MODELING OF THE ACOUSTO-ELECTROMAGNETIC METHOD FOR IONOSPHERE MONITORING

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INTRODUCTION

For experimental researches of an acoustic channel of the lithosphere-ionosphere interaction, a method of the acousto-electromagnetic (AE) monitoring of the ionosphere is an effective one. Using the ground-based facility, this method includes such physical technologies as the permanent short wave electromagnetic (EM) sounding of the ionosphere by different methods and its periodical operated dosed acoustic excitation. That allows periodically getting the EM responses of the ionosphere on the standard acoustic excitation on the basis of which it is possible to estimate the ionosphere's current status. By taking into account this information, it is possible to detect the acousto-ionospheric disturbances (AID), caused by influence of natural infrasonic excitations, which accompany preparation and passing of, for example, such natural cataclysms, as earthquakes. At practical realization of the AE-method, the authors used the ground-based operated parametric acoustic emitter, the highly sensitive decameter radio telescope (RT) URAN-3 and special short-wave radio transmitters. The task of modeling of acoustic excitation of the ionosphere on the basis of the use of the multilayered earth model is considered in the report.

PROBLEM STATEMENT

A few mechanisms of lithosphere-ionosphere interaction at the earthquakes are being considered. Some researchers [1] prove an acousto-gravitational mechanism of lithosphere-ionosphere interaction at the earthquakes. Other researches [2] assert that at the earthquakes, the nature of excitations transfer to ionosphere is of electromagnetic one. In spite of a large number of experimental investigations, only in some works there were attempts to explain theoretically the disturbances, which are observed in the atmosphere and ionosphere and which are caused by the lithosphere sources. As a rule, in theoretical works the acoustic waves, inside gravity waves, non-linearity of medium, influence of viscosity, stratification of zonal wind on the propagation of waves have been considered separately. Such models cannot explain all spectrums of atmosphere and ionosphere disturbances, caused by lithosphere sources.

In a light of a rapid development of computer engineering, investigation of propagation of atmosphere waves by numerical solving of nonlinear equations of hydrodynamics began [3]. Application of numerical methods allows taking into account compatible many factors, which influence the propagation of acousto-gravitational waves in the real environment and therefore increase the modeling reliability. However, numerical methods in comparison with analytical ones have some limitations, which are connected with possibility to obtain only special calculated results, an obstacles of conducting a qualitative analysis because of the absence of theoretical correlations between investigated values, unhandiness etc. An approach, which bases on the employment of environment's multilayer model, is deprived of such limitations. Such approach is a natural one, taking into account the atmosphere's height stratification (including ionosphere heights) according to the acoustic, electrical, thermo dynamical and other parameters. It is easy to describe wave processes in the atmosphere and ionosphere by this approach. Besides, such approach gives wide possibilities to vary models in each layer preserving their adequacy to real processes and possibilities to get solutions in the form of analytical correlations.

A number of works are devoted to questions of multilayer modeling of the process of inside and gravitational waves propagation [4]. The main feature of the present work is cumulative consideration of processes of propagation of ground acoustic excitation to the ionosphere, electromagnetic sounding of the ionosphere by decameter EM radiation and technologies of registration, receiving and processing of signals using the RT URAN-3. Two-stage algorithm of determination and identification of AID using the RT URAN-3 is suggested. On the first stage, determination of AID according to the results of ionosphere's monitoring on the basis of application of Bayes recognition procedure, which is one of the most effective in case of complex systems diagnostic, is conducted. A set of informative parameters is very important for the Bayes procedure. Based on these parameters, their classification and a-priori probability of their appearance at the acoustic excitation and in the case of its absence is conducted. A-priori probabilities of the selected features (informative parameters) in a received signal are determined on the basis of preliminary multiple sounding of

the ionosphere with and without the acoustic excitation. These probabilities are correct regularly depending on the time of day, season, and solar and geomagnetic activity and by the operator command. On the second stage, after the detection of AID, an identification of parameters of ionosphere heterogeneities, according to the data that have been observed using the RT URAN-3, is conducted based on correlations, received by mathematical modeling. Such identification connects the measuring parameters with characteristics of ionosphere heterogeneities.

