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NONLINEAR STAGE OF PROPAGATION OF WAVE DISTURBANCES IN THE TOPSIDE IONOSPHERE

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ABSTRACT

This paper is continued investigations of propagation of disturbances of plasma concentration in the topside ionosphere. A mathematical modeling of the nonlinear stage of instability development has been carried out. It is shown that in the region of a maximum enhancement of perturbations, the relative fluctuations of plasma density can make up several tens of percent.

In [1,2,3] these authors showed the possibility of an enhancement of plasma density wave disturbances during their downward propagation in the topside ionosphere. The physical setting of the problem was as follows. A harmonic disturbance of plasma density with a typical period of tens to hundreds of seconds was specified on a certain upper boundary (700-800 km). Sources for such disturbances can be provided, in particular, by different types of oscillations of the neutral atmosphere, such as AGW and IGW, and effects of magnetospheric origin. The propagation of this disturbance along geomagnetic field lines was considered. It was shown that as the disturbances propagate downward, their amplitude can increase significantly, so that a region of strong plasma density fluctuations with the vertical size of the disturbances on the order of several tens of kilometres can be produced at about 500-600 km altitudes. Because the spatial growth rates of enhancement of the disturbances were quite significant, it is of interest to evaluate the range of validity of the linear approach and examine nonlinear questions arising in the case of the propagation of intense disturbances.

In previous work the basic equation describing the dynamics of small disturbances of electron density in plasma *n*, for the case of the ambipolar motion of charges along geomagnetic field lines, was derived from linearized equations of motion and continuity for electron-ion gas in conditions of the nightside mid-latitude ionosphere. In carrying out the linearization, the plasma density and hydrodynamic velocity were represented as the sum of the time-independent background part and a small, harmonically time-dependent addition: $N = N_0 + n * e^{i\omega t}, V = V_0 + \mathrm{v} * e^{i\omega t}$, and terms of second order of smallness were n*v discarded. In accordance with the character of the phenomenon under study, a nonlinearity of the form n*v will manifest itself in the generation of higher frequency harmonics of external action ω. In order to take the higher harmonics into account, the following mathematical description of the nonlinear processes was developed. Let the plasma density and hydrodynamic velocity be represented as the sum:

$$N = N_0 + \sum_{j=1}^{m} n_j * e^{i*j\omega t}, \; V = V_0 + \sum_{j=1}^{m} \mathrm{v}_j * e^{i*j\omega t}. \qquad (1)$$

next, we substitute (1) into the equation of motion and continuity of electron-ion gas:

$$N\frac{\partial \mathrm{V}}{\partial t} = -gN - \nu N \mathrm{V} - c^2 \frac{\partial N}{\partial z} \qquad (2)$$

$$\frac{\partial N}{\partial t} + \frac{\partial N\mathrm{V}}{\partial z} + \beta N = 0 \qquad (3)$$

By combining terms with identical exponentials, we obtain the equation for background density and m equations describing harmonics with the fundamental in m respectively. A natural assumption is made that harmonic amplitudes decrease with the harmonic number. Furthermore, higher harmonics are generated by lower harmonics like forcing actions. Equations for the fundamental (4) and second (5) harmonics are given below, and we may limit our consideration to them.

$$\frac{d^2 n_1}{d^2 z} - \frac{dn_1}{dz}\left(\frac{1}{Hp} + \frac{1}{H}\frac{\nu}{\nu + i\omega} + \frac{i\omega \mathrm{V}_0}{c^2}\right) + n_1\left[\left(\frac{1}{HH_p} + \frac{i\omega \mathrm{V}_0}{c^2 H}\right)\frac{\nu}{\nu + i\omega} - \frac{i\omega \frac{dN_0}{dz} + (\beta + i\omega)(\nu + i\omega)}{c^2}\right] = 0. \qquad (4)$$

$$\frac{d^2 n_2}{d^2 z} - \frac{dn_2}{dz}\left(\frac{1}{Hp} + \frac{1}{H}\frac{\nu}{\nu + 2i\omega} + \frac{2i\omega \mathrm{V}_0}{c^2}\right) + n_2\left[\left(\frac{1}{HH_p} + \frac{2i\omega \mathrm{V}_0}{c^2 H}\right)\frac{\nu}{\nu + 2i\omega} - \frac{2i\omega \frac{dN_0}{dz} + (\beta + 2i\omega)(\nu + 2i\omega)}{c^2}\right] = \frac{i\omega}{c^2}\left(\frac{\partial n_1 \mathrm{v}_1}{\partial z} - \frac{\nu}{(2i\omega + \nu)H} n_1 \mathrm{v}_1\right) \qquad (5)$$

In the above equations the axis z is pointing down, and the origin of coordinates lies at 800 km, H is the height scale of the main component of the neutral atmosphere, atomic oxygen, H_p is the plasma height scale, ν is the collision frequency of ions with neutral atoms, V_0 is the hydrodynamic velocity of plasma (vertical component), c is the ion sound velocity, and β is the linear recombination coefficient. The quantities ν and β were assumed to be exponentially dependent on the height, and the velocity V_0 was calculated in terms of a numerical model of the ionosphere and is also a function of height. The other parameters were taken to be constant. The conditions of the nightside ionosphere of middle and moderately high latitudes were considered and modeled.

