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Proceedings of International Conference "Atmosphere, ionosphere, safety" (AIS-2016) include materials reports on: (I) — response analysis of the atmosphere — ionosphere to natural and manmade processes, various causes related geophysical phenomena and evaluate possible consequences of their effects on the human system and process; (II) — to study the possibility of monitoring and finding ways to reduce risk. Scientists from different countries and regions of Russia participated in the conference. Attention was given to questions interconnected with modern nanotechnology and environmental protection. Knowledge of the factors influencing the atmosphere and ionosphere can use them to monitor natural disasters and to establish the appropriate methods on this basis.

Content of the reports is of interest for research and students specializing in physics and chemistry of the atmosphere and ionosphere.

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8. M. V. Klimenko, V. V. Klimenko, I. E. Zakharenkova et al., The global morphology of the plasmaspheric electron content during Northern winter 2009 based on GPS/COSMIC observation and GSM TIP model results, Adv. *Space Res.,* 2015, 55(8), pp. 2077—2085.
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Simulation of Vertical Propagation of Acoustic Gravity Waves in the Atmosphere Based on Variations of Atmospheric Pressure and Research of Heating of the Upper Atmosphere by Dissipated Waves

Sergey P. Kshevetskii[1], Yuliya A. Kurdyaeva[1], Nikolay M. Gavrilov[2], and Ivan V. Karpov[1,3]

[1]Physics Department, Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia
[2]Atmospheric Physics Department, Saint-Petersburg State University, 198504,Ulyanovskaya 1, Saint-Petersburg, Russia
[3]Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation, Western Division, Russian Academy of Sciences, 236017, pr. Pobedy 41, Kaliningrad, Russia

On modern representations, the acoustic-gravity waves vertically propagating from the troposphere heights and dissipating in the upper atmosphere can bring essential contribution to the upper atmosphere energy balance. The effect of the atmosphere heating by dissipated waves is insufficiently studied now. In the given research, the problem of vertical propagation of waves generated by meteorological phenomena is stated, and the effects of heating up the atmosphere by these waves is studied.

Now it is supposed that the majority of AGWs propagating in the atmosphere arise at tropospheric heights.

They are obliged by their origin to meteorological phenomena. Detailed modeling of meteorological processes is inconveniently in view of their complexity and variety. The waves propagating from meteorological sources lead to variations of atmospheric pressure, which are well registered now. Therefore, we hope to study many parameters of these waves, being based on the information on variations of the atmospheric pressure. We hope to restore the parameters of waves propagated upward from tropospheric sources with use data on variations of atmospheric pressure.

These ideas force us to state and study the problem of vertical propagation of AGWs in the atmosphere and of the influence of these waves on atmosphere parameters. We will apply the source of waves utilizing observable variations of atmospheric pressure.

As the problem of wave propagation from a boundary pressure source is only a little studied mathematically now, we start our consideration with the simplified problem of wave generation and propagation in two-dimensional model of the atmosphere.

The model equations are:

$$
\begin{gathered}
\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho w}{\partial z}=0, \\
\frac{\partial \rho u}{\partial t}+\frac{\partial \rho u^2}{\partial x}+\frac{\partial \rho u w}{\partial z}=-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x_i}\xi(z)\frac{\partial u}{\partial x_i}, \\
\frac{\partial \rho w}{\partial t}+\frac{\partial \rho u w}{\partial x}+\frac{\partial \rho w^2}{\partial z}=-\frac{\partial P}{\partial z}+\frac{\partial}{\partial x_i}\xi(z)\frac{\partial w}{\partial x_i}, \qquad (1)\\
\frac{1}{\gamma-1}\left(\frac{\partial P}{\partial t}+\frac{\partial P u}{\partial x}+\frac{\partial P w}{\partial z}\right)=-P(\nabla\vec{v})+\frac{\partial}{\partial x_i}\kappa(z)\frac{\partial T}{\partial x_i}+\xi(z)\frac{\partial v_k}{\partial x_i}\frac{\partial v_k}{\partial x_i}+Q(z), \\
Q(z)=-\frac{\partial}{\partial z}\kappa(z)\frac{\partial}{\partial z}T_0(z)
\end{gathered}
$$

