Features of a high-latitude ionospheric parameters modeling

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Abstract. Among the various methods to specify conditions of radio-waves propagation in the ionosphere empirical models play an important role. However, their accuracy in high-latitude region is not sufficiently estimated. In this paper, the International Reference Ionosphere model IRI is used. According to Russian ionospheric stations Gorkovskaya, Lovozero, Salekhard estimations of conformity of model values of parameters to experimental magnitudes are given from May 2017 till January 2018. The particular attention is paid to parameter $MUF_{3000F2}$ for these stations and to coefficient $M(D)$ for a path Gorkovskaya - Lovozero. It is shown, that these coefficients possess sufficient reliability. Adapting the model to the current diagnostic data has allowed to reduce root-mean-square deviation for $MUF(D)$ almost two times from 31.4 % to 17.2 %. For the identification and localization of disturbances in high latitudes, it is possible to use measurements of the total electron content.

1. Introduction
At present, interest to a high-latitude ionosphere has significantly increased. The importance of these regions is rapidly growing due to increasing of economic and scientific activity. One of the main ways of information interchange in this area is propagation of HF radio-waves. Despite the provision of northern regions with stations of vertical sounding, the need to use models of the ionosphere does not decrease. Models VOACAP, ICEPAC, ITUREC533 are most widely used in high latitudes (e.g., [1] and the references in it, [2]), however recently there has been interest to use the model IRI [3, 4]. All these models are based on the same maps URSI and CCIR for monthly medians of critical frequency $foF2$ and propagation coefficient $M(3000)F2$. Most widely, the model IRI is used to calculate $foF2$. The paper [5] includes the description of the model with the latest modifications. Papers [3, 6, 7] provide examples of using this model in high latitudes. To confirm this use, the model values of the parameters are compared with experimental magnitudes. Traditionally, it concerns to parameters in a maximum of the layer F2: the critical frequency $foF2$ and the maximum height $hmF2$. In the given work the attention is given also to parameter $M3000F2$ which can play an essential role at the monitoring and predicting of a condition of the ionosphere as a medium for propagation of radio-waves since it directly defines the maximum useable frequency $MUF_{3000F2} = M3000F2 * foF2$. The peculiarity is that parameter $M3000F2$ can be predicted by means of the model IRI like parameters $foF2$ and $hmF2$, therefore it is important to evaluate the correspondence between model and experimental values. The present work uses data of graphs of diurnal courses of ionospheric parameters of three stations Gorkovskaya (60.27°N, 29.38°E), Lovozero (67.97°N, 35.02°E), Salekhard (66.5°N, 66.5°E) and MOF of paths Gorkovskaya - Lovozero (length of the path D=900 km). This data is provided by AARI (Saint Petersburg) on the site (http://geophys.aari.ru/) from the end of 2016. The stations and periods with the largest number of data are selected. As the model IRI,
we used the online version IRI2016 on the site (<http://omniweb.gsfc.nasa.gov/vitmo/iri2016_vitmo.html>). Ionospheric stations in the given region are located rarely therefore possibility of using measurements of the total electron content ТЕС is being investigated. Values of ТЕС are calculated according to global maps JPL from the IONEX (IONosphere map Exchange) files (a site ftp://cddis.gsfc.nasa.gov/pub/gps/products/ionex/).

2. Another section of your paper
The obtained statistical data are given in Tables 1-2 in the example of the Lovozero station in the form of root-mean-square deviations σ of the model parameters foF2 and hmF2 from experimental values. The results are presented for both median (med) and instant (ins) values characterizing variations of day by day. Estimations for instantaneous values concern to the use of model (median) values as the daily magnitudes. The research period includes 9 months which have the greatest amount of data. For stations Gorkovskaya and Salekhard, a range of values and behaviour are the same, what is confirmed by the mean values of Table 3.

