TELECOMMUNICATIONS AND RADIO ENGINEERING

VOLUME 79, ISSUE 4, 2020

begell
New York • Connecticut

TELECOMMUNICATIONS AND RADIO ENGINEERING

Volume 79, Issue 4 **2020**

CONTENTS

DISTRIBUTED COMPUTING NETWORKS

SOCIAL NETWORKS AND DATA MINING

Telecommunications and Radio Engineering, 79(4):335-342 (2020)

APPLIED RADIO PHYSICS: SPACE, ATMOSPHERE, AND EARTH'S SURFACE RESEARCH

EMPIRICAL MODELING OF VARIATIONS OF ELECTRON DENSITY IN THE UNDISTURBED MID-LATITUDE D-REGION OF THE IONOSPHERE

A.M. Gokov,[1,♦] O.F. Tyrnov,[2] Yu.V. Buts,[1] & E.N. Kovalenko[3]

[1]*S. Kuznets Kharkiv National University of Economics, Ministry of Education and Science of Ukraine, 9a, Nauka Ave., Kharkiv 61166, Ukraine*

[2]*V. Karazin Kharkiv National University, 4, Svobody Sq., Kharkiv 61022, Ukraine*

[3]*Kharkiv National University of Radio Electronics, 14 Nauka Ave., Kharkiv 61166, Ukraine*

[♦]Address all correspondence to: A.M. Gokov, E-mail: 19amg55@gmail.com

An empirical statistical model of the height-time variations of the electron density in the undisturbed D-region of the middle latitude ionosphere is presented. The model is based on the largest experimental data bank in Ukraine at present and is an important and necessary step for creating methods for predicting the state of the Earth's ionosphere in order to take into account its influence on human industrial activity.

KEY WORDS: *electron density, mid-latitude D-region of the ionosphere, model of region D, partial reflection method*

1. INTRODUCTION

The solution of many scientific and practical problems requires knowledge of information on variations in ionospheric parameters, primarily, height s profiles of the electron concentration $N(z)$ and collision frequencies $\nu(z)$ of electrons with neutral molecules (z is the height above the Earth's surface). At the present time, in spite of the relatively numerous experimental studies, there are no reliable global models of the height-time variations of the main parameters of the ionosphere D-region. This is caused, first of all, by the complexity and high cost of carrying out long-term experimental research, and the absence on the planet of even the minimum necessary network of experimental facilities for research. Coordinated studies of the D-region for modeling purposes are still not carried out on the existing experimental facilities in the world. Relatively long observations are carried out at 2–3 points in different regions of the planet sporadically and are mainly aimed at solving other problems. Therefore the exceptional value is the long-term systematic experimental observations on the basis of which it is possible to build a model of the D-region.

Despite the relatively small amount of experimental data on $N(z)$ in the D-region, the already accumulated information is used as initial data to search for ways and principles for constructing empirical models of the distribution of $N(z)$ in the mid-latitude D-region [1-11]. A relatively complete model is the mid-latitude D-region model, which is being developed in Nizhny Novgorod on the basis of homogeneous data obtained by the method of partial reflections (PR) [5]. The algorithm for constructing the empirical model is based, like that of other authors, on the systematization of experimental data and the determination of the dependence of $N(z)$ on various factors affecting the value and nature of the distribution of $N(z)$. These main factors are the zenith angle of the Sun, a season of the year, solar activity, geomagnetic latitude and geomagnetic activity.

In our work, we used the observational data bank by the PR method at V.N. Karazin Kharkiv National University (KhNU) using stationary and mobile complexes [12] at middle and high latitudes (near the cities of Kharkiv, Volgograd and Murmansk). Data bank includes both systematic background observations and observations during of some ionospheric phenomena in the period of 1981–2018.

To construct a model of electron concentration profiles in the mid-latitude lower ionosphere, 4.600 $N(z)$ profiles with an evenly distributed over the seasons were used. The data were obtained under undisturbed conditions only using the PR method, which is one of the important differences from the models [1-11]. To obtain $N(z)$ profiles two or more methods were simultaneously applied [13,14], which is necessary and made it possible to minimize the errors in determining the parameters of the lower ionosphere. Relative to the daily (day) changes for each season, the same in the number of arrays of measurements $N(z)$ were used with an approximately uniform distribution in the daytime.

