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HIGH LATITUDE GRADIENT DRIFT INSTABILITY IN THE IONOSPHERIC F-REGION: EFFECTS OF COULOMB COLLISIONS AND ELECTRIC FIELD

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A linear kinetic theory of the gradient drift instability is generalized in order to include the combined effects of a strong electric field and Coulomb collisions in the F - region of the polar ionosphere. The ionospheric conditions under which the growth rate of the instability is a maximum are determined.

Gradient drift instability is one of a number of major type instabilities, which are displayed in the F- region of the polar ionosphere. It is generated in result of electrodynamic moving of denser plasma into regions with smaller density and vice versa [*Gershman et al.*, 1984; *Tsunoda*, 1988].

The aim of this paper is generalization of the linear kinetic theory of such instability with taking into account the effects of an external electric field and Coulomb collisions in the high latitude ionospheric F - region.

The basis for research of collective fluctuations of plasma is the dispersion relation, which follows from the solution of the kinetic equations by method of characteristics [*Gary and Cole*, 1983; *Tereshchenko*, 1994]. For simplicity we shall restrict ourselves by consideration of plasma with the density N changing only along the x-axis (in the meridional direction). The uniform electric field E_0 is directed along the y-axis and the geomagnetic field B_0 along the z -axis. Referring to the real conditions in the F-region ionosphere we suggest that the gyrofrequency of α species charged particles $\omega_{B\alpha}$ (electrons or ions) is great compared to their characteristic frequency of collisions ν_α. Collisions are described by the "relay-race" model for the Brownian motion of particles in the external electromagnetic field, derived from the BGK and Lenard – Bernstein collision terms [*Tereshchenko*, 1994].

For the wavelength λ being much shorter than the plasma density gradient scale length L ($\lambda \ll L$) (and propagation in the direction orthogonal to the geomagnetic field, the dispersion relation has the form

$$k^2 D_e^2 + \sum_{\alpha = e,i} t_\alpha \left[1 - \frac{\left(\omega - \mathbf{k}\cdot\mathbf{u}_\alpha - k_y V_{d\alpha}\right)\Gamma_\alpha}{\omega - \mathbf{k}\cdot\mathbf{u}_\alpha + i\,\nu_\alpha\left(1-\Gamma_\alpha\right)} \right] = 0, \qquad (1)$$

where D_e is the electron Debye length; k is the module of the wave vector k;

$$t_\alpha = \frac{T_e}{T_{\alpha z}}; \qquad \Gamma_\alpha = e^{-\mu} I_0(\mu); \qquad \mu_\alpha = \frac{k_\perp^2 T_\perp}{m\,\omega_{B\alpha}^2};$$

$$T_{iz} = T_n + \frac{1}{3}\left(1 - \frac{\nu_{in}^r}{\nu_i + \nu_q}\right) m u_{0\perp}^2; \qquad \nu_i = \nu_{in} + \nu_{in}^r + \nu_q;$$

$$T_{i\perp} = T_n + \frac{1}{2}\left[1 - \frac{1}{3}\left(1 - \frac{\nu_{in}^r}{\nu_i + \nu_q}\right)\right] m u_{0\perp}^2; \qquad T_{ez} = T_e;$$

$$V_{de} = -t V_{di} = T_e / m_e\, \omega_{Be} L; \qquad L = \partial \ln N / \partial x;$$

$$\mathbf{u}_i = \frac{c E_0}{B_0}\left(\mathbf{e}_x + \frac{\nu_n + \nu_n^r}{\omega_B}\mathbf{e}_y\right);$$

I_0 is the modified Bessel function of the zero order for electron;
m_e, T_e, ω_{Be} and ν_e are the electron mass, temperature (in energy units), gyrofrequency and total frequency of collisions, respectively; ω is the angular frequency of plasma waves; ν_{in}^r and ν_{in} are the ion-neutral collision frequency for resonance change exchange and polarisation interaction, respectively; ν_q is the Coulomb collisions frequency of ions; T_n and T_i are the neutral and ion temperatures; $\mathbf{u}_0 = \mathbf{u} - \mathbf{u}_n$ is the relative drift velocity of ions and neutral particles; c is the light velocity in vacuum; $\mathbf{e}_x$ and $\mathbf{e}_y$ are the unit vectors along the corresponding co-ordinate axes. The subscripts z and $\perp$ denote the directions, parallel and perpendicular to $\mathbf{B}_o$, respectively.

