EPSC Abstracts
Vol. 7 EPSC2012-142 2012
European Planetary Science Congress 2012

Vortices in nonadiabatic unstable atmosphere and redistribution of dust particles

Yu. N. Izvekova (1), S. I. Popel (1), P.K. Shukla (2), and L. Stenflo (3)
(1) Institute for Dynamics of Geospheres RAS, Moscow, Russia (besedina_yn@mail.ru / Fax: +7-499-1376511), (2) Ruhr University Bochum, Germany, (3) Linköpings universitet, Linköping, Sweden

Abstract

We study a possibility of instability development of acoustic-gravity waves. It is shown that the existence of regions in the atmosphere where the instability conditions are satisfied is due to the cooperation of thermal flow of solar radiation, infrared emission of the atmosphere, water vapor condensation, as well as thermal conductivity. We discuss redistribution of dust particles in the ionosphere due to the interaction between dust and vortices. We consider acoustic-gravity vortices which can be formed at the altitudes of 110 – 120 km as well as the behavior of dust particles in these vortices. We study a possibility of the formation of dust flows in a vertical direction as a result of the interaction with dust vortices. We also discuss large-amplitude vortices observed in Earth's troposphere and their possible structure.

1. Basic equations

We use a local frame of reference with axis x directed to the east, axis y to the north, and axis z pointed upward. Acoustic-gravity (AG) waves propagating in Earth's atmosphere are described by the following equations:

$$\frac{\partial \mathbf{V}}{\partial t}+\left(-\eta\Delta+\mathbf{V}\nabla\right)\mathbf{V}+\nu_d\left(\mathbf{V}-\mathbf{v}_d\right)=-\frac{\nabla P}{\rho}+\mathbf{g}, \tag{1}$$

$$\frac{\partial \rho}{\partial t}+\nabla\cdot\left(\rho\mathbf{V}\right)=0, \tag{2}$$

$$\frac{\partial P}{\partial t}+\left(\mathbf{V}\nabla\right)P+\gamma P\,\mathrm{div}\mathbf{V}=\frac{P}{c_V\rho T}\nabla\mathbf{J}_\mathbf{c}- -\frac{P}{c_V\rho T}\nabla\mathbf{J}_\mathbf{a}+\frac{P}{c_V\rho T}\nabla\mathbf{J}_k-\frac{P}{c_V\rho T}\nabla\mathbf{L}, \tag{3}$$

$$\frac{\partial \rho_d}{\partial t}+\nabla\cdot(\rho_d\mathbf{v}_d)=0, \tag{4}$$

$$\rho_d\left(\frac{\partial}{\partial t}-\eta\Delta+\mathbf{v}_d\cdot\nabla\right)\mathbf{v}_d+\rho_d\nu_d\left(\mathbf{v}_d-\mathbf{V}\right)= =-\nabla P_1+\rho_d\mathbf{g}. \tag{5}$$

Here, $\mathbf{V}$ ($\mathbf{v}_d$) is the speed of neutrals (dust), ρ (ρ_d) is the density of neutrals (dust), $\mathbf{g}$ is the acceleration of gravity, γ is the ratio of specific heat, ν_d is the collision frequency with the dust, η is the kinematics viscosity, P_1 is the perturbation of equilibrium pressure, which includes electron, ion, and dust contributions. On the right-hand-side of the Eq. (3) $\mathbf{J}_\mathbf{c}$ describes the heat flux in the atmosphere due to the solar radiation, $\mathbf{J}_\mathbf{a}$ refers to the infrared emission, $\mathbf{J}_k$ refers to the heat flux due to water vapor condensation, and $\mathbf{L}$ characterizes heat flux due to the thermal conductivity [2]. Eqs. (1)–(3) describe the dynamics of neutrals, while Eqs. (4)–(5) describe the dynamics of the dust component. We study instability regions for the altitudes up to 130 km. Calculations made for a nonadiabatic atmosphere show that at altitudes of 110–130 km instability of AG-waves develops. As a result, formation of acoustic-gravity vortices is possible at these altitudes.

2. Dust particles in a vortex

In the approximation of short-wavelength, low-frequency perturbations propagating along vertical plane, and of relative infinitesimality of pressure-density disturbances, the set of equations (1)–(3) admits solution as localized nonlinear vortical structures propagating with a constant velocity along the latitude. These solutions describe a pair of vortices of equal intensity rotating in the vertical plane in opposite directions. A numerical analysis has been carried out of the motion of the particle in the vortex velocity field with taking into account the gravity as well as the force acting on the particle by the neutrals. Thus, dust particles with a size of 10 nm can reside in a vortex with a radius of 3 km, moving at velocity of 100 m/s at the altitude of 110 km for about 10 min., while smaller particles have greater residence times. In a slower vortex, the residence time for particles increases.

