Tidal wind as a possible link of coupling between atmospheric waves activity and sporadic E formation

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Abstract

The horizontal tidal wind in the mesosphere lower thermosphere region (MLT) is considered as a source of atmospheric gravity waves (AGWs) and vortical type perturbations generation. It is shown that at mid-latitude these atmospheric waves, evolving in the tidal wind, can lead to vertical convergence of heavy metallic ions of this region and Formation of sporadic E (Es) layer. The process of sporadic E formation by short-period AGWs (close to Bunt-Vaisala period) and by the stationary type vortical perturbations with the same spatial scale, excited in the horizontal shear flow is demonstrated using numerical simulations. The possibility of oscillation of Es layers electron/ions density by period less than BV period under influence of short-period AGWs is shown and the possible coupling of these processes with quasi-periodic echoes is also noted. In our numerical experiment the mid-latitude nighttime Es layers formed under influence of these atmospheric waves, which are possibly generated by horizontal tidal wind, mostly move downward, this is an observed phenomena. It is noted that investigation of sporadic E formation by atmospheric waves evolving in the tidal wind is important for study of the in situ developing processes in the lower thermosphere determining atmosphere-ionosphere dynamical coupling as well as for revealing their possible dynamical coupling with lower atmosphere.

Atmospheric gravity waves and vortical perturbations in the horizontal shear flow

Atmospheric waves spectrum in the horizontal shear flow,

$$\boldsymbol{u_0 = ay}$$

for isothermal atmosphere have the following form (Didebulidze Kafkalidis, Pataraya, JASTP, 2004):

$$\omega_{a,g}^2(t) = \frac{1}{2}c_s^2\left(|\mathbf{k}(t)|^2 + \frac{1}{4H^2}\right) \pm \sqrt{\frac{1}{4}c_s^4\left(|\mathbf{k}(t)|^2 + \frac{1}{4H^2}\right)^2 - \omega_b^2 c_s^2\left[\left(1+\frac{10}{R_h}\right)k_x^2 + k_t^2(t)\right]},$$

$$\omega_{sh} = 0,$$

here $R_h = \omega_b^2 / a^2$ and $k_t(t) = k_y - ak_x$. $\mathbf{k}(t) = \mathbf{k}(k_x, k_t(t), k_z)$ is the time variant wavenumber.

In addition with acoustic and gravity waves the presence of vortical type waves (shear wave) also noteceable. The linearized set of continuity, motion and adiabatic equations, which considers the horizontal shear flow, can be solved analytically for the spatial Fourier harmonics of perturbed atmospheric parameters in the case of small value of shear (i.e. $R_h >> 10$). The solution has following form:

$$u_k(t) = -\frac{A_{sh}\left(k_z - \frac{i}{2H}\right)\left(k_x^2 + k_y^2\right)^2}{k_x^2\left(k_z^2 + \frac{1}{4H^2}\right)} \frac{k_t(t)}{k_x^2 + k_t(t)^2}$$

$$v_k(t) = \frac{A_{sh}\left(k_z - \frac{i}{2H}\right)\left(k_x^2 + k_y^2\right)^2}{k_x\left(k_z^2 + \frac{1}{4H^2}\right)} \frac{1}{k_x^2 + k_t(t)^2}$$

$$w_k(t) = 0$$

The shear wave corresponds to the standing type of an incompressible $(\nabla \cdot \mathbf{v} = 0)$ vortical perturbation $((\nabla \times \mathbf{v}_k)_z = const)$.

In the isothermal atmosphere the atmospheric wave velocity vector $\mathbf{v}(u, v, w)$ components are described by the following form:

$$u(x, y, z, t) = e^{z/2H} \cdot \mathrm{Re}\{u_k(t)\exp[i\phi(x, y, z, t)]\}$$

$$v(x, y, z, t) = e^{z/2H} \cdot \mathrm{Re}\{v_k(t)\exp[i\phi(x, y, z, t)]\}$$

$$w(x, y, z, t) = e^{z/2H} \cdot \mathrm{Re}\{w_k(t)\exp[i\phi(x, y, z, t)]\}$$

$z = h - h_0$ is the difference between an actual and some initial height h_0 and H is the atmospheric (neutral gas) scale height.

Evolution of AGWs in the horizontal shear flow

AGWs evolving in the shear flow. The amplitudes and frequency of these perturbation changes in time and they transform to short period oscillations.

