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THE CHARACTERISTICS OF LITHOSPHERIC ORIGIN ULF EM RADIATION IN THE LITHOSPHERE-ATMOSPHERE-IONOSPHERE-MAGNETOSPHERE SYSTEM

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The penetration of ultra low frequency (0.01—100 s^{-1}) electromagnetic (ULF EM) radiation throughout ionosphere are calculated numerically for source in the lithosphere and in the magnetosphere. The changes of perturbation area shape during propagation in the ionosphere are investigated for different «antennas» types in the lithosphere which excite this EM radiation. The wave and spatial characteristics of penetrated into upper ionosphere ULF EM field are determined. The influence of altitude profile's main parameters of ionospheric plasma and geophysical condition onto the penetration effect of ULF EM radiation throughout ionosphere is discussed.

1. INTRODUCTION

It is known that before earthquake the anomalous phenomena in the atmosphere, ionosphere and at the ground surface have been observed. These phenomena have a form of changes of ionosphere parameters, intensity of atmospheric emission and EM radiation. However, the electromagnetic phenomenon such as EM radiation has been observed most often than other ones. To identify the observed radiation as one excited by lithospheric source it is necessary to know the characteristics of EM radiation as one excited by the lithospheric source.

Following Gokhberg hypothesis, we consider that the large-scale ULF currents appear in the seismic zone before earthquakes. The possibility of this effect is considered by Molchanov et al, 1994 in (1) where it was obtained that macrocurrents with typical sizes ~ 10—100 km can be excited in the lithosphere during earthquake preparation period. The penetration of ULF EM waves is considered earlier in (2) on the basis of model of lithosphere-atmosphere-ionosphere-magnetosphere (LAIM) system with axial symmetry and essential simplifications. The better penetration for the frequency ~ 1 Hz is obtained. However, it is not clear how the shape of EM perturbation in the ionosphere (400—800 km) is compared with the shape of current source and its location in the lithosphere. We suppose that only the accurate calculations of penetration of EM field throughout the LAIM media which is modeled without essential simplifications permit to obtain the characteristics of EM radiation of lithospheric origin and by means of these characteristics the identification and determination of the parameters of lithospheric source are possible.

In this paper we present the calculation results of penetration of ULF EM radiation throughout LAIM media obtained by use of the model of LAIM system taking into account the smooth changes of permittivity tensor with respect to altitude, inclination of geomagnetic field and volume lithospheric current of different geometry (we consider both cases of $\mathrm{div}J = 0$ and $\mathrm{div}J \neq 0$). We carry out the search of influence of the geophysical conditions and geometric type of current on the penetration effect of ULF EM radiation throughout LAIM system and obtain the wave and spatial characteristics of this radiation and comparative characteristics of geometrical sizes and spatial structure of EM radiation at the satellite altitudes with geometrical sizes and type of lithospheric current. We also evaluate the amplification effect of EM radiation of lithospheric source which could take place in the area with captured particles of radiation belts. The losses on the reflection of ULF EM radiation propagating in magnetosphere from the ionosphere in the magneto-conjugated points. The latter consideration is important for the possibility of observation of the lithospheric EM radiation at the satellites during long time period.

2. THE MODEL AND BASIC EQUATIONS

The Cartesian coordinate system is used, so that the axis z was directed perpendicularly to the surface of the Earth. We suppose that the permittivity of all medium is changing along z-direction only, but in tangential plane xy, the permittivity of all medium remains constant.

The lithosphere and atmosphere being isotropic spaces, therefore their tensors of permittivity are diagonal. The lithospheric permittivity is $\varepsilon_l = 1 - i4\pi\sigma_l/\omega$, where σ_l is lithosphere conductivity, and the atmospheric permittivity is $\varepsilon_A = 1$. In the lithosphere we put the volume current with an arbitrary geometry which shape is defined later. Taking into account an inclination of geomagnetic field to the vertical direction $\angle \mathbf{zH} = \theta$ in the ionosphere, we rewrite the ionospheric permittivity tensor as

$$\varepsilon_{\alpha\beta} = \begin{vmatrix} \varepsilon\cos^2\theta + \eta\sin^2\theta & ig\cos\theta & (\eta - \varepsilon)\cos\theta\sin\theta \\ -ig\cos\theta & \varepsilon & ig\cos\theta \\ (\eta - \varepsilon)\cos\theta\sin\theta & ig\cos\theta & \varepsilon\sin^2\theta + \eta\cos^2\theta \end{vmatrix}. \quad (1)$$

where ε, g and η are well-known permittivity tensor elements in cold two component MHD plasma without inclination of the geomagnetic field.