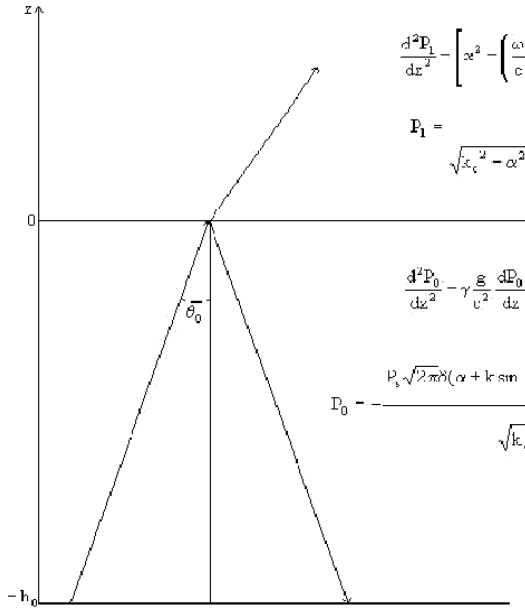
For the modeling of acousto-ionosphere interaction, an adaptive approach is used. It foresees creation of the system's parametric model, reception of ionosphere response from the acoustic excitation as on the basis of the model, so experimentally and minimization of a disparity between a model and experimental response by selection of the model's parameters. The structure of the model of lithosphere-ionosphere interaction includes:

- the models of acoustic influence on ionosphere (hydrodynamic, photochemical, electrostatic, electromagnetic and other models);
- the models of acousto-ionosphere disturbances (changing of electronic concentration, plasma waves);
- the models of methods of registration of acousto-ionosphere disturbances parameters (radio-astronomy, inclined sounding and dispersion methods).

At the selection of coordinate system, we will take into account the geometry of mutual location of main elements of the system of ionosphere's AE monitoring. The on-ground acoustic emitter, decameter RT URAN-3 (highly sensitive receiving system) and the transmitting terminal are located at the same meridian. Therefore, let us direct axis z vertically up, axis y – along the meridian, and we will be limited by two-dimensional case of wave's propagation in the ZY plane.

SOLUTION

Let us consider the simplest two-layer model. Let's assume, that the acousto-gravitational wave [4, 5], which transforms in an acoustic one in the top layer, propagates in the base layer. By applying an integral Fourier transform by variable y, and using boundary conditions (equalities of pressures and their derivatives on z) at interface z=0, we should get the solution for transforms as follows:



$$\frac{d^2P_1}{dz^2} - \left[\alpha^2 - \left(\frac{\omega}{c}\right)^2\right]P_1 = 0$$

$$P_1 = \frac{P_0\sqrt{2\pi}\delta(\alpha + k\sin\theta_0)j\gamma_0 e^{\frac{h_0}{2H}+j\sqrt{k_c^2-\alpha^2}z}}{\sqrt{k_c^2-\alpha^2}\sin\gamma_0 h_0 + j\sqrt{\left(\frac{\omega}{c}\right)^2 - \alpha^2\left(1-\left(\frac{\omega_g}{\omega}\right)^2\right)}\sin\left(\gamma_0 h_0 + \operatorname{arctg} 2H\gamma_0\right)}$$

$$\frac{d^2P_0}{dz^2} - \gamma\frac{g}{c^2}\frac{dP_0}{dz} - \left[\alpha^2\left(1-\left(\frac{\omega_g}{\omega}\right)^2\right) - \left(\frac{\omega}{c}\right)^2\right]P_0 = 0$$

$$P_0 = -\frac{P_0\sqrt{2\pi}\delta(\alpha + k\sin\theta_0)e^{\frac{1}{2H}(z+h_0)}\left(\sqrt{k_c^2-\alpha^2}\sin\gamma_0 z + j\sqrt{\left(\frac{\omega}{c}\right)^2 - \alpha^2\left(1-\left(\frac{\omega_g}{\omega}\right)^2\right)}\sin\left(\gamma_0 z + \operatorname{arctg} 2H\gamma_0\right)\right)}{\sqrt{k_c^2-\alpha^2}\sin\gamma_0 h_0 + j\sqrt{\left(\frac{\omega}{c}\right)^2 - \alpha^2\left(1-\left(\frac{\omega_g}{\omega}\right)^2\right)}\sin\left(\gamma_0 h_0 + \operatorname{arctg} 2H\gamma_0\right)}$$

$$k_c = \frac{\omega}{c_1}; \quad \gamma_0 = \sqrt{\left(\frac{\omega}{c}\right)^2 - \left(\frac{1}{2H}\right)^2 - \alpha^2\left(1-\left(\frac{\omega_g}{\omega}\right)^2\right)}$$

It is considered that Fourier transform of the primary field looks like: $P_0\sqrt{2\pi}\,\delta\,(\alpha + k\sin\theta_0)$.