The data of the global network of geophysical observations of the state of space weather were also used. Developed in the work empirical statistical model of the $N(z)$ profile of the mid-latitude D-region is based on the largest experimental data bank in Ukraine at present and is an important and necessary step for creating methods for predicting the state of the Earth's ionosphere in order to take into account its influence on human industrial activity.

2. VARIATIONS OF *N*(*z*)-PROFILE DEPENDING ON THE SOLAR ZENITH ANGLE

Variations of the $N(z)$-profile in the mid-latitude D region depending on the zenith angle of the Sun were studied by measurements by the PR method near Kharkiv in different seasons of the year from 1978 to 2018. The data obtained during daylight hours were analyzed.

On the basis of the experimental data bank obtained in V.N. Karazin KhNU the averaged regional model dependences of the electron density on the Solar zenith angle $N_{\grave{\imath}}\ (z,\chi)$ are constructed for different heights levels in the D-region (z = 75, 80, 85 km). To construct such a model, identical arrays of 680 (68 daily observation cycles) profiles $N(z)$ were used.

The corresponding dependencies for different seasons of the year are shown in Fig. 1 (standard deviations indicated by vertical line segments).

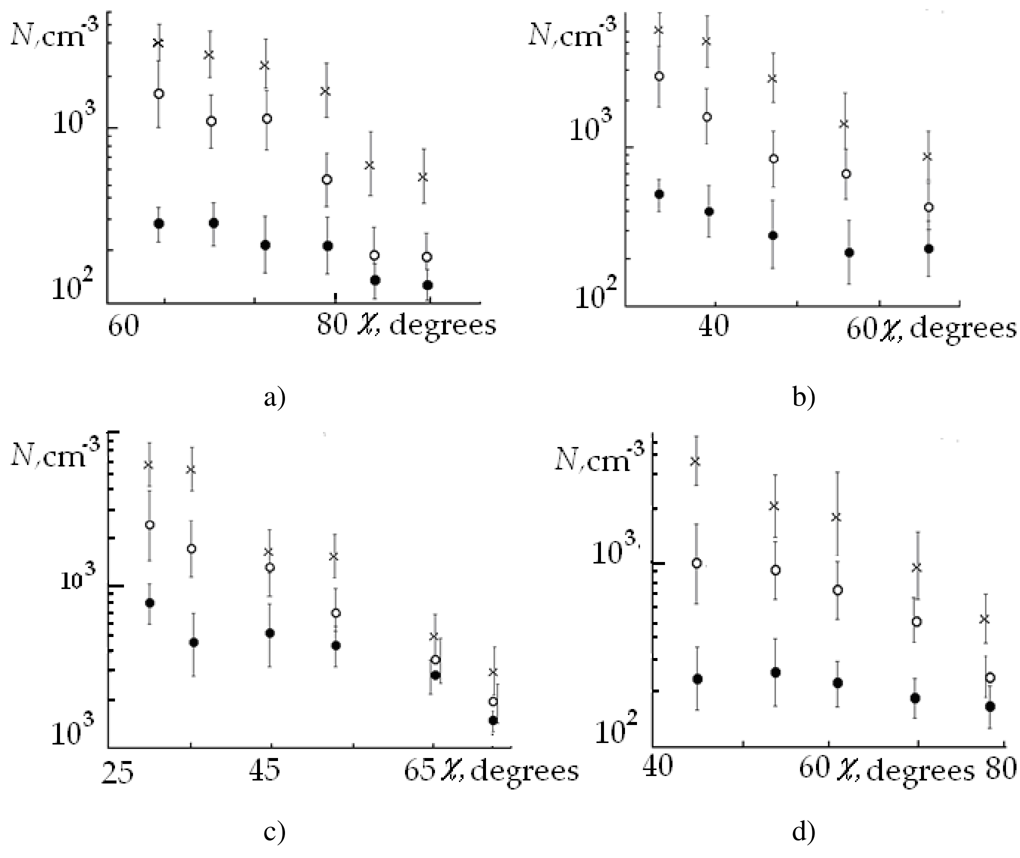

FIG. 1: Dependences of $N_M\,(z,\chi)$ for winter (a), spring (b), summer (c), autumn (d) obtained by the PR method at mid-latitude (points for z = 75 km, circles for z = 80 km, crosses for z = 85 km)

They were approximated by the following relationship:

$$N_{\grave{i}}\ (z,\chi)=N_0(z)\cdot\cos^n\chi_{eff.}, \tag{1}$$

where $N_0(z)$ is the profile at the zenith angle $\chi=0$, $\chi_{eff}(t)=\chi(t+\Delta t)$; $\Delta t(z)$ is the time shift of the curve diurnal variation of $N(z,t)$ relative to the local noon.

