EPSC Abstracts
Vol. 9, EPSC2014-458, 2014
European Planetary Science Congress 2014

Nonlinear structures and dust in the unstable atmosphere

Yu. N. Izvekova (1-3), S. I. Popel (1-3), O. Ya. Izvekov (3), and L. Stenflo (4, 5)
(1) Institute of Geosphere Dynamics, Russian Academy of Sciences, Moscow, Russia (e_mail: besedina_yn@mail.ru)
(2) Space Research Institute, Russian Academy of Sciences, Moscow, Russia
(3) Moscow Institute of Physics and Technology (State University), Dolgoprudnyi, Moscow region, Russia
(4) Ruhr University Bochum, Germany
(5) Linköpings universitet, Linköping, Sweden

Abstract

We consider nonadiabatic stratified atmosphere and define regions unstable for acoustic-gravity waves. Possibility of vortex formation at different altitudes is discussed. We also study parametric instability in dusty ionized atmosphere in terms of possibility of nonlinear dust structures formation.

1. Instability of acoustic-gravity waves

We study 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. We show that in Earth's atmosphere there are regions where the instability develops. Then we numerically study instability regions for different wave numbers and we conclude that acoustic-gravity waves can be unstable in the troposphere and at ionospheric altitudes. For example, Figure 1 shows instability growth rate for different wave numbers in the range of altitudes up to 120 km. We also obtain the localized solutions in the form of vortices corresponding to those observed in Earth's troposphere [4].

2. Dust particles in the ionosphere

Dust particles in the Earth's ionosphere are important objects of study today. The main sources of ionospheric dust are meteor fluxes, during which ablation occurs, and at the altitudes of 80 - 120 km supersaturated vapors mainly of alkaline earth metals are formed. Condensation of supersaturated metal vapors leads to formation of secondary dust particles with densities higher than that of primary particles. Maximum densities of nanosize dust particles of meteoric origin are 10^4 cm^{-3} and are reached at 80-90 km. In particular, Perseids generate "metallic" layer of about 1 km depth and about 10 km in horizontal direction. This layers are observed using lidar. Ionospheric dust particles can be formed as a result of water vapor condensation. Convective transport of particles of volcanic ash and soot particles from large fires can also be the source of dust in the ionosphere. Dust particles in partially ionized plasma obtain electric charge and become essential plasma component. Dusty plasma acquires unique physical properties.

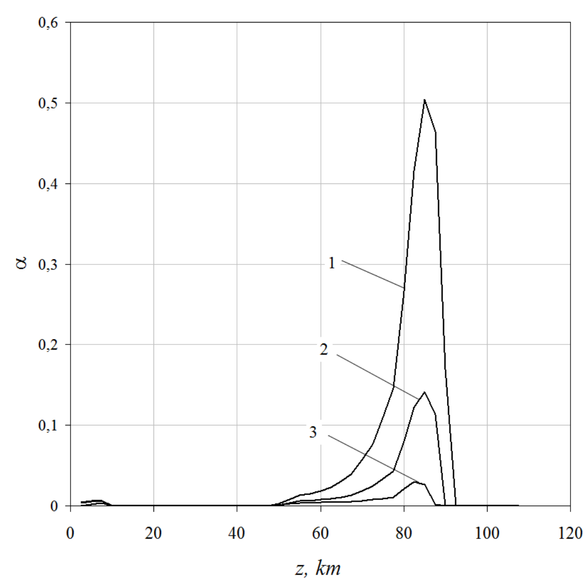

Figure 1: Instability growth rate α versus altitude z for horizontal wave number $k_x = 10^{-3}$ and different vertical wave numbers: 1 - $k_z = 10^{-1.5}$, 2 - $k_z = 10^{-1.7}$, 3 - $k_z = 10^{-2}$

