https://doi.org/10.48368/bgs-2023.1.N15

Емпиричен медианен модел за прогнозиране на височината на максимума на средноширинна йоносферна станция

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Key words: *йоносфера, емпиричен модел, височина на максимума*

Резюме
Целта на настоящето разследване е да представи методика за определяне стойностите на височината на максимума на йоносферната F2-област в спокойно състояние. Добре известна е зависимостта на цялата йоносфера от нивото на слънчевата активност, която се явява един от основните фактори при емпиричното моделиране на йоносферата. За да се анализира зависимостта между hmF2 и слънчевата активност, представена чрез F107, е направен регресионен анализ по месеци. Резултатите показват, че оптималната зависимост е близка до линейна. Като резултат е предложен емпиричен медианен модел за средносрочно прогнозиране на hmF2 за територията на град Рим - Италия в зависимост от слънчевата активност, сезона и универсалното време. В заключителната си част тази разработка представя и примери за работата на модела в избрани месеци. Получените грешки са съответно средна ME=0.000км и средноквадратична RMS=11.068км ,което е достатъчно точно за практически цели като прогнозиране на радиотрасета. Изборът на тази йоносферна станция е свързан с факта, че тя се намира на географска ширина, съвпадаща с географската ширина на София, което предполага сходни характеристики на йоносферата и приложимост на резултатите за територията на България.

An empirical median model for forecasting the height of the peak electron density of a mid-latitude ionospheric station

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Key words: *ionosphere, empirical model, height of the peak electron density*

Abstract
The purpose of this investigation is to present a methodology for determining the values of the height of the peak electron density of the ionospheric F2 region in quite conditions. The dependence of the entire ionosphere on the level of solar activity, which is one of the main factors in empirical modeling of the ionosphere, is well known. To analyze the relationship between hmF2 and solar activity represented by F107, a regression analysis was performed by months.The results show that the optimal dependence is close to linear. As a result, an empirical median model for predicting hmF2 for the territory of the city of Rome- Italy, depending on solar activity, the season and universal time, is purposed. In the concluding part, this study also presents examples of the model`s performance in selected months. The resulting errors are respectively mean error ME=0.000km and root mean square error RMSE = 11.068km, which is accurate enough for practical purposes such a radio paths prediction. The choice of this ionospheric station is related to the fact that this station is located at the geographic latitude coinciding with the latitude of Sofia, which suggests similar characteristics of the ionosphere and applicability of the results for the territory of Bulgaria.

1. Introduction
The ionosphere is formed due to photoionization of neutral atmosphere by solar radiation and exhibits latitudinal, longitudinal, altitudinal as well as diurnal and seasonal variations. The behavior of the ionosphere depends on the geomagnetic field, geomagnetic activity and solar activity [1,2]. Nowadays, short-wave communications have been widely used in our daily life. The height of the peak electron density (hmF2) is very important for short wave communication. The changes in this quantity will directly affect the selection and design of parameters such as the radio wave radiation elevation and the working frequency band in short wave communication lines, and then affect the distance and efficiency of communication.

https://doi.org/10.48368/bgs-2023.1.N15

The basic aim of this study is the creation of an empirical model for forecasting the median height of the peak electron density depending on the month, hourof the day (UT)and the level of solar activity represented by solar radio flux F10.7. The proposed empirical model is synthesized on the basis of statistical processing of the data from the Rome-Italy ionospheric station for the period from 2000 to 2022. In the study, it was established that the dependence of the modeled quantity on solar activity at a fixed month and fixed universal time is close to linear. The diurnal behavior of hmF2 is represented by its Fourier decomposition up to the fourth harmonic. The constants of the model were determined according to the least squares method. The proposed model can have a practical application in predicting the propagation of radio waves with ionospheric reflection, in particular in determining the maximum and minimum usable frequency of radio communications at a given distance [3].

2. Data

The solar radio flux at 10.7 cm is a good indicator of solar activity. The F10.7 radio emissions originates high in the chromosphere and low in the corona of the solar atmosphere. In the present study solar activity is described by F10.7 and it is provided from: https://omniweb.gsfc.nasa.gov/. The data for the ionospheric station Rome -Italy (Station Code RO041, 41.9°N, 12.5°E), subject to this work, are taken from Global Ionosphere Radio Observatory (GIRO) https://giro.uml.edu/didbase/scaled.php. Ionospheric data from different types has wide application in geophysics and geodesy [4,5].

3. Variations in solar activity and monthly median values of the height of the peak electron density

This section presents comparisons of variations in solar activity (see Figure1) and monthly median values of hmF2. Comparing the two figures shows the influence of solar activity on the height of the peak electron density. The influence of solar activity is clearly seen in the median course shown in Figure 2. In 2008, which is a year of low solar activity, the median values of hmF2 are between 160 km and 310 km (see Figure 2, left panel). In 2001, the median hmF2 values were between 230 km and 380 km, which is typical of high solar activity years (see Figure 2, right panel). The next step is to find the optimal relationship between the two quantities through regression analysis.

