vec{E}_0$.

These data are directly connected with our problem. It is not significant that in our case we have not sphere but semisphere because it is situated above an infinite conductive plane. Its influence leads to the condition $J \equiv J_z$ at $z=0$. It is easy to fulfil this condition by mirror reflection of all charges in the plane $z=0$. In the case under consideration it is necessary to reflect all parameters of the upper medium: at $z<0$ the semisphere with $\sigma = \sigma_1$ is immersed in the nonhomogeneous medium with $\sigma = \sigma_0 \exp(-z/H)$. The direction of current $\vec{J}_0$ is not changed at $z<0$ under mirror reflection of charges.

As it was already said the radius of the semisphere is assumed small enough and we will neglect alterations of air conductivity at $z \le R$. Then, in accordance with the analogy mentioned above perturbations of field and current outside the sphere near its boundary are produced by central dipole

$$p = \frac{J_0 R^3(\sigma_1 - \sigma_0)}{\sigma_0(2\sigma_0 + \sigma_1)} \qquad (4)$$

with vertical orientation.

4. The electric field produced by point charge in the nonhomogeneous atmosphere

We need to calculate the action of dipole p at heights $z \gg H$, where nonhomogeneity of the air clearly displays. Therefore, we come back to the initial set of equations (2). Let us assume first that electric field $\vec{E}$ and current $\vec{J}$ are produced by point charge q. The exact solution of the problem was found not long ago for a spherical capacitor with an exponential height profile of the atmosphere conductivity [4]. But in our case, when we do not consider global effects, it is possible to confine ourselves with flat gap between the Earth and ionosphere. Then the equations (2) can be solved in such a way [5]. Substituting $\vec{E} = -\nabla\varphi$ and taking into account (1) we can write the following equation for φ :

$$\Delta\varphi + \frac{1}{H}\frac{\partial\varphi}{\partial z} = 0.$$

In cylindrical coordinates z, x, θ, φ does not depend on θ and it is convenient to use new function $\psi = \varphi \exp(z/2H)$. The proper equation is

$$\Delta\psi - \frac{\psi}{4H^2} = 0.$$

Its solution for point charge q in the origin of coordinates, which vanishes at $z \to \infty$ is $\psi = q\exp(-r/2H)/r$, where $r = \sqrt{x^2 + z^2}$. Accordingly,

$$\varphi = \frac{q}{r}\exp\left(-\frac{r+z}{2H}\right), \qquad (5)$$

and electric field components E_x and E_z are

$$E_x = qx\left(\frac{1}{r^3} + \frac{1}{2Hr^2}\right)\exp\left(-\frac{r+z}{2H}\right),$$
$$E_z = \frac{q}{r}\left(\frac{z}{r^2} + \frac{z}{2Hr} + \frac{1}{2H}\right)\exp\left(-\frac{r+z}{2H}\right). \qquad (6)$$

By means (6) it is possible to draw schematically the picture of electric force lines (they are also the lines of current $\vec{J} = \sigma\vec{E}$) in the air. The differential equation for $\vec{E}$ force line is following:

$$\frac{dz}{dx} = \frac{E_z}{E_x} = \frac{z(1 + r/2H + r^2/2zH)}{x(1 + r/2H)}.$$

Near the source where $z \ll H$

$$\frac{dz}{dx} \cong \frac{z}{x} \text{ and } z = x\,ctg\theta_0. \qquad (7)$$

We have designated by $ctg\theta_0$ the constant of integration in accordance with its geometrical sense. It is seen that near the source where nonhomogeneity of the air does not manifest itself the lines of electric forces $\vec{E}$ and current $\vec{J}$ form a "fan" of straight lines going out under different angles θ_0.

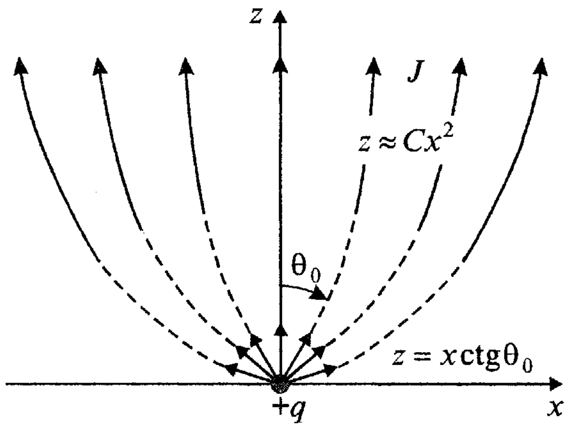

Fig. 2

At large altitudes where $z \gg H$ the picture changes drastically. Let us restrict ourselves with a region almost above the source where $x^2 \ll zH$. Here,

$$\frac{dz}{dx} \cong \frac{2z}{x}, \text{ and } z \cong Cx^2. \qquad (8)$$

where C is an integration constant. It determines one of the $\vec{E}$ - force lines which form a totality of parabolas stretching themselves along z - axis in the direction of σ growths (Fig. 2).