In the equations, ρ is density, u, w are horizontal and vertical velocity components $\vec{v}=(u,w)$; P is pressure; g is the acceleration of gravity, γ is an adiabatic index; $\xi(z)$, $\kappa(z)$ are coefficients of viscosity and thermal conductivity; $T_0(z)$ is a background temperature. Here x and y axis are horizontal. The axis z is directed upward. In index labels: $i,k=1,2$; $(x_1,x_2)=(x,z)$; $(v_1,v_2)=(u,w)$. The symbol t designates time and $P=\frac{\rho RT}{\mu(z)}$, where $\mu(z)$ is a gas molecular weight.

A background state of the atmosphere and dependence of equations coefficients on z has been taken from the empirical MSIS2000 model of the atmosphere. The source $Q(z)$ is introduced into the model to make a background state be stable.

The boundary conditions at the altitude h=5000 km are standard:

$$
\left(\frac{\partial T}{\partial z}\right)_{z=h}=0, \left(\frac{\partial u}{\partial z}\right)_{z=h}=0, (w)_{z=h}=0
$$

At research of the problem of a vertical propagation of waves, it is convenient to take boundary conditions along horizontal borders of the simulated field to be periodic:

$$u(x+L,z,t)=u(x,z,t),\ v(x+L,z,t)=v(x,z,t), w(x+L,z,t)=w(x,z,t),$$
$$\rho(x+L,z,t)=\rho(x,z,t), T(x+L,z,t)=T(x,z,t)$$

Here L is a period.

The two-dimensional hydrodynamic equations considering viscosity and heat conductivity usually demand of three boundary conditions at the border. For example, from a mathematical point of view, the following boundary conditions are admissible:

$$(T)_{z=0}=0, (u)_{z=0}=0, (w)_{z=0}=0$$

However, we intend to assimilate experimental data of variation of pressure at the Earth surfaces in our statement of the problem of vertical propagation of acoustic-gravity waves. That is, we wish to solve the problem in which the condition $(P)_{z=0}=f(x,t)$ instead of the condition $(w)_{z=0}=0$ is used. It is unusual, non-standard statement of a hydrodynamic problem. Use of this condition can entail changes of other standard conditions on the bottom border, because if we refuse from on the bottom border needs to be set also the density. Thus, the question of admissible conditions on the bottom border demands special mathematical research and the question of correctness of the problem that we desire to state and to solve is worthy.

We solve equations (1) with finite-difference methods with using of explicit-implicit schemes. The algorithm of numerical integration of the equations is described in papers [1], [2], [3].

The equation system (1) is nonlinear and therefore is difficult for strict analysis of correctness of the statement of the problem. Therefore, at the analysis we use admissible simplifications of the equation system. The amplitude of acoustic-gravity waves near the Earth surface is usually very small. Therefore, at research of correctness of the problem, we linearize the equation system (1). It is known, that viscosity and heat conductivity below 100 km weakly influence waves, therefore, we will neglect of dissipative terms too.

The linearized system of equations is derived from (1) standardly. Neglecting also of dissipative terms, we obtain the system of equations

$$\begin{aligned}
&\frac{\partial\rho_0(z)\psi}{\partial t}+\frac{\partial\rho_0(z)u}{\partial x}+\frac{\partial\rho_0(z)w}{\partial z}=0,\\
&\frac{\partial\rho_0(z)u}{\partial t}=-\frac{\partial\rho_0(z)gH(z)(\psi+\phi)}{\partial x},\\
&\frac{\partial\rho_0(z)w}{\partial t}=-\frac{\partial\rho_0(z)gH(z)(\psi+\phi)}{\partial z},\\
&\frac{\partial\rho_0(z)\phi}{\partial t}+(\gamma-1)\left[\frac{\partial\rho_0(z)u}{\partial x}+\frac{\partial\rho_0(z)w}{\partial z}\right]+\frac{\alpha(z)}{H(z)}\rho_0(z)w=0,
\end{aligned}\tag{2}$$

