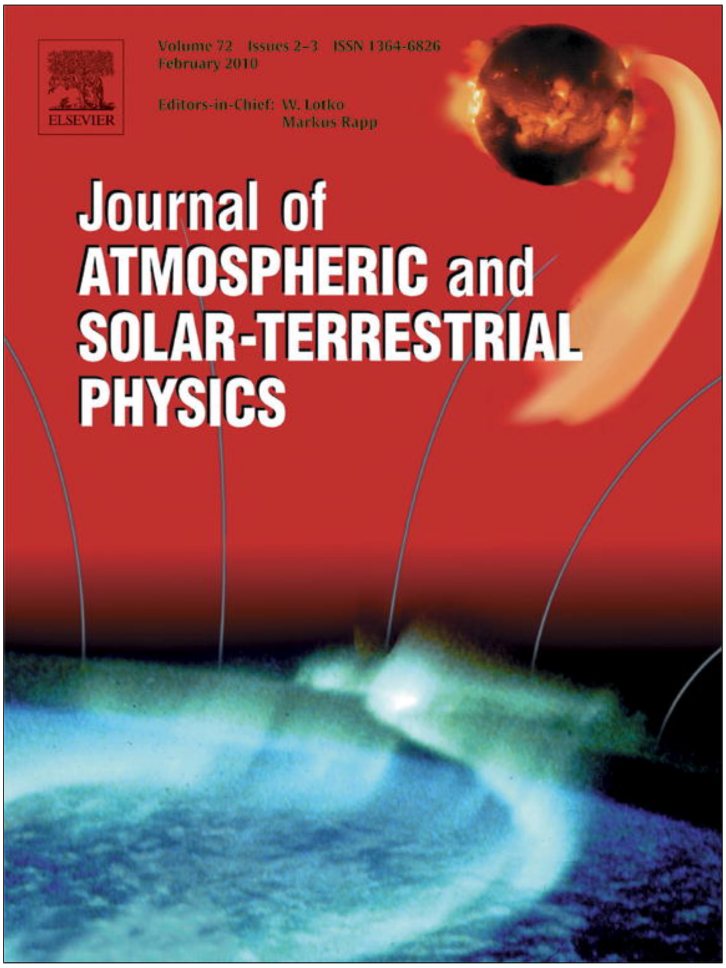
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The effect of wind on the gravity wave propagation in the Earth's ionosphere

V.M. Sorokin [a,*], O.A. Pokhotelov [b]

[a] Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation, Russian Academy of Sciences, IZMIRAN, Troitsk, Moscow Region 142190, Russian Federation
[b] Institute of Physics of the Earth, Russian Academy of Sciences, Moscow 123995, 10 Bolshaya Gruzinskaya, Russian Federation

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ABSTRACT

The effect of ionospheric wind on the gravity wave propagation is studied. These waves arise in the ionosphere due to intensification of their sources near the Earth's surface during enhanced seismic activity. The influence of the wind on these waves is connected with the Ampere's force that produces the ion-drag force acting on the atmosphere. This results in the occurrence of the discrete wave spectrum the maximum of which increases in proportion to the numbers of the natural scale. Furthermore, these waves are amplified during propagation from the source region in the direction perpendicular to the wind direction. These peculiarities of the gravity waves can be used for monitoring of seismic activity based on the ionosphere sounding.

1. Introduction

Among the causes that provide the ionospheric response to the lithospheric processes is the generation of acoustic waves near the Earth's surface which then propagate upwards (Liperovsky et al., 1992, 2008; Pokhotelov et al.,1995). Some researches using *in situ* observations have demonstrated a close link of the ionospheric observations with the enhancement of seismic activity (Chmyrev et al., 1997; Molchanov and Hayakawa, 1998; Afonin et al., 1999). It has been assumed that certain processes in the lower atmosphere such as low-frequency Earth's vibrations, the atmospheric heating and gas emanation can lead to generation and their upward propagation of the gravity waves and subsequent perturbation of the ionosphere (Gokhberg et al., 1996; Mareev et al., 2002). The existence of such sources has been confirmed by observation of temperature variations in the near Earth's surface layer by a few degrees that accompany seismic activity (Tronin, 1999). The study of the effects due to propagation of gravity waves to the ionosphere is based on the theory of wave propagation in the neutral atmosphere. Sorokin and Fedorovich (1982), Kaladze et al. (2007, 2008) studied the action of the external geomagnetic field on the gravity waves in the ionosphere at rest. Similar method has been used by Kaladze et al. (2003) for the study of planetary waves in the ionospheric E-layer. In this case the wave motion of the neutral gas together with the ionized component in the magnetic field generates the electric current. This current is influenced by the magnetic field. Due to the collisions of molecules with ions this force changes the wave elasticity and damping. External actions on the ionosphere such as electric field or wind result in other wave effects. The influence of the electric field leads to the wave instability associated with Joule heating (Sorokin et al., 1998). The effects that accompany plasma and electromagnetic phenomena have been analyzed by Sorokin et al. (2001, 2003).

