"Physics of Auroral Phenomena", Proc. XIX Annual Seminar, Apatity, pp.81-84, 1996
© Kola Science Centre, Russian Academy of Science, 1996
Polar Geophysical Institute

DYNAMICS OF THE AURORAL THERMAL WAVE IN THE F2-REGION OF IONOSPERE

V.G.Vlasov, and G.O.Zhizhko *(Irkutsk State Technical University, Irkutsk, Russia)*

In the auroral arcs above the F2-region maximum, the high level of high-frequency electrostatic waves (their intensity reaches 0.5 V/m) [1, 2, 3], anomalously high electron temperatures ($T_e \sim 10000$ K) and their transverse gradients ($\partial T_e/\partial r_\perp \sim 1000$ K/km) [4-7], ion outflows with the longitudinal velocities of about 1 km/s [7, 8], as well as auroral decametric radiation (ADR) with rapid decrease in frequency, leaving that region [9], are recorded. According to the mechanism developed in [10], all described factors can be reflection of such phenomenon as the auroral thermal wave, arising from the collective interaction of the auroral electron beams with the F2-region of the ionosphere. In the present paper a study of this thermal wave in view of the ion inertia is continued.

The auroral electron beams are formed in the double layers at the altitudes of several thousand kilometers and propogate trough the ionosphere and magnetosphere up to the E-region, where they lose all their energy because of collisions with the neutral particles. Registration of high–frequecy noise in the F-region testifies to the collective interaction of these unstable electron beams with ionospheric plasma. The fact that the unstable beams are detected by satellites and rockets in the low ionosphere means that they stabilize on their whole propagation path, exept the local areas. As shown in [11, 12], usual monotonous large–scale inhomogeneities of the geomagnetic field and of the plasma density stabilize the auroral electron beams both on maser cyclotron and Cherenkov resonances. The nature of this stabilization is the rapid escape of the waves from the generation region in the wave number space. The rate of change of the wave number is determinated from the Hamilton's equation :

$$\dot{k}_\parallel = -\frac{\partial \omega}{\partial r_\parallel}. \tag{1}$$

Generation of the waves is possible only in the region of small longitudinal gradients of plasma density, which is always the region of the F-layer maximum. Collective dissipation of the energy of the auroral electron beam is possible only here.

Nonlinear process that effectively limits the plasma waves energy in this region, is as follows [10]: the part of the beam's electron energy that is delivered to the plasma waves, is then transferred to the long-wavelength region, owing to scattering of the plasma waves due to ion beatings or ion–sound waves where the final dissipation to heat occurs in collisions of thermal electrons with the ions, atoms and molecules of the ionosphere. Besides, simultaneously the nonlinear conversion of the plasma waves in the radiation at double plasma frequency ($f \simeq 2f_p$) occurs.

The length of collective relaxation of the electron beam decreases with the increase in the electron temperature and, if it becomes less than the region of small gradients of the plasma density, just it will limit the region of plasma turbulence.

Simulation of the auroral thermal wave was accomplished with experimental data obtained at the Norilsk station. At the Norilsk an experimental study of ADR was made in the range 22–36 MHz using a frequency-scanning receiver with a scanning period of 4.4 s. The ADR was recorded only when an aurora of class 3 was in the zenith. The radiation itself was observed as bursts with duration of about 10 s, with rapid decrease in frequency from 29 to 22 MHz (see Fig.1).

The nonstationary behavior of the termal plasma at the collective interaction with auroral electron beam in the ionosperic F2-region is described by the following system of hydrodynamical equations :

$$\begin{aligned} \frac{\partial n}{\partial t} &= -\frac{\partial n v_i}{\partial r_\parallel} \\ m_i \frac{\partial v_i}{\partial t} &= -m_i v_i \frac{\partial v_i}{\partial r_\parallel} - \frac{k}{n}\frac{\partial n(T_e+T_i)}{\partial r_\parallel} - m_i g - m_i v_i \nu_i \\ \frac{3}{2} k n \frac{\partial T_e}{\partial t} &= \frac{\partial}{\partial r_\parallel}\left(K_e \frac{\partial T_e}{\partial r_\parallel}\right) + Q_e - L_e . \end{aligned} \tag{2}$$

Here n is electron density, v_i is ion velocity, T_e and T_i are electron and ion temperatures respectively. The continuity equation of plasma particles neglects particle sources and sinks because the ionization and recombination time is substantialy larger than the collective heating time. The ion momentum equation includes the pressure and gravity forces, and the force of friction of ions with neutrals. This equation involves gravitational acceleration g and ion mass m_i. The collective heating source Q_e is involved in the energy balance equation, in which k is Boltzmann's constant. The analitic expressions for the coefficients of system (2) are taken from the following sources : the cooling power of electron L_e is borrowed from [13], the heat conduction coefficient K_e and the collision frequencies of ions with atoms and molecules ν_i are the same as in [14], and the collective heating power is taken from [10]. The neutral atmosphere was specified according to the empirical model MSIS–86 [15]. The system was numerically solved following an implicit difference scheme with the space step of 0.5 km in the region of the auroral thermal wave passage.

