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A global empirical model of the ionospheric topside electron density

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Abstract

As it was mentioned in many publications, the Bent model for the topside ionosphere used in IRI is not adequate, especially for the periods of high solar activity. Additional efforts are necessary to improve the empirical presentation of the electron concentration vertical distribution in topside ionosphere. The present paper is review of attempts to create the empirical model of the topside vertical profile undertaken within the frame of IRI Task Force Activity Workshops held at ICTP, Trieste. The Intercosmos-19 topside profiles database was used. The profile was approximated by Epstein function with the altitude dependent F2 layer thickness parameter B_{2u}. The main task was to find if the latitudinal dependencies of the model parameters have the regular character. The model was presented as the set of coefficients characterizing the profile for different latitudes, season and local time. Up to now the model is limited by the period of high solar activity. Attempts were made on revealing the longitudinal dependencies and its inclusion in the model.

Keywords: Ionosphere; Topside electron density; IRI

1. Introduction

Growing importance of GPS and other space technologies puts forward the urgent need to improve our knowledge of the structure and dynamics of the topside ionosphere. That's why creation of the adequate model of the topside profile of electron concentration seems to be topical. Such effort was undertaken within the frame of NASA Grant NRA 98-OSS-03(5.2) "Intercosmos-19 topside sounder data rescue project" (*http://antares.izmiran.rssi.ru.projects/IK19/*) and regular IRI Task force Activity Workshops held at Abdus Salam International Centre for Theoretical Physics (Trieste, Italy). The main source of the data was Intercomos-19 satellite (Pulinets, 1989) topside sounding database. 10000 profiles were used up to the moment. We looked for the simplest approximation having in mind the possible use of our results onboard the satellite, what conditioned the use of minimal number of parameters and table-like model presentation (Depuev and Pulinets, 2001). Except the latitude, local time and season coverage, the problem of topside profile presentation in magnetically disturbed conditions was regarded as well. The disturbed conditions were studied to reveal the dependence of the profile model parameters on the geomagnetic activity (Depuev et al., 2001). The most important was subdivision of the model coefficients by the longitudinal sectors. Regardless the longitudinal effect in ionosphere was reported many years ago (Ben'kova et al., 1990), there were no presented up to now the global distribution

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of the electron concentration in the topside ionosphere which takes into account the longitudinal effect. The essential discrepancy of the IRI model with experimental data in some longitudinal sectors was demonstrated in (Pulinets et al., 2002). The main limitation of the model in the present state is the solar cycle coverage. It envelopes only the period of high solar activity.

2. Selection of the profile approximation

Regardless the complex (peacewise-smooth) presentation of the topside profile in the present IRI model (Bilitza, 2001), it is observed sometimes quite essential difference between the model and experimental results. One of such examples is presented in the Fig. 1 where the combined topside–bottomside experimental profiles are compared with IRI model profiles for the point corresponding to Tucuman ionospheric station (Argentina). Both afternoon (Fig. 1(a)) and early morning (Fig. 1(b)) profiles demonstrate the discrepancy with IRI, especially, in the upper part of the topside profile. At the same time the NeQuick model (Leitinger et al., 1999) with the Epstein approximation used for the topside profile, demonstrates the good fit to the experimental data.

Epstein function is one from the family of exponential approximations of the topside profile proposed in the literature. Several of them were tried to compare with experimental topside profiles, namely: exponential approximation $N(z) = \exp(-\beta z)$, Chapman approximation

$$N(z) = \exp\left(a \times \left(1 - \frac{z}{H_s} - \exp\left(\frac{z}{H_s}\right)\right)\right),$$

where H_s is ionosphere scale height, $a = 1-\alpha$-Chapman profile, $a = 0.5-\beta$-Chapman profile. And finally, the Epstein approximation expressed as:

$$N(z) = 4.0 \times \frac{\exp\left(\frac{z}{B_{2u}}\right)}{\left(1 + \exp\left(\frac{z}{B_{2u}}\right)\right)^2},$$