The value χ_{eff} is calculated from the ratio:

$$\cos\chi_{eff.}=\sin\varphi'\cdot\sin\varphi_0'+\cos\varphi_0'\cdot\cos\left[(t-\Delta t-12)\cdot 360^0/24\right], \tag{2}$$

where t is the time of observation in hours; φ' is the geographical latitude of the observation points in degrees; $\varphi_0'=23.45^0\sin\left(m_1'\cdot 360^0/365\right)$; m_1' is the number of days, starting on 21 March.

In our measurements, it was experimentally determined that a $\Delta t\simeq 50$ min. Our numerous observations showed that the seasonal changes of Δt did not exceed 10%. Further, we assumed that $\Delta t\approx const$. Based on this and based on the experimental data for all seasons of the year and height levels for each approximating curve, the values of the coefficients n are determined by the least-squares method.

In Fig. 2 the histograms of $W(n)$ distributions for seasons and heights of 75, 80 and 85 km are presented.

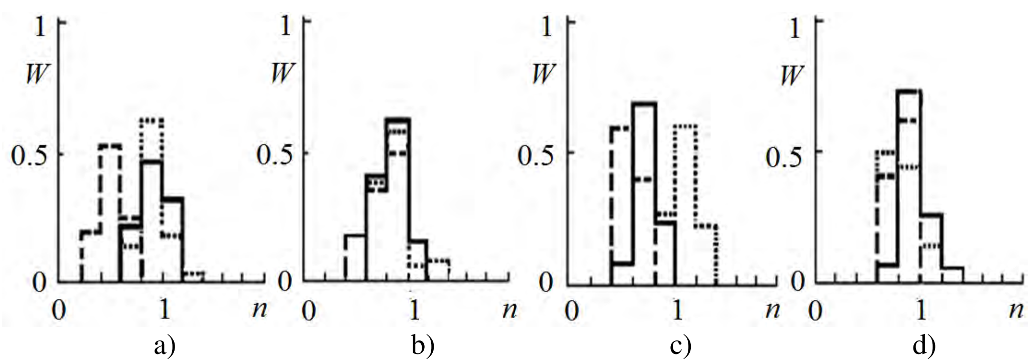

FIG. 2: The histograms of $W(n)$ for winter (a), spring (b), summer (c), autumn (d) and heights of z = 80 km (solid lines), 75 km (dashed lines), 85 km (points)

The dependence $\Delta t(z)$ on the height (in km) to our data is well approximated by the relation obtained in [5]:

$$\Delta t(z)=0.35\left\{1+0.637\,arctan\left[\frac{1000\times(z-74.7)}{(z-60)(90-z)}\right]\right\}. \tag{3}$$

For convenience, the obtained values of n were approximated in the heights range z = 70–90 km by the function:

$$n(z) = 0.98 \cdot \cos\left(360^0 \cdot \frac{80.0 - z}{132}\right). \tag{4}$$

Analysis of our data in this model showed that the character of variations of N due to the zenith angle of the Sun for all seasons is the same.

It can be seen from the above that the variations in the electron density due to the zenith angle of the Sun have both altitudinal and seasonal differences. The most probable values n of the exponent in the formula (4) are 0.95±0.15. This fact is important in constructing a statistical empirical model of the electron density distribution in the D region.

Note that the largest dispersion in the electron concentration in the dependences $N(z, \chi)$ is observed in winter. This is explained by the fact that in the analyzed dataset hit data obtained during the winter anomaly.

3. VARIATIONS OF THE *N*(*z*) PROFILE DUE TO CHANGES IN SOLAR ACTIVITY

Analysis of our bank of experimental data obtained by using the PR method in different seasons of the year showed that the changes in $N(z)$ as a function of solar activity is comparatively small. They are in better agreement with the changes in the number of sunspots *R*, than with their average monthly number of *W*. For the study we took data obtained during daylight hours during 1980–2018.