5. The dipole field in the nonhomogeneous atmosphere

Let us consider a dipole formed by two charges $\pm q$ in the points $z_0 \pm \delta$. We will estimate the "point" dipole field by means of equation (5) and limits $q \to \infty$, $\delta \to 0$ with $p = 2\delta q = const$.

For dipole situated on a ground ($z_0 = 0$)

$$\varphi = \frac{pz}{r^3}\left(1+\frac{r}{2H}\right)\exp\left(-\frac{r+z}{2H}\right), \qquad (9)$$

$$E_x = \frac{pxz}{r^5}\left[3\left(1+\frac{r}{2H}\right)+\frac{r^2}{4H^2}\right]\exp\left(-\frac{r+z}{2H}\right), \qquad (10)$$

$$E_z = \frac{p}{r^3}\left[\frac{3z^2}{r}\left(\frac{1}{r}+\frac{1}{2H}\right)+\frac{r}{2H}\left(\frac{z}{2H}-1\right)+\right.$$
$$\left.+\frac{z}{2H}+\frac{z^2}{4H^2}-1\right]\exp\left(-\frac{r+z}{2H}\right). \qquad (11)$$

At small distances $r \ll H$ the formulas (10), (11) transform themselves into known equations for a dipole field in a homogeneous medium:

$$E_x \cong \frac{3pxz}{r^5}, \; E_z \cong \frac{p(3z^2-r^2)}{r^5}. \qquad (12)$$

The current components J_x, J_z differ from (12) only by factor σ_0:

$$J_x \cong \frac{3p\sigma_0 xz}{r^5}, \; J_z \cong \frac{p\sigma_0(3z^2-r^2)}{r^5}. \qquad (13)$$

Now we should come back to our main problem of influence of air conductivity growth in the semispherical region (Fig. 1). In accord with electrostatic problem we should search the solution of the equations (2) in a form:

a) inside the semisphere a homogeneous current J_1 flows along z - axis;

b) outside the semisphere two currents flow: the initial current J_0 along z - axis and the additional current with components (13).

At the boundary of the semisphere conductivity σ jumps from σ_1 (inside) to σ_0 (outside), but the normal (radial) current component and tangential field E_0 component ought to be continuous:

$$J_1\cos\theta = J_x\sin\theta + J_z\cos\theta + J_0\cos\theta,$$
$$-\frac{J_1\sin\theta}{\sigma_1} = \frac{J_x\cos\theta}{\sigma_0} - \frac{J_z\sin\theta}{\sigma_0} - \frac{J_0\sin\theta}{\sigma_0}.$$

Using these formulas and (13) we should obtain two algebraic equations for two parametres p and J_1 with following solution:

$$J_1 = \frac{3J_0\sigma_1}{2\sigma_0+\sigma_1}, \; p = \frac{J_0R^3(\sigma_1-\sigma_0)}{\sigma_0(2\sigma_0+\sigma_1)}.$$

The value p coincides with (4) which was written by electrostatic analogy.

So far as we assume $\sigma_1 \gg \sigma_0$

$$J_1 \cong 3J_0, \; p \cong \frac{J_0R^3}{\sigma_0} = E_0R^3. \qquad (14)$$

One can see that the current in the perturbation region grows about three times, but electric field intensity decreases here, because

$$E_1 = J_1/\sigma_1 \cong 3J_0/\sigma_1 \cong 3E_0\sigma_0/\sigma_1 \cong 0{,}3E_0$$

(we put as earlier $\sigma_1 \cong 10\sigma_0$). The found solution of the initial set of equations satisfies all necessary conditions: $J_x = 0$ at $z=0$, $J \to 0$ at $r \to \infty$, and J_r and E_θ are continuous at the semisphere boundary.

Now we can calculate fields and currents at all heights using the complete formulas (10) and (11) because the value of p is known. If $z \gg H$ and $x^2 \ll zH$ it is possible to take $r \cong z$ and

$$E_x \cong \frac{px}{4H^2z^2}\exp\left(-\frac{z}{H}\right),$$

$$E_z \cong \frac{p}{4H^2z}\exp\left(-\frac{z}{H}\right). \qquad (15)$$

Obviously, the main components of electric field and current almost above the semisphere are E_z and J_z which are equal

$$E_z \cong \frac{J_0R^3}{4zH^2\sigma_0}\exp\left(-\frac{z}{H}\right) = E_0(z)\frac{R^3}{4zH^2},$$

$$J_z \cong J_0\frac{R^3}{4zH^2}. \qquad (16)$$

These variations of E_z and J_z arise on the background of the initial values $E_0(z)$ and J_0. Therefore, the relative variations are

$$\frac{E_z(z)}{E_0(z)} = \frac{J_z(z)}{J_0} \cong \frac{R^3}{4zH^2} \cong 10^{-2} \qquad (17)$$

(we have taken $R \cong H$, $z \cong 10H$).

