

Formation and Behavior of Es Layers Under the Influence of AGWs Evolving in a Horizontal Shear Flow

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ABSTRACT

The formation of mid-latitude sporadic E (Es) layer under the influence of atmospheric gravity waves (AGWs), evolving in the background horizontal wind with a horizontal linear shear (horizontal shear flow), is studied. The AGWs, which are *in-situ* excited in the horizontal shear flow, interact with metallic ions through ion-neutral collisions and Lorentz forcing, influence the ion vertical motion and lead to their convergence into thin horizontal layers. In order to investigate the formation of sporadic E, 2-D numerical simulations are performed and temporal evolution of multi-layered sporadic E is demonstrated. It is found that ion/electron density of Es layer depends on the direction of background wind and on the value of shear parameter. The increase of the shear parameter value of the cyclonic type shear increases density of converged charged particles. It is shown that the ion/electron density of Es layers also depends on the horizontal and vertical amplitudes of AGWs' velocity perturbations, and spatial location of the layers is determined by the vertical wavelength of atmospheric gravity waves.

1. INTRODUCTION

The ionosphere sporadic E (Es layer) mostly are formed in the lower thermosphere. At this altitude, the behavior of the neutrals plays an important role in the dynamics of the ions/electrons [Kelley, 2009; Hultqvist, et al., 2011]. It is assumed that the formation of the mid-latitude Es is a result of neutral-ion collisions and Lorentz force acting on the ions [Axford, 1963; Whitehead, 1989 and references therein]. In the case of horizontal neutral wind, with vertical shear, the thin layer of converged ions could occur in the vicinity of the horizontal plane where wind velocity changes direction (zero wind-nodes).

Above mentioned mechanism of Es formation is known as “the “windshear” theory ” [Mathews, 1998 and references therein; Haldoupis, 2012 and references therein]. Appearance of inhomogeneous wind could be related to various dynamical processes in the lower thermosphere, the tidal motion is one of the most important phenomena at this region. Atmospheric waves, such as planetary waves, tidal motion, gravity waves and the vortical perturbations with same spatial scale [Chimonas, 1971; Shalimov and Haldoupis, 2002; Arras, et al., 2009; Didebulidze and Lomidze, 2008; 2010] could also influence the Es formation.

In the presented work we show that AGWs, excited in horizontal shear flow could lead to the formation of Es. Increase of shear parameter of the horizontal wind causes increase in the AGW amplitudes and transformation AGW into the short-period oscillations occurs and velocity amplitude increases significantly in vertical direction. In this case, cyclonic type shear also causes the ions horizontal convergence, in addition high amplitude AGWs cause horizontal and vertical

convergence of the ions at the nodes of velocity perturbations and these circumstances could lead to the formation of sporadic E.

In this case the formation of sporadic Es moving downward, the process important for the quasi-periodic echoes, and at certain meridional locations the formation of almost horizontal thin layers is possible. The distance between these thin layers is approximately equal to the vertical wavelength of AGWs.

2. SPORADIC E FORMATION AND EVOLUTION UNDER THE INFLUENCE OF AGW

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

$$\mathbf{V}_n = \mathbf{u}_{0n} + \mathbf{v}_n . \quad (1)$$

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 \mathbf{u}_{0n} has linear shear in horizontal y direction:

$$u_{0n}(y) = ay . \quad (2)$$

In our case velocity perturbation $\mathbf{v}_n(u_n, v_n, w_n)$, corresponds to the AGWs evolving in the horizontal shear flow, Eq.(2).

In order to investigated the formation and behavior of sporadic E influenced by AGWs, evolving in the horizontal shear flow, we have solved, equation of continuity for ions/electrons in the two dimensional case (i.e. $\frac{\partial}{\partial y}, \frac{\partial}{\partial z} \neq 0$). The ions (mainly Fe^+) horizontal and vertical drift velocities are

determined by their ambipolar diffusion and by neutral velocities which are modified by AGWs evolving in the shear flow [Didebulidze and Lomidze, 2010]:

In order to study influence of background shear flow and influence of AGWs, evolving in this shear flow, on the ion/electron convergence process, as the first step we study behaviour of ion/electron density distribution under influence of only ambipolar diffusion and then we investigate evolution of ion/electron density under influence of both factors-diffusion and AGWs.

