Formation and behavior sporadic E under the influence of atmospheric gravity waves

Goderdzi G. Didebulidze, G. Dalakishvili, G. Matiashvili

didebulidze@iliauni.edu.ge

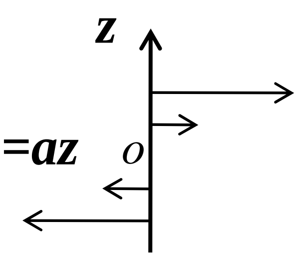
ILIA STATE UNIVERSITY

Abastumani Astrophysical Observatory

Theory of sporadic E formation by atmospheric waves

Windshear theory:

The mid-latitude Es is a result of neutral-ion collisions and Lorentz force acting on the metallic ions (Axford, 1963). In the case of horizontal neutral wind with a vertical shear , the thin layer of converged ions could occur in the vicinity of the horizontal plane where the wind velocity (V_n) changes direction (zero wind nodes).



$\boldsymbol{V_n = az}$

$$\frac{k_B T_i}{N_i}\nabla N_i + M_i \nu_{in}\left(V_{\mathbf{i}} - V_{\mathbf{n}}\right) - e\left(\mathbf{E} + V_{\mathbf{i}} \times \mathbf{B}\right) = 0$$

neutral-ion collisions

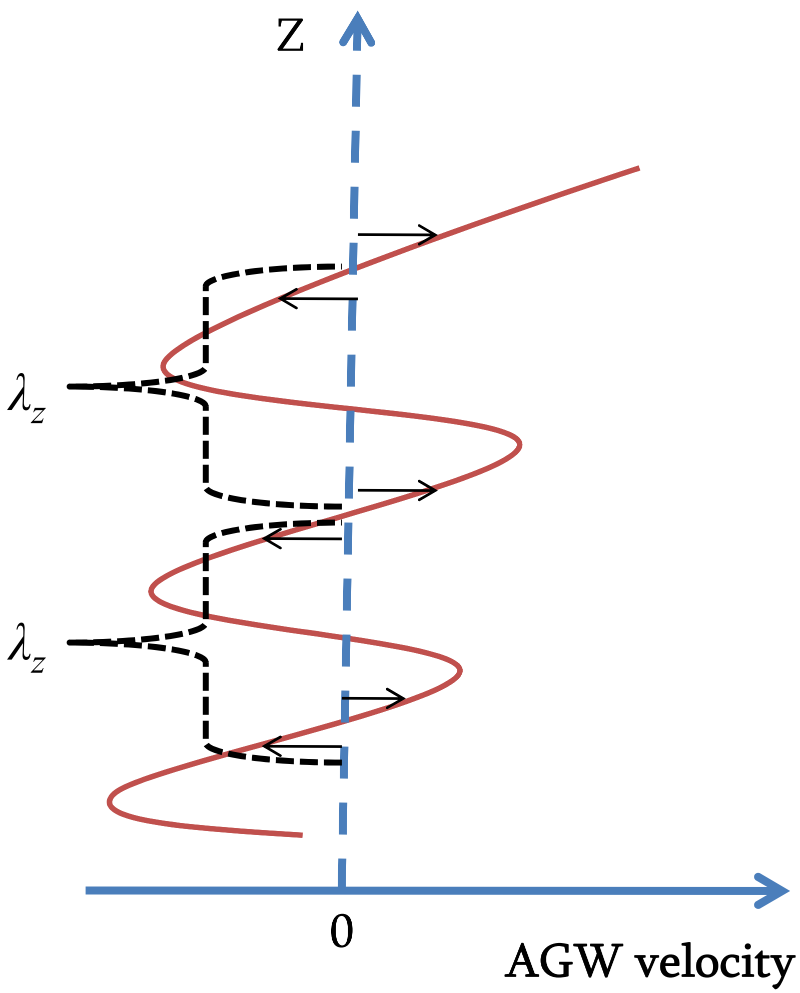
Lorentz force

We consider horizontal (v_i) and vertical (w_i) drift of ions, when neutrals velocity is composed of background horizontal wind velocity - $\mathbf{u}_{0n}$ and velocity perturbation $\mathbf{v}_n$ produced by atmospheric waves i.e.:

$$\mathbf{V}_{\mathbf{n}} = \mathbf{u}_{0n} + \mathbf{v}_n$$

Here u_n, v_n, w_n are the horizontal x, y and the vertical z components of perturbed velocity $\mathbf{v}_n(u_n, v_n, w_n)$, respectively. We assume that, horizontal (x) background wind velocity (1) $\mathbf{u}_{0n} = constant$ or has linear shear in horizontal y direction, $u_{on}(y) = ay$. In our case velocity perturbation $\mathbf{v}_n(u_n, v_n, w_n)$, corresponds to the AGWs evolving in the horizontal background wind.

Ions vertical convergence by AGWs



For simplicity the isothermal model (Hines, 1960) of AGWs is used and dispersion equation have the following form:

$$(\omega - k_x u_{on})^2 = \frac{1}{2} c_s^2 \left(\mathbf{k}^2 + \frac{1}{4H^2} \right) - \sqrt{\frac{1}{4} c_s^4 \left(\mathbf{k}^2 + \frac{1}{4H^2} \right)^2 - \omega_b^2 c_s^2 (k_x^2 + k_y^2)}$$

H is atmospheric scale height, $k_{x,y,z}=2\pi/\lambda_{x,y,z}$ are the horizontal and vertical wave numbers

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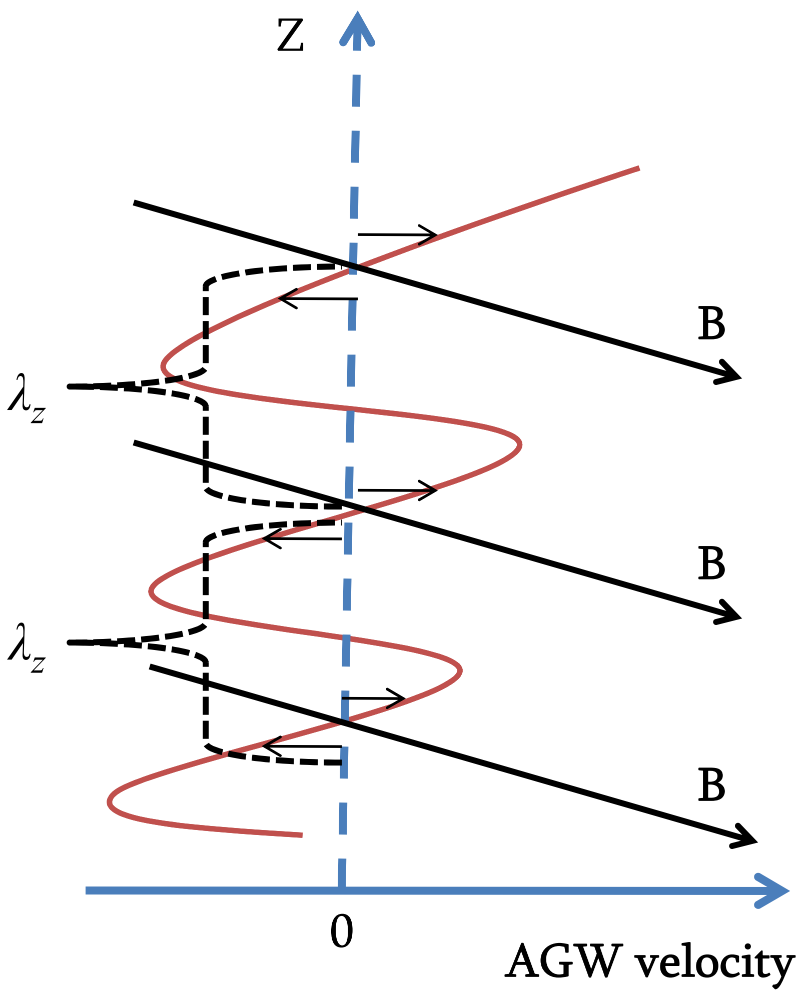

