"Physics of Auroral Phenomena", Proc. XXVII Annual Seminar, Apatity, pp. 109-111, 2004

Polar Geophysical Institute

ANALYTICAL MODEL OF [NO], N_e AND T_n IN THE D-REGION OF THE IONOSPHERE

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Abstract. The analytical expression for [NO], [Ne] based on the numerical results was obtained. This expression clearly describes the altitude behavior of nitric oxide and electron density in the D-region.

The high region of 50-100 km of the ionosphere of the Earth so far presents the least investigated part. It is explained as a complication of the theoretical description of ion interfacing with photochemical and dynamic processes. Accurate and sufficiently reliable regular natural experiments are not available here. Therefore great hopes are attached to computing experiments, which are meant for studies and prognostication of complexes of polyvalent nonlinear processes. Their theoretical and experimental investigation using traditional methods is difficult or impossible.

One-dimensional non-stationary model of midlatitude mesosphere for height range of 50-500 km includes the processes of molecular diffusion, turbulent mixing and more than 200 photochemical reactions. It allows us to consistently calculate the distribution of the following components: $O(^3P)$, $O(^1D)$, $O(^1S)$, O_2, $O_2(^1\Delta_g)$, $N(^4S)$, $N(^2D)$, NO, NO_2, N_2O, H, H_2, OH, H_2O, HO_2, H_2O_2, CO, CO_2, O^+, O_2^+, NO^+, N^+,N_2^+, Y^+, Y^-, Ne, where Y^+, Y^- – total concentration of positive ions and negative ions.

General inputs of the model are the coefficients of chemical reactions, fluxes of ultra-violet solar radiation, absorption and ionization cross-sections for the neutral components, the boundary condition for the temperature and coefficient of vertical mixing.

Temporal distributions of neutral and ionic components in the co-ordinates connected with local vertical (axis Z), in the altitude interval 50-500 km defined the solution of diffusion equations:

$$\frac{\partial n_k}{\partial t} = \frac{\partial}{\partial z}\left(D_k \cdot \frac{\partial n_k}{\partial z} + \overline{D_k} n_k \right) - \alpha_k n_k + P_k , \tag{1}$$

where n is the concentration of K-th component, α_k, P_k are the rates of loss and production of particles in photochemical reactions (see the paper [1] for details).

Equation (1) is the nonlinear differential equation of parabolic type. Let us transform the equation (1) to the form:

$$\frac{\partial}{\partial t}\left(\frac{w_k}{q_k} \right) = \frac{\partial}{\partial z}\left(\frac{D_k}{q_k} \cdot \frac{\partial w_k}{\partial z} \right) - \frac{\alpha_k}{q_k} w_k + P_k , \tag{2}$$

where $w_k = n_k q_k = n_k e^{-\int_{z_0}^{z} \frac{\overline{D_k}}{D_k} dz}$

For equation (2) it is easy to construct an absolutely stable implicit, conservative difference scheme, which is solved using cut-and-try approach.

In the interval of 50-100 km concentrations of ions O^+, O_2^+, N_2^+, NO^+, N^+, Y^+, Y^-, O_2^- are calculated by the equation in the form:

$$\frac{dn_i}{dt} = P_i - \alpha_i n_i . \tag{3}$$

For daytime conditions the basic source of [NO] is the reaction of "hot" atoms $O^*(^1D)$ with molecules N_2 in the region menopause:

$$O^*(^1D) + N_2 \rightarrow \begin{matrix} N(^4S) + NO, V \\ N_2 + O(^3P), (1-V) \end{matrix}, \alpha = 2{,}4 \cdot 10^{-9} \tag{4}$$

where V is a quantum efficiency of first channel (equal to 0.06) and the reactions:

$$N(^4S) + O_2 \rightarrow NO + O \tag{5}$$

(which depends on the temperature) and

$$N(^2D) + O_2 \rightarrow NO + O . \tag{6}$$

The "hot" atoms $O^*(^1D)$ are produced in the processes of photodissociation of O_2 molecules by solar radiation with $\lambda \le 128 nm$.