The solving of exact electromagnetic equations is needed because the penetration of ULF radiation occurs in the near zone of radiation and wave zone is forming for considered frequency range 1—100 s^{-1} on the altitudes over 4000 km, where the geometric optics method can be applied. We calculate the penetration of ULF EM field throughout lithosphere, atmosphere and ionosphere, where the sharp changes of permittivity take place, but for propagation in the magnetosphere the geometric optics approximation is used.

Starting from the well-known differential equation for electric field

$$\Delta\mathbf{E} - \nabla(\nabla\cdot\mathbf{E}) = \frac{1}{c}\frac{\partial}{\partial t}\left(\frac{1}{c}\frac{\partial(\widehat{\varepsilon\mathbf{E}})}{\partial t} + \frac{4\pi}{c}\mathbf{J}\right), \quad (2)$$

which follows from the Maxwell equations, and applying the Fourier-transform in xy plane, we obtain the equations for the tangential electric field amplitudes

$$\frac{d}{dz}\left[\frac{\varepsilon_{33} - k_y^2/k_0^2}{D}\frac{dE_x}{dz} + \frac{k_x k_y}{k_0^2 D}\frac{dE_y}{dz} + i\frac{k_x}{D}\Upsilon + \frac{4\pi k_x}{\omega D}J_z\right] + i\frac{\varepsilon_{13}}{D}\frac{d}{dz}\Lambda +$$
$$+(k_y^2 + k_0^2\tilde{\varepsilon}_{11})E_x + (k_x k_y + k_0^2\tilde{\varepsilon}_{12})E_y + i\frac{4\pi\omega}{c^2}\left(\frac{\varepsilon_{13}}{D}J_z - J_x\right) = 0, \quad (3)$$

$$\frac{d}{dz}\left[\frac{\varepsilon_{33} - k_x^2/k_0^2}{D}\frac{dE_y}{dz} + \frac{k_x k_y}{k_0^2 D}\frac{dE_x}{dz} + i\frac{k_y}{D}\Upsilon + \frac{4\pi k_y}{\omega D}J_z\right] + i\frac{\varepsilon_{13}}{D}\frac{d}{dz}\Lambda +$$
$$+(k_x k_y + k_0^2\tilde{\varepsilon}_{21})E_x + (k_x^2 + k_0^2\tilde{\varepsilon}_{22})E_y + i\frac{4\pi\omega}{c^2}\left(\frac{\varepsilon_{13}}{D}J_z - J_y\right) = 0. \quad (4)$$

Here, the following definitions are used: the $\propto\exp[i(...)]$ dependence for all wave components; k_i and ω are the components of wave vector in i-projection and frequency respectively; $\varepsilon_{\alpha\beta}$ are components of the permittivity tensor; $0 = \varepsilon_{33} - (k_x^2 + k_y^2)/k_0^2$; $\tilde{\varepsilon}_{\alpha\beta} = \varepsilon_{\alpha\beta} - \varepsilon_{13}\varepsilon_{3\beta}/D$; $\Upsilon = \varepsilon_{31}E_x + \varepsilon_{32}E_y$; $\Lambda = k_x E_x + k_y E_y$; $k_0 = \omega/c$; c is light velocity in vacuum.

3. THE BOUNDARY CONDITIONS

We introduce the upper bound in the magnetosphere over sharp changes of plasma parameters and lower bound in the lithosphere under current source. We consider that semi-infinite homogeneous spaces are situated outside the bounds. We assume that waves of the Alfven (AW) and magnetosonic (MS) types radiate from the upper bound into magnetospheric semi-infinite space and the waves of E- and H-types radiate from the lower bound into lithospheric semi-infinite space due to dispersion properties of these medium in the considered frequency range. The wave numbers in the introduced coordinate system are $k_{z1} = -k_x/\tan\theta + k_0/\varepsilon^{1/2}\cos\theta$ and $k_{z2} = (k_0^2\varepsilon - k_x^2 - k_y^2)^{1/2}$ for AW and MS respectively. The tangential components of EM field (E_τ, H_τ) over upper boundary could be expressed in the term of wave amplitudes

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = \hat{\rho}\begin{pmatrix} C_A \\ C_{MS} \end{pmatrix}, \qquad \hat{\rho} \equiv \frac{1}{k_0\sqrt{\varepsilon}}\left\|\begin{matrix} k_x - k_0\sqrt{\varepsilon}\sin\theta & -k_y \\ k_y & k_x - k_{z2}\tan\theta \end{matrix}\right\|, \tag{5}$$

$$\begin{pmatrix} H_x \\ H_y \end{pmatrix} = \hat{\gamma}\begin{pmatrix} C_A \\ C_{MS} \end{pmatrix}, \qquad \hat{\gamma} \equiv \left\|\begin{matrix} \dfrac{k_y a_{11}\tan\theta + k_{z1}a_{21}}{k_0} & \dfrac{k_y a_{12}\tan\theta + k_{z2}a_{22}}{k_0} \\ \dfrac{-k_x a_{11}\tan\theta - k_{z1}a_{11}}{k_0} & \dfrac{-k_x a_{12}\tan\theta - k_{z2}a_{12}}{k_0} \end{matrix}\right\|. \tag{6}$$

