LITHOSPHERIC ELECTROSTATIC FIELD PENETRATION: INFLUENCE OF THE ATMOSPHERIC AND IONOSPHERIC CONDUCTIVITY

ПРОНИКНОВЕНИЕ ЛИТОСФЕРНОГО ЭЛЕКТРОСТАТИЧЕСКОГО ПОЛЯ: ВЛИЯНИЕ АТМОСФЕРНОЙ И ИОНОСФЕРНОЙ ПРОВОДИМОСТИ

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Классический подход к расчету проникновения электростатического поля с поверхности земли в ионосферу заключается в рассмотрении измененного уравнения Пуассона, которое имеет следующий вид: $\nabla.\left(\text{€}\cdot\vec{\nabla}\Phi\right)=\Psi_{source}$, где €, Φ, и Ψ_{source} - электрическая проводимость, потенциал электрического поля и составляющая внешнего источника, соответственно. Параметры проникновения сильно зависят от тензора проводимости €. В упрощенном случае составляющая источника не учитывается ($\Psi_{source}=0$), и предполагается, что наклонение составляет 90°, это дает простое уравнение тензора проводимости. На основе этих предположений мы пытаемся рассчитать проникновение электростатического поля вплоть до орбитальных высот спутника DEMETER (примерно 700 км). Для этой цели необходимо следующее: распределение проводимости должно покрывать большой диапазон высот (от 0 км до примерно 1000 км над поверхностью Земли), и должны быть определены условия верхней границы для распространения электрического поля.

Introduction

Theoretical investigations of the electric field penetration from the Earth’s surface into the ionosphere are generally based on the approach of Park and Dejnakarintra (1973). Up to now, several authors investigated this problem using some modified kind of their model (Pulinets et al., 1998; Grimalsky et al., 2003). The general conclusion is that electric fields can effectively penetrate into the ionosphere and disturb the ionospheric plasma under certain circumstances. The field penetration is more effectively at night and the field intensity value critically depends on the characteristic source dimension, which could be described by the earthquake preparation area (Dobrovolsky et al., 1979). Pulinets et al. (2003) concluded that the electric field effectively penetrates into the ionosphere when the source area is greater than 100 to 200 km. This corresponds to a magnitude greater than 4.6 to 5.3, which is some kind of threshold value for the ionospheric sensibility. Grimalsky et al. (2003) estimated a critical value for the ground electrostatic field of the order of 1 to 3 kV/m. This value was also discussed in the frame of in-situ measurements (Vershinin et al., 1999). Pulinets and Boyarchuk (2004) collected some general characteristics of electromagnetic phenomena. Seismically induced anomalous variations in the ionosphere appear on the average up to 5 days prior to the earthquake. Thus it is possible to use them as short-term precursors. Today it is widely accepted, that pre-seismic effects are theoretically possible and that they can propagate to ionospheric heights. Several authors have already considered satellite observations (e.g., Jason et al., 2002). In-situ observations of ionospheric plasma parameters showed characteristic variations in the critical frequency foF2 (Silina et al., 2001), the total electron content (Liu et al., 2004), the ion temperature (Sharma et al., 2006) or the local ion and electron density (Parrot et al., 2006). In the following, we also concentrate to the DEMETER mission (Cussac et al., 2006). In this connection it is important to understand how electromagnetic fields from lithospheric origin penetrate into higher altitudes of the atmosphere. Particular interest is given to the electromagnetic emissions which occur at the orbital altitude of the DEMETER micro-satellite. The most significant results concerning the penetration of an electrostatic field into the ionosphere are related to the upper boundary condition (Grimalsky et al., 2003). The physical background is described as following: The electrostatic field should be calculated in a region $[0, z']$, where the altitude z' belongs to some region within the ionosphere. The value of the ionospheric conductivity increases by many orders of magnitude with increasing altitude. In this paper the electrostatic field up to some region $z = z_{up}$, where $z_{up} \geq z'$, is considered. The boundary $z = z_{up}$ separates the region below (with finite conductivity), from the region above (with nearly infinite conductivity). A boundary condition for the layer $z = z'$ is used.