The main purpose of our study is to analyze the modification of gravity waves by wind in the ionosphere. The properties of waves modified by this influence can then be used for interpretation of observations of the ionosphere perturbations during enhancement of seismic activity.

The paper is structured in the following fashion: in Section 2 the basic equations for the gravity wave in the moving ionosphere are derived. The enhancement of these waves provided by the wind is studied in Section 3. The formation of the wave spectra is discussed in Section 4. Our discussion and conclusions are found in Section 5.

2. Equation for the gravity waves in the moving ionosphere.

The role of the magnetic field $\mathbf{B}$ in the conductive ionosphere is controlled by the Ampere's force $\mathbf{F}$ given by

$$\mathbf{F} = (\mathbf{j} \times \mathbf{B})/c; \quad (1)$$

* Corresponding author.
E-mail addresses: sova@izmiran.ru, v_sorokin@mtu-net.ru (V.M. Sorokin).

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where **j** is the electric current. The latter is connected with the wind velocity **V** through the generalized Ohm's law:

$$\nu_e\mathbf{j}+\omega_e(\mathbf{j}\times\mathbf{n})+\frac{\omega_e\omega_i}{\nu_{in}}(\mathbf{n}\times(\mathbf{j}\times\mathbf{n}))=\frac{e^2N}{m}\mathbf{E}'. \quad (2)$$

Here $\mathbf{E}'=\mathbf{E}+(\mathbf{V}\times\mathbf{B})/c$. Furthermore, **E** is the electric field, **V** is the wind velocity, ν_e and ν_{in} are the collision frequencies of the electrons and ions with the neutrals, ω_e and ω_i are the electron and ion gyrofrequencies, respectively, N is the electron number density, e is the magnitude of the electron charge, c is the velocity of light, m is the electron mass and $\mathbf{n}=\mathbf{B}/B$ is the unit vector along the magnetic field **B**. The influence of the geomagnetic field on the charged particles is important at the altitudes higher than 80 km. At these altitudes the generalized Ohm's law (2) can be rearranged in terms of the Ampere's force **F** as

$$\frac{\omega_i}{\nu_{in}}(\mathbf{n}\times\mathbf{F})+\mathbf{F}=eN\mathbf{E}'. \quad (3)$$

From the definition of **F** it is evident that $\mathbf{B}\cdot\mathbf{F}=0$. Thus, at the altitudes under consideration $\mathbf{B}\cdot\mathbf{E}'=0$ and therefore $\mathbf{B}\cdot\mathbf{E}=0$. The latter assumes that the electric field arising in the plasma motion is orthogonal to the external magnetic field. Keeping this in mind one can substantially simplify the analysis of the wind influence on the gravity waves. Let us consider the horizontal plasma transport in the vertical magnetic field. We assume the wind velocity and other plasma parameters to be uniform in the horizontal plane. We introduce the Cartesian system of references (x, y, z) with the z-axis directed upwards. Since the system is stationary the electric field is curl free $\nabla\times\mathbf{E}=0$. The latter assumes that $\mathbf{E}=const$ with altitude. From the condition $\mathbf{E}(z\to\infty)=0$ one obtains that electric field vanishes everywhere. In this case in the stationary flow the electric field is not generated. For such conditions only the wind remains as the external source and the electric field can be illuminated. The net electric field reduces to the dynamo field, i.e. $\mathbf{E}'=(\mathbf{V}\times\mathbf{B})/c$. From Eq. (3) one obtains

$$\mathbf{F}=-\rho[\nu_P\mathbf{V}-\nu_H(\mathbf{V}\times\mathbf{n})], \quad (4)$$

where

$$\nu_P=\nu_{ni}\frac{\kappa_i^2}{1+\kappa_i^2},\quad \nu_H=\Omega_i\frac{1}{1+\kappa_i^2},$$
$$\nu_{ni}=\nu_{in}N/N_n,\quad \Omega_i=\omega_iN/N_n,\quad \kappa_i=\omega_i/\nu_{in}.$$

Furthermore, $\rho=MN_n$ is the mass density of the neutral gas, M is the reduced mass of ions and molecules, N_n is the molecule number density and N is the ion number density. The coefficients in Eq. (4) depend on the neutral gas mass density ρ, the temperature T and the ion number density N, i.e. $\nu_P=\nu_P(\rho,T,N)$ and $\nu_H=\nu_H(\rho,T,N)$.