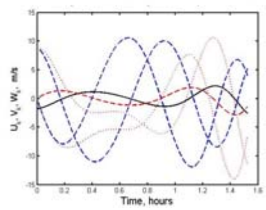

Fig. 1. Evolution of spatial Fourier amplitudes of AGWs. Here, the linear shear $a = 5 \cdot 10^{-4} s^{-1}$ *and the shear wave horizontal and vertical wavelengths* $\lambda_x = \lambda_y = 120\,km, \lambda_z = 12km.$

The ions density N_i in the lower thermosphere can be described by the following continuity equation:

$$\frac{\partial N_i}{\partial t} + \frac{\partial}{\partial y}(N_i v_i) + \frac{\partial}{\partial z}(N_i w_i) = 0,$$

Where v_i and w_i are ions drift velocity in horizontal (y) and vertical (z) directions:

Here $T = (T_e + T_i)/2$ is mean plasma temperature, k_B is Boltzmann constant, I is the magnetic dip angle, $\kappa = \nu_{in}/\omega_i$, ν_{in} is ion-neutral collision frequency, $\omega_i = eB/M$ is ion gyrofrequency, M is ion mass.

$$\mathrm{v}_i = \left[(u_o + u)\sin I + \kappa\left(v - \frac{2k_B T}{N_i M_i \nu_{in}}\frac{\partial N_i}{\partial y}\right) + \left(w - \frac{2k_B T}{N_i M_i \nu_{in}}\frac{\partial N_i}{\partial z}\right)\cos I\right]\frac{\kappa}{1+\kappa^2}$$

$$\mathrm{w}_i = \left[-(u_o + u)\sin I\cos I - \kappa\cos I\left(v - \frac{2k_B T}{N_i M_i \nu_{in}}\frac{\partial N_i}{\partial y}\right) + \left(\kappa^2 + \sin^2 I\right)\left(w - \frac{2k_B T}{N_i M_i \nu_{in}}\frac{\partial N_i}{\partial z}\right)\right]\frac{1}{1+\kappa^2}$$

Evolution/generation of Es under influence of AGWs evolving in the background wind

In particular cases, AGWs could lead to the efficient convergence of the charged particles. The distance between layers is determined by vertical wavelenghth.

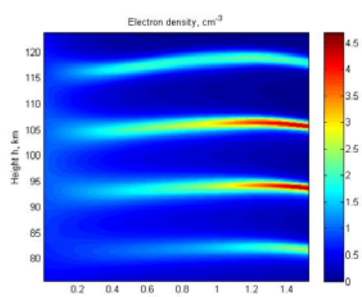

Figure 2. Temporal evolution of electron density height profile. Parameters are same as on Figure 1.

Evolution of vortical perturbations in background wind and their influence on formation of Es

The vortical type perturbation (shear wave) evolving in the horizontal shear flow can transformed into short-period AGW, which can cause of this wave double frequency oscillations in the Es layer.

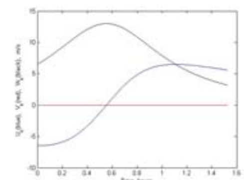

Fig.3. Evolution of spatial Fourier amplitudes of vortical perturbations . Parameters are same as on Fig.1 and Fig.2. Analytical model is illustrated.

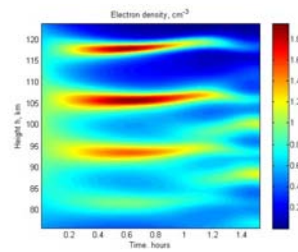

Figure 4. *Temporal evolution of electron density height profile. Evolution of electron density is governed by vortical mode of perturbations evolving in the background flow. Parameters are same as on figure.*

Conclusion

The formation and behavior of the sporadic E under an influence of atmospheric gravity waves (AGWs) and vortical type perturbation (shear wave) evolving in the horizontal shear flow has been considered.

2D numerical simulations are performed and it was shown that in the case when phase welocity of the AGWs evolving in the background flow is close to the velocity of background wind these perturbations could lead to the formations of horizontal, thin layers of the charged particle.

It is also shown that , while amplitude of vertical perturbation evolving in the horizontal shear flow remains high enough, near the region where the velocity of horizontal shear flow is zero, the shear waves could cause convergence of the charged particle in the thin layers.

The spatial distribution of the thin layers converged electrons is determined by vertical wavelengths of perturbations.

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