$$O_2 + h\nu \rightarrow O^*(^1D) + O(^3P) \tag{7}$$

The losses of NO molecules occur in the reactions:

$$N(^4S) + NO \rightarrow N_2 + O \tag{8}$$
$$NO + h\nu \rightarrow N + O$$

Using conditions of photochemical balance for $[N(^4S)]$ and $[NO]$ and the reactions (4) – (8), the system of algebraical equations can be obtained:

$$\alpha_5[N(^4S)][O_2] + \alpha_8[N(^4S)][NO] = P + J_{NO}[NO],$$
$$\alpha_8[N(^4S)][NO] + J_{NO}[NO] = P + P_1 + \alpha_5[N(^4S)][O_2],$$

where

$$P = \alpha[O^*(^1D)][N_2]V, \qquad P_1 = \alpha_6[N(^2D)][O_2],$$
$$[O^*(^1D)] = \frac{J_{O_2}[O_2]}{(\alpha[O_2] + \alpha_4[N_2])}.$$

The solution of this system is given by the equations:

$$\left[N\left(^4S\right)\right] = \frac{2P + P_1}{2\alpha_8[NO]},$$
$$[NO] = \frac{P_1}{4J_{NO}} + \sqrt{\left(\frac{P_1}{4J_{NO}}\right)^2 + \frac{\alpha_6(2P + P_1)}{2\alpha_9 J_{NO}}[O_2]}, \tag{9}$$

which describe the distributions of the components in the mesosphere of the Earth. The altitude distribution of temperature for neutral and ionic gases is given by :

$$T_z = \begin{cases} T_m + 3{,}6(z - z_m), z > z_m \\ T_m + 7{,}5\cos^2\left(\dfrac{\pi}{2}\dfrac{(z - z_0)}{30}\right), z \le z_m \end{cases}$$

$$T_m = 195 - 0{,}087(F_{10,7} - 130),$$
$$z_m = 87 - 0{,}28(t - 1972{,}5),$$

where T_m, z_m, t are the temperature, height of the menopause and year. This formula has been derived from the results of papers [2], [3]. Height distributions of P and P_1 for different solar activity conditions are shown in Fig. 1.

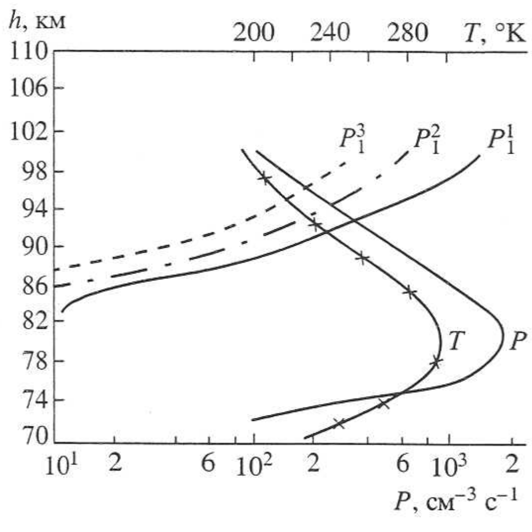

Fig. 1. Height distribution of temperature T for winter anomaly conditions averaged over experimental data: P is NO production rate by reaction (4). P_1^1, P_1^2, P_1^3 are NO production rates by reaction (6) for high, medium and low solar activity.

Fig. 2 demonstrates [NO] distributions for conditions as for Fig. 1, calculated by formula (9).

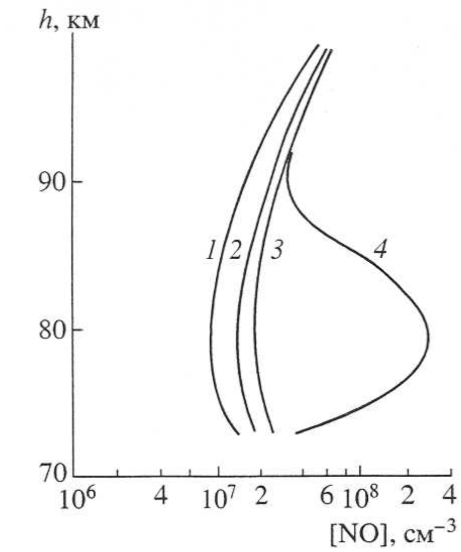

Fig. 2. The calculated [NO] height distribution for winter anomaly conditions (4), for medium (2), low (1) and high (3) solar activities.

Knowing the height-time distribution of NO, the ionization of which is the principal source of the ionosphere's D-region, it is easy enough to calculate the electron concentration, for the day- and night-time conditions, by the formula:

$$n_e = \sqrt{\frac{q}{\alpha_{ef}}},$$

where q is the ionization rate and α_{ef} is the effective recombination coefficient.

References

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