In upper panel of Fig. 1 is demonstrated that due to the ambipolar diffusion, the maximal density of ions (10^4 cm^{-3}) decreases and becomes approximately half of initial maximum after 1.8 hour. However, in this case the location of density maximum does not change significantly. Presence of AGW changes process of evolution of ion/electron density height distribution significantly. Bottom panel of Fig. 1 shows that AGWs, described on middle panel of Fig. 1, significantly influences height distribution of ion/electron density. In this case ion/electron density height distribution resembles quasi-periodic echoes (Hysell, et al., 2013 and references therein). AGWs lead to the formation of the thin layers, moving downwards, in the vicinity of initial maximum and the location of initial density maximum. Here we see that, during 0.5 h, in the region 90-120 km Es type layers are formed. The distance between these layers coincides with vertical wavelength of AGW (12 km). In these layers, the ion/electron density is higher than initial maximal density and higher than density in the case when density changes under influence of

only ambipolar diffusion (upper panel Fig. 1). After certain time AGWs could lead to formation of multilayered sporadic E.

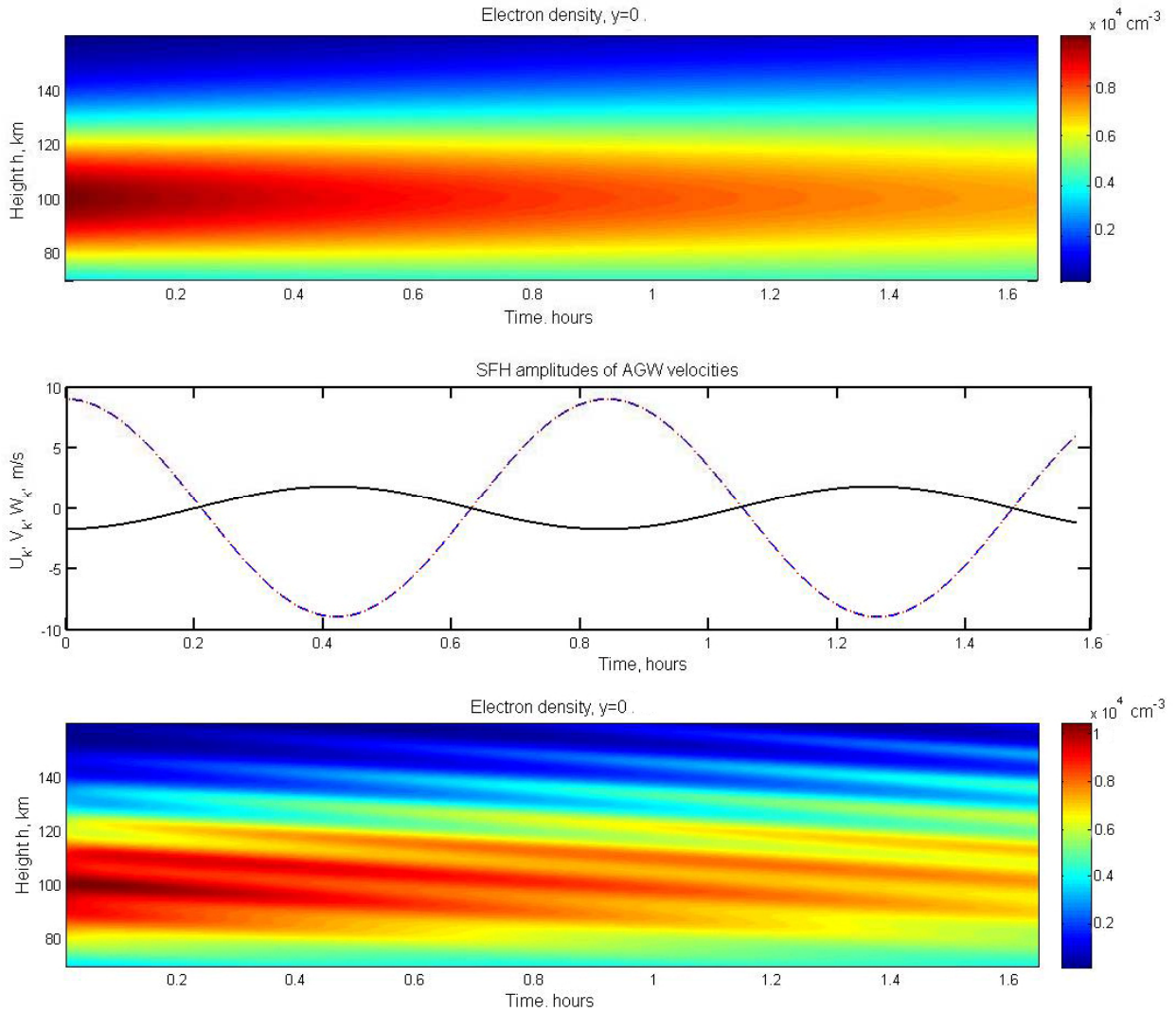


Figure 1. Upper panel shows evolution of ion/electron initial distribution (Gaussian type distribution with maximum at height 100 km and half width 16 km), in the lower thermosphere, under influence of only ambipolar diffusion. Middle panel represents time dependence of spatial Fourier harmonics (SFH) amplitudes of AGW velocity perturbation components u_k, v_k $u_k = v_k$ (dashed line), and w_k (solid line), the bottom panel demonstrates evolution of ion/electron density in the case of presence of AGW and diffusion without background wind ($u_{on} == 0$ in Eq. 1). Vertical wavelength $\lambda_z = 12 \text{ km}$ and horizontal wavelengths $\lambda_x = \lambda_y = 120 \text{ km}$.