The Ampere's force **F** is among other forces that controls the plasma motion of the ionosphere. The balance between **F** and other forces such as the plasma pressure gradient, the gravitational and Carioles forces defines the structure of the quasi-stationary wind in the ionosphere (Geisler, 1966). The propagation of the gravity waves controls the plasma transport and connected with this process the wave variations of the parameters ν_P and ν_H. This can violate the equilibrium between the Ampere's force and those forces that exist at each point before the arrival of the wave. The plasma transport is accompanied by the change of its parameters at the point where all external forces are compensated. Let us denote the variations of the wind **v**, density ρ_1, pressure $p_1$and Ampere's force **f** around their stationary values

$$\mathbf{V}=\mathbf{V_0}+\mathbf{v},\quad \rho=\rho_0+\rho_1,\quad p=p_0+p_1\quad \text{and}\quad \mathbf{F}=\mathbf{F_0}+\mathbf{f}.$$

In the ionosphere at rest $\mathbf{V_0}=0$ the perturbation of the Ampere's force $\mathbf{f_1}$ is defined by velocity **v** and plasma parameters equal to their unperturbed values ν_{P0} and ν_{H0}:

$$\mathbf{f_1}=\mathbf{F}(\mathbf{V}_0=0)=-\rho_0[\nu_{P0}\mathbf{v}-\nu_{H0}(\mathbf{v}\times\mathbf{n})].$$

The variation of the Ampere's force **f** of the wave motion in the presence of the wind one can find from the condition of transport of the deviation of the net force from its value in the ionosphere at rest together with plasma $d(\mathbf{F}-\mathbf{f}_1)/dt=0$. Retaining only terms of the first order of smallness one obtains

$$\frac{\partial(\mathbf{f}-\mathbf{f}_1)}{\partial t}+(\mathbf{V}_0\cdot\nabla)(\mathbf{f}-\mathbf{f}_1)+(\mathbf{v}\cdot\nabla)\mathbf{F}_0=0. \quad (5)$$

The system of equations for the gravity waves in the presence of the wind reduces to (Gossard and Hooke, 1975)

$$\rho_0\left[\frac{\partial\mathbf{v}}{\partial t}+(\mathbf{V}_0\cdot\nabla)\mathbf{v}+(\mathbf{v}\cdot\nabla)\mathbf{V}_0\right]=-\nabla p_1+\rho_1\mathbf{g}+\mathbf{f},$$
$$\frac{\partial\rho_1}{\partial t}+(\mathbf{V}_0\cdot\nabla)\rho_1+(\mathbf{v}\cdot\nabla)\rho_0=0,\quad \nabla\cdot\mathbf{v}=0. \quad (6)$$

In what follows we assume that the wind velocity does not depend on altitude, i.e. $(\mathbf{v}\cdot\nabla)\mathbf{V}_0=0$. Let us pass to the moving system of coordinates using the transformation $\partial/\partial t+\mathbf{V}_0\cdot\nabla=\partial/\partial\tau$. Assuming that all variables vary with time as $\exp(-i\omega\tau)$, from Eqs. (5) and (6) one obtains

$$i\omega\rho_0\mathbf{v}=\nabla p_1-\rho_0\mathbf{g}-\mathbf{f},\quad i\omega\rho_1=(\mathbf{v}\cdot\nabla)\rho_0,\quad i\omega\mathbf{f}=i\omega\mathbf{f}_1+(\mathbf{v}\cdot\nabla)\mathbf{F}_0. \quad (7)$$

From the last equation in (7) follows that variation of **f** consists of two terms. They can be calculated using the expansion of (4) in power series on small deviations of independent variables with the use of conservation laws. The first term on the right-hand side of Eq. (7) is connected with the properties of wave propagation in the ionosphere at rest. The second one, which is proportional to the vertical gradient of the Ampere force, is due to the influence of the ionosphere wind. The estimate of the values of these terms shows that for the frequencies $\omega>V_0/z_0$ (where z_0 is the spatial scale of the vertical inhomogeneity of the Ampere's force) the first term exceeds the second term. The latter means that the vertical inhomogeneity of the Ampere force only weakly influences the wave propagation. In this case the wave propagates similar to the case of the ionosphere at rest. For the lower frequencies $\omega<V_0/z_0$ the second term is dominant. Therefore, the perturbation of the Ampere force is defined by gradient of its vertical inhomogeneity. Below we will consider possible effects in the ionosphere connected with the vertical inhomogeneity of the Ampere force.