where B_{2u} is the layer semithickness, and changes linearly with the altitude: $B_{2u} = B_{2u0} + kz$ $(z = h - h_m\mathrm{F2})$. Everywhere $N(z)$ is the normalized electron concentration: $N(z)=(Ne(z))/(N_m\mathrm{F2})$ The errors were calculated in the following way:

$$\varepsilon = \frac{\int |\, Ne(z)^{\mathrm{ex}} - Ne(z)^{\mathrm{model}} \,|\ \mathrm{d}z}{\int Ne(z)^{ex}\,\mathrm{d}z}$$

what is the integral along the whole profile and reflects the overall discrepancy with the experimental profile. The accuracy of different formula approximation was analyzed in detail in (Zhang et al., 1998). Here an example of experimental and model profiles comparison is presented (Fig. 2). Approximation errors ε are marked in parenthesis. The best fitting by Epstein function is obvious. The ε in different geophysical conditions ranged from 0.027 to 0.364. In the case of Epstein function approximation the model includes (except necessary geophysical parameters like coordinates, time, solar and geomagnetic indices) only 4 parameters: $N_m\mathrm{F2}$ (or $f_o\mathrm{F2}$), $h_m\mathrm{F2}$, B_{2u0}, and k. These parameters are given in the model in tabulated form with 10° step in latitude and 30° step in longitude.

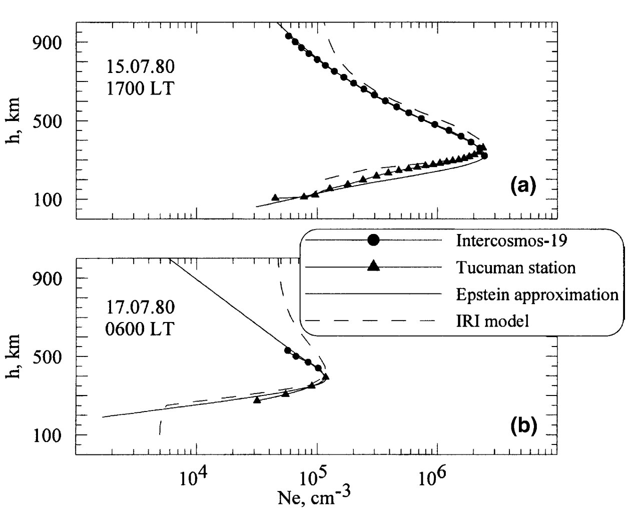

Fig. 1. Comparison of experimental topside ● and bottom side ▲ profiles with IRI model (dashed line) and Epstein approximation.

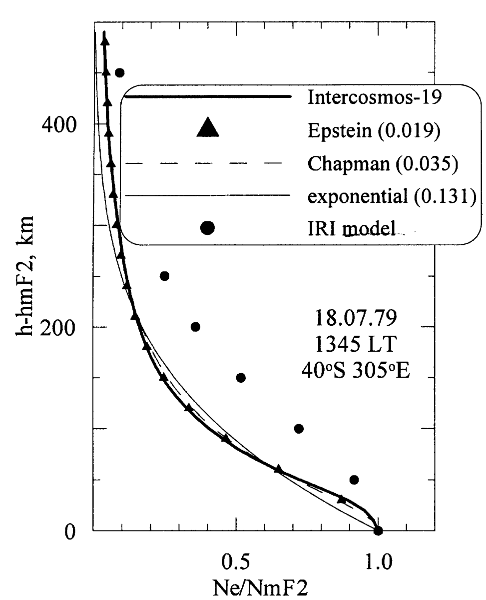

Fig. 2. Comparison of experimental (bold line) topside profile with Epstein (triangles), Chapman (dashed thin line), exponential (thin line) approximations and IRI model (dots).