The coefficients of matrix before vectors of MS and AW amplitudes are found using projections of equation $[\mathbf{E}, \mathbf{k}] = -k_0\mathbf{H}$. In the latter derivations the wave numbers of AW and MS waves and the relation $E_z = -E_x\tan\theta$ were used, which is valued due to great conductivity along a geomagnetic field for the considered altitudes. Under upper bound the equations (3), (4) are satisfied and simplified using the relations $\eta \gg \varepsilon \gg g$ and $E_z = -E_x\tan\theta$. After equating the tangential magnetic field above upper boundary, we get the upper boundary conditions

$$\begin{aligned} &i\frac{dE_y}{dz} + (\mu_{11} - k_y\tan\theta)E_x + \mu_{12}E_y = 0, \\ &i\frac{dE_x}{dz} - \mu_{21}E_x + (\mu_{22} + k_x\tan\theta)E_y = 0. \end{aligned} \tag{7}$$

Here the following definition $\mu = \hat{\rho}\hat{\gamma}^{-1}$ is used.

The conditions at lower boundary is found after applying analogous procedure and is not cited here.

4. PROPAGATION IN THE MAGNETOSPHERE

The trajectory of quasi-AW ray is shifted perpendicularly to geomagnetic field lines during propagation between magneto-conjugated points as a result of $k_\perp$. To estimate this value, it is necessary to consider the accurate local dispersion relation for the Alfven wave in a cold plasma: $\omega = V_A k_\parallel/(1 + k_\perp^2 c^2/\omega_{pe}^2)^{1/2}$. The ray trajectories of AW were calculated and the dependence of transverse displacement of ray on the geomagnetic longitude of initial point of the ray was obtained. For the initial transverse component of the wave vector $k_\perp \sim 100\ \text{km}^{-1}$, the calculations give for the shift ΔX the value of the order 10 km for the McIlvan parameter $L = 4.5$. Therefore, transverse ray shift really might not be taken into account in the calculation of wave amplification along one path between magneto-conjugated points.

The most simple case of the cyclotron instability is AW — proton interaction in the outer radiation belt when a wave vector **k** is parallel to the geomagnetic field $\mathbf{H}_0$. For the AW-proton interaction and bi-Maxwellian distribution function of energetic ions (which are a small admixture to the background plasma), maximum possible increment of cyclotron instability K_{AMP} (where $K_{AMP} \equiv \text{Im}(k)$) is achieved at the magnetic equator and it is equal to [gulielmy]:

$$K_{AMP} = -\frac{\sqrt{\pi}}{2k^2c^2}\frac{\omega_{pi}^2}{S_{i\parallel}}\omega_{Hi}\left(\frac{T_{i\perp}}{T_{i\parallel}} - 1\right)\exp\left[-\left(\frac{\omega - \omega_{Hi}}{kS_{i\parallel}}\right)^2\right]. \quad (8)$$

Here ω_{pi} and $S_{i\parallel}$ are plasma frequency and longitudinal thermal velocity of warm ion species, respectively, c is the velocity of light, k is a wave number of EM waves. The estimation for the wave amplification coefficient during one pass along the field line: $\propto \exp\int k^{//}dl$.

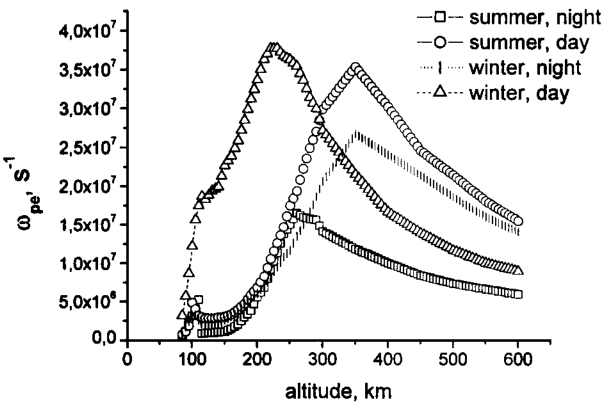
5. THE RESULTS

We carry out the numerical simulation to use the following approach. In the horizontal plane xy we introduce the periodical boundary conditions and replacement of the continuous spectrum to the discrete one is used. The volume current with spatial distribution function

$$j_{x,y,z} = \cosh^{-1}[(x - L_x/2)/l_x]\cosh^{-1}[(x - L_y/2)/l_y]\cosh^{-1}[(x - h_z/2)/l_z]$$

is located under ground surface. In the area restricted by boundary conditions the equations (3), (4) are calculated numerically by means of flexible grid and using the sweep method. Such typical parameters for numerical calculation are used: the conductivity of lithosphere is $\sigma_l = 10^4$ s^{-1}, the sizes of current source in xy plane are 50×50 km, the size of current source in z direction is 20 km, the depth of the source location is 40 km, the size of periodic boundary conditions are $L_x = L_y = 2000$ km, the angles of geomagnetic field inclination are $\theta = 0...-20°$, the number of mode in the Fourier-transform are $n_x = n_y = 50$, the satellite altitude is $h_z = 600$ km. The input data of ionospheric parameters is taken from Fatkulin, 1981.