Dispersion relation (1) is a quadratic equation with respect to ω. The system is stable, if the imaginary part of the roots of this equation is positive. This takes place if the following inequality is held:

$$k_y V_{di} \left(\mathbf{k}\,\mathbf{u}_i - \mathbf{k}\,\mathbf{u}_e \right) > \frac{(1+t)}{t} \frac{(1-\Gamma_i)}{\Gamma_i} \mu_e \nu_e \nu_i . \qquad (2)$$

This result corresponds to the case when $\mu_e \nu_e > \nu_i$.

There is a stabilising effect, caused by the electron collisions. From (2) it also follows, that for development of the instability the Pedersen drift of ions and diamagnetic velocity should have the same sign. Otherwise, the system will be stable.

The left-hand side of the inequality (2) describes an increase of the electron density perturbations caused by the Pedersen drift and diamagnetic currents, while the positive right-hand side represents damping due to parallel electron diffusion. The charge neutrality condition requires ambipolar diffusion. For instability with the wavelength of a few hundred meters and parameters of the ionosphere at heights of the F-region (i.e. at $\mu_i << 1$ and $\nu_i >> \mathbf{k}\,\mathbf{u}_i$, $k_y\,V_{di}$, $4c\,E_o/B_oL$) diffusion is a slow process and does not affect with excitation of the instability. In this case the expression for the complex frequency ω can be written in the following approximation:

$$\omega \;\equiv\; \omega_r + i\gamma \;\cong\; k_y V_{di} + i \frac{\mathbf{k}\,\mathbf{u}_i\, k_y V_{di}}{\mu_i \nu_i},$$

from which it follows that the growth rate γ is determined by the expression:

$$\gamma \;=\; \frac{c E_0}{B_0 L} \left(1 - \frac{\nu_q}{\nu_i} \right) \frac{T_{iz}}{T_{i\perp}} . \qquad (3)$$

It is clear from Eq. (3) that γ decreases with increasing ν_q and increases with increasing $T_{iz}/T_{i\perp}$. Therefore the height profile of γ can have a maximum. Note that formula (3) differs from the well-known one [*Gary and Cole,* 1983; *Ossakow, et al.*, 1978] by including of the effects of Coulomb collisions and strong electric field.

The results of the numerical solution of dispersion equation (1) for the plasma parameters (the electron density, ion temperature, electric field intensity), obtained by the incoherent scattering and model calculations of the ionospheric gas composition above Tromsö during the measurements *Tereshchenko* [1995] are presented in Fig. 1.

The figure shows that the growth rate decreases with height above the earth for electric field intensity up to 30 mV/m. It has a maximum when $E_0 > 30$ mV/m at the height of 200 km.

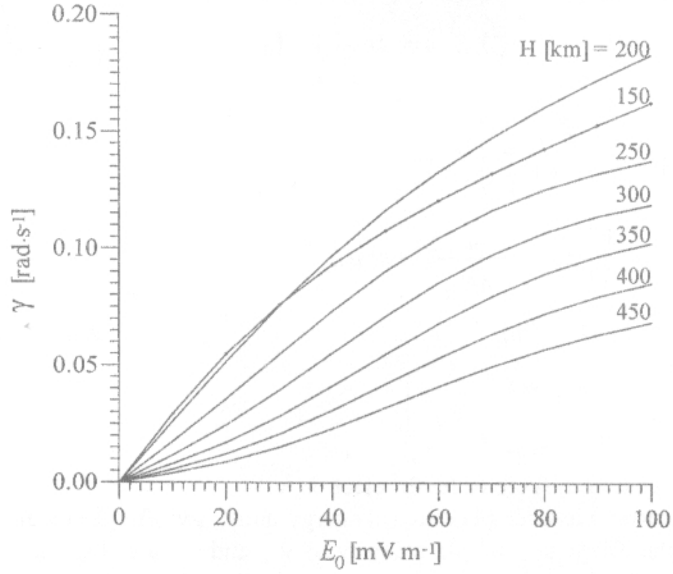

Fig. 1. The growth rate of the gradient drift instability as a function of the electric field intensity at various heights in the ionosphere ($\lambda = 0.1L = 612$ m).

Thus, in this paper we have performed analytical and numerical analysis of the effects of the external electrical field and Coulomb collisions on the growth rate of the gradient drift instability in the F-region of the polar ionosphere. It is shown that the growth rate has a maximum in the altitude range from 150 to 250 km above the earth.

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