Let us neglect the first term on the right-hand side of the last equation in (7). Furthermore, in (7) let us exclude **f** and ρ_1. This allows us to obtain the connection between **v** and p_1

$$\mathbf{v}=\frac{1}{i\omega\rho_0}\left[\frac{\mathbf{G}}{(\omega_g^2-\omega^2)}\frac{\partial p_1}{\partial z}+\nabla p_1\right],\quad \mathbf{G}=\frac{\mathbf{g}}{H}-\frac{1}{\rho_0}\frac{d\mathbf{F}_0}{dz},$$
$$\omega_g=\sqrt{g/H},\quad \rho_0\sim\exp(-z/H).$$

Substituting these expressions into the equality $\nabla\cdot\mathbf{v}=0$ which represents the gas incompressibility condition in the field of the wave one finds the equation for propagation of the gravity waves in the ionosphere in the presence of the horizontal wind

$$\omega^2\left(\nabla^2+\frac{1}{H}\frac{\partial}{\partial z}\right)p_1-\omega_g^2\left(\nabla^2-\frac{\partial^2}{\partial z^2}\right)p_1+\frac{\Omega^2}{F_0}(\mathbf{F}_0\cdot\nabla)\frac{\partial p_1}{\partial z}=0,\quad \Omega^2(z)=\frac{1}{\rho_0}\frac{dF_0(z)}{dz}. \quad (8)$$

The properties of the wave propagation in the ionosphere, connected with the wind, are defined by the vertical gradient of the Ampere's force Ω^2. For $\Omega^2=0$ Eq. (8) reduces to the classical equation for the gravity waves in the neutral atmosphere.

3. Enhancement of the gravity waves by ionosphere wind

Eq. (8) shows that the wind does not influence the gravity wave propagation in the direction perpendicular to $\mathbf{F}_0$. Let the

Ampere force to be directed along the x-axis in the Cartesian system of references. In this case Eq. (8) is

$$(\omega^2-\omega_g^2)\left(\frac{\partial^2 p_1}{\partial x^2}+\frac{\partial^2 p_1}{\partial y^2}\right)+\omega^2\frac{\partial^2 p_1}{\partial z^2}+\Omega^2(z)\frac{\partial^2 p_1}{\partial x\partial z}+\frac{\omega^2}{H}\frac{\partial p_1}{\partial z}=0. \quad (9)$$

In general the analysis of Eq. (9) is quite cumbersome. It is reasonable first to make a qualitative analysis of the expected results. The main properties of the gravity wave propagation under influence of the ionosphere wind one can reveal analysing Eq. (9) in the limiting case of slow and fast variations of the parameter $\Omega^2(z)$. First, let us consider Eq. (9) with constant coefficients. One can search its solution in the form

$$p_1=\xi\exp(ax+bz),$$
$$a=-\frac{\omega^2\Omega^2}{H[4\omega^2(\omega_g^2-\omega^2)+\Omega^4]},\quad b=-\frac{2\omega^2(\omega_g^2-\omega^2)}{H[4\omega^2(\omega_g^2-\omega^2)+\Omega^4]} \quad (10)$$

The function ξ satisfies the equation

$$(\omega^2-\omega_g^2)\left(\frac{\partial^2\xi}{\partial x^2}+\frac{\partial^2\xi}{\partial y^2}\right)+\omega^2\frac{\partial^2\xi}{\partial z^2}+\Omega^2\frac{\partial^2\xi}{\partial x\partial z}+\frac{\omega^2 b}{2H}\xi=0.$$

The Green's function Φ of this equation depends on R

$$R=\sqrt{x^2+\left[1+\frac{\Omega^4}{4\omega^2(\omega_g^2-\omega^2)}\right]y^2+\left(1-\frac{\omega_g^2}{\omega^2}\right)z^2-\frac{\Omega^2}{\omega^2}xz}.$$

and yields the equation

$$\frac{1}{R^2}\frac{d}{dR}\left(R^2\frac{d\Phi}{dR}\right)+\kappa^2\Phi=0,\quad \kappa=\frac{2\omega^3\sqrt{\omega_g^2-\omega^2}}{H\left[4\omega^2(\omega_g^2-\omega^2)+\Omega^4\right]}.$$