The frequency filtration property of LAIM system is determined by filtration properties of the lithosphere and ionosphere. In the ionosphere, the amplitude-frequency characteristics (AFC) have a maximum of the penetration of ULF EM into magnetosphere from ground surface in the frequency range 1—10 s^{-1} (see figs. 2-4). The precise value of frequency of the maximum penetration of EM radiation through ionosphere depends on the ionospheric conditions. The penetration effect throughout the middle latitude is the most effective for night-time condition then for day-time (fig. 1). The first factor, which determines a value of EM field penetrated into the magnetosphere, is electron concentration profile (fig. 2). In the case of sharp electron concentration profile the main part of EM radiation to be reflected from it. The second important factor, which sufficiently influences the penetration effect is profile of total ion collisions. The value of penetrated on the satellite altitudes EM field for the case of current with



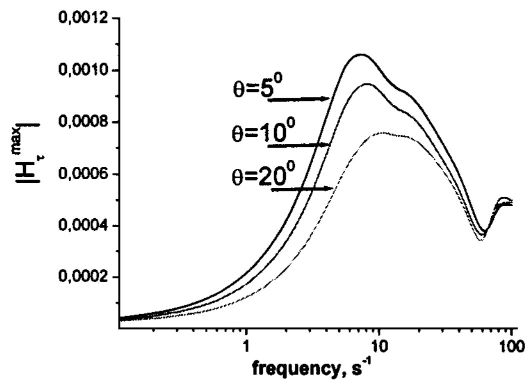
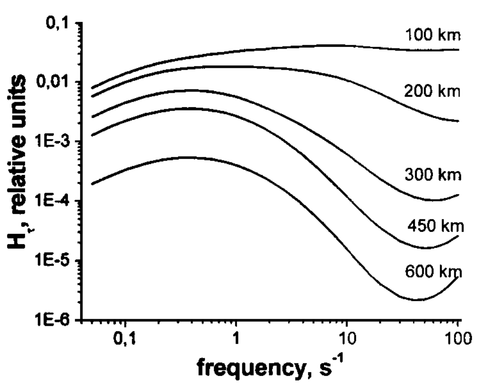


Fig. 1. Profile of plasma frequency in the ionosphere
Fig. 2. The dependencies of amplitude-frequency characteristics (AFC) on angle of geomagnetic field inclination at the altitude 600 km



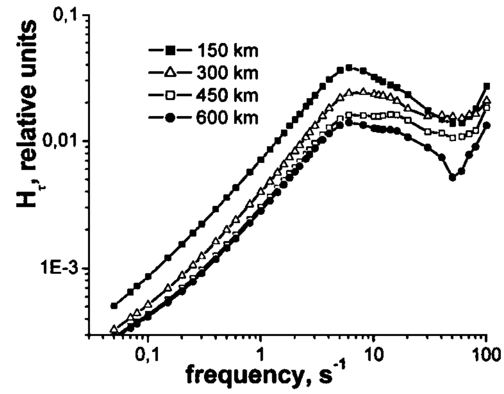
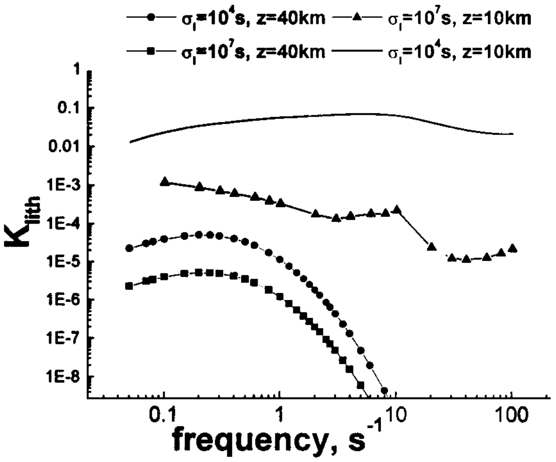


Fig. 3. AFC for different altitudes under day-time summery geophysical conditions. $\theta = 0$

Fig. 4. AFC for different altitudes under night-time summery geophysical conditions. $\theta = 0$