Here $\rho_0(z)$ is a background density of the atmosphere; $\alpha(z)=\gamma-1+\gamma\frac{dH(z)}{H(z)}$, $\psi=\frac{\rho-\rho_0(z)}{\rho_0(z)}$, $\phi=\frac{T-T_0(z)}{T_0(z)}$, $H(z)=\frac{RT_0(z)}{g\mu}$. The horizontal boundary conditions are periodic, with the period L. The upper boundary condition

$$(w)_{z=h}=0 \tag{3}$$

We put the lower boundary condition for the pressure:

$$\left(\rho_0(z)gH(z)(\psi+\phi)\right)_{z=0}=f(x,t), \tag{4}$$

where f (x, t) is a function defined from experimental data.

As we solve the problem of propagation of a boundary regime, the initial conditions correspond to absence of waves are used:

$$u(x,z,0)=w(x,z,0)=\phi(x,z,0)=\psi(x,z,0)=0. \tag{5}$$

The following statement is proved: the system of the equations (2) with initial conditions (5), and boundary conditions (3), (4) is correct.

Thus, the boundary conditions for the equations (1), including the boundary condition for pressure, look as follows:

$$(T)_{z=0}=T_0(0),(\rho)_z=0=\rho_0(0),\ (u)_{z=0}=0,\ \ (P)_{z=0}=f(x,t)$$

Thus, boundary conditions for temperature and density essentially affects only in a thin layer near the Earth surface, while the boundary condition for pressure defines the solution globally, at all heights.

The authors have experimental data on the surface pressure variations during thunderstorm phenomena 10—11 April 2006. The data were obtained in observations at the infrasound station IS17 [4]. These variations of pressure are used in calculations of a wave propagation and atmosphere heating.

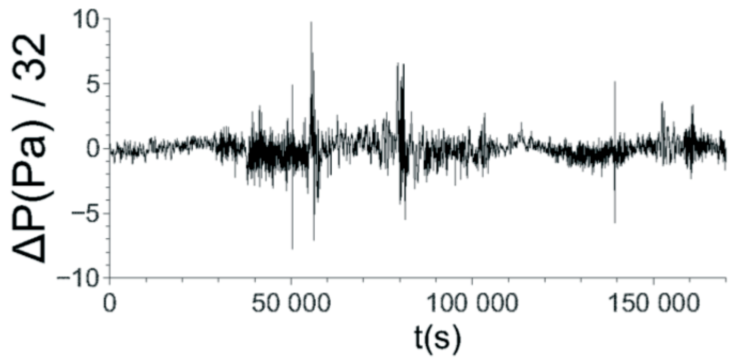

FIGURE 1. Experimental data on Δp(x0; t) variations for April 10—11, 2006, which were obtained at the IS17 infrasonic station (6:70N; 4:90W).

Within the framework of two-dimensional nonlinear hydrodynamic model of atmospheric processes, the additive to the temperature caused by heating of the atmosphere by the waves going from below from variations of atmospheric pressure is simulated. In the simulations, the source with pressure variations is set on the bottom border.