Table 1. Root-mean-square deviations of model parameters foF2 and hmF2 from experimental values

| LOZ | month | foF2  | MHz | σ(med) | σ(ins) | % | % | km | km | σ(med) | σ(ins) | % | % |
|-----|-------|-------|-----|--------|--------|---|---|----|----|--------|--------|---|---|
|     | May2017 | 0.25  | 0.26 | 6.39   | 6.50   | 95.55 | 112.96 | 29.43 | 33.18 |
|     | June2017 | 0.11  | 0.27 | 2.60   | 6.39   | 104.96 | 116.99 | 30.76 | 33.57 |
|     | July2017 | 0.19  | 0.36 | 4.39   | 8.63   | 113.95 | 121.78 | 32.55 | 34.38 |
|     | Aug2017  | 0.25  | 0.33 | 6.38   | 8.52   | 95.10 | 107.28 | 29.11 | 32.22 |
|     | Sept2017 | 0.32  | 0.60 | 8.72   | 15.63  | 40.81 | 71.65  | 14.09 | 24.44 |
|     | Oct2017  | 0.43  | 0.70 | 12.30  | 17.96  | 33.76 | 43.44  | 12.58 | 16.43 |
|     | Nov2017  | 0.67  | 0.73 | 22.23  | 21.27  | 36.32 | 47.11  | 13.19 | 18.15 |
|     | Dec2017  | 0.72  | 0.57 | 27.34  | 19.17  | 56.04 | 58.87  | 20.15 | 23.95 |

Table 2. Root-mean-square deviations of model parameters M3000F2 and MUF3000F2 from experimental values

| LOZ | M3000 | MUF |
|-----|-------|-----|
|     | month | σ(med) | σ(ins) | % | % | σ(med) | σ(ins) | % | % | σ(med) | σ(ins) | % | % |
|     | May2017 | 0.11  | 0.16 | 3.42 | 5.15 | 1.24 | 1.48 | 9.81 | 11.65 |
|     | June2017 | 0.15  | 0.17 | 4.85 | 5.52 | 0.95 | 1.61 | 7.46 | 11.90 |
|     | July2017 | 0.16  | 0.20 | 5.21 | 6.48 | 1.50 | 1.98 | 11.63 | 15.11 |
|     | Aug2017  | 0.28  | 0.38 | 8.79 | 11.66 | 1.86 | 2.55 | 15.16 | 20.18 |
|     | Sept2017 | 0.12  | 0.16 | 3.86 | 4.84 | 2.19 | 2.56 | 18.87 | 20.46 |
|     | Oct2017  | 0.18  | 0.36 | 5.49 | 10.66 | 2.06 | 3.77 | 17.79 | 28.62 |
|     | Nov2017  | 0.17  | 0.21 | 5.03 | 6.13 | 2.69 | 3.23 | 27.26 | 27.40 |
|     | Dec2017  | 0.26  | 0.28 | 8.06 | 7.97 | 3.04 | 2.82 | 35.40 | 27.14 |
Table 3. The average values characterizing conformity between
the model and experiment

|       | GRK      | LOZ      | SAL       |
|-------|----------|----------|-----------|
|       | mean     | med      | ins       | mean     | med      | ins       |
| foF2  | 10.80    | 14.61    | 12.46     | 14.10    | 13.18    | 12.52     |
| hmF2  | 22.32    | 26.17    | 22.05     | 26.15    | 22.95    | 25.23     |
| M3000F2 | 6.34    | 9.26     | 5.75      | 7.53     | 6.14     | 9.12      |
| MUF3000F2 | 16.93   | 23.95    | 19.07     | 21.63    | 19.32    | 21.64     |

Everywhere with a few exceptions, values for medians are less than for instantaneous values. For σ(foF2), an increase from summer values of ~3% to winter around 27% is typical. σ(hmF2) reaches a maximum in the summer of 33% and a minimum in autumn months (~12%). σ(M3000F2) is large in the summer (9%) and falls in the autumn to 3.4%. σ(MUF3000F2) is in a range of 7-35%, i.e. M3000F2 has the best statistical results. The average estimations of Table 3 are significantly smaller than estimations of [3] for a polar cap and are close to middle-latitude estimations. It allows investigating the specific features of MUF behaviour.

3. Specific features of MUF behaviour

In figure 1, comparison of medians with experimental values of MUF3000F2 for three chosen stations for several months is given.