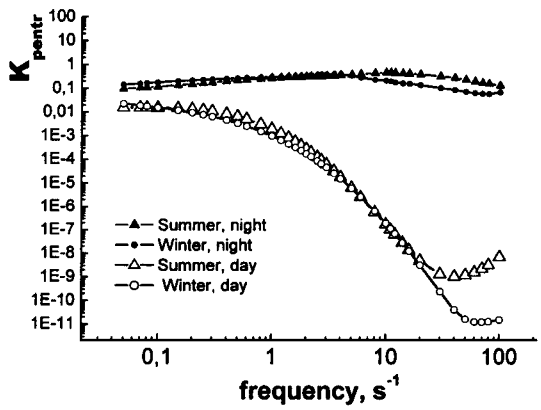
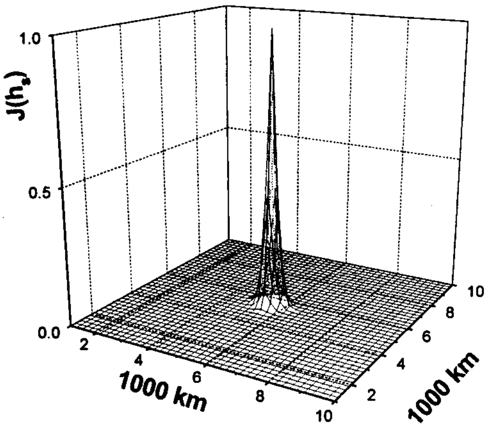


Fig. 5. Frequency dependence of the coefficient of the EM energy penetration from the lithosphere into the lower ionosphere for different localization depths of the source and for different lithosphere conductivity

Fig. 6. Frequency dependence of the coefficient of the EM energy penetration from the lower ionosphere into the satellite altitude into the ionosphere for different geomagnetic conditions

div$J = 0$ and with div$J \neq 0$ is approximately equal to each other and weakly depends on the geometric sizes. The strong dependence on the summary direction of current takes place. Thus, the EM radiation from the horizontal current is penetrated at least one order bigger than from vertical current.

The amplitude value of a current in a lithosphere is unknown, therefore we have studied the relation of value of EM field disturbances in the ionosphere to the value of current in the lithosphere and marked by transmission coefficient $K_{pentr} = W_{sat}/W_D$, $K_{lith} = W_D/W_{lith}$, where $W = \int [E, H^*]_z ds$ and the indexes correspond to altitude. The dependencies of this parameters on frequency is presented in figs. 5, 6. The relation of tangential magnetic value at the ground level to the tangential magnetic value at the altitude 600 km for frequencies are 100—1000, 10—100, 10^4—10^6 for the frequencies 0.1 s^{-1}, 1—10 s^{-1}, 10—100 s^{-1} respectively. Note that the value of penetration coefficient K_{lith} depends on the lithospheric conductivity, the depth of the current source and the distribution of source density along z-direction. Therefore, only the EM radiation for the current source from near-surface region with high density along the altitude and with the value of current 10^{-6}—10^{-4} A/cm^2, the value of EM radiation 0.1—1 nT at the altitude 600 km is possible.



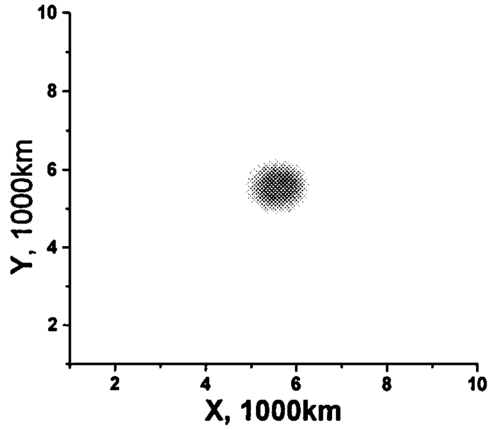
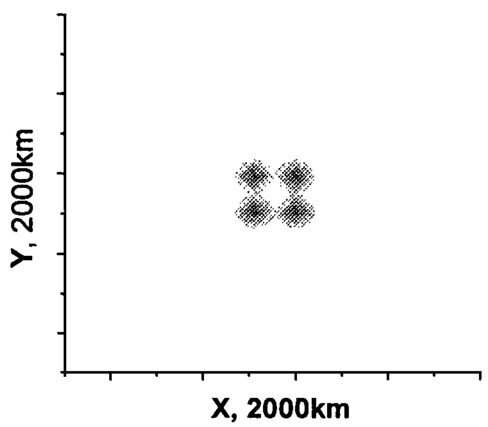


Fig. 7. The spatial distribution of current source amplitude. divJ ≠ 0

Fig. 8. The spatial distribution of EM field amplitude at the satellite altitude (600 km). $\theta = 0$ for the source shown in Fig. 5