6. Discussion

Let us begin with some numerical estimations. The unperturbed fair weather field at $z \cong 60$ km is equal $\sim E_0(0)e^{-10} \cong 5\cdot 10^{-3}$ V/m. An influence of E on the ionosphere may be characterized by so called plasma field E_p. If $E \ge E_p$ electrons are heated and their temperature T_e exceed markedly the temperature of heavy particles T: $(T_e - T)/T \cong E^2/E_p^2$. It leads to variations of collision frequency and ionization balance in the ionosphere. For the lower ionosphere $E_p \cong 3\cdot 10^{-1}$ V/m and perturbed field, as follows from sec. 2, is equal $\sim 2E_0(z = 60\ \text{km}) \cong 10^{-2}$ V/m. It means that the electron temperature T_e will be changed at $\Delta T \sim TE^2/E_p^2 \sim 30$ K. In principle, such heating may produce noticeable variations in the ionosphere but the effect will be disguised by natural fluctuations of $E_0(z)$ which are not connected with EQ.

If we would turn out attention to the second model under consideration (semisphere with increased conductivity) the result will be much worse because the expected disturbances of E_0 are about $\sim 10^{-2}$ of initial value, i.e. $\sim 5\cdot 10^{-5}$ V/m at $z \cong 60$ km. This value is too small as compared with E_p and cannot produce noticeable variations in the ionosphere parametres.

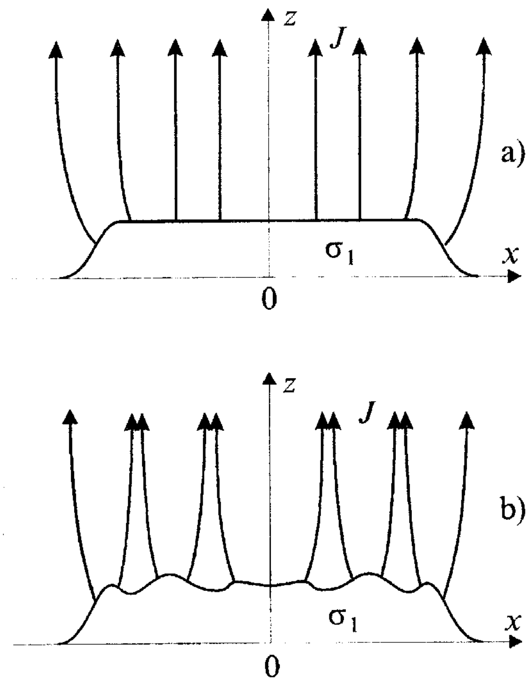

Fig. 3

In such a way we come to two opposite conclusions concerning possibility of ionosphere heating due to air conductivity growth over the future EQ. Obviously, this contradiction is connected with the model of air conductivity. But what may be expected in reality? There are no measurements of σ which are necessary to choose the model with complete certainty. Nevertheless, it is possible to imagine the real model in general.

If gas emanation around epicentre of a future EQ is more or less homogeneous, the region of increased σ and the structure of current lines resembles the picture in the Fig. 3a. The current lines are almost parallel in the central part of the picture and here the conclusions of Sec. 2 are valid. The boundary effects are described approximately with equations (16). Here, the current density decreases. The picture in Fig. 3b seems to be more realistic. Irregularity of gas emanation gives rise to wavelike structure of the boundary which surrounds the region with $\sigma_1 \gg \sigma_0$. Current lines bend in different directions and it leads to increase or decrease of current density in different regions of the ionosphere. The picture in a whole resembles the scattering of light rays after passing through the glass plate with distorted thickness. In this case the regions of light focusing and defocusing arise.

For the exact calculation of $E(z)$ and $J(z)$ disturbances one needs to know (at least in the statistical sense) the structure of region with increased σ. However, the mean value $\bar{J}$ (excluding boundary effects) will be approximately equal J_0. It means that the conclusions of Sec. 2 may be considered as realistic enough if they will be applied to mean values of $\bar{J}_z$ and $\bar{E}_z$.

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Изменения электрических полей и токов в нижней ионосфере при возрастании проводимости в приземном слое воздуха над областью будущего землетрясения

П.В. Блиох

Рассматриваются вариации токов и электрических полей в нижней ионосфере, вызываемые возрастанием проводимости в приземном слое воздуха в период подготовки землетрясения. Обсуждаются две модели: а) плоско-слоистое возмущение проводимости, б) полусферическая область над эпицентром землетрясения.

Зміни електричних полів і струмів в нижній іоносфері при зростанні провідності в приземному шарі повітря над областю майбутнього землетрусу

П.В. Бліох

Розглядаються варіації струмів та електричних полів в нижній іоносфері, що викликаються зростанням провідності у приземному шарі повітря в період підготовки землетрусу. Обговорюються дві моделі: а) плоскошарувате збурення провідності, б) півсферична область над епіцентром землетрусу.