2. Dust flows

The involvement of a large number of dust particles into the vortical motion can result in the formation of the dust vortex. In [1] a possibility of realization of the solution of Eqs. (4)–(5) in the form of a dipole vortex in the presence of vertical gradient of the dust density is noted. We investigate a possibility of realization of solutions in the form of vertical dust flows – streamers. We consider excitation of dust flow by dust vortices of large amplitude as a result of the modulational instability. Taking into account that $\Omega << \omega_0$ and $q << k_0$, one can show that the growth-rate of the instability resulting in the streamer formation $q_z << q_x$ at $\gamma > \nu_d$ is $\gamma = \sqrt{2}/5|\psi_0|q_x k_0$ ($\Omega = i\gamma$). Here Ω and q (ω_0 and k_0) are the characteristic frequency and the wave vector that characterize excitation of dust flows (dust vortex), ψ_0 is the amplitude of the Fourier component of the dust vortex corresponding to ω_0 and k_0. Using an estimate $|\psi_0| = 2\pi v/k_0$, where v is the rotation speed of the dust vortex, we obtain $q_x > 5\nu_d/\left(2\sqrt{2}\pi v\right)$. At the altitudes higher than 100 km effects of viscosity set bottom limits on the size of the flow, while minimum flow size increases with the altitude.

3. Vortices in the troposphere

It has been shown that in Earth's atmosphere there are regions where the instability develops. To obtain the dispersion equation we transform and linearize the set of Eqs. (1)-(4) complemented by the equation of state and search the solution in the form of $\exp\left(z/2H_0\right)\exp\left(-i\omega t + ik_x x + ik_z z\right)$, where H_0 is the characteristic depth of the atmosphere which slightly varies for different altitudes. The instability conditions are satisfied if $\mathrm{Re}(\omega) > 0$ and $\mathrm{Im}(\omega) > \eta K^2$, where K is a wave number. Then we study instability regions for different wave numbers and we conclude that acoustic-gravity waves can be unstable in the troposphere. This results in the formation of acoustic-gravity vortices in the troposphere. The localized solutions in the form of vortices corresponding to those observed in Earth's troposphere [3] are obtained.

4. Summary and Conclusions

We have studied the instability of acoustic-gravity waves in the atmosphere with taking into account thermal flows of solar radiation, infrared emission of the atmosphere, water vapor condensation, as well as thermal conductivity. It has been shown that in Earth's atmosphere (at the tropospheric and ionospheric altitudes) there are regions where the instability develops. We have considered the behavior of nanoscale dust particles in the acoustic-gravity vortex which is formed as a result of the development of the convective instability at the altitudes of 110 – 120 km. It has been shown that dust particles of the size of 10 nm can exist in the vortex of the size of 3 km during the time of about 10 minutes, while smaller particles are inside the vortex longer than 10 minutes. The speeds acquired by the grains as a result of their interaction with the vortex can be of the order of the sound speed. Hence, the layers of meteoritic dust at the altitudes of 110 – 120 km (which have usually the width of about 1 km) can change their form, the dust can be redistributed over the whole existence region of the vortex. Moreover, transition of particles up to altitudes of 130 km, where AG-vortices can form and exist, becomes possible. The presence of the regions with positive gradients of density against the background of the dipole vortices can result in the generation of streamers as a result of the nonlinear interaction with the dust vortex. A possibility of formation of acoustic-gravity vortices with the parameters close to those of large-amplitude vortices observed in Earth's troposphere is shown.

Acknowledgements

This work is supported by the Division of Earth Sciences of the Russian Academy of Sciences (the basic research program No. 5 "Nanoscale particles: conditions of formation, methods of analysis and recovery from mineral raw").

References

[1] Hasegawa, A. and Shukla, P.K. Phys. Let. A., Vol. 332, pp. 82-85, 2004.

[2] Lyahov, V.V.: Acoustic-gravity waves in a nonadiabatic atmosphere, Izvestiya, Atmospheric and Oceanic Physics, Vol. 43, N 3, pp. 308-316, 2007.

[3] Ramamurthy, M.K., Collins, B.P., Rauber, R.M., and Kennedy, P.K.: Evidence of very-large-amplitude solitary waves in the atmosphere, Nature, Vol. 348, pp. 314-317, 1990.