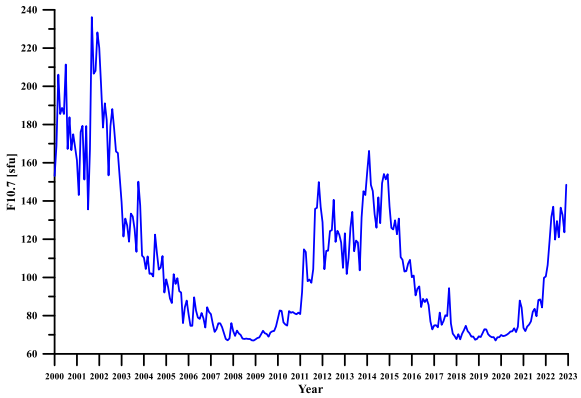


Figure 1. Behavior of the values of F10.7 by years for the entire considered period.

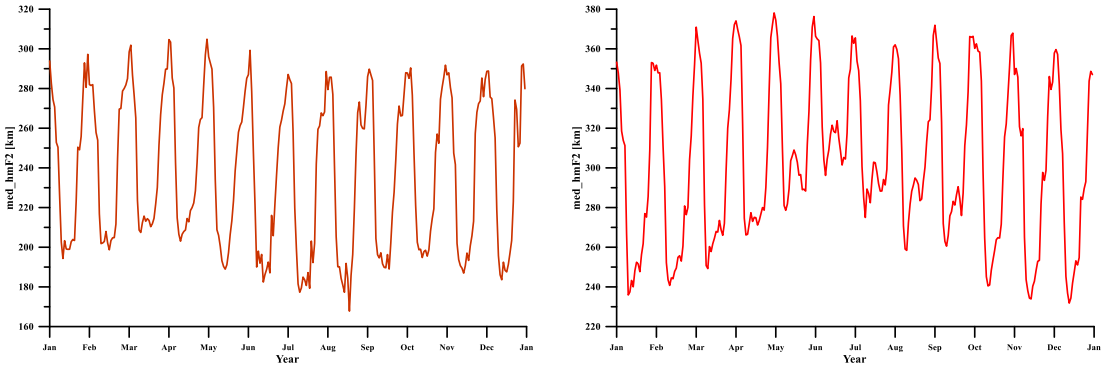


Figure2. Monthly median variability of hmF2 for ionospheric station Rom for two years of low solar activity 2008 (left panel) and high solar activity 2001 (right panel).

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4. Regression analysis to determine optimal dependence in model synthesis

In this part of the present work, the methodology for searching for the most appropriate dependence between the considered parameters is presented. Figure 3 shows the dependence of hmF2 values on F10.7 values for the months January (Figure 3, top row of panels) and June (Figure 3, bottom row of panels) at a fixed hour of day for all years in the interval 2000-2022. In all selected months and hours, the dependence is close to linear, as hmF2 increases with increasing solar activity. The given example (see Figure 3) also shows the different behavior depending on the season.

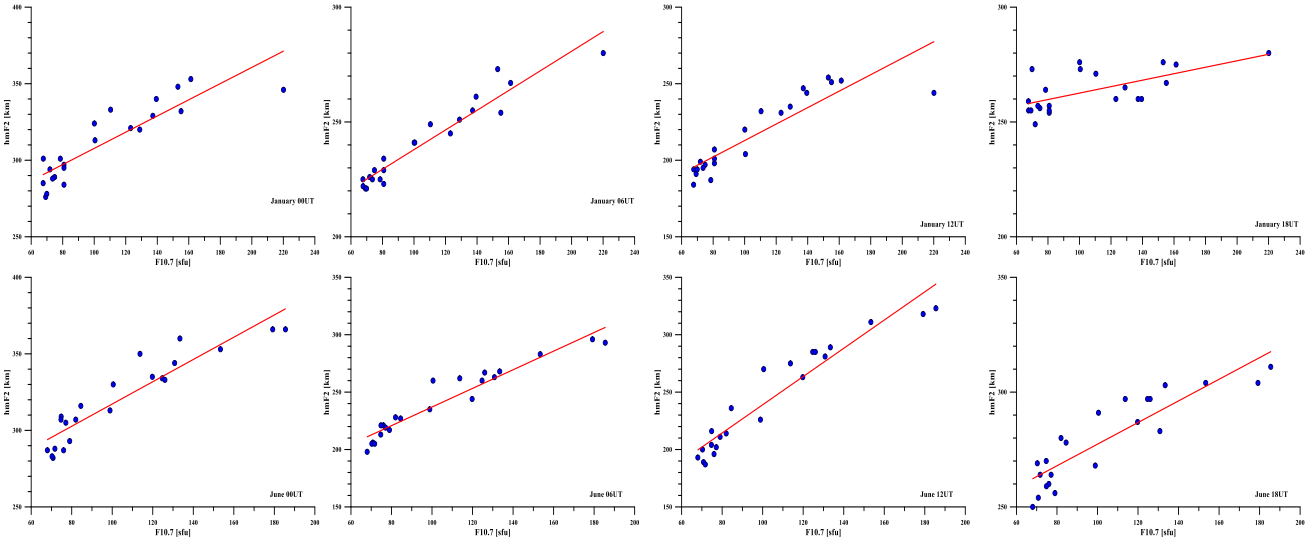


Figure 3. Regression analysis for selected hours of the day for a typical winter (January) and summer (June) month.

5. Synthesis of the model

Based on the linear dependence obtained between solar activity and the height of the peak electron density through regression analysis, a methodology for predicting the median values of hmF2 is proposed. The time scale of changes in solar activity is about 11 years, so it is much longer than the time scale of seasonal changes. Therefore, the dependence on solar activity is represented as an amplitude modulation of the seasonal