Model Calculation

For calculations, a cylindrical coordinate system (f, r, z) with origin in the epicenter and *z*-axis directed upward is used. The distribution of the electrostatic field potential Φ can in general be determined from the modified Laplace equation $\nabla \cdot \left(\hat{s} \cdot \vec{\nabla} \Phi \right) = 0$

$$-\frac{\partial}{\partial x}\left[s\,(z)\frac{\partial}{\partial x}\Phi(x,z)\right] - \frac{\partial}{\partial z}\left[s\,(z)\frac{\partial}{\partial z}\Phi(x,z)\right] = 0, \quad (1)$$

$$\frac{\partial}{\partial z}\Phi(x,z)\big| z = 0 = -E_0(x), \quad (2)$$

$$\left\{\frac{\partial}{\partial x}\left[\sum\nolimits_p \frac{\partial}{\partial x}\Phi(x,z)\right] - s\,(z)\frac{\partial}{\partial z}\Phi(x,z)\right\}\Big| z = z_2 = 0. \quad (3)$$

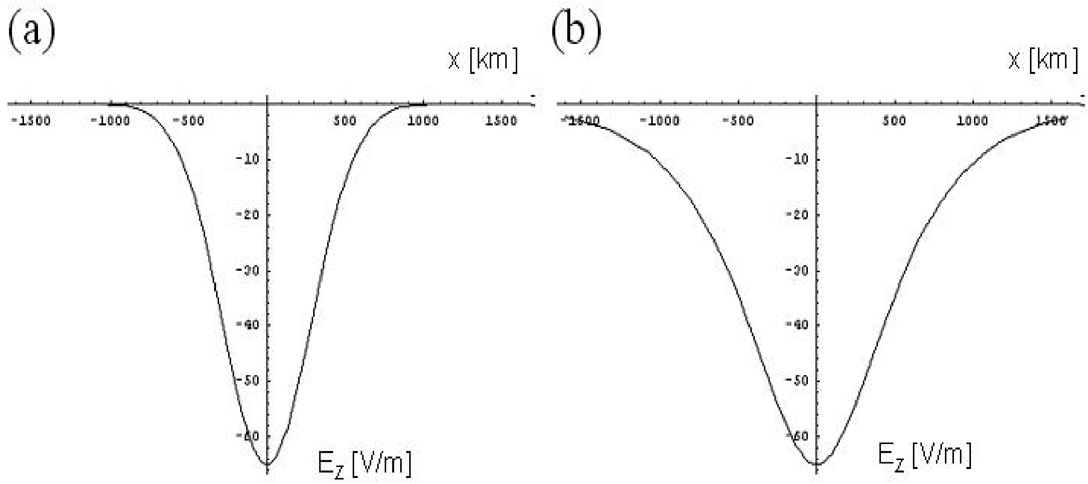

Fig.1: Vertical electrostatic field on the Earth's surface: (a) Gaussian-like distribution, (b) CosH^{-1}-like distribution. Spatial parameters are the same as in Pulinets et al. (1998).

Equations (2) and (3) are the lower and upper boundary conditions, respectively. Two different distributions for the vertical electrostatic field on ground are assumed (Figure 1)

$$E_0(x) = -\vec{E}_0 \exp\left[-\left(x/(a/2)\right)^2\right], \quad (4)$$

$$E_0(x) = \frac{-\overline{E}_0}{\cosh[x/(a/2)]}. \quad (5)$$

where a is the characteristic source parameter and $\overline{E}_0$ is the initial value of the electrostatic field on the Earth's surface. The exponential case is the same as that used by Pulinets et al. (1998).

Both values are in agreement with estimations of the electrostatic source in connection with an earthquake preparation process.

The conductivity is assumed to be isotropic in the altitude $0 \le z \le z_2$ where $z_2 = 90km$ is the upper altitude range. The general form of the conductivity is $s(z) = \bar{s}\exp[z/h]$. Different models of the conductivity are used, as shown in Table 1.