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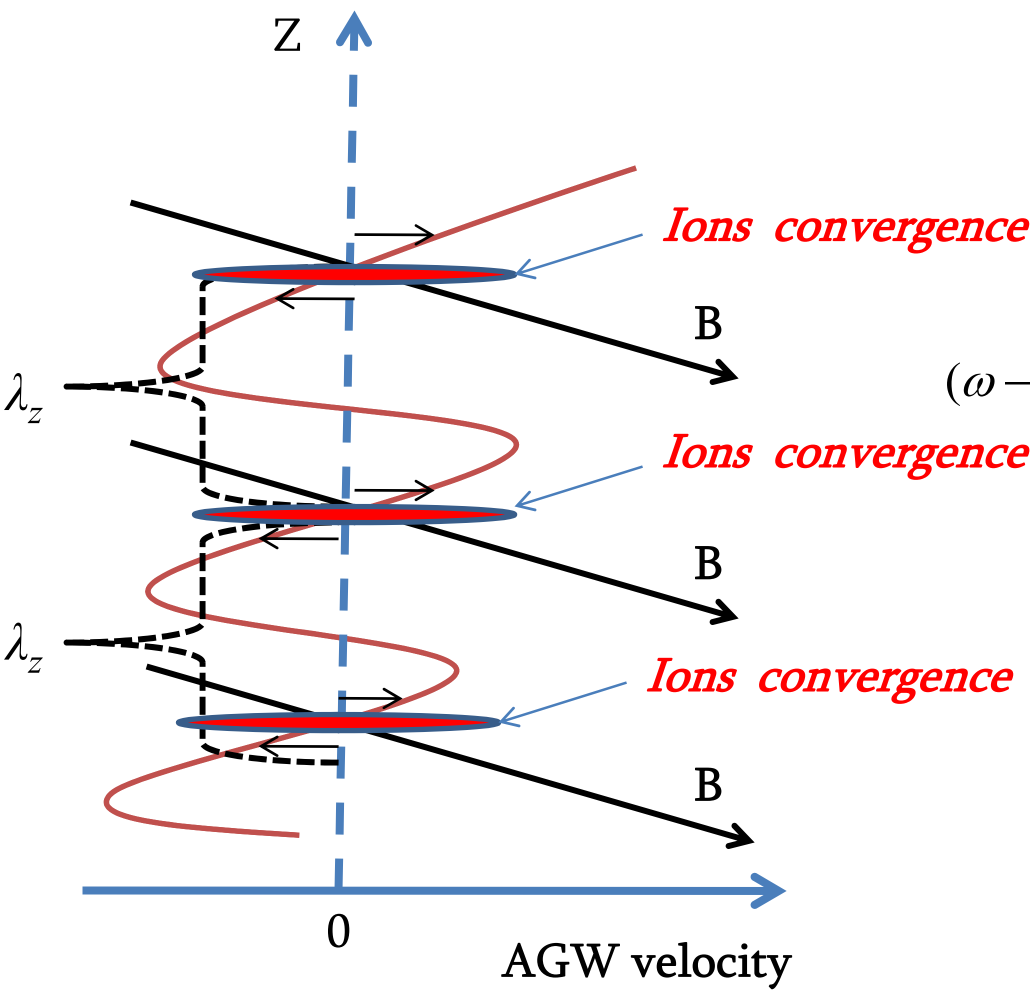

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Ions vertical distribution under an influence of AGWs and background horizontal wind

The ions density N_i in the lower thermosphere can be obtained by solution of the following continuity equation:

$$\frac{\partial N_i}{\partial t} + \frac{\partial}{\partial y}(N_i v_i) + \frac{\partial}{\partial z}(N_i w_i) = q - l$$