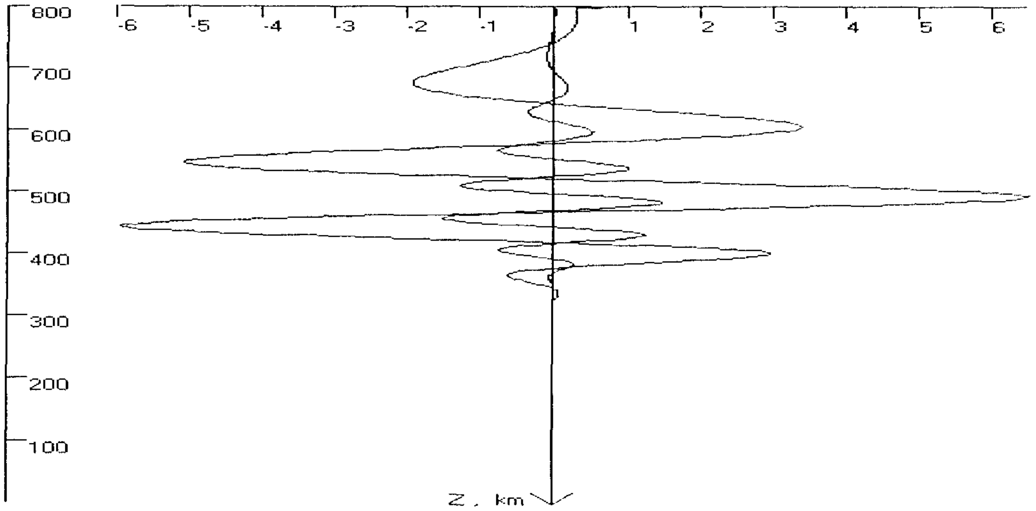

Figure 1.

Fig. 1 presents the fundamental (with the frequency $\omega=0.05\,c^{-1}$) and second harmonics in the linear regime. An essentially nonlinear regime in a state of saturation will occur whenever the second harmonic becomes comparable with the fundamental harmonic - the initial assumption about decreasing amplitudes does not hold. It is the estimates of this state that are of the greatest interest.

Fig. 2 plots the dependence of a maximum of the ratio of the second harmonic to the fundamental versus ratio of the fundamental to the background for the frequencies $\omega=0.1\,c^{-1}$ и $\omega=0.01\,c^{-1}$.

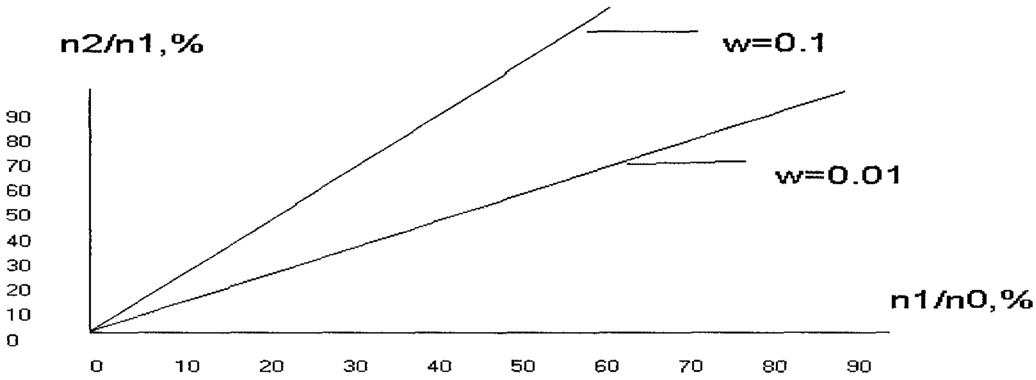

Figure 2.

As can be seen from the figure, a developed nonlinearity in the saturation regime will occur in the case of disturbances of the fundamental harmonic in the region of its maximum on the order of 20-30% of the background. Such strong disturbances can penetrate below the F2-layer peak and, hence, the results obtained in this study can be used to explain the well-known F-spread phenomenon at vertical-incidence radio soundings of the mid-latitude ionosphere.

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