Table 1: Various models of the isotropic atmospheric conductivity

$\bar{s} = 5 \cdot 10^{-14}$ $h = 6\ km$	Dejnakarintra and Park (1974)
$\bar{s} = 6 \cdot 10^{-13}$ $h = 11\ km$	Holzworth et al. (1985)
$\bar{s} = 10^{-13}$ $h = 5\ km$	Molchanov et al. (1994)
$\bar{s} = 2 \cdot 10^{-13}$ $h = 6.5\ km$	Pulinets et al. (1998)

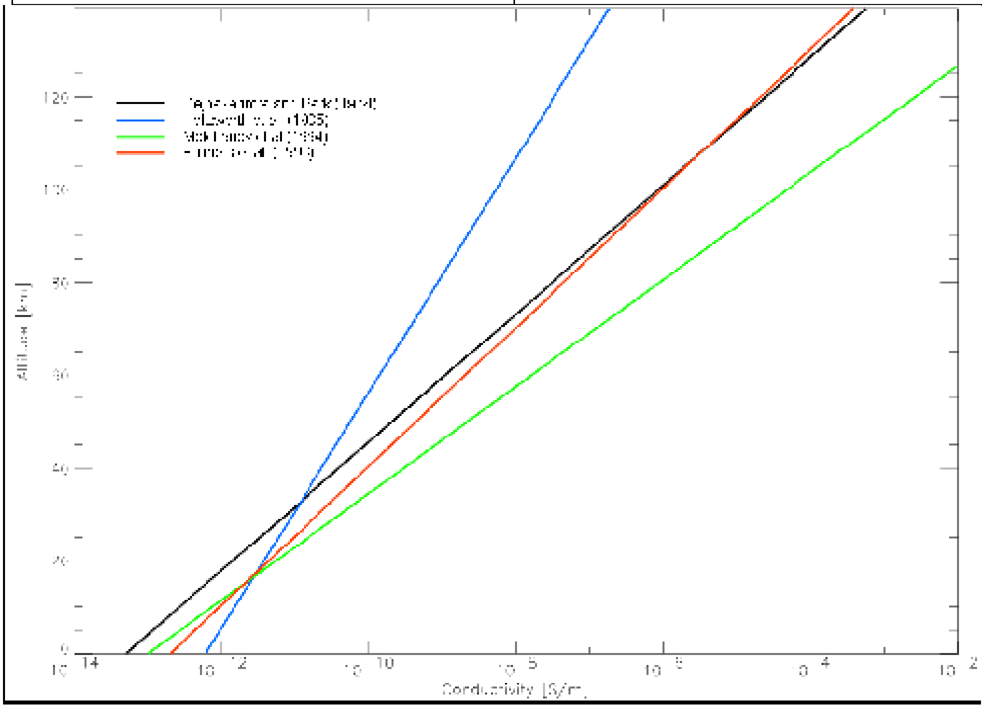

Fig.2: Isotropic atmospheric conductivity.

In each case, the integrated conductivity $\sum p$ is assumed to be $\sum p = 10\,S$ in day-time and in auroral zone and $\sum p = 0.1\,S$ in night-time. The general solution of equation (1) is

$$\Phi(x,z) = \int_0^\infty \cos[kx] \cdot \left(Ae^{l_1 z} + Be^{l_2 z}\right) \cdot dk, \tag{6}$$

where A and B are found from the boundary conditions (2) and (3),

$$l_{1,2} = -\frac{1}{2h} \mathrm{m} \sqrt{\left(\frac{1}{2h}\right)^2 + k^2},$$

$$A = \frac{1}{p\,l_1} \cdot \left(\int_0^\infty E_0(x)\cos[kx] \cdot dx - l_2 B \right)$$

$$B = -\frac{1}{p\,l_1} \cdot \left(\frac{l_2}{l_1} - \frac{e^{l_2 z_2}\left(\sum_p k^2 + s(z) l_2\right)}{e^{l_1 z_2}\left(\sum_p k^2 + s(z) l_1\right)} \right)^{-1} \int_0^\infty E_0(x)\cos[kx] \cdot dx$$

The components of the electrostatic field are given by

$$E_x(x) = \frac{\partial}{\partial x}\Phi(x,z)\,|_{z=z2} \qquad E_y(x) = -\frac{\partial}{\partial y}\Phi(x,z)\,|_{z=z2} \qquad E_z(x) = -\frac{\partial}{\partial y}\Phi(x,z)\,|_{z=z2} \qquad (7)$$

Our results obtained for night-time conditions $\left(\sum_p = 0{,}1S\right)$ are given in Figure 3.

