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STUDY OF HIGH-LATITUDE D-REGION IONOSPHERE CHARACTERISTICS DURING PERIODS OF POLAR MESOSPHERIC ECHO (PME) APPEARANCES

V.D. Tereshchenko, A.P. Osepian, V.A. Tereshchenko (*Polar Geophysical Institute, Murmansk, 183010, Russia; E-mail: vladter@pgi.ru*)

Abstract. Based on partial reflections data and theoretical profiles of the electron density the structure of region D of an ionosphere is determined during appearance the Polar Mesospheric Summer and Winter Echoes (PMSE and PMWE). Methods of determination of the charged dust and metal ions concentration are offered during these events.

Introduction

The presence of mesospheric reflections on the medium and shorter radio waves was first noticed more than half a century ago. However, systematic studies of this phenomenon started only in 80th years of the last century [Bremer et al., 1996]. The main attention was spared to the summer of reflections in the VHF band, named Polar mesospheric summer echoes (PMSE). Polar mesospheric echo are quite strong scattered signals in excess of the noise level by 20-30 dB. It is believed that the cause of PMSE is formation at altitudes of 80-90 km of charged aerosols (particles of ice), which are observed visually as noctilucent clouds.

For the first time the structures of PMSE in the data of medium frequency radar at 2.7 MHz were found research workers Polar Geophysical Institute (PGI) in 1991 during the international experiment "Noctilucent cloud-91» (NLC-91) [Vlaskov et al., 1994]. This result was confirmed in paper [Bremer et al., 1996]. Later it was found that such reflections exist in all seasons [Tereshchenko et al, 2002]. Intensive mesospheric reflections, which were observed in winter, are called Polar mesospheric winter echoes (PMWE). These reflections occur at altitudes of 55-80 km of the mesosphere, which were considered free of aerosols. Typically, PMWE observed during the intrusion of solar protons with energies from several MeV up to hundreds of MeV, and high-energy electrons from the magnetosphere [Tereshchenko et al, 2008].

Radio echoes at high latitudes, obtained in different seasons have different properties. The nature of these reflections up to the end is not understood. It is possible that the formation of medium-reflections play decisive role sharp gradients of electron density and high levels of atmospheric turbulence. Mechanisms of formation in the mesosphere irregularities of electron concentration with the size needed for the scattering signals in different wavelengths are currently the subject of further study.

This paper presents the characteristics of the ionospheric D-region during the registration of the polar mesospheric echoes. The necessary conditions for the appearances of intense mesospheric reflections are determined.

Facility characteristics and methods of study

Observations of the method of partial reflections (PR) were made on facility of the PGI with the following parameters: operating frequency – 2.65 ÷ 2.78 MHz, the transmitter power in a pulse – 60 kW, pulse duration – 15 ms, repetition frequency – 2 Hz. Reception of scattered signals were receiving-transmitting antenna with a beam width at half power 19º×22º. Alternately, take two circular polarizations, which amplified receiver with a bandwidth of 40 kHz. The registration of the signal amplitudes was carried out in the altitude range 50-146 km. The step of the data reading was 0.5-1.5 km. A detailed description of the equipment is presented in paper [Tereshchenko et al, 2003]. On average data by means of differential absorption of radio waves was calculated electron density profile $N_e(h)$ as described in paper [Belikovich et al, 2003].

For an explanation of the physical processes occurring at heights of D-region, the model of lower ionosphere PGI [Smirnova et al., 1988] is used. The model allows to calculate density of four positive ions O_2^+, NO^+, Cl_1^+, Cl_2^+, four negative ions O_2^-, O^-, CO_3^-, NO_3^-, and electrons N_e, as the ion production rate *q*, effective recombination coefficient α_{eff}, differential and integrated absorption of radiowaves. The initial ion clusters $O_2^+(H_2O)_n$, and $NO^+(H_2O)_n$, where n=1, 2, 3…, and most complicated secondary ion clusters $H^+(H_2O)_n$ are denoted Cl_1^+ and Cl_2^+, respectively.

Results of measurements and the analysis

A typical example of the behavior of the amplitude reflection and the electron density in the lower ionosphere during the registration PMSE is shown in Figure 1.