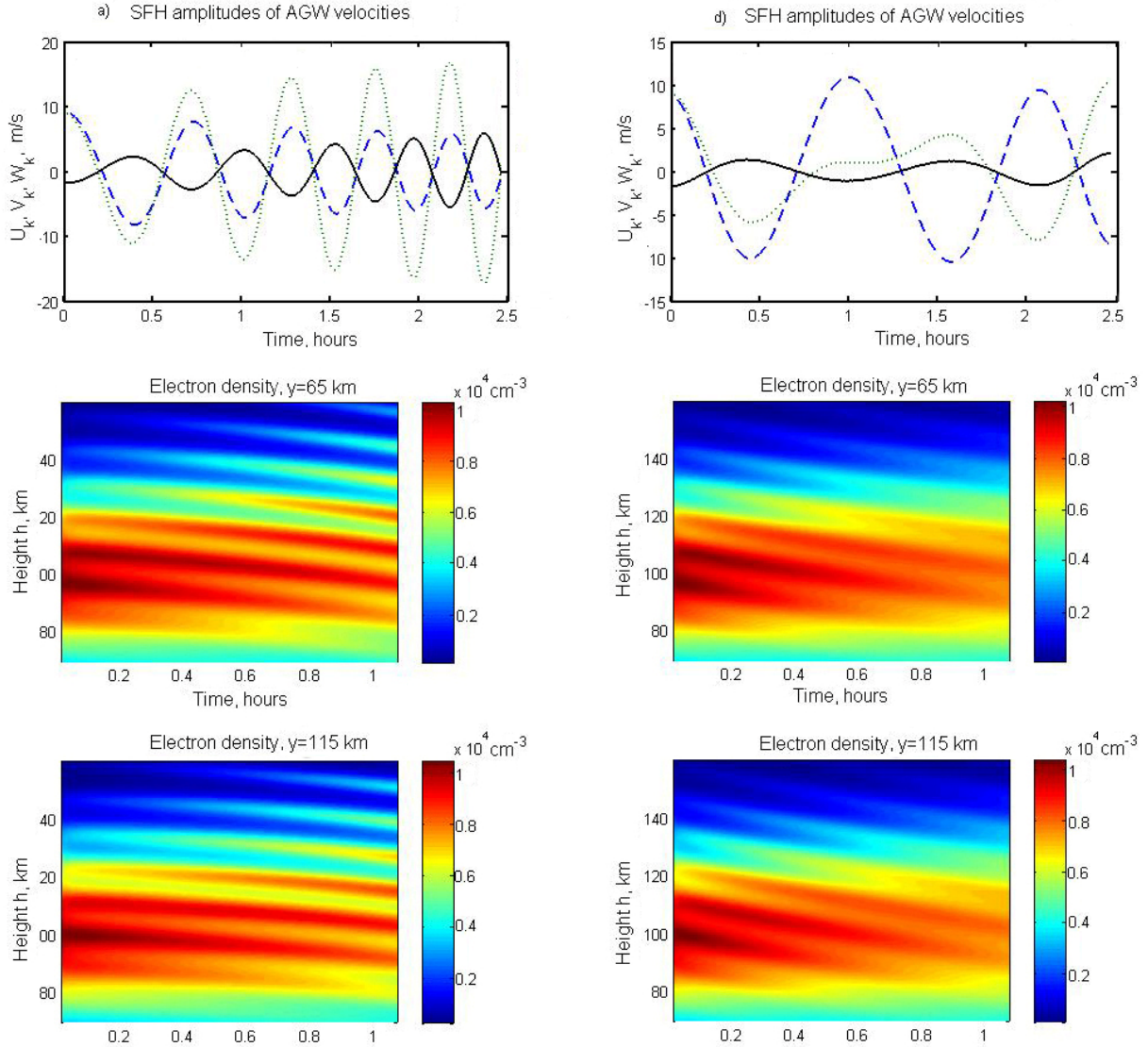


Figure 2. Upper panel show evolution of the spatial Fourier amplitudes $u_k(t)$ (dashed line), $v_k(t)$ (dotted line) and $w_k(t)$ (solid line) neutrals velocity perturbations associated with AGWs. Two cases are demonstrated- left column a) corresponds to cyclone type shear of background wind velocity $a = -2.5 \cdot 10^{-4} \text{ s}^{-1}$ (and right column b) demonstrates case of anticyclone type shear. Snapshots illustrate behavior multilayered sporadic E under influence of AGWs (shown on upper panels). Middle snapshots correspond to meridional coordinate $y=65$ km and bottom panels demonstrate case of meridinal location $y=115$ km. Wave parameters are same as in Fig. 1

Figure 2 shows formation of multilayered sporadic E after 0.2-0.4 hours. The distance between these layers is about 12 km in our case and maximal values of density, which is more than occurs at altitudes 90-120 km. The electron/ion density in the converged regions is higher than initial, maximal density and then density in the regions evolved only under influence of the background shear flow. The above mentioned layer are formed in the case of cyclone type background wind as well as in the case of anticyclone type shear flow. However, in the case of the cyclone type background wind the electron density in the converged region is larger than in the case of anticyclone type background wind.

It is important to note that, in the case of cyclone type background wind, thin layer of converged ions/electrons (snapshots in the left column), at meridional coordinates $y=65$ km and $y=115$ km, move downwards with lower velocity than the layers of converged charged particle at same meridional location in the case of anticyclone background wind (snapshots in the right column).