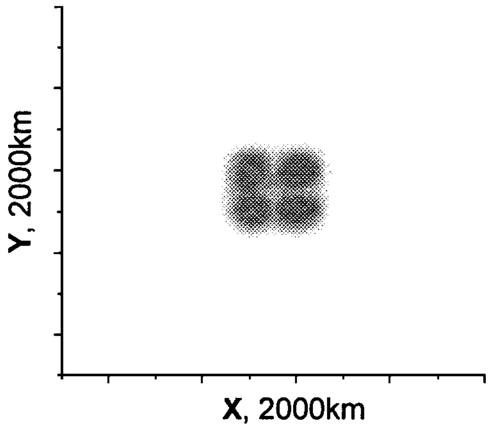
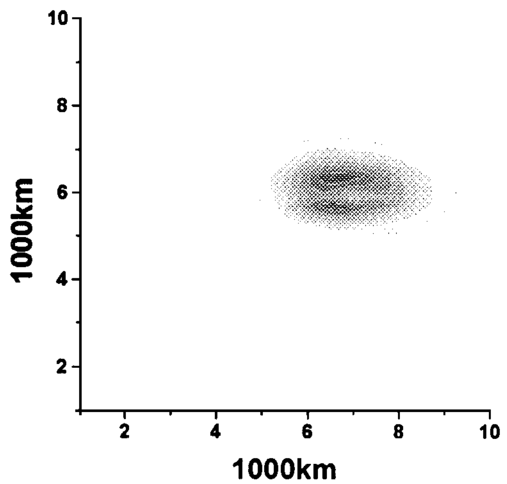


Fig. 9. The spatial distribution of current amplitude for four sources in the lithosphere

Fig. 10. The spatial distribution of the amplitude of EM field radiated by four lithospheric current sources at the satellite altitude for $\theta = 0$

The shape of a spatial distribution of EM field in the satellite altitude is similar to the shape of spatial distribution of current source if geomagnetic field is not oblique (figs. 7, 8). This result also takes place for several spatially separated current sources with a distance from each other about the natural sizes of sources (see figs. 9, 10). The area of distribution of EM field in the satellites altitude (~100×100 km) is much larger than the area of spatial distribution of current source (50×50 km) for the vertical lithospheric current and not larger for horizontal lithospheric current, see figs. 13, 14.

In the oblique geomagnetic field the center of spatial distribution of EM field shifts along geomagnetic field proportionally to its angle value and greatly elongates so that its size along geomagnetic field becomes 200—300 km (fig. 11) and depends on the value of inclination angle. Perpendicular to the geomagnetic field direction the shape of EM radiation is not elongated. The described effect is more intense for the case of vertical lithospheric current than for the opposite case and takes place for currents with divJ = 0 and divJ ≠ 0 (fig. 16). The total radiation in the ionosphere from several spaced currents are changing the shape of radiation from each current source and looks like a spot greatly elongated along the direction of the geomagnetic field (fig. 12).



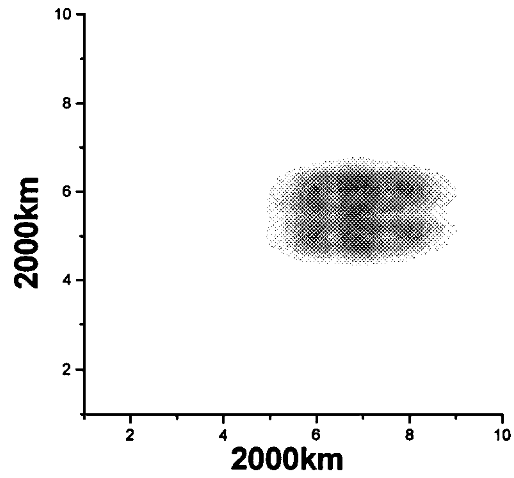
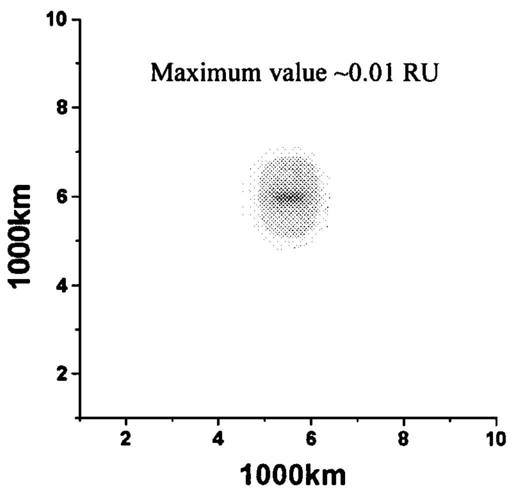


Fig. 11. The spatial distribution of EM field amplitude at the satellite altitude and θ = 20° for the source shown in Fig. 7

Fig. 12. The spatial distribution of the amplitude of EM field radiated by four lithospheric sources at the satellite altitude and θ = 20° for the current source shown in Fig. 9



