"Physics of Auroral Phenomena", Proc. XXI Annual Seminar, Apatity, pp.71-74, 1998

Polar Geophysical Institute

THE EVOLUTION OF THE SPECTRUM OF THE PLASMA IRREGULARITIES

A.M.Lyatskaya, S.S.Oschepkova *(Institute of Physics, University of St.-Petersburg, Russia)*

At high latitudes the sources of the irregular structures are structured particle precipitations, highly regular magnetospheric convection electric field and field-aligned currents, all of them being accompanied by plasma instabilities. The decay of the irregularities is affected by the diffusion as well as by coupling along the magnetic field lines to the conductive E - region and magnetosphere. The spectrum of the irregularities covers dimensions from a few cantimeters to 20-50km.

The evolution of the plasma irregularity in the ionosphere has been investigated for more than three decades. A number of three-dimensional models have been developed to study the plasma irregularity evolution in the ionosphere [e.g. *Ma and Shunk*, 1991]. In most of such models the current exchange between the irregularity and magnetosphere is not taken into account.

In our investigations [e.g. *Pudovkin et al.*, 1987] we considered the electric coupling along the magnetic field lines not only to the compressive E - region plasma but to the magnetosphere as well. The physical mechanism which provides the irregularity - magnetosphere and the irregularity - E-region coupling is the same. But if the current exchange between the irregularity and conductive E-layer leads to the rebuilding of the E-layer conductance, the irregularity - magnetosphere coupling due to the field-aligned currents do not change the wave conductivity of the magnetosphere. When the recombination chemistry is included, large perturbations of the E-region conductance are inhibited, so the E-region becomes more similar to the magnetospheric conductance layer.

The equations governing the evolution of the irregularity written in the dimensionless form with excluding inertia, neutral wind, electron-ion collisions and including the wave number dependence as a function of k take in the common notations the following form (cf. *Heelis et al.*, 1985) for the current density:

$$J_p = [\sigma_{ip} + \sigma_{ep}] \cdot \mathbf{E} - e \cdot [d_{i\perp} - d_{e\perp}] \cdot \nabla_p N$$

for the conductivity:

$$\sigma_{ae,p} = \frac{e^2 \cdot \nu_{ae} \cdot N}{m_{ae} \cdot (\Omega_{ae}^2 + \nu_{ae}^2)}$$

for the perpendicular to **B** diffusion coefficient:

$$d_{ae\perp} = \frac{kT_{ae}\nu_{ae}}{m_{ae} \cdot (\Omega_{ae}^2 + \nu_{ae}^2)}$$

where index "p" denotes the Pedersen direction, index "ae" is related to ion and electron, Ω_{ae} is the gyrofrequency, ν_{ae} is the effective frequencies of collisions for electron and ion. For instance,

$$\nu_e = \nu_{en} + \nu_{ei}$$

We can write the height-integrated values for the current density:

$$J_p(k) = \Sigma_0[1 + \frac{\Delta N}{N_0}(k)] \cdot E(k) - e \cdot D_0 \nabla_p [\Delta \cdot N(k)]$$

the Pedersen conductivity in the E and F layers:

$$\Sigma_0 = \int_{z_0}^{z_1} (\sigma_{ip} + \sigma_{ep}) \cdot dz$$

the diffusion coefficient:

$$D_0 = \int_{z_0}^{z_1} (d_{i\perp} - d_{e\perp}) \cdot dz$$

Using the condition $\mathrm{div} J_p = 0$ or $\nabla_p J_p^E = -\nabla J_p^F$ the equation for the electric field can be written as:

$$[\Sigma_0^F + \Sigma_0^E] \cdot E(k) = -ek\left[D_0^F \frac{\Delta N^F}{N_0^F} + D_0^E \frac{\Delta N^E}{N_0^E}\right](k)$$

and the equations for the disturbances in the both layers as

$$\frac{\partial}{\partial t}\Delta N^F(k) = -\frac{k}{e}\Sigma_i^L E(k) - k^2 D_i^F \Delta N^F(k)$$

$$\frac{\partial}{\partial t}\Delta N^E(k) = -2\alpha\left(N_0^E\right)^2 \frac{\Delta N^E(k)}{N_0^E} - \frac{k}{e}\Sigma_i^E E(k) - k^2 D_i^E \Delta N^E(k)$$

where index "0" is related to the background values, E и F -indices - to the corresponding layer, $\Delta N = N - N_0$ is the perturbation of the plasma density in the irregularity.