Let's note that the solution of this equation, which conforms to the wave process in the form of inhomogeneous plane wave, reflects the exponential growth of excitation's amplitude with the height and the frequency's disperse dependence from the wave vector direction. According to this disperse dependency, only LF waves are able to propagate up at the angle to horizon (moreover, with the increase of angle the frequency decreases according to the cosine law). Note that increasing of the layers number causes no difficulties, as during the joint of the equations solutions at the border of two

adjacent layers we will get the linear relations between complex amplitudes, which can be presented in the recurrent matrix form [7]. So, the increasing of layers results in increasing of number of co-factors in the product of matrix.

Modeling of the Electromagnetic Sounding of Acoustically Excited Ionosphere.

Acousto-gravitational waves cause oscillations of electronic concentration in atmosphere and these oscillations can be detected by methods of ionosphere's radio sounding. The get expressions for the field of acousto-gravitational waves define changes of plasma inductivity. For the modeling of processes in the ionosphere layers, we have used several scenarios that conform to the observed dominating effects and appropriate possible LF processes. The simplest scenario is a propagation of plane monochrome acoustic wave in the ionosphere layer, which forms periodic modulation of inductivity. In this case, the task of EM sounding reduces to the propagation of EM field in the heterogeneous non-stationary medium. Due to the significant frequency diversity of the excited acousto-gravitational and registered EM fields, we get differential equation in partial derivatives with slowly variable factors. To solve these equations we will apply a quasi-stationary method, which allows presenting a solution in the form of series of derivatives of slowly variable factors.

Let's consider the radio-astronomy (RA) method (with an incident plane TM-wave) in frameworks of the two-layer model of medium. Time dependency $e^{-i\omega t}$ will be omitted here and below. Quasi-stationary approximations, received by join method, will be the following:

$$E_0(\alpha, z) = \frac{\gamma_1 - jk\cos\theta_e}{\gamma_1 + \gamma_0} e^{-\gamma_0 z} \sqrt{2\pi}\,\delta(\alpha + k\sin\theta_e),$$

$$E_1(\alpha, z) = -\frac{jk\cos\theta_e + \gamma_0}{\gamma_1 + \gamma_0} e^{-\gamma_1 z} \sqrt{2\pi}\,\delta(\alpha + k\sin\theta_e).$$

Here $E_0(\alpha, z)$, $E_1(\alpha, z)$ – Fourier transforms; e_x – field components in the base and top layers correspondingly, $\gamma_{0,1} = -j\sqrt{k_{0,1}^{\ 2} - \alpha^2}$, $k_{0,1}$ – wave number in the base and top layers, $\mathrm{Re}\,\gamma_{0,1} > 0$. The wave number of the top layer k_1 holds the information about ionosphere heterogeneities.

For the more general three-layer model expression of Fourier transform of the observed field remains in the form of:

$$E_0(\alpha) = \frac{2\sqrt{2\pi}\gamma_1(jk\cos\theta_e - \gamma_2)\delta(\alpha + k\sin\theta_e)}{(\gamma_0 - \gamma_1)(\gamma_2 - \gamma_1)e^{-(\gamma_1+\gamma_2)z_1} - (\gamma_0 + \gamma_1)(\gamma_2 + \gamma_1)e^{(\gamma_1-\gamma_2)z_1}} e^{-jkz_1\cos\theta_e - \gamma_2 z_1}$$

This expression allows investigating the dependencies of the transmission coefficient and conditions of reception from parameters of layers, and in addition – to take into account the wave properties of ionosphere at the acoustic excitation.

Another class of models deals with the method of inclined sounding. The specific of modeling in this case lies in taking into account the sounding source. For assigning the structure of the sounding field, let's consider the antenna in the form of long conductor, which is located perpendicularly to meridian. In this case, we have E-component along the conductor and two H-components in the plane, which is perpendicular to the conductor (TM-wave). So, from here, let's analyse of propagation of waves of this type. The Fourier transform of the sounding field we write down as:

$$E_{\mp}(\alpha, z) = -j\sqrt{2\pi}\, e^{j\alpha y_0} \frac{e^{\mp j\sqrt{k^2 - \alpha^2}(z_0 - z)}}{2\sqrt{k^2 - \alpha^2}}.$$

Here: if $z < z_0$ take sign "-", if $z > z_0$ – sign "+", y_0, z_0 are the coordinates of antenna's location in meridian plane ZY. For the two-layer medium with border, which is distant from the antenna within h_0, the Fourier transform of the observed field looks like:

$$E_0(\alpha, z) = E_-(\alpha, z = -h_0) - \frac{(\gamma_0 + \gamma_1)e^{\gamma_0 h_0}(\Delta E' + \gamma_0 \Delta E) + (\gamma_0 - \gamma_1)e^{-\gamma_0 h_0}(\Delta E' - \gamma_0 \Delta E) + 2\gamma_0(E_+^{\ \prime} + \gamma_1 E_+)}{2\gamma_0(\gamma_0 + \gamma_1)}$$

Here: $\Delta E = E_-(\alpha, z = -h_0) - E_+(\alpha, z = -h_0)$, sign " ' " means derivative by z, $(E_+^{\ \prime} + \gamma_1 E_+)$ is calculated at *z=0*. In a way, similar as for the RA-method, we will receive an expression for the three-layer model. These expressions are a

basis for receiving of the inverse dependencies of parameters of the medium model (ionosphere heterogeneities) from the observed informative parameters.