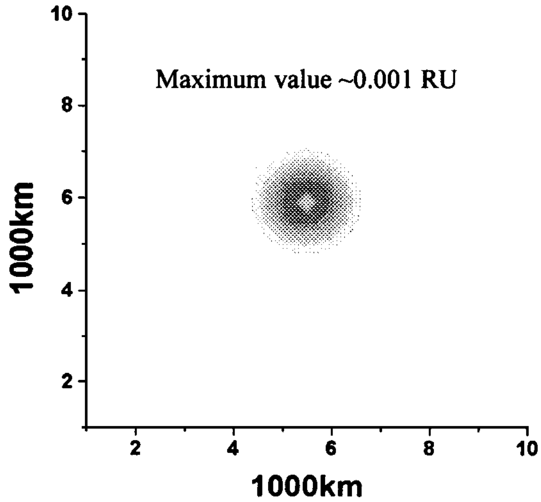
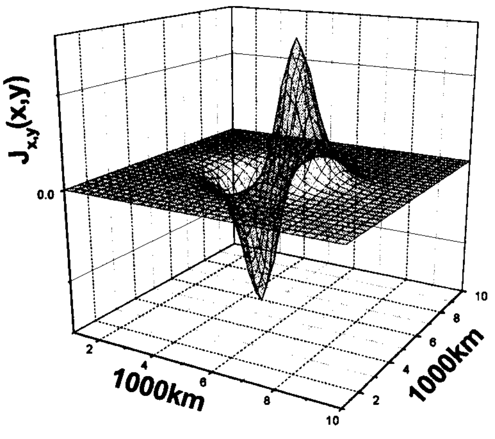


Fig. 13. The spatial distribution of tangential magnetic field amplitude at the satellite altitude for tangential lithospheric current. RU — relative units, θ = 0

Fig. 14. The spatial distribution of tangential magnetic field amplitude at the satellite altitude for vertical lithospheric current. θ = 0

The shape and the value of EM radiation penetrated from source with div**J** ≠ 0 into satellite altitudes (figs. 15—16) do not essentially deviate from the case of source div**J** = 0. This effect takes place also if geomagnetic field is oblique. The spatial distribution of EM field on the ground surface strongly depends on spatial distribution of current source in the lithosphere. We note also that the maximums of horizontal distribution of EM field amplitude at the ionospheric altitude correspond geometrically to the maximums of derivatives of vertical lithospheric current by horizontal directions (fig. 14). In turn, the minimum in the center of the horizontal magnetic field «spot» in the ionosphere corresponds to the maximum in the center of vertical current distribution in the lithosphere. At the same time, the spatial dimensions of EM radiation distribution in the ionosphere for $J_z \gg J_\tau$ are bigger than in the case $J_\tau \gg J_z$ (figs. 13—14). It is interesting to note that the effective widths of the tangential EM field distributions determined, say, by the «half of power density level» are approximately the same at the



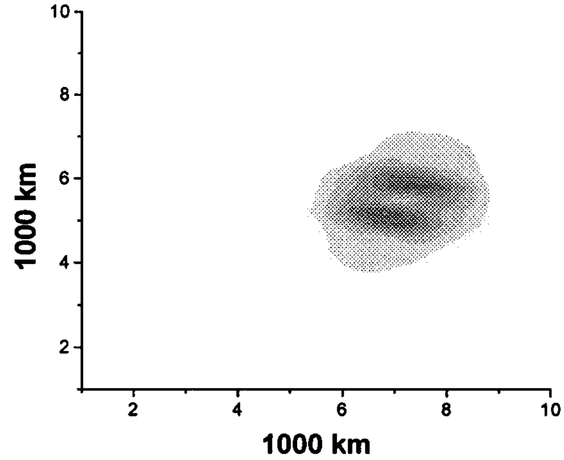
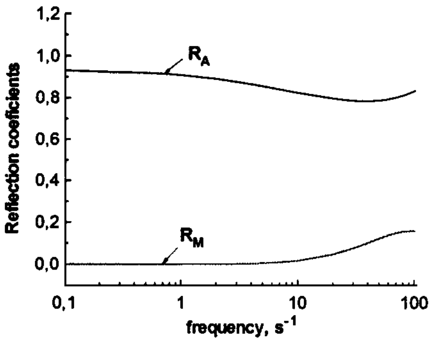


Fig. 15. The spatial distribution of the lithospheric current source for the case div **J** = 0

Fig. 16. The spatial distribution at the satellite altitude of the amplitude of EM field, radiated by the current source shown in Fig. 9. θ = 20°



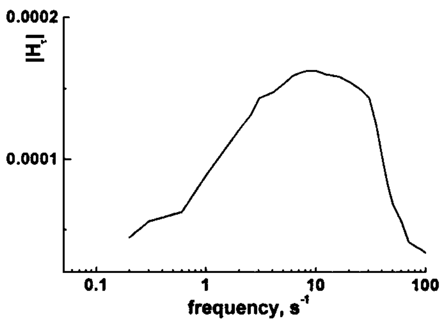


Fig. 17. The reflection of AW and transformation into MSW coefficients R_A and R_{MS} for a case of an incidence of AW from the ionosphere

Fig. 18. The value of amplitude of magnetic field taking into account the penetration of the EM field radiated from the lithosphere into the magnetosphere, reflection from the magneto-conjugated point and amplification caused by cyclotron instability

ground and satellite altitude levels in both cases $J_\tau \gg J_z$ and $J_z \gg J_\tau$.