The model of the interaction of the plasma irregularity with the conductive E-layer presented above permits to solve the evolution problem of the spectrum of the ionospheric plasma irregularities drifting in the electric field of the magnetosphere convection.

We have performed calculations of the spectrum dynamics for the different ratios of the conductivities in the E and F layers with and without recombination processes in the range from 10m to 5000m for the spectrum which has been taken in the form:

$$A = A_0\left[1 + \left(\frac{K}{K_c}\right)^2\right]^{-1/2}$$

where K_c is the critical wave number equal to 3×10^{-3} m^{-1} (or $\lambda_c \approx 2\times10^3$ m^{-1}). The results of the calculations are presented in Figures 1-5. The relative changes of the electron density and irregularity amplitude are shown for the E and F layer, respectively.

In Fig.1 the evolution of the spectrum is shown with the recombination processes being taking into account. During the first 10 seconds the peak of the electron density changing is observed at wavelengths 100-500 m. Beyond this range of the spectrum the change of the electron density does not exceed one per cent of the background value of the electron density.

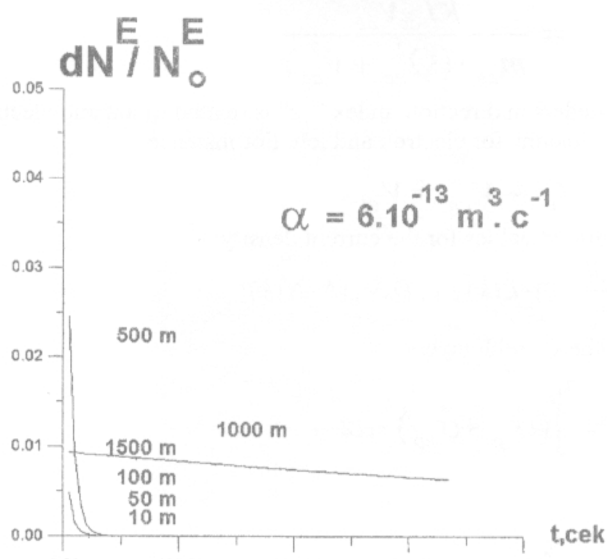

Fig.1.The evolution of the spectrum for wavelengths 10-1500 m with the recombination processes being taking into account.

During the next 20 seconds the amplitude of the irregularity at the wavelengths 1000-1500 m in the E-layer increases up to 50 per cent of the background value and further slow and decay of the whole irregularity is observed.

For large dimensions (more than 1500m) the irregularities stay undisturbed in the F-layer for rather long time, with the image in the E-layer not exceeding 20 per cent of the background level. In Figs.2 and 3 the results of the calculations for the E and F layers are presented for a weak recombination processes, $\alpha = 10^{-14}$ m^3 s^{-1}.

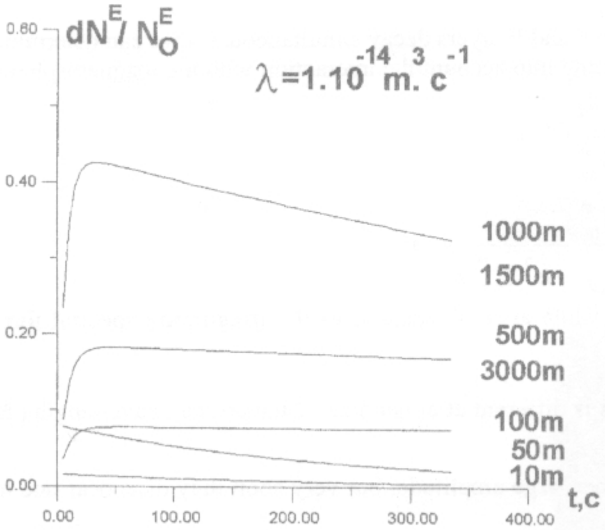

Fig.2. The evolution of the spectrum with a weak recombination process for wavelengths 10-3000 m in the E-layer.