3. Longitudinal effect

The necessity to subdivide the model in longitudinal intervals is explained by essential difference of the model parameters in different longitudinal sectors. As an example one can see in the Fig. 3 the daytime behavior of the model parameters at the geomagnetic equator for winter (left panel) and summer (right panel) seasons. In the case of the peak parameters they are accompanied by the similar curves using IRI model parameters to demonstrate the discrepancies of the models in different longitudinal sectors. One can see that the wave-like longitudinal behavior of the critical frequency is not reproduced by IRI, as well as peculiarities of the peak height behavior within the longitudinal sector 30°–120°. The IRI comparison with the

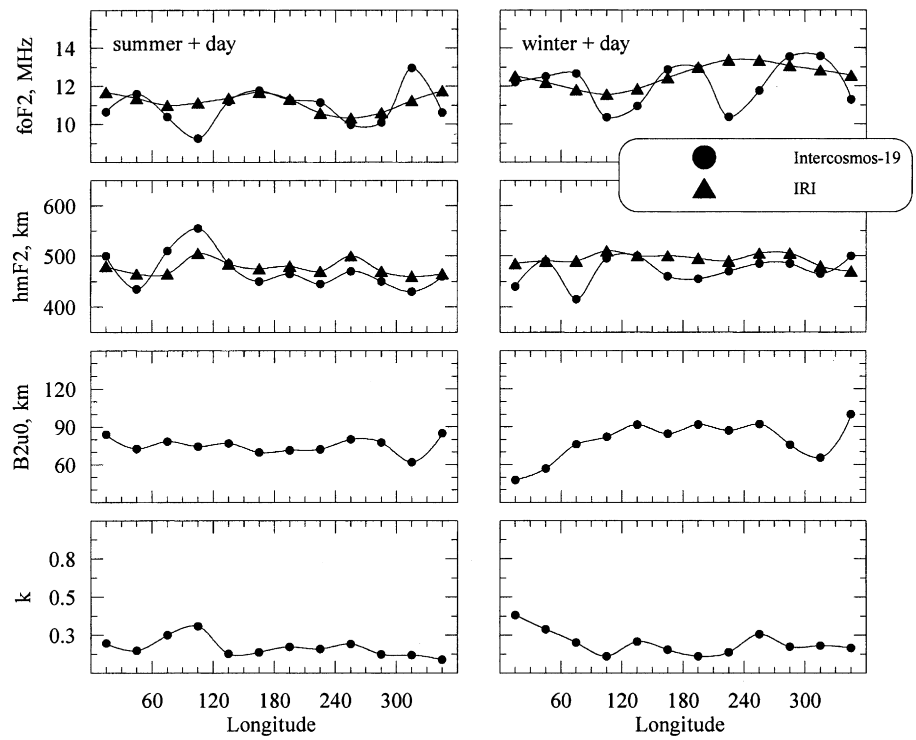

Fig. 3. Model parameters longitudinal distribution for the daytime summer (in Northern hemisphere) conditions (left panel) and daytime winter conditions (right panel). Triangles – the IRI model, points – Epstein approximation based on Intercosmos-19 data.

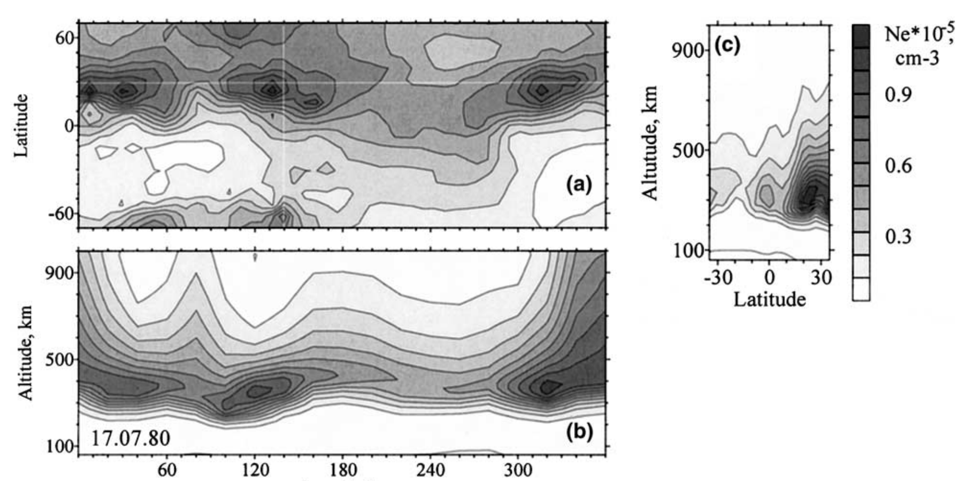

Fig. 4. Global map of the peak density distribution: (a) longitudinal at 30°N and; (b) latitudinal at 140°E; (c) vertical cross-sections of the ionosphere for summer nighttime conditions.