In the magnetosphere, a main part of EM energy propagates as the waves of AW type because harmonics with AW wave number has a maximum amplitude value. When AW propagates in the radiation belts with the concentration of captured protons 0.1 cm^{-3} the amplification coefficient increases with the frequency and for $\omega \approx 50$ s^{-1} it is equal to 1.25. We have to conclude that this linear mechanism of amplification cannot provide sufficiently good amplification of amplitude value. However, this amplification mechanism for ULF EM waves can be sufficient for maintenance of value of a penetrated in the magnetosphere EM radiation at the high geomagnetic latitude if losses due to reflection from ionosphere are not large. The losses of EM energy in the magnitosphere are small because the energy propagates in the form of AW in the frequency range of maximum penetration effect through ionosphere.

The reflection coefficient essentially depends on the frequency in the considered frequency range 0.1—100 s^{-1} and it changes in the range 0.8—0.92 (fig. 17). Taking into account the reflection losses and amplification due to cyclotron instability, it is possible to conclude: when the ULF EM radiation of lithospheric origin penetrates into the magnetosphere at the magnetic shell with captured protons, then its amplitude varies slowly. The shape of amplitude-frequency characteristics obtained from numerical calculation for tangential magnetic field value, when the penetration into magnetosphere, the amplification in the magnetosphere, and the reflection at the ionosphere boundary in magneto-conjugate point are taken into account, is presented in fig. 18.

SUMMARY AND CONCLUSIONS

We got the following characteristics for ULF EM radiation excited from the lithosphere on the basis of 3D static continuity numerical model:

Type of waves with maximum amplitude value penetrated from the lithospheric source in the magnetosphere is Alfven waves.

The ULF EM radiation penetrated to magnetosphere has a maximum in frequencies ~ 1—10 s^{-1} (K_{pentr} ~ 10^{-4}). The coefficient of EM penetration from the ionosphere depends essentially on the geomagnetic condition, on the summary direction of current and on the conductivity of the lithosphere and weakly on geometrical configuration of current source and the angle of geomagnetic field inclination. The EM radiation penetrates most effectively in the magnetosphere from the horizontal current. At a ratio of value of ULF EM field on the ground to value of ULF EM field in the satellite altitude (600 km) is 10—100 under conditions of maximum penetration effect. The main losses in ionosphere are connected with the profile of electron density. The second important parameter for penetration of ULF EM throughout ionosphere is the value of total ion collision;

The shape of spatial distribution of EM radiation penetrated in the magnetosphere is similar to the lithospheric current one if geomagnetic field is not oblique. The spatial sizes in the *xy* plane of EM radiation penetrated in the magnetosphere are small for horizontal current and larger for vertical lithospheric current.

In the oblique geomagnetic field the shape of ULF EM radiation elongates parallel to the ground plane in the direction of geomagnetic field inclination and does not changes perpendicular to it. The center of spatial distribution of EM radiation shifts to the location of source in the lithosphere in the direction of obliqueness similar to $H \cdot \tan\theta$, where H is altitude. The same situation takes place for the currents with div**J** = 0 and div**J** ≠ 0. The shape of spatial distribution of EM radiation from the several isolated current sources takes a form of one greatly elongated spot and discerning of its structure in the lithosphere by satellite observation is difficult.

The cyclotron instability can be effective for maintenance of value of ULF EM penetrated in the magnetosphere under the geophysical condition when the reflection from ionosphere is not smaller than 0.8. This condition is sufficient for middle latitude, however, the question about amplification of lithospheric origin ULF EM demands more accurate investigation;

The obtained numerical results are close to satellite observations, see, for example, Bilichenko et al, 1990 and Liperovsky et al, 1992. We conclude that EM radiation penetrates into the magnetosphere as AW and can have the amplitudes 0.1—1 nT if the effective mechanisms of transformation of elastic energy to EM energy take place in the lithosphere and the currents with amplitudes 10^{-6}—10^{-4} A/cm^2 appear before earthquake. The ULF EM radiation excited in the lithosphere can be identified by the frequency and spatial characteristics of LAIM system and the center of current location and its characteristic sizes will be easily determined from observation at the satellites and ground observatories. We believe that recording and identification of radiation of lithospheric origin is possible.

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