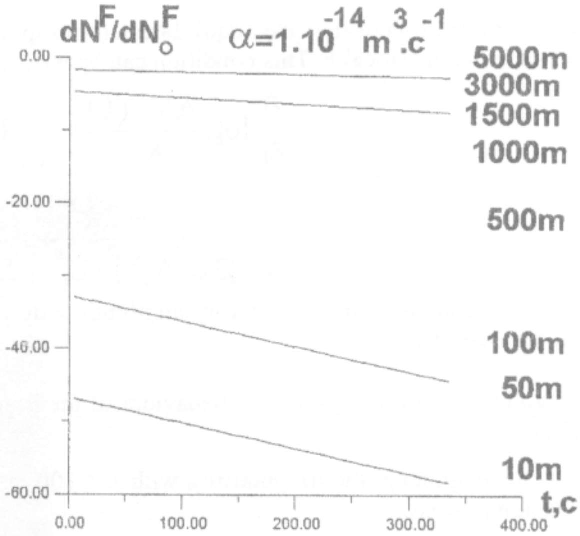

Fig.3. The evolution of the spectrum with a weak recombination process for wavelengths 10-5000 m in the F-layer.

At small wavelengths $\lambda < 100$ m the amplitude of the irregularity in F-layer in the first 10 seconds diminishes by 1-2 orders of magnitude (-20 -40 dB), and in the E-layer the irregularities appeared are at the level of 2 per cent of the background magnitude during 7minutes.

The results of the calculations for the wavelengths $\lambda = 100$ m and $\lambda = 1000$ m for the different recombination coefficients $\alpha = 2\times10^{-13}$, 6×10^{-13} and 4×10^{-12} m^3 s^{-1} are presented in Figs.4 and 5, respectively. One can see a significant effect of recombination: increase of the recombination coefficient leads to the immediate decay of the irregularity at wavelength $\lambda = 100$ m and slow evolution at wavelength $\lambda = 1000$ m. The process is stabilised with time and the irregularity amplitudes become constant at a low level.

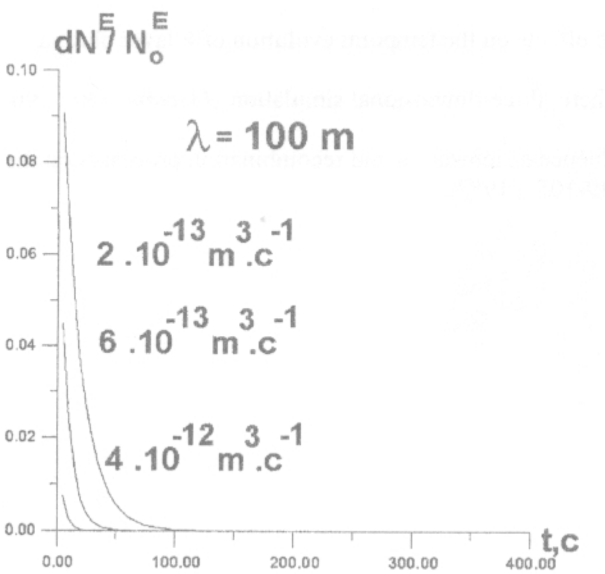

Fig.4. The results of the calculations for the wave length of 100m for the different recombination coefficients $\alpha = 2\times10^{-13}$, 6×10^{-13} and 4×10^{-12} m^3 s^{-1}