The solution of this equation is the Green's function of the point monochromatic source of the form

$$\Phi=\frac{\exp(i\kappa R)}{R}. \quad (11)$$

The plot of (11) in the plane $y=0$ is depicted in Fig. 1. The entire space is decomposed into two regions bounded by the conical surface $R=0$. Inside the cone, i.e. in the region adjacent to the *z-axis*, the gas oscillates synchronously with the exponentially decreasing from the source region amplitude. In this region R is an imaginary quantity. Outside this region the waves are diverging from the cone surface. Their phase surfaces $R=const$ represent the hyperboloids. The cone axis and hyperboloids deviate from the vertical direction under the angle α. When the influence of the gradient of force $\mathbf{F}_0$ on the plasma motion is small, i.e. $\Omega=0$, the axis becomes vertical. The surfaces of cones and hyperboloids represent the surfaces of rotation relative to the z-axis. In this case the waves propagate in accordance with theory of their propagation in the atmosphere at rest. For the real conditions Ω is much smaller than ω_g. Therefore, the deviations of the propagation characteristics of the gravity waves in the real wind ionosphere structures from those in atmosphere at rest are quite small. The main effect that characterizes the influence of the force $\mathbf{F}_0$ is connected with the exponential decay of the wave amplitude. Its decrease during propagation in the direction opposite to the action of the force is observed in the region where the value of the force increases with the altitude. For this range of altitudes, where the force decreases with the altitude, the wave amplitude increases in the direction of the action of the force. The exponential increase of the amplitude of the internal gravity waves is described by Eq. (10). The spatial scale of the amplitude variations $L=1/a$ for the frequencies that are not very close to zero and to ω_g can be approximately found from the relation

$$L\approx-(\omega_g^2-\omega^2)H/\Omega^2\approx-g/\Omega^2\approx-g/(dF/\rho_0 dz). \quad (12)$$

Eq. (12) shows that in the frequency range where the Ampere's force becomes smaller with the altitude the growth of the wave amplitude arises in the direction opposite to the direction of $\mathbf{F}_0$. In the region where the force increases with the altitude the growth of the wave amplitude arises in the direction of the force. The force $\mathbf{F}_0$ can be directed either parallel or perpendicular to wind velocity. The values of both scales $L_\perp$, L_{11} are depicted in the Fig.2. One sees that both these scales attain the maximum values of the order 10^4 km at the altitudes of the E-layer. At the altitude, where $L_\perp$ attains the smallest value (see Fig. 2), the Ampere's force decreases with the altitude. Thus, the wave amplification arises in the direction opposite to the action of the force. The exponential wave growth in the layer points out on the instability of this layer. Due to the vertical inhomogeneity of the Ampere's force the wind energy is cascading into the wave energy.

4. Formation of the gravity wave spectrum by ionosphere wind

As it has been already mentioned above the presence of the wind in the ionosphere does not influence the wave propagation

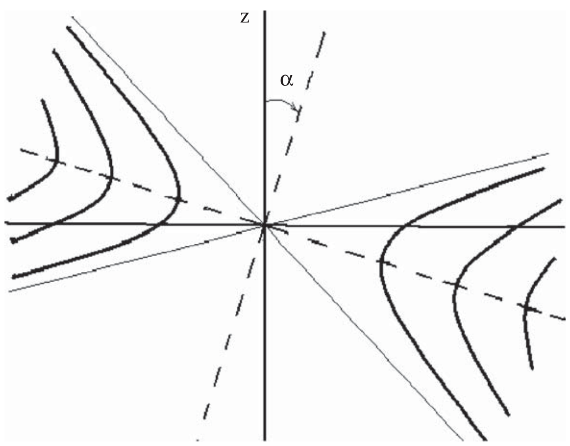

Fig. 1. Phase surfaces of the Green's function for the ionospheric IGW where their propagation is influenced by wind.