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

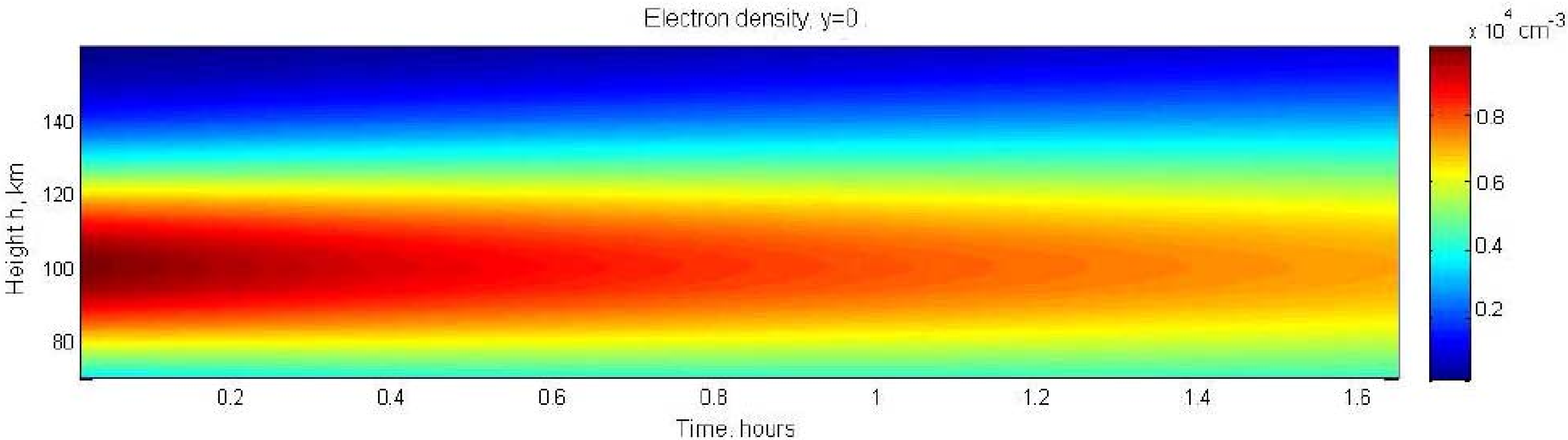
$$v_i = \left[(u_{on} + u)\sin I + \kappa \left(v - \frac{2k_B T}{N_i M_i \nu_{in}} \frac{\partial N_i}{\partial y} \right) + \left(w - \frac{2k_B T}{N_i M_i \nu_{in}} \frac{\partial N_i}{\partial z} \right) \cos I \right] \frac{\kappa}{1+\kappa^2}$$

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

The atmospheric wave velocities

Ambipolar diffusion

Evolution of the ions/electrons density height distribution in the case of absence of AGWs