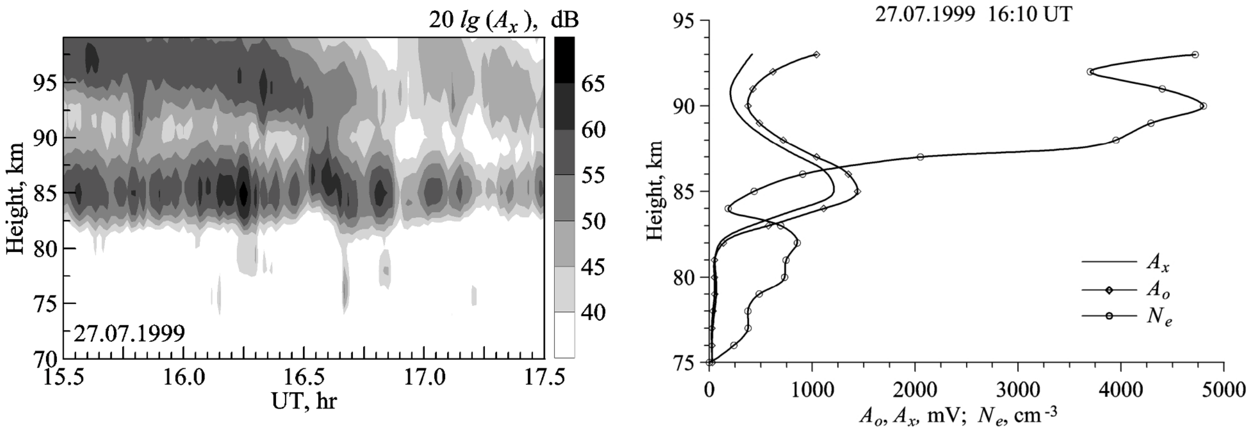

Fig. 1. Time-altitude dependence of the amplitude reflections of the ordinary (A_o) and extraordinary (A_x) waves and $N_e(h)$-profile of electron density

It is visible that the intense reflections of medium radiowaves are formed at altitudes 84-87 km near the cold summer mesopause. A characteristic feature of the observed reflections is that they come from areas with lower mesospheric electron density. According to our estimates, reducing the electron density associated with the appearance of PMSE, can range from 2 to 6 times.

To clarify the causes of such low density of electrons was studied the effect of atomic oxygen on the altitudinal distribution of different types of ions and the electron density. The results of model calculations for electrons in the conditions of a quiet ionosphere and during the intrusion of solar protons are presented in Figure 2. The solid line in the figure on the left shows the profile of the electron density, measured by incoherent scattering (IS).

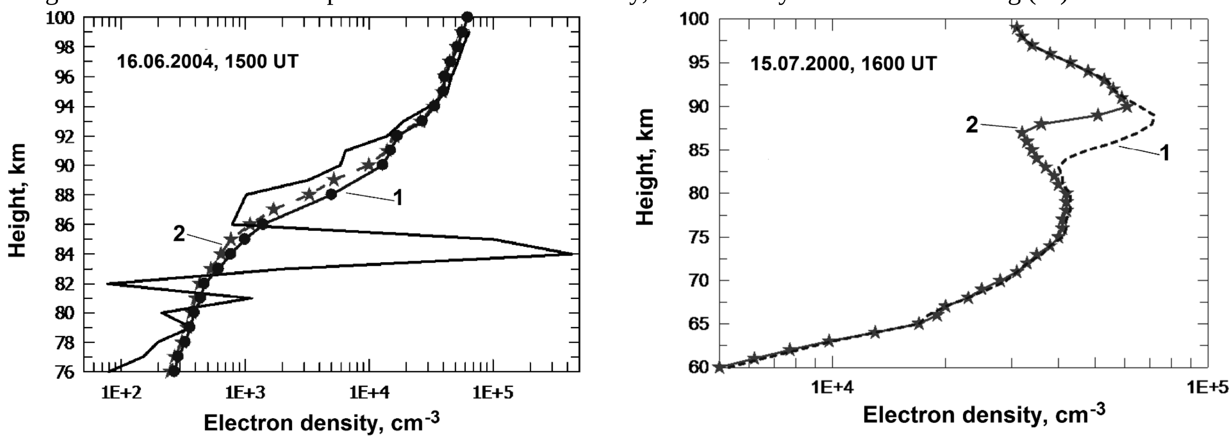

Fig. 2. To determine the influence of atomic oxygen on the electron density distribution in the lower ionosphere. 1 – to small neutral components of the mesosphere in quiet conditions, 2 – in disturbed conditions

Calculations show that a marked decrease in electron density up to 2-3 times by reducing the concentration of atomic oxygen in the 5-10 times are only during the intrusion of solar protons. In quiet conditions, our model could not explain the structural features of the D-region ionosphere with the appearance of PMSE.

To explain the observed dependence was suggested by the hypothesis of an essential role of dusty plasmas in D-region. In this case, you must accept that the recombination of positive and negative charges mainly occurs on dust particles. It is known, that because of the higher electron mobility compared with positive ions, neutral particles are taking a negative charge. On these negatively charged dust particles occurs the recombination of positive ions. With the account, the plasma recombination on dust particles, balance equation can be written as follows:

$$\frac{dN_e}{dt} = q - \alpha_e N_e N^+ - \alpha_{Cl} N_e N_{Cl}^+ - \beta N_e + \gamma N^- - \delta_e N_e N_d ,$$

$$N^+ + N_{Cl}^+ = N_e + N^- + Z_d N_d , \quad \delta_i N^+ = \delta_e N_e , \qquad (1)$$

where N^+, N_{Cl}^+, N^-, and N_d are the positive ion, cluster, negative ion and dust particle number densities, respectively; q is ionization rate; α_e, and α_{Cl} are the dissociative recombination coefficients of positive ions with electrons and clusters; β, and γ are the electron attachment and detachment coefficients; δ_e, and δ_i are the flow rates of positive ions and electrons on dust particles; Z_d is the average charge of dust particles (in units of elementary charge). Note that the processes of electron attachment to oxygen molecules in triple collisions and detachment of electrons from fotodetachment and interaction with the excited atomic oxygen quickly balance each other, so the members βN_e, and γN^- can be omitted.