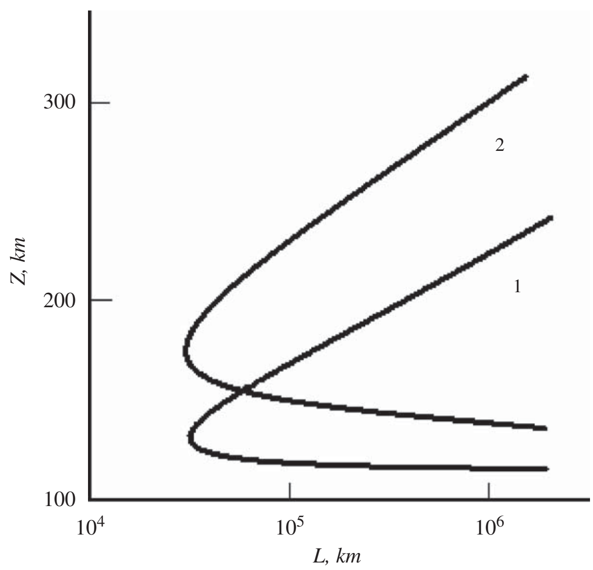

Fig. 2. Variation of the horizontal scales of the IGW amplitude amplification. The curves correspond to (1) $L_\perp$ and (2) $L_\parallel$.

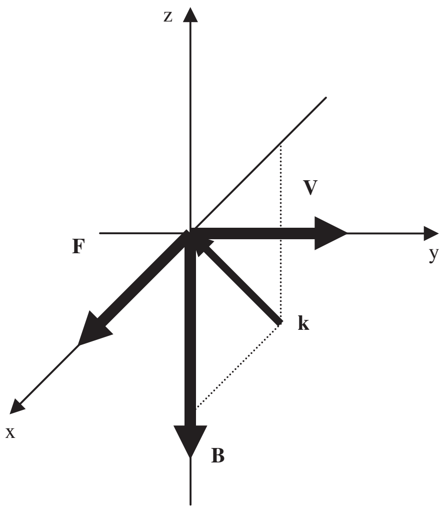

Fig. 3. The used coordinate system.

in the direction of the Ampere's force $\mathbf{F}_0$. In other words, the wave in the ionosphere is influenced only by the component of the Ampere's force parallel to the wave propagation. The used system of coordinates is depicted in Fig. 3. The main influence on the wave propagation perpendicular to the wind velocity provided by the force, described by the term $\rho \nu_H(\mathbf{V}\times\mathbf{n})$ in Eq. (4). The value of this force is defined by

$$F_0 = \rho_0 \nu_{H0} V_0. \tag{13}$$

The altitude profile of $\Omega^2(z)$ point out on the fact that influence of the Ampere's force (13) is mainly important in range of altitudes 120–170 km. In order to elucidate the role of this force let us analyze Eq. (9) in the case of fast variation of $\Omega^2(z)$ in the thin layer. For that purpose we make use of the following mathematical method. Let us consider the wave propagation with the wave vector lying in the (x, z) plane. We assume that Ω^2 is nonzero only in the layer $-l/2<z<l/2$. Let us consider the wave propagation in such a system if the wavelength substantially exceeds the width of the layer l. In order to reveal the influence of the layer on the wave propagation we consider the asymptotic limit $l\to 0$ and $\Omega^2(z=0)=\Omega_0^2\to\infty$ keeping the quantity $\eta=\int_{-\infty}^{\infty} dz\Omega^2 = l\Omega_0^2$ to be constant. In this case the layer becomes the boundary between the upper and lower semi-spaces through which the waves propagate without influence of the wind. The influence of the wind is described by the boundary conditions which satisfy the continuity of pressure and its derivatives during the passage through this boundary. Let us assume that the pressure in the wave varies as $p_1 \approx \exp(ikx)$. Then Eq. (9) in the layer reduces to

$$\frac{d^2p_1}{dz^2}+\left(\frac{1}{H}+\frac{ik\Omega^2}{\omega^2}\right)\frac{dp_1}{dz}-k^2\left(1-\frac{\omega_g^2}{\omega^2}\right)p_1=0. \tag{14}$$

Outside the layer the pressure perturbation yields Eq. (14) for Ω^2=0. Its solution is

$$z>0;\quad p_1=c_1\exp(\kappa_1 z),\quad z<0,\quad p_1=c_2\exp(\kappa_2 z),$$
$$\kappa_{1,2}=-\frac{1}{2H}\pm\sqrt{\frac{1}{4H^2}+k^2\left(1-\frac{\omega_g^2}{\omega^2}\right)}. \tag{15}$$

The boundary conditions at z=0 are derived in the Appendix and are

$$p_1(z=+0)=p_1(z=-0);\quad \frac{dp_1(z=+0)}{dz}=\frac{dp_1(z=-0)}{dz}\exp\left(-\frac{ik\eta}{\omega^2}\right). \tag{16}$$