In the previous research of the auroral thermal wave done in [10], the system (2) was solved without considering the inertia of ions. The equations of continuity and of ion momentum were reduced to a diffusion equation, i.e. instead of (2) the system of two equations of the second degree was solved. As the calculations have shown, the account of ion inertia resulted first in significant slowing down of the lift rate of the auroral thermal wave, and second in rather weak influence of the variation of the ionospheric plasma parameters on the velocity of the auroral thermal wave, such as hight of the F2-region maximum ; initial high profiles of the electron and ion temperatures ; energy and degree of energy homogeneity of the electron beam. Such stability of the lift rate of the auroral thermal wave allows to use measurements of the drift velocity of the auroral radiation at $2f_p$ to calculate the density profile in polar arcs above the F2-region maximum. Figure 1 gives the measured and calculated drift of the ADR frequency. Because of the time resolution in the experiment being weak, we do not show plasma density profile corresponding the measured velocity of the frequency drift.

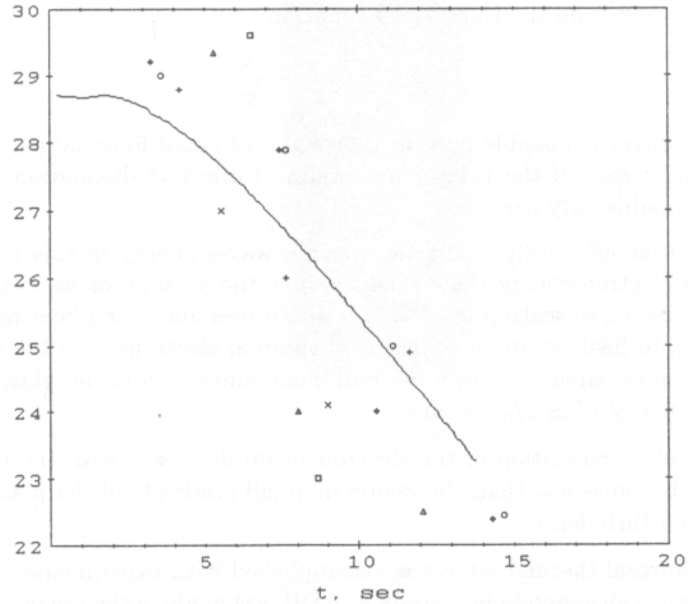

Figure 1: The frequency drift of ADR. The calculated drift is shown with solid line, and other all designations are marked for 6 bursts measured at the Norilsk station on 16 and 17 December 1984 under a discrete auroral arc.

The numerical simulation of the auroral thermal wave has shown, that it is a complex phenomenon involving the following processes :

1) The auroral electron beam excites plasma turbulence in the region of small density gradients near the F2-layer maximum, and it results in the significant plasma heating. A small fraction of the beam energy is transformed into radiation at $2f_p$.

2) The region of plasma turbulence in a few seconds becomes smaller than that of small density gradients and occupies only its upper part, as a consequence of decrease in the length of the collective relaxation of the electron beam

3) The plateau is formed on the density profile with a high interval of the order of several kilometers. The change longitudinal plasma density gradients resulting from the electron temperature rise, leads to displacement of the upper boundary of small gradients and, consequently, of this region itself.

4) The upward displacement of the generation region into the region of smaller plasma density is accompanied with decrease in the radiation frequency.

5) Gradually, the collective heating region gets narrower and disappears at the hight of about 360 km.

The dynamics of the profiles of the electron temperature, of the ion velocity, and of the scales of longitudinal inhomogeneity of plasma density are demonstrated in figure 2.