Using the expression $q = \alpha_{eff} N_e^2$ and equation (1) in the stationary case, we have

$$\alpha_{eff} = \left(1 + \lambda^- + \lambda_d^-\right)\left(\bar{\alpha}_e + \bar{\alpha}_i \lambda^- + \bar{\delta}_{id} \lambda_d^-\right), \qquad (2)$$

where $\lambda^- = N^- / N_e$; $\lambda_d^- = Z_d N_d / N_e$; $\bar{\alpha}_i$ is the weighted average rate of neutralization of ions; $\bar{\delta}_{id}$ is the weighted average rate of flow of ions on dust particles. The bar is used to denote the weighted average rate for all kinds of positively charged plasma particles.

Hence, the presence of dust particles increases the effective recombination coefficient, which in turn should reduce the concentration of electrons. Therefore, determination of the effective loss factor may be an effective method of dust determination in the mesosphere. So determining the effective loss factor in the presence of PMSE, and in his absence, from equation (2) you can get the formula

$$N_d \approx \frac{N_{e0}}{Z_d} \sqrt{\frac{\bar{\alpha}_e}{\bar{\delta}_{id}}}, \qquad (3)$$

where N_{e0} is the concentration of electrons in the absence of dust ($N_d = 0$).

The results of the PMWE observations on facilities IS and PR are shown in Figure 3 [Osepian et al, 2007]. It shows the profile of power IS signal (left), amplitude PR waves and electron density profile (right) during the intrusion of solar protons.

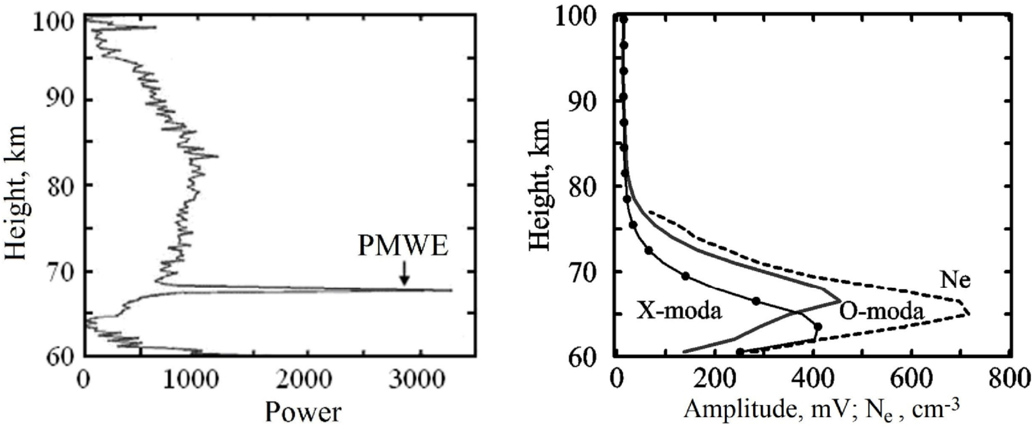

Fig. 3. Comparison of incoherent scattering and partial reflection at 12:30 UT January 17, 2005

The profile power IS signal is seen a narrow peak (PMWE), corresponding to very intense reflection layer at a height of about 70 km thick ≤1.5 km. At the same time, intense echoes were registered on the PR facility. A satisfactory agreement between the two radar data indicates that, perhaps, have observed the same phenomenon.

According to geophysical data of the ionosphere over the PR facility was leaking around the area of the longitudinal current [Tereshchenko et al, 2008]. The consequence could be to increase the plasma concentrations of mesospheric meteoric and formation of thin layers, limited by sharp gradients of electron density. The electrons, shielding layers of metal ions, are no longer free. This can lead to considerable enhancement of the scattered power, because scattering of electrons becomes a collective or coherent. Using data from the two radio-physical methods of IS and PR can estimate the concentration of meteoric ions and background plasma parameters.

Thus, the presence of intense mesospheric radioreflections during disturbances in the winter may be associated with the formation of meteoric layers in the lower of the D-region. However, this hypothesis does not yet have convincing experimental confirmation, because the ionic composition of the longitudinal current leakage is not investigated yet.

Conclusion

The results show that PMSE of the medium waves are formed at the altitudes near to the cold summer mesopause (84-87 km) in conditions of strong reduction of the electron concentration, and PMWE – at the altitudes below 80 km in conditions of sharp increase of the electron concentration. On basis of comparison of experimental and theoretical profiles of the electron density and the analysis of geophysical environment necessary conditions for appearances of intensive mesospheric reflections are determined. It was shown, that for formation of PMSE at the heights near to the summer mesopause presence of negative charged aerosols or dust, and for appearance of PMWE – presence in average D-region of the polar ionosphere of layers of meteoric ions is necessary. However, these conclusions demand the further experimental studying. Determination of the effective recombination coefficient at a time of polar mesospheric reflections can be a convenient method for determining the concentration of dust and metal ions in the polar mesosphere.

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