The first condition denotes the continuity of plasma pressure when we pass the layer whereas the second one denotes the variation of the phase of the derivative by the $k\eta/\omega^2$. The influence of the layer is described by the integral characteristics η, the value of which can be calculated using the formula

$$\eta=\int_{-\infty}^{\infty} dz\Omega^2(z)=\int_{-\infty}^{\infty}\frac{dz}{\rho_0}\frac{dF_0}{dz}=\int_{-\infty}^{\infty}\frac{dz}{H}\frac{F_0}{\rho_0}. \tag{17}$$

Substituting solution (15) into boundary condition (16), one obtains

$$\kappa_1=\kappa_2\exp(-ik\eta/\omega^2) \tag{18}$$

In the case when in the equality (18)

$$k\eta/\omega^2=2\pi n;\quad n=1, 2, 3, \ldots$$

one finds the condition k_1=k_2, from which we obtain the dispersion equation for the gravity waves that gives the phase velocity v_p

$$k^2=\frac{\omega^2}{4H^2(\omega_g^2-\omega^2)},\quad v_p=\frac{\omega}{k}=2H\sqrt{\omega_g^2-\omega^2}$$

Excluding k, we find the discrete spectrum of the wave frequencies ω_n and corresponding wave periods T_n

$$\omega_n=\eta/2\pi v_p n,\quad T_n=T_0 n,\quad T_0=4\pi^2 v_p/\eta\quad n=1, 2, 3, \ldots, \tag{19}$$

According to the boundary conditions (16), under condition (19), the plasma pressure and its normal derivative are continuous when we pass the layer at $z=0$. This means that Ampere's force does not influence the wave propagation. Condition (18) does not put any constrains on the propagation of the waves with other frequencies. However, the influence of the layer in which $\Omega^2\neq 0$ on wave propagation results in their scattering. Thus, one can conclude that the waves the frequencies of which do not satisfy condition (19), damp stronger. This means that intensification of seismic source of gravity waves will lead to dominant growth of the wave perturbations with discrete spectrum the period of which yields condition (19). The values of these periods must be multiple T_0. The value of η can be estimated making use of Eq. (17), i.e. $\eta\approx(l/H)(F_0/\rho_0)_{\max}$. Fig. 4 shows the variation of the integrand F_0/ρ_0 on the altitude. The depth of the layer l and the smallest value of $(F_0/\rho_0)_{\max}$ one can calculate from the figure $l\approx 60$ km and $(F_0/\rho_0)_{\max}\approx 45$ cm/s^2. Assuming H=10 km, one finds $\eta\approx 2.7\times 10^2$ cm/s^2. The horizontal phase velocity of the gravity waves constitutes the value of the order of 10^4 cm/s.

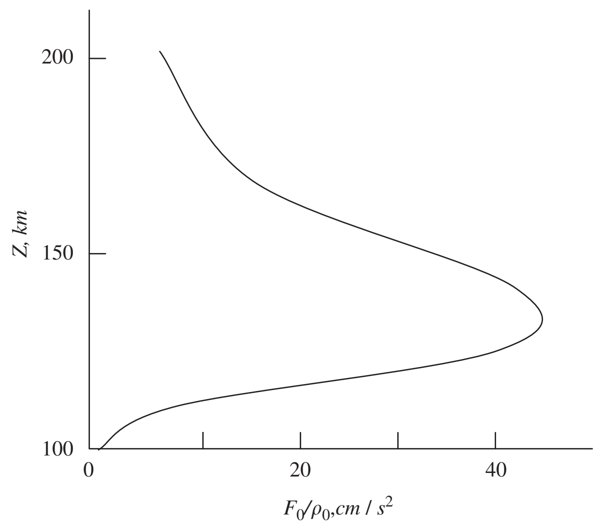

Fig. 4. Altitude variation of the integrand (F_0/ρ_0) in Eq. (17).

According to Eq. (19) one obtains T_0=24 min. These estimations have of course the qualitative character. It is connected with the used method of the analysis, uncertainty of the real properties of the ionosphere and its possible deviation from the accepted model. However, the very fact of the appearance of the discrete spectra is connected with the existence of the transition layer in which $\Omega^2 \neq 0$.