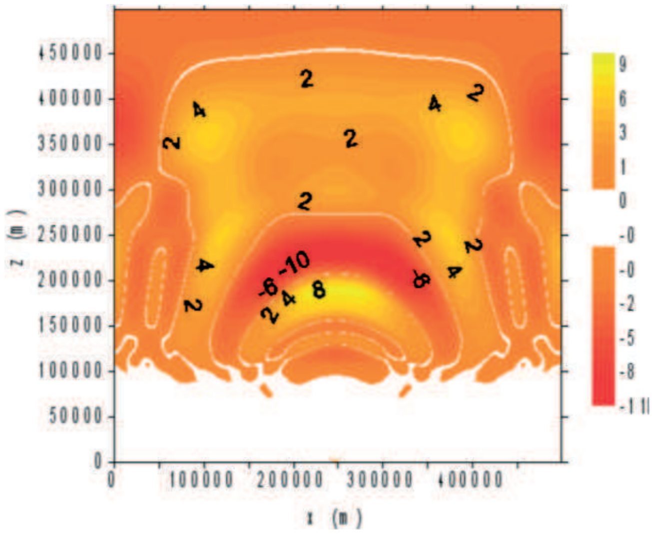

FIGURE 2. Wave perturbation of temperature from the local source of pressure variations at t = 21 minutes.

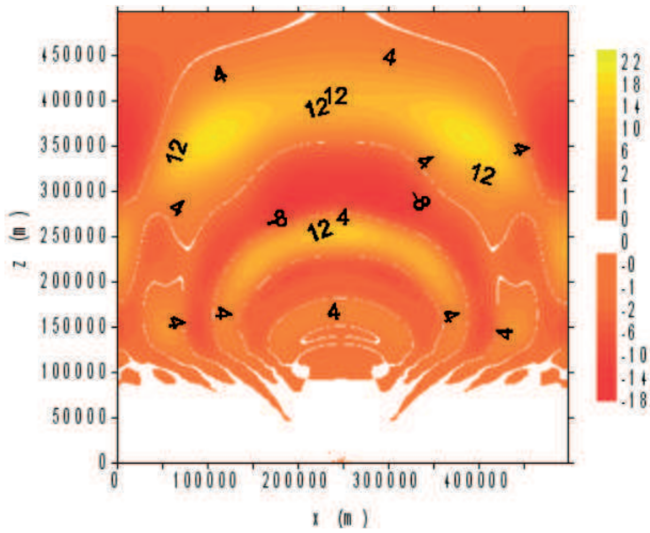

FIGURE 3. Wave perturbation of temperature from the local source of pressure variations at t = 39 minutes.

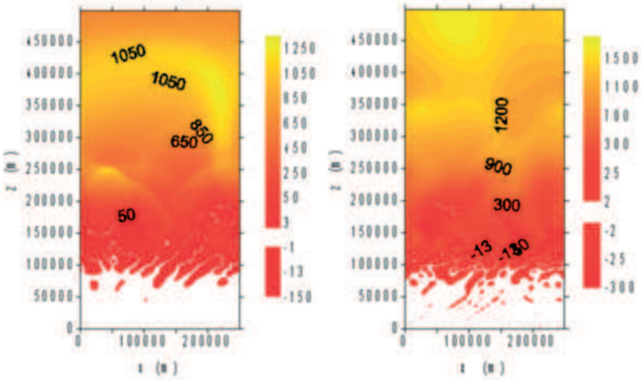

FIGURE 4. The addition to the temperature caused by the heating of the upper atmosphere by the source of pressure variations distributed along the bottom border, at t = 28 min (left) and t = 45 min (right). The temperature is stabilized.

In Fig. 2, 3, the wave propagation from the localized source of the pressure variations upon the bottom borders is shown.

In Fig. 4, the simulated heating of the atmosphere by the test source distributed along the bottom border is shown.

We see that 30 minutes are enough for atmosphere heating by the acoustic-gravity waves going from the tropospheric heights. That is, link of processes in the troposphere and the upper atmosphere is fast enough. Despite the heating of atmosphere by the waves going from below, the temperature is stabilized in time less than 1 hour. That is, in time less than 1 hour after source inclusion, balance between the inflows of heat at the expense of dissipation of waves, and energy drains has come. As to amplitude of the heating, the two-dimensional model gives a little overestimated heating owing to a two-dimensional geometry, and the surface source certainly needs to be calibrated.

Thus, the numerical model allowing simulation of vertical propagation of acoustic-gravity waves and of the heating of the upper atmosphere by waves from the fluctuations of atmospheric pressure is developed.

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