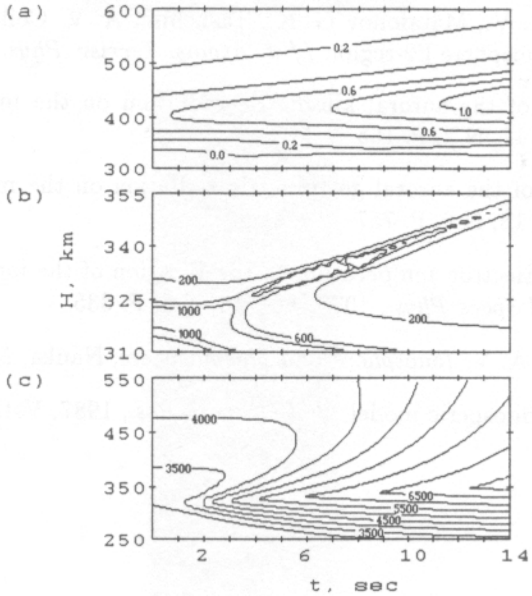

Figure 2: The dynamics of the profiles of ion velocity v_i, km/s (a); and of scales of longitudinal inhomogeneity of plasma density $L_{p_\parallel} = 1/\omega_p^2 \cdot \partial\omega_p^2/\partial r_\parallel$ (b) ; and of electron temperature T_e, K (c)

The velocity of ascent of the auroral thermal wave was about 2 km/s, and electron temperature reached in maximum about 7000 K at the hight of ~360 km. Besides, above the collective heating region the appreciable ion acceleration arise connected with increase in longitudinal gradients of the plasma pressure. The ion velocity has reached 1 km/s in maximum at the hight about 400 km. Duration of existence of the thermal wave has appeared to be about 15 seconds.

References

[1] Kellogg P. J., Monson S. J., Whalen B. A. Rocket observation of high frequency waves over a strong aurora // *Geophys. Res. Lett.*, 1978, Vol. 5, N 1, P. 47

[2] Benson R. F., Wong H. K. Low-altitude ISIS observations of auroral radio emission and their significance to the cyclotron maser instability // *J. Geophys. Res.*, 1987, Vol. 92, N 2, P. 1218

[3] Beghin C., Rauch J. L., Bosqued J. M. Elecrtrostatic plasma waves and HF auroral hiss generated at low altitude // *J. Geophys. Res.*, 1989, Vol. 94, P. 1359

[4] Fontheim E. G., Brace L. H., Winningham J. D. Properties of low-energy electron precipitation in the cleft during periods of unusualy high electron temperatures // *J. Geophys. Res.*, 1987, Vol. 92, N 11, P. 12267

[5] Basu Su., Basu S., Mackenzie E., et al. Simulations of density and electric field fluctuation associated with velocity shears in the auroral oval // *J. Geophys. Res.*, 1988, Vol. 93, N 1, P. 115

[6] Wahlund J.–E., Opgenoorth H. J., Haggstrom I., Winser K. J., Jones G. O. L. EISCAT observations of topside ionosperic ion outflows during auroral activity: revisited // *J. Geophys. Res.*, 1992, Vol. 97, N 3, P. 3019

[7] Blelly P.–L., Alcayde D. Electron heat flow in the auroral ionosphere inferred from EISCAT–VHF observations // *J. Geophys. Res.*, 1994, Vol. 99, N 7, P. 13181

[8] Anderson P. C. et al. A proposed production model of rapid subauroral ion drifts and their relationship to subauroral evolution // *J. Geophys. Res.*, 1993, Vol. 98, N 4, P. 6069

[9] Vall A. A., Klimenko V. V. Decametric radionoise bursts during the injection of electrons in the ionoshere // *Geomagnetism and aeronomy*, 1987, Vol. 27, N 1, P. 146

[10] Vlasov V. G., Klimenko V. V., Matafonov G. K., Tashchilin A. V. Collective heating and radiation dynamics of the auroral ionosphere F2-region // *J. Atmos. Terrisr. Phys.*, 1992, Vol. 54, N 7/8, P. 995

[11] Vlasov V. G. Generation of the auroral kilometric radiation on the maser cyclotron resonance // *Phisica plasmy*, 1991, Vol. 17, N 2, P. 165

[12] Vlasov V. G. Generation of the auroral gectometric radiation on the maser cyclotron resonance // *Phisica plasmy*, 1992, Vol. 18, N 6, P. 757

[13] Shunk R. W., Nagy A.F. Electron temperature in the F-region of the ionospere: theory and observations // *Rev.Geophys. and Space Phys.*, 1978, Vol. 16, N 3, P. 335

[14] Krinberg I. A., Tashchilin A. V. *Ionosphere and plasmasphere*, Nauka, Moscow, 1984.

[15] Hedin A. E. MSIS–86 thermosperic model // *J.Geophys.Res.*, 1987, Vol. 92, N 5, P. 335