5. Discussion and conclusions

It has been shown that interaction of the ionospheric wind with geomagnetic field leads to the appearance of Ampere's force the vertical gradient of which influences the properties of gravity waves. The activization of the seismic source of these waves and enhancement of their upward flux is accompanied by the ionospheric perturbations that imply the following features:

There is an appearance of discrete wave spectrum with the periods multiple to $T_0 n$. The spectrum is distinguished due to the averaging over certain time domains. The amplitude of perturbations is enhanced in the direction perpendicular to the wind direction in the ionosphere. The comparison of directions of the magnetic field, the ionospheric wind and Ampere's force shows that for the westward wind dominating during winter time the waves propagating to the equator are enhanced whereas those propagating polar ward become weaker. Thus, during enhancement of seismic activity the related ionospheric perturbations, for example during winter time, should prevail those which are situated southward of seismic region.

The conclusions of the given paper are confirmed by observations of the background wave perturbations in the ionosphere. The particular peculiarity of these perturbations is their asymmetry of propagation. The perturbations propagate northward during summer time and southward in the northern hemisphere (Munro, 1957; Davies and Jones, 1971; Francis, 1975). In a series of papers there were made the attempts of theoretical interpretations of the observed seasonal asymmetry of propagations (Charney and Drasin, 1961; Hines and Reddy, 1967; Cowling et al., 1971). In these papers there have been carried out the studies related to filtration of atmospheric waves when they enter the stratospheric wind structures. The wind directions in these structures are the subject of the seasonable variations (Webb, 1966). It has been assumed that observed ionospheric perturbations are connected with the internal gravity waves propagating from the lower atmosphere up to the ionospheric altitudes. The basic difficulty of such mechanism is due to the fact that interaction of waves with the wind in the neutral atmosphere leads to their directed filtration only in the wind direction. Since the dominant direction of the wind in the upper atmosphere is the zonal direction then it is evident that this mechanism cannot explain the observed meridional direction of the wave propagation. The situation becomes different if one considers the influence of the wind on the wave propagation in the ionosphere. The wind in the ionosphere represents the plasma motion in the external magnetic field. It is the geomagnetic field that provides mainly meridional direction of the wave propagation when they pass the wind structures with zonal wind direction. The analysis of the averaged spectra of the background perturbations points out on the presence of spectral lines yields condition (19). This selection of frequencies differs from those inherent to the resonator since in each instant one can observe the waves with different frequencies. Only in the course of averaging over sufficiently large time domains one can observe the waves with different frequencies when the waves with definite frequencies can be distinguished.

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Appendix

In the layer Eq. (9) takes the form

$$\frac{d^2 p_1}{dz^2} + \left(\frac{1}{H} + \frac{ik\Omega_0^2}{\omega^2}\right)\frac{dp_1}{dz} - k^2\left(1 - \frac{\omega_g^2}{\omega^2}\right)p_1 = 0.$$

The solution of this equation is

$$p_1 = c_1 \exp(\mu_1 z) + c_2 \exp(\mu_2 z),$$

$$\mu_{1,2} = -\frac{1}{2}\left(\frac{1}{H} + \frac{ik\Omega_0^2}{\omega^2}\right) \pm \sqrt{\frac{1}{4}\left(\frac{1}{H} + \frac{ik\Omega_0^2}{\omega^2}\right)^2 + k^2\left(1 - \frac{\omega_g^2}{\omega^2}\right)}.$$

This solution allows us to find the connection of the pressure with its derivatives at the upper and lower layer boundaries

$$p(l/2) = p(-l/2)\exp(\mu_1 l) + \left[\frac{dp(-l/2)}{dz} - \mu_1 p(-l/2)\right] \times \frac{\exp(\mu_2 l) - \exp(\mu_1 l)}{\mu_2 - \mu_1};$$

$$\frac{dp(l/2)}{dz} = p(-l/2)\mu_1 \exp(\mu_1 l) + \left[\frac{dp(-l/2)}{dz} - \mu_1 p(-l/2)\right] \times \frac{\mu_2 \exp(\mu_2 l) - \mu_1 \exp(\mu_1 l)}{\mu_2 - \mu_1}$$

In the limiting case $l \to 0$, $\Omega_0^2 \to \infty$ and $l\Omega_0^2$=*const* one obtains $\mu_1 \to 1/\Omega^2 \to 0$ and $\mu_2 \to -ik\Omega^2/\omega^2 \to -\infty$. Then the boundary condition at the plane z=0 is

$$p(z=+0) = p(z=-0); \quad \frac{dp(z=+0)}{dz} = \frac{dp(z=-0)}{dz}\exp\left(-\frac{ik\eta}{\omega^2}\right),$$

where $\eta = \int_{-\infty}^{\infty} dz(dF/\rho_0 dz) = \int_{-\infty}^{\infty}(dz/H)(F/\rho_0)$.

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