Based on the experimental data, the averaged model depends of the electron density $N_M(z, R)$ on the number of sunspots R for different heights (z = 75, 80, 85 km) in the mid-latitude D-region are constructed. To construct the model used an array of 760 data profiles of $N(z)$ with the same distribution by season. Profiles $N(z)$ were previously recalculated for $\chi_{eff.}$ = 0. According to experimental data, it was found that the dependences of the electron density on solar activity are satisfactorily described by the expression:

$$N_M(z, R) = N_{R0}(z) \cdot \exp(\alpha \cdot R), \ \alpha(z) = 0.02\left(1 - \frac{11.333}{z - 50.0}\right), \tag{5}$$

where $N_{R0}(z)$ is the dependence $N_{\grave{\imath}}(z, R)$ at $R = 0$; $\alpha(z)$ is the experimental approximation of the coefficient α.

4. SEASONAL CHANGES IN ELECTRON DENSITY

Knowledge of seasonal variations in the $N(z)$ profile in the lower ionosphere is very important for constructing both regional and global models of the lower ionosphere. In this case, the main difficulty is a large difference (scatter) in the experimental values of *N* in the winter period, because there is a so-called winter anomaly. This phenomenon is caused by the meteorological control of the lower part of the ionosphere.

We studied seasonal variations in the $N(z)$ profile based on measurements of $N(z)$ both at constant zenith angles of the Sun and near the local noon in two mid-latitude regions: in the region of Kharkiv and Volgograd. For modeling, we selected $N(z)$ profiles obtained only under similar undisturbed conditions. When modeling seasonal changes in $N(z)$ in the mid-latitude lower ionosphere, the model [5] was taken as the basis. In this model, seasonal variations in the height profile of electron density are described by the empirical expression:

$$lg\,N(M,z)=\left\{\begin{aligned}&0.7\cdot cosk\cdot\left[1+\frac{8\cdot 10^{5}(z-75)}{5\cdot 10^{6}+(z-75)^{6}}\right]+\\&+0.086\cdot cos2k\cdot\left[1+\frac{3040\cdot(z-72.5)}{9500+(z-72.5)^{4}}\right]+\\&+0.0022\cdot cos3k\cdot\left[1-\frac{900\cdot(z-80)}{5\cdot 10^{6}+(z-80)^{2}}\right]\end{aligned}\right\}, \tag{6}$$

where *M* is the day of the year, beginning of January 1st.

We carry out multiple verifications of these empirical parameters for all data obtained by the PR method in the two mid-latitudinal regions (in the region of Kharkiv and Volgograd).

It was found that this dependence equally accurately describes the experimental data for these two different mid-latitude regions. The error was less than 10-15%. This may indicate of its applicability and versatility.

5. CHANGES IN ELECTRON DENSITY DUE TO GEOMAGNETIC ACTIVITY AND GEOMAGNETIC LATITUDE

It is known that geomagnetic disturbances arise quite often. And it has been experimentally established many times that they contribute to significant changes in the height profile $N(z)$ in the lower ionosphere. It is very important that such disturbances in different regions cause, as was shown by different researchers, disturbances in $N(z)$ profile of different time scales – from a tens seconds to hours or days or more.

It is also important that the response of the lower ionosphere of middle latitudes to geomagnetic disturbances in different regions may be delayed by hours or days and may not coincide with them in duration (see, for example, [13] and references therein). Therefore, modeling of such variations of $N(z)$ in our time is probably not possible.

To characterize general regularity or features it is possible to construct a dependence of the electron density in the lower ionosphere, for example, on the average daily value of the geomagnetic activity index <Kp>. Such an attempt was made in the work [5].

We made a comparison of a large number of individual experimental data obtained by the PR method (in V.N. Karazin Kharkiv National University) in two mid-latitude regions, with the results of calculations based on empirical dependence on the work [5]. This comparison showed that in almost all cases there are significant differences between them.

Changes in the electron concentration due to geomagnetic latitude have been experimentally confirmed many times (see, for example, [13] and references therein). However, modeling these variations of $N(z)$ seems to be a very difficult task due to the great complexity of organizing and conducting coordinated experimental investigations.

To characterize the general regularities (or features), it is possible to construct an empirical dependence of the electron concentration in the lower ionosphere on the geomagnetic latitude. However, attempts to build such models using heterogeneous arrays of experimental data obtained by different methods in different regions very often lead to conflicting results. For example, in [5], on the basis of the NIRFI databank and known literature data obtained by different methods in different regions, a certain preliminary dependence of the electron concentration in the lower ionosphere on geomagnetic latitude was obtained.

