EPSC Abstracts,
Vol. 4, EPSC2009-41, 2009
European Planetary Science Congress,

Vortex motions and dust particle transport in the ionosphere

Yu.N. Besedina (1), S.I. Popel (1), P.K. Shukla (2)

(1) Institute for Dynamics of Geospheres, Moscow, Russia (besedina_yn@mail.ru / Fax: +7-499-1376511)
(2) Ruhr University Bochum, Germany

Abstract

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 surface dust vortices.

Dust Particles in Acoustic-Gravity Vortex

Propagation of perturbations in dusty Earth's atmosphere is described by the following equations

$$\frac{\partial \mathbf{V}}{\partial t} + (\nu_d - \eta\Delta + \mathbf{V}\nabla)\mathbf{V} = -\frac{\nabla P}{\rho} + \mathbf{g}, \quad (1)$$

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

$$\frac{\partial P}{\partial t} + (\mathbf{V}\nabla)P + \gamma P \,\mathrm{div}\mathbf{V} = \frac{P}{c_V RT}\nabla\mathbf{J}, \quad (3)$$

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

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

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 Eq. (3), the energy flux $\mathbf{J}$ is contained, which is determined by thermal balance of the atmosphere. Eqs. (1)–(3) describe the dynamics of neutrals, while Eqs. (4)–(5) describe the dynamics of the dust component of the ionospheric plasma.

In non-adaibatic atmosphere [1] the acoustic-gravity waves are unstable at the altitudes of 110 – 120 km. Thus at these altitudes the formation of acoustic-gravity vortices is possible.

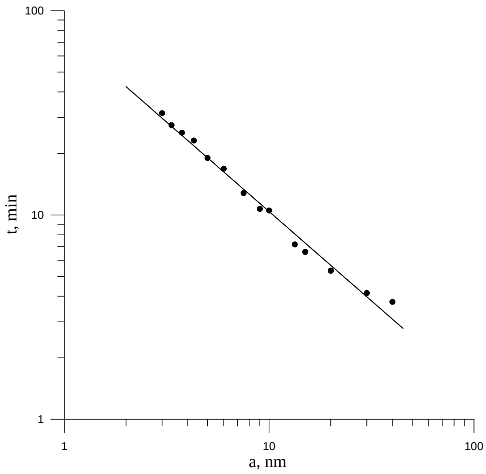

Figure 1: The dependence of lifetime of the grain in the vortex with the radius of 3 km moving with the speed 100 m/s on the grain size.

Under the assumptions of short-wavelength, low-frequency perturbations propagating along vertical plane, small dissipation, and relative smallness of perturbations of the pressure and the density [2], the set of equations (1)–(5) admits solutions in the form of localized nonlinear vortex structures propagating with a constant velocity. 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 grain by the neutrals. The dependence of lifetime of the grain in the vortex on its size is given in Figure 1 for the vortex with the radius equal to 3 km moving with the speed 100 m/s. Figure 1 shows that dust grains

EPSC Abstracts,
Vol. 4, EPSC2009-41, 2009
European Planetary Science Congress,

of the size of 10 nm can exist in the vortex during the time of about 10 minutes, while smaller grains are inside the vortex longer than 10 minutes. For slower vortex the time of existence of dust particles in the vortex increases.

Vertical Dust Flows

Inclusion of a large number of dust grains in the vortex motion can result in the formation of the dust vortex. In [3] 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 surface vortices of large amplitude as a result of the modulational instability. For this purpose we assume that

$$\rho_{ds} = \rho_{0\pm} e^{\pm i(\mathbf{k}_0 \cdot \mathbf{r} \mp \omega_0 t)} + \sum_{+,-} \rho_{\pm} e^{i(\mathbf{k}_\pm \cdot \mathbf{r} - \omega_\pm t)},$$
$$\psi_s = \psi_{0\pm} e^{\pm i(\mathbf{k}_0 \cdot \mathbf{r} \mp \omega_0 t)} + \sum_{+,-} \psi_{\pm} e^{i(\mathbf{k}_\pm \cdot \mathbf{r} - \omega_\pm t)},$$
$$\psi_z = \varphi e^{i(\mathbf{q} \cdot \mathbf{r} - \Omega t)},$$

where $\omega_\pm = \Omega \pm \omega_0$, $\mathbf{k}_\pm = \mathbf{q} \pm \mathbf{k_0}$. Here ω $(\mathbf{k_0}, \psi_s)$ and Ω $(\mathbf{q}, \psi_z)$ are the frequencies (wave vectors, functions of current) of the surface dust vortices and dust flows, respectively; $\rho_d = \rho_{ds} + \rho_{d0}$.

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 $q_z << q_x$ is $\gamma = 10|\psi_0| q_x k_0$ ($\Omega = i\gamma$). In the absence of the viscosity the sufficient condition for the instability development is $\gamma > \nu_d$. Using an estimate $|\psi_0| = 2\pi v / k_0$, where v is the rotation speed of the dust vortex, we obtain $q_x > \nu_d / 20\pi v$. Thus for the rotation speed of the dust vortex equal to 100 m/s and its size of the order of 100 m, the formation of vertical dust fluxes is possible at the altitudes of about 120 km for dust grain sizes of about 10 nm. The time of the existence of dust grain in the vortex for the above parameters exceeds several times the characteristic time of the instability development.

Discussion

Thus we have considered the behavior of nanoscale dust grains 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 grains 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 grains are inside the vortex longer than 10 minutes. For slower vortex the time of existence of dust particles in the vortex increases. 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. Furthermore, due to an appearance of the dust flows, some plasma instabilities can develop in the vicinity of the vortex. 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.

Acknowledgements

This study was supported by the Division of Earth Sciences, Russian Academy of Sciences (the basic research program “Nanoscale particles in nature and technogenic products: conditions of existence, physical and chemical properties, and mechanisms of formation”) and by the Division of Physical Sciences, Russian Academy of Sciences (the basic research program “Plasma physics in the Solar system”). One of the authors (S.I.P.) acknowledges the financial support of the Dynasty Foundation.

References

[1] Lyahov, V.V. (2007) *Izvestiya, Atmospheric and Oceanic Physics,* 43, N 3, 308-316.

[2] Aburdzhania, G.D. Self-organization of the nonlinear vortex structures and the vertical turbulence in the dispersive media. (ComKniga, Moskow, 2006) [in Russian]

[3] Hasegawa, A. and Shukla, P.K. (2004) *Phys. Let. A.,* 332, 82-85.