Intercosmos-19 topside data in low latitudes for the nighttime conditions was made by Deminova (2003). The longitudinal variations are observed not only in low latitudes but at all latitudes as well (Deminov and Karpachev, 1998), so it seems that longitudinal coverage is very important feature of the presented model.

4. 3-Dimensional model presentation

In principle, the model gives an opportunity to present ionosphere in three dimensions. Taking into account that 3-dimensional visualization is not so simple, we present three cross-sections to get flavor of such possibility and to see the real irregularities in the global scale revealed by the model (Fig. 4). Light lines in Fig. 4(a) make a note of latitude and longitude of ionosphere vertical sections in Figs. 4(b) and (c).

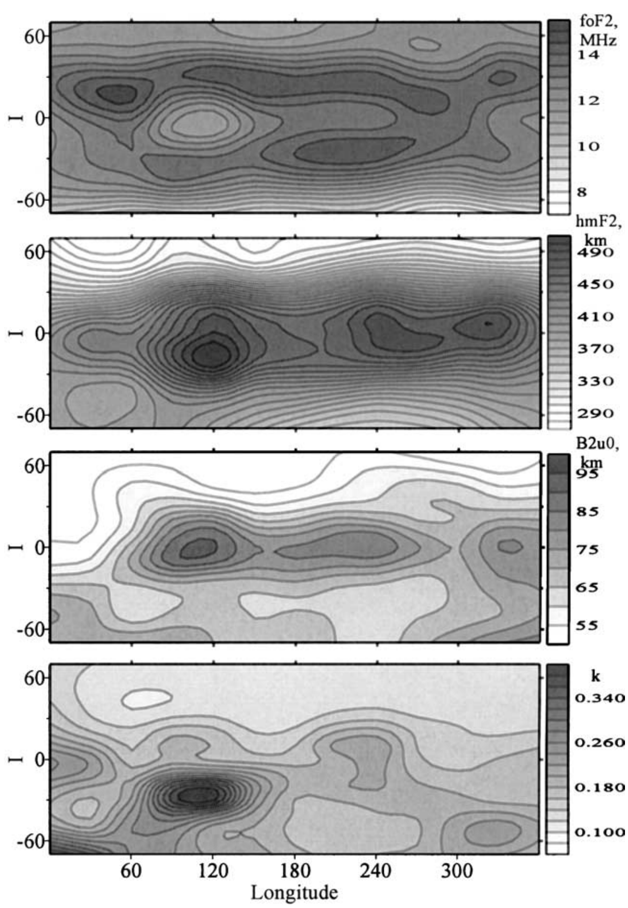

Fig. 5. The global distribution of the empirical model parameters (from top to bottom): f_oF2, h_mF2, B_{2u0}, and k for the winter daytime conditions.

5. Global map model parameters presentation

In Fig. 4 the different cross-sections of the ionosphere were presented demonstrating the longitudinal irregularities in terms of the electron concentration. Every model parameter has its own contribution in the observed picture. To reveal their role in observed picture they can be presented in the form of the global maps. Fig. 5 demonstrates the maps for all four model parameters for the winter daytime (10–14 LT) conditions. To have the better resolution in low latitudes the maps are presented in the terms of magnetic inclination.

6. Conclusion

Empirical model of the topside profile of the electron concentration was created using the database of Intercosmos-19 satellite topside sounding. The model revealed strong longitudinal irregularities showing essentially different vertical and horizontal distribution of the electron density in the same geophysical conditions. The most remarkable longitudinal features are the extend of equatorial anomaly development at different longitudes and main ionospheric trough position and shape. Up to now the model is limited by the period of high solar activity, but efforts are undertaken to accomplish the model using the data from other satellites of topside sounding (Alouette, Cosmos 1809). The model is presented in the table form and can be used in the satellite applications when the ionospheric corrections are necessary for the current geophysical conditions.

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