We have compared this model dependence with numerous experimental $N(z)$ profiles obtained on our equipment by the PR method at different latitudinal observation points (in the region of Kharkiv, Volgograd, and Murmansk) for different seasons of the year (see, e.g., [13]). This comparison showed that in almost all cases there are significant differences between them. According to the authors, they can be caused, in the first place, by the imperfection of this model. This is due to the heterogeneity of the data used, as well as regional features.

6. CONCLUSION

Based on the bank of experimental $N(z)$ profiles obtained in V.N. Karazin Kharkiv National University under non-disturbed conditions, a model of height-temporal variations of electron density in the undisturbed regional mid-latitude D-region of the ionosphere is constructed. It made a comparison with other known regional models. It has been established that there are differences (often large) between them. These differences can be caused both by the imperfection of models (for example, low statistical support, heterogeneity of data, different accuracy of obtaining profiles, etc.), and regional features.

REFERENCES

1. Danilov, A.D. and Ledomskaya, S.Yu. (1983) The empirical model of the region D. Principles of construction and a data bank, *Proceedings of the IEM*, **13**(102), pp. 28-51.
2. Nesterova, I.I. and Ginzburg, E.I., (1985) *Catalog of the Electron Concentration Profiles of Region D of the Ionosphere,* Novosibirsk, Russia: IG and G Publ., 210 p., (in Russian).
3. Smirnova, N.V., Sagidullin, F.S., and Mizun, Yu.G., (1987) *Catalog of the electron concentration profiles in the high-latitude ionosphere obtained by the partial reflection method: comparison with the results of the theoretical model of the D-region*, preprint, PGI of the USSR Academy of Sciences Publ., Murmansk, Russia, **56**, 30 p., (in Russian).
4. Smirnova, N.V., Ogloblin, O.F., and Vlaskov A., (1985) *Models of Electron Concentration in the D-Region of the Ionosphere,* preprint, PGI of the USSR Academy of Sciences Publ., **84-08-36**, 32 p., (in Russian)
5. Belikovich, V.V., Benediktov, E.A, Vyakhirev, V.D. et al., (1992) The empirical model of the distribution of the electron density of the midlatitude ionospheric D-region, *Geomagnetism and Aeronomy*, **32**(6), pp. 95-103, (in Russian).
6. Fatkullin, M.N., Zelenova, T.I., Kozlov, V.K. et al., (1981) *Empirical Models of the Mid-Latitude Ionosphere,* Moscow, Russia: Nauka, 256 p., (in Russian).
7. Friedrich, M. and Torkar, K.M., (1991) D-region electron density model based on rocket borne wave propagation data, *Adv. Space Res.* **11**(10), pp. 101-104.
8. Rawer, K., Bossy, L., Kutiev, I. et al., (1990), *International Reference Ionosphere-1990,* Publ., URSI, Committee on Space Research, 58 p.
9. McNamara, L.F., (1979) Statistical model of the D-region, *Radio Sci*., **14**(6), pp. 1165-173.
10. Marcz, F., (1983) Latitude dependence of geomagnetic storms after effects in ionospheric absorption, *J. Atmos. Terr. Phys.,* **45(**5), pp. 281-284.
11. Coyne, T. and Belrose, J.S., (1972) The diurnal and seasonal variations of electron densities in the midlatitude D-region under quit condition, *Radio Sci.* **7**(1), pp. 163-164.
12. Tyrnov, O.F., Garmash, K.P., Gokov, A.M., Gritchin, A.I. et al., (1994) The Radiophysical Observatory for Remote Sounding of the Ionosphere, *Turkish Journal of Physics*, **18**(11), pp. 1260-1265.
13. Gokov, A.M., (2014) *Midlatitude Ionospheric D-Region Response to Natural Effects*, Published by: LAP LAMBERT Academic Publishing. Saarbrucken, 300 p. ISBN: 978-3-659-62182-6.
14. Gokov, A.M., (2003) Simultaneous Determination of Electron Density and Electron-Neutral Molecule Collision Frequencies in the Ionospheric D-region by a Partial Reflection Technique, *Telecommunications and Radio Engineering*, **60**(10-12), pp. 145-158.