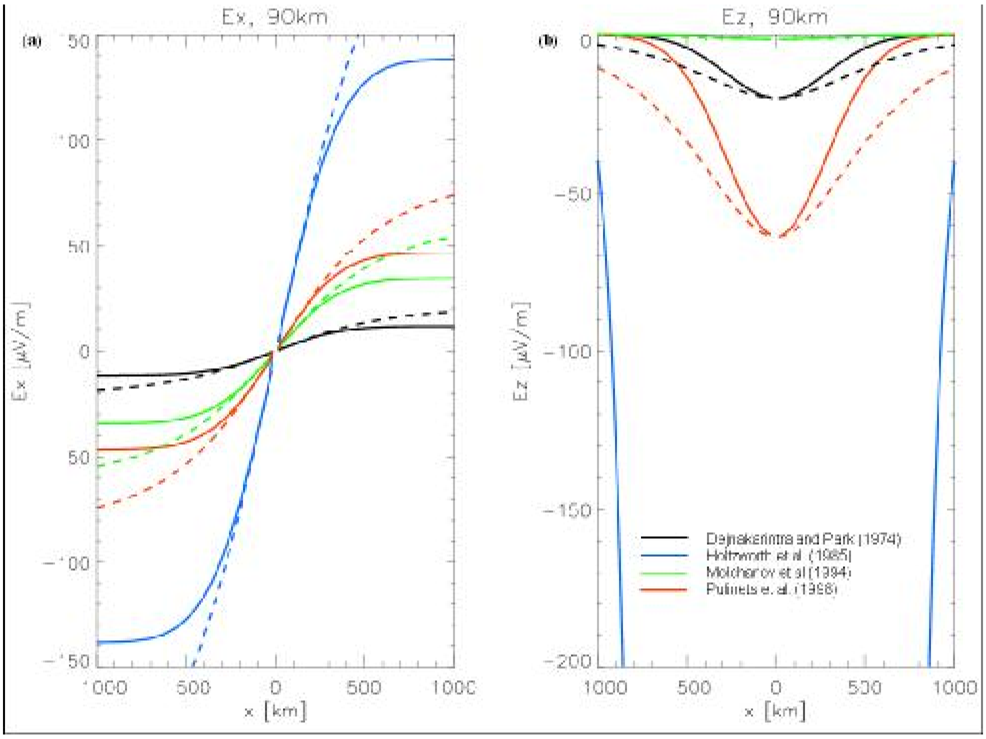

Fig.3: Components of the electrostatic field at z = 90 km: (a) Horizontal component E*x*, (b) Vertical component Ez. Solid and dashed lines corresponds to an Gaussian-like and a CosH^{-1}-like distribution on the Earth's surface.

Discussion

A similar model calculation was done by Pulinets et al. (1998). They started from the same basic equation (1), with a Gaussian-like vertical electrostatic field distribution as lower boundary condition (equation (4)). They used $\overline{E}_0 = -65$ V/m and a = 800 km. For the conductivity distribution they used the same as given in Table 1 for the altitude range $0 \le z \le 65km$. For the altitude region $65 \le z \le 90km$ they added another exponential-like distribution. In general, there are three important remarks concerning their model:

- They estimated the maximum value of the Ex-component in the range of mV/m (10^{-3}) for Altitudes $\ge 90km$. In our calculations, the maximum is lower, namely 10^{-5}.
- The formula of the horizontal electrostatic field given by Pulinets et al. (1998) is puzzling voncerning the term k^n.
- The spatial parameter ***a*** = 800 km used by Pulients et al. (1998), seems to be doubtful. The spatial size of the so-called earthquake preparation area is in the range of 200 km (Pulinets and Boyarchuk 2004).

As a fact, we obtained a weaker penetration of the horizontal electrostatic field into the ionosphere. Results are at least one order of magnitude lower than those of Pulinets et al. (1998).

Because the conductivity along geomagnetic field lines is much greater than the conductivities perpendicular to the field lines, and because of the assumption, that geomagnetic field lines are parallel in the upper ionosphere, the electric field intensity will not change significantly in higher altitudes. This is taken into account in the effective upper boundary condition (equation (3)). Thus, the electric field at the altitude z = 90 km can be used to calculate effects in higher regions.

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