![Figure 1. Features of behaviour of medians MUF3000F2 of three stations](image)

In the summer months, MUF3000F2 for all stations are close. In the autumn, MUF3000F2 for station Salekhard has the greatest variability. In the winter time, the MUF3000F2 has the clear daily course. For station Gorkovskaya, values are higher due to latitudinal dependence of foF2. These data are obtained from ionograms of vertical sounding. It is interesting to compare these results to data of oblique sounding. It can be done for a path Gorkovskaya - Lovozero with length D~900 km. The aim is to compare the model and experimental values of MUF3000F2 and M(D). For this purpose, calculations have been performed by a method of characteristics with using the initial model IRI and
its adaptations to parameters of current diagnostics [8]. Experimental values of M(D) have been obtained in two ways: 1) according to measured MOFF2 by division them into the foF2 magnitudes in the middle of the path, 2) by recalculation of values MUF3000F2 for the corresponding path length D. Results are shown in figure 2. The solid red dots in the left part of the figure show the experimental values for 33 measurement cases, hollow circles concern a curve for the original model IRI (without adaptation), triangles correspond to adaptation of the model using foF2, measured on the path ends since these foF2 values are most often available. Rhombuses correspond to adaptation of the model using experimental values of foF2 and hmF2.

Figure 2. Comparison of propagation characteristics on the path Gorkovskaya - Lovozero in January 2018

It is seen that each next step leads to a better match. SMSE for these variants have been 31.4 %, 25 % and 17.2 %. Among the reasons of a residual deviation, it is possible to name inaccuracy of coefficient M(D) and discrepancy between the forms of the model and real N(h)-profiles. To find M(D) contribution the right part of figure 2 is presented. It is seen that values of M(D) correspond to each other with SMSE =4.5 %. At the same time, problems with model parameter В0 describing the N(h)-profile of the F2 layer were detected in some papers (e.g., [9]).

4. The usage of the total electron content of the ionosphere

The obtained estimations concern average conditions. At the same time interest represents research of such conditions during disturbances when instantaneous values significantly differ from averages. During the period under consideration there were a few disturbances. Disturbance in September was the strongest, but there are no data on foF2. Next disturbance was in November. Its nature is presented in figure 3 as a behaviour of the Dst index.

Figure 3. Behaviour of the Dst index in November 2017

A moderate disturbance with minimum value Dst =-72 nT is seen on November, 7-9th. Figure 4 shows behaviour of parameters foF2 and TEC for the station Lovozero on November, 7-9th together with a median. For foF2, values for the model IRI are also given.

Conformity of behaviour of foF2 and TEC is visible. Positive disturbance during day and night time, good conformity between a median foF2 and experimental value in quiet day 9.11.2017 and absence of some data foF2 are peculiarities. The same picture is observed at stations Gorkovskaya and Salekhard.
Figure 4. An illustration of behaviour of parameters foF2 and TEC during disturbance in November 2017

The usage of TEC allows identifying and localizing areas of disturbances in entire region. For this purpose, dependences of TEC on a longitude for specific latitudes are calculated. An example for a latitude of 67.5° is shown in Fig. 5, which shows the behavior of TEC in conjunction with the median and its relative deviation from the median for the moments of maximum amplification UT = 10 and UT = 20.

Figure 5. An example of disturbance of the ionosphere in the region of longitudes for latitude 67.5° on November, 7th 2017

For UT=10, δTEC decreases with a longitude. Prominent feature are great values of deviations and excess of night deviations over diurnal ones.

5. Conclusion
Ionospheric models are widely applied to setting and forecasting of an environment condition. In the given paper, the model IRI is used for conditions of northern European part of Russia. Estimations of accuracy of average values of parameters foF2, hmF2, M3000F2, MUF3000F2, presented in Table 3, are close to middle-latitude magnitudes. At model adaptation to parameters of current diagnostics, in this case on measurements in final points of a path, the model can adequately describe a condition of environment. Comparison of model and experimental values shows reliability of coefficients MUF3000F2 and M(D). Feature of behaviour of the ionosphere in high latitudes are positive disturbances. Deviations of parameters from a median can exceed 100 %. The usage of the total electron content allows defining a condition of the ionosphere to any point around paths, identifying and localizing disturbances.

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