3. Dust flows

In dusty ionized atmosphere equations describing dust dynamics should be added to the main system. We study the case when collisions between stationary neutrals with electrons and ions are more frequent than those between electrons and ions and phase speed and wavelength of the perturbations is much smaller than the electron and ion thermal speeds and electron and ion collisional mean free pass respectively. Interaction of dust particles with acoustic gravity vortices at ionospheric altitudes was studied in [3]. This can lead to formation of initial vortical perturbations in dust cloud. Instability growth leading for dust flows generation as a result of nonlinear interaction of dust vortices with dust flows is characterized by the growth rate γ. Furthermore 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. For vertical flow (streamer) vertical wave number q_z should be much smaller than horizontal wave number q_x : $q_z << q_x$. Growing instability for this case have been studied earlier [1]. Possibility of formation of vertical dust flows at the altitudes higher than 90 km was shown. At lower altitudes formation of dust flows is restricted due to frequent collisions with neutrals ν_d . At the altitudes higher than 100 km effects of viscosity η set bottom limits on the size of the flow, while minimum flow size increases with the altitude. Here we study possibility of formation of zonal flows, i. e. $q_x << q_z$. For linear stage of instability development, for the case $\eta q^2 << \nu_d$, taking into account $\Omega << \omega_0$, and assuming low dissipation for dust vortex (ω_0 is a real value) we get growth rate for zonal flows:

$$\gamma = \frac{4\omega_0^2 A\nu_d k_0^2\left(\nu_d^2 - 3Ak_0^2\right)}{\nu_d^6 + 4A\nu_d^4 k_0^2 + 4A\nu_d^2 k_0^4 + 4\nu_d^4\omega_0^2 + 24A\nu_d^2\omega_0^2 k_0^2 - 36A^2\omega_0^2 k_0^4},$$

$$A = \frac{2\left|\mathbf{y}\times\mathbf{q}\cdot\mathbf{k_0}\right|^2 \left|\psi_0\right|^2 q_z k_{0z}}{q^2 k_0^2}.$$

For $q_z k_{0z} > 0$ growing instability is possible while $\nu_d^2 > 3Ak_0^2$. For the opposite situation $q_z k_{0z} < 0$, which corresponds to $A < 0$, the denominator should be negative:

$$\nu_d^6 + 4A\nu_d^4 k_0^2 + 4A\nu_d^2 k_0^4 + 4\nu_d^4\omega_0^2 + 24A\nu_d^2\omega_0^2 k_0^2 - 36A^2\omega_0^2 k_0^4 < 0.$$

Thus we have shown that one of the dust transport mechanisms in the ionosphere is that related to zonal flows generated as a result of parametric interaction with dust vortices.

4. Summary and Conclusions

In the nonadiabatic atmosphere with thermal flows of solar radiation, infrared emission of the atmosphere, water vapor condensation, and thermal conductivity acoustic-gravity waves can be unstable in the troposphere and at the ionospheric altitudes. At these altitudes nonlinear vortical structures can be formed. Presence of dust at the ionospheric altitudes modify ionospheric plasma properties. As a result of nonlinear interaction with dust vortices dust flows in vertical and horizontal directions can be generated.

Acknowledgements

This work was supported by the Russian Foundation for Basic Research (projects nos. 14-05-31410 мол_а and 14-05-90106_Kirghizia_a).

References

[1] S. Benkadda, D. N. Klochkov, S. I. Popel, and Yu. N. Izvekova, Nonlinear Excitation of Zonal Flows and Streamers in Plasmas, Physics of Plasmas Vol. 18, No. 5, 052306, 2011.

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

[3] Yu. N. Izvekova, S. I. Popel, and P. K. Shukla, Vortices and Dust Streamers in Earth's Ionosphere, in: Dusty/Complex Plasmas: Basic and Interdisciplinary Research (AIP Conference Proceedings; Vol. 1397), Edited by V.Yu. Nosenko, P.K. Shukla, M.H. Thoma, H.M. Thomas, American Institute of Physics, Melville, New York, pp. 243-244, 2011.

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