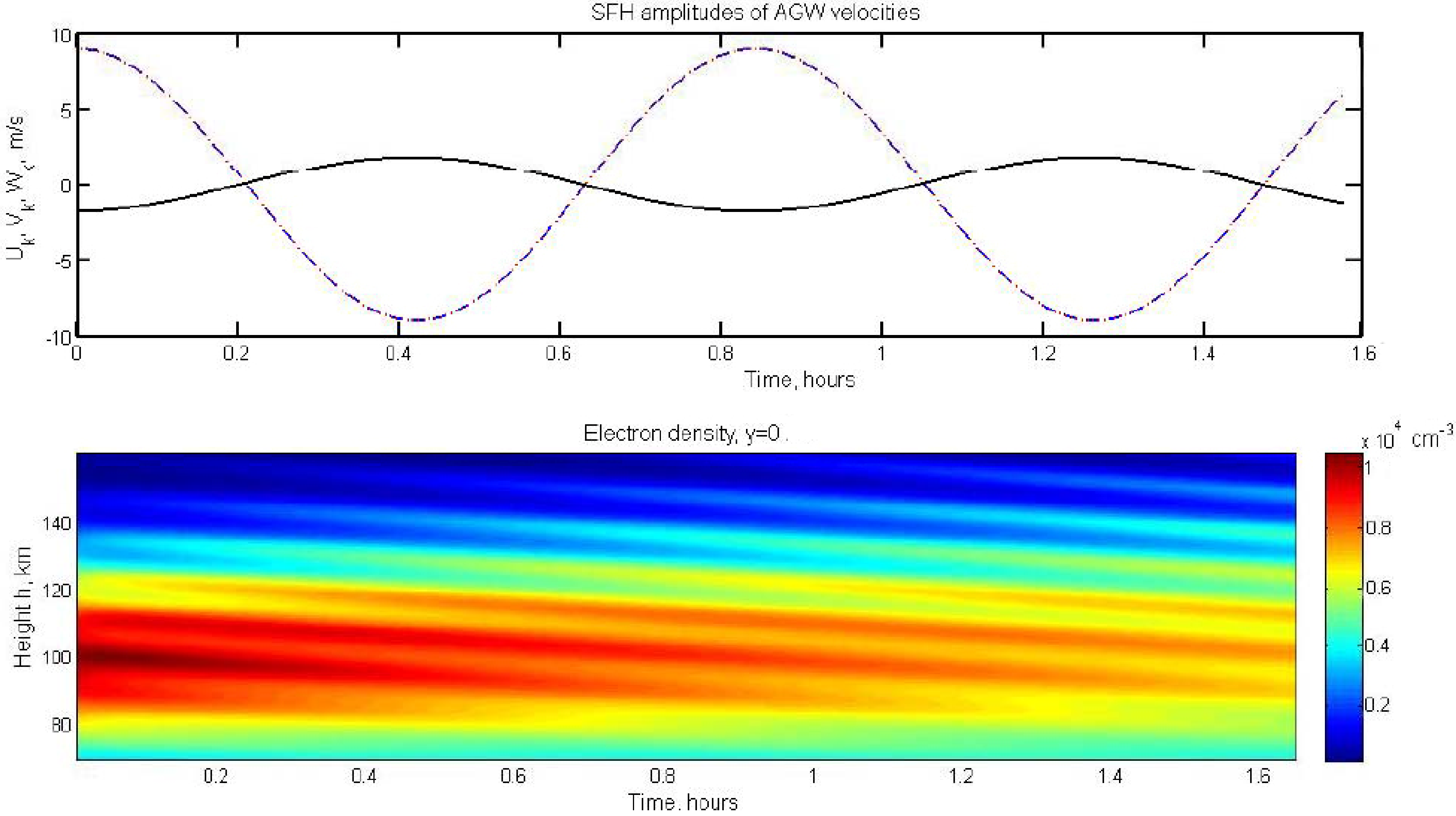


The initial distribution of the ions is described by the following Gaussian type function:

$$N_i(z,t=0) = N_m \exp\left\{-\frac{(z-z_m)^2}{H_{eff}^2}\right\}$$

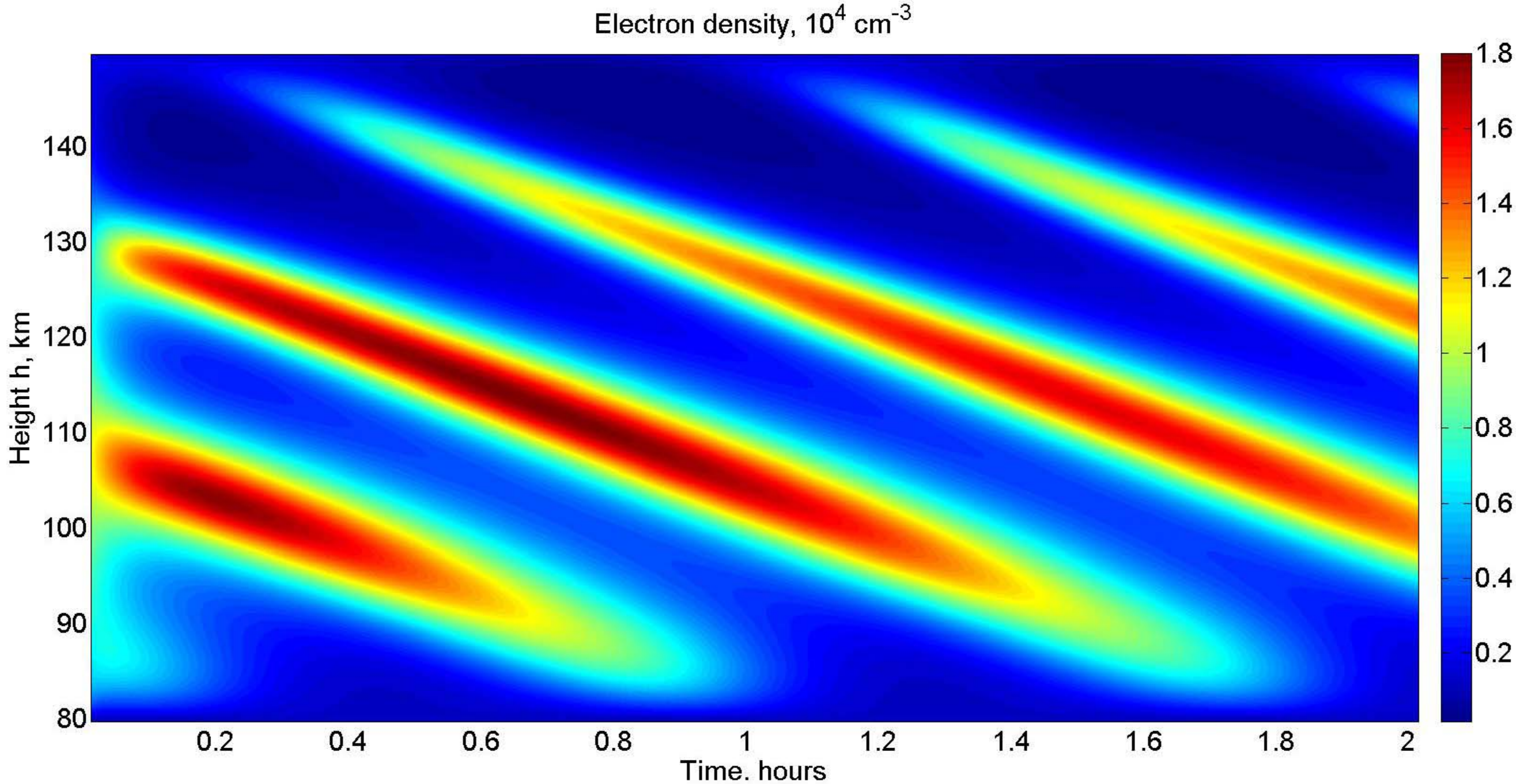
N_m is maximal ions density ($10^4 cm^{-3}$) at the height $z=z_m=100\ km$. The scale height $H_{eff}=20\ km$. The initial distribution of ions is described by Gaussian type function:

Influence of AGWs on the ions/electrons density height distribution



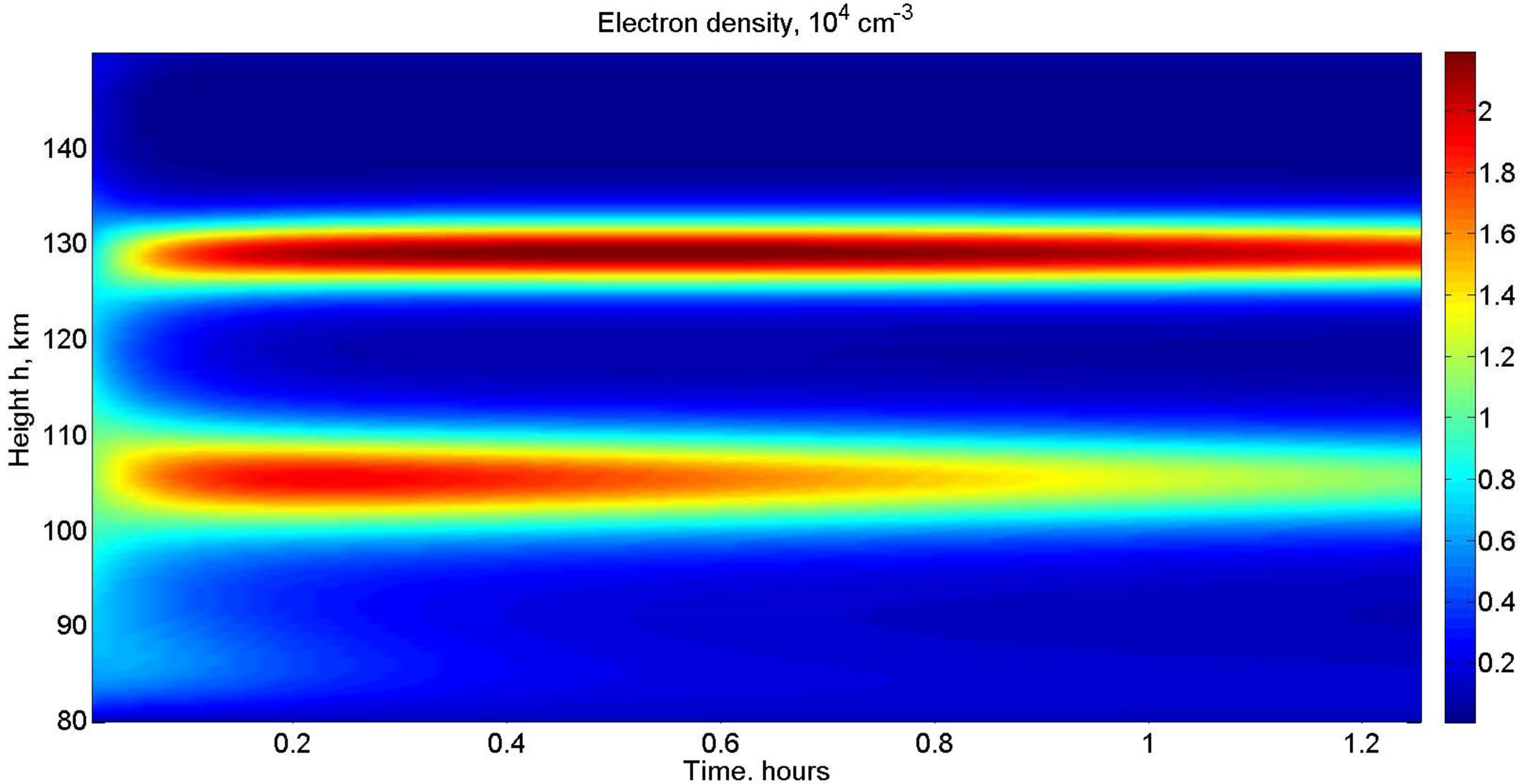
H=10 km, $\lambda_{x,y}$ =120 km, λ_z =12 km, u_{on}=0 *(Didebulidze et al., JASTP, 2015).*

The ions vertical convergence by AGWs in the presence of horizontal background wind



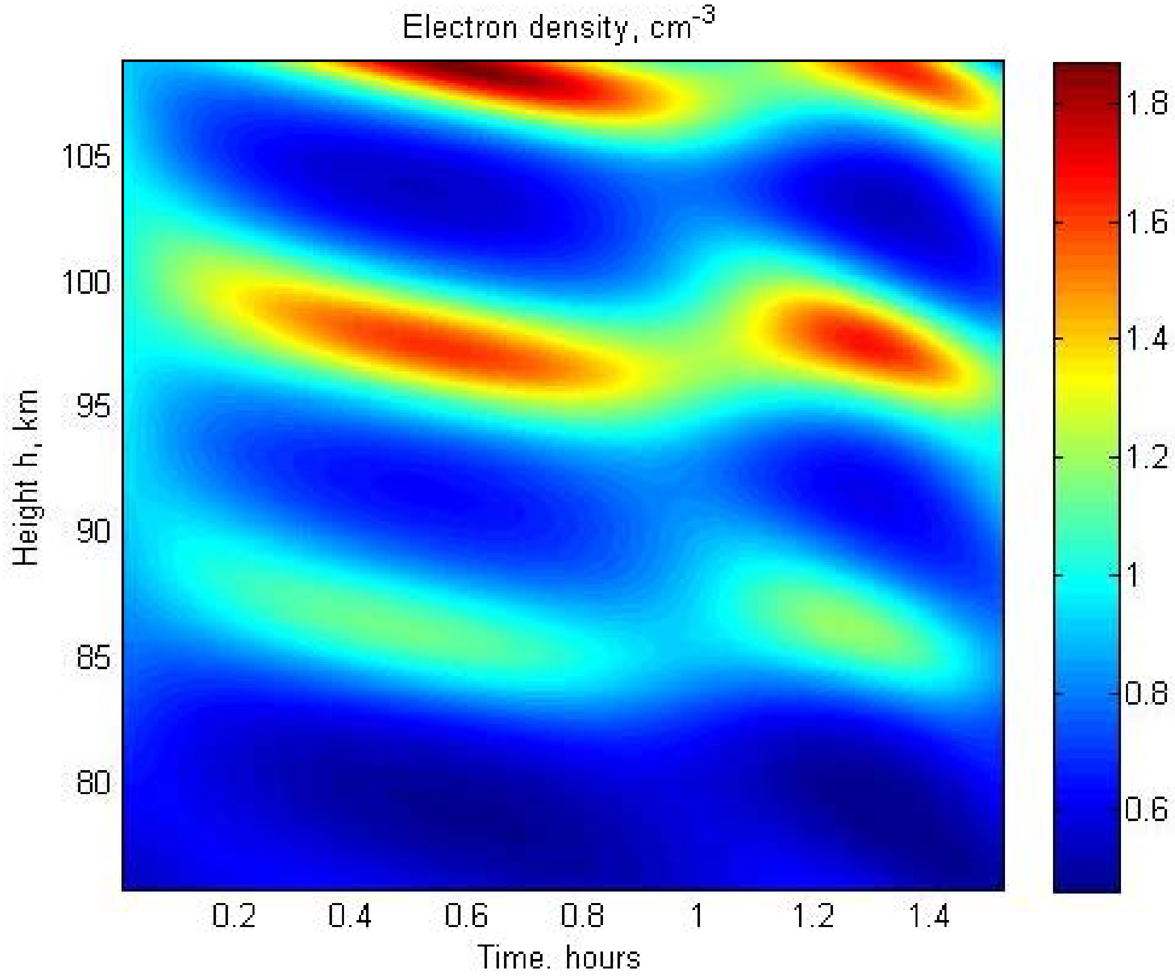
H=10 km, $\lambda_{x,y}$ =120 km, λ_z =24 km, u_{on}=*40 m/s*.

The formation Es layers by AGWs in the case of presence of horizontal background wind with V_{phx}=-u_{on}



u_{on} =-87 m/s

The formation of quasi-periodic echoes like structures by AGWs evolving in the horizontal inhomogeneous ($u_o = ay$) background wind



H=10 km, $\lambda_{x,y}$ =120 km, λ_z =12 km.

CONCLUSIONS

We have shown that the declined propagation (k_x, $k_z \neq 0$) of the AGWs can influence on ions/electrons vertical convergence. The condition that the value of the AGWs horizontal phase velocity (ω_g/k_x) is close to the value of background horizontal wind velocity ($-u_{on}$), is convenient for ions convergence into horizontal thin layers and formation multilayered sporadic E (Es layers).

The distances between Es layers formed by are about AGWs vertical wavelengths λ_z.

The ions/electrons density oscillations with shorter AGWs periods in the Es layers, accompanied by their declined motions, is similar to quasi-periodic echoes observed structures.

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