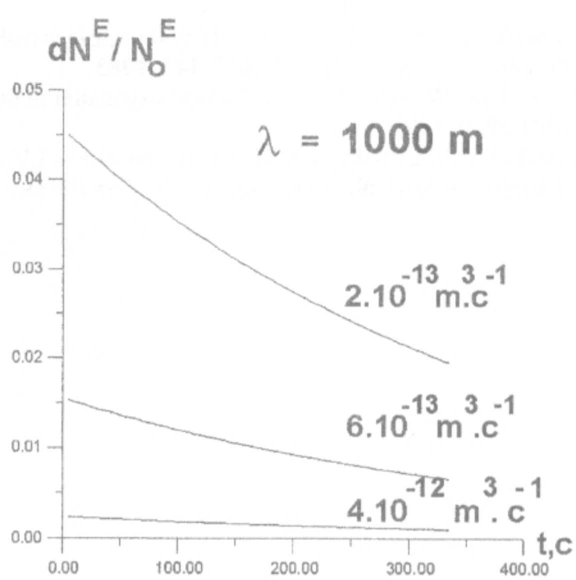

Fig.5. The same as in Fig.4, but for the wave length of 1000m.

It has been shown that the background concentration determines the wave number beyond which the structure amplitude decay rate is almost independent of its scale size. The spectrum evolution is determined by the relative contribution of the two terms, one of which is $2\alpha \cdot \left(N_0^E\right)^2 (\Sigma_0^F + \Sigma_0^E + \Sigma_w)$ and the other is $k^2 \Sigma_0^F D_i^E$.

From the condition of the quasi-equilibrium (both spectra in the F and E layers decay simultaneously) we can determine the value of the critical k. This condition can be written with taking into account the interaction with the magnetosphere:

$$\frac{\partial}{\partial t} \log \frac{\Delta N^F(k)}{N_0^F} = \frac{\partial}{\partial t} \log \frac{\Delta N^E(k)}{N_0^E} = \frac{-2k^2 D_i^F \Sigma^E \alpha \left(N_0^E\right)^2}{N_0^F \left[2\alpha \left(N_0^E\right)^2 (\Sigma_0^E + \Sigma_0^F + \Sigma_w) + k^2 \Sigma_0^F D_i^E\right]}$$

For large scale sizes the irregularity amplitude will diminish, while at small scale sizes the irregularity spectral form will be preserved.

As can be seen from Figs.4,5 the behaviour of the irregularities is different at either side of the critical wave length ($\leq$ 1.5 km).

1) At the beginning, the irregularities with $\lambda < 100$ m have rather large amplitude, but very soon they disappear due to diffusion process.

2) The irregularities with $\lambda < 1.5$ km even at the beginning contribute only about 3 per cent to the initial magnitude and preserve their amplitude with time.

3) The irregularities with λ =1-1.5 km at the beginning yield 0.06-0.08 of the initial magnitudes and preserve these amplitudes later.

The results obtained in this work will be used for the construction of a time-dependent model of plasma irregularity structure in the high-latitude ionosphere. Comparison of the experimental spectra in the daytime cusp and auroral oval has been planned to be performed for the estimation of the magnetospheric effect in the evolution of the irregularity spectrum.

Acknowledgements. The study was supported by Russian Foundation for the Basic Research (RFBR), grant # 96-02-17182 and by the Ministry of High School, grant # 97-40-1.13-20.

References

Heelis, R. A.,J. F. Vickrey and N. B Walker, Electrical coupling effects on the temporal evolution of F layer plasma structure, *J.Geophys.Res.*, 90,437-445, 1985.

Ma, T.-Z.,R. W. Schunk, Plasma cloud expansion in the ionosphere; three-dimensional simulation, *J.Geophys.Res.*, 96, 5793-5810, 1991.

Pudovkin M.I., Lyatskaya A.M., Golovchanskaya I.V., The influence of ionization and recombination processes on the dynamics of ionospheric plasma, *J.Atm.Terr.Physics.*, 49, 1049-1057, 1987.