Modeling of information technologies of reception of decameter radiation by the radio telescope URAN-3

The task of diagnostics of ionosphere using the RT URAN-3 is reduced to determination of the ionosphere's simulated functions according to the results of observations. The model of the locked-on narrow-band signal can be presented as:

$$e(t) = R(t)\cos(\omega_0 t + \varphi(t)).$$

Here $R(t)$ and $\varphi(t)$ – slowly variable functions, which, in the case of diagnostics of ionosphere are called as the ionosphere's modulatory functions [8].

Signal $e(t)$ may be represented as two mutually orthogonal (quadratic) components $W_c = R(t)\cos\varphi(t)$ and $W_s = R(t)\sin\varphi(t)$, which are the basis for determination of the ionosphere's modulatory functions. A single-point and spatial-spaced receptions are distinguished. In the case of single-point reception, $\varphi(t)$ can be presented as:

$$\varphi(t) = \Omega(t)t + \varphi_0,$$

and $\Omega(t)$ can be integrated as Doppler frequency shift caused by movable ionosphere heterogeneity.

The most general and informative method of investigation of processes in the ionosphere, which conforms the abilities of radio physical facilities on the base of the RT URAN-3, is a method of spatial-spaced reception [8]. Its important advantage is that in this case it is possible to work with the received signal in the framework of the model:

$$e(t) = R(t)\cos(\omega_0 t + \vec{k}(t)\vec{r} + \Omega(t)t + \varphi\ ),$$

where $R(t), \vec{k}(t), \Omega(t)$ – slowly variable modulatory functions of ionosphere moreover $\vec{k}(t)$ can be interpreted as a wave vector of the received wave. In this case, it is possible to define slow variations of the direction of wave propagation, and also spatial length and speed, which also slowly vary. These slow variations can be interpreted by an influence of ionosphere excitation's motion. Based on the experimentally defined modulatory functions of ionosphere and mathematical correlations of the appropriate field, we can identify the parameters of the ionosphere heterogeneities.

CONCLUSIONS

The ideology of modeling of acousto-gravitational channel of lithosphere-ionosphere interaction at earthquakes and technologies of remote diagnostics of the induced ionosphere excitations using radio physical complexes on the base of decameter radio telescope URAN-3 are presented. The results of investigations can be used for development of acousto-electromagnetic method of ionosphere diagnostics. The work has been done in the framework of the project STCU-1681.

REFERENCES

[1] Gokhberg M.B., Shalimov S.L. "Lithosphere-ionosphere interaction and its modeling". *Russian magazine of sciences about the Earth*, vol. 2, No. 2, April 2000 (in Russian).

[2] Pulinets S. "Ionospheric Precursors of Earthquakes. Recent Advances in Theory and Practical Applications". *TAO*, vol. 15, No. 3,413-435, September 2004.

[3] Akhmedov R.R. "Numerical simulation of generation of acousto-gravitational waves and ionosphere disturbances caused by ground-based and atmosphere sources". *The abstract of the dissertation of the candidate of physical and mathematical sciences,* The Moscow State University, 2004, 19p. (in Russian).

[4] Kozak L.V. "Disturbances of f circumterrestrial space, caused by the ground energy sources". *The abstract of the dissertation of the candidate of physical and mathematical sciences*, Kharkiv, The O.Ya. Usikov Institute of Radio Physics and Electronics, 2003, 13p. (in Russian).

[5] Hines C.O. "Internal atmospheric gravity waves at ionospheric heights". *Can. J. Phys*., 1960, 38, pp.1441-1481.

[6] Grigoryev G.I. "Acousto-Gravitational Waves in the Earth atmosphere (review)". *Proceedings of Institutes of Higher Education. Radio physics,* 1999, 42, №1, pp.3-25 (in Russian).

[7] Bautin A.V., Eryshov N.M., Polyakov Yu.A. "About calculation of coefficients of reflection and transmission of radio waves through a stratified medium". *Radio Engineering and Electronics*. 1976, v.21, №2, pp.382-385 (in Russian).

[8] Afraimovich E.L. "Interference methods of the ionosphere sounding". Moscow: Nauka, 1982, 198 p. (in Russian).