As we see, increase of cyclone type shear, at time interval when along with convergence increases amplitudes of horizontal and vertical components of velocity perturbations caused by AGWs, the additional increase of ion/electron density in the thin layers occurs.

The change of downward motion of Es formed at certain meridional region, due to the change AGW amplitudes at these regions and under influence of AGWs changes of evolution of ions drift velocity horizontal and vertical component.

3. CONCLUSIONS

We have shown that AGWs, evolving in the horizontal shear flow, can form midlatitude nighttime multilayered sporadic E.

Existence of horizontal shear flow with cyclone type shear flow could lead to the horizontal convergence of the ions. Density of the ions in the converged region increases with increase of shear $|a|$ of the background horizontal wind. Such, horizontal convergence of ions/electrons could help to formation of thin, horizontal layers of electrons/ions in the lower thermosphere under influence of AGWs evolving in the background shear flow. With increase of shear parameter a , of the cyclone type shear flow leads to the increase of amplitudes of horizontal and vertical components, of the neutral velocity perturbations associated with AGWs. In turn, neutrals motion (velocity) influences drift of the heavy, metallic ions and cause their convergence in the thin horizontal layers. Distance between these locations layers is approximately equal to the vertical wavelength of AGW.

We demonstrated possibility of formation, thin, horizontal sporadic E layers under influence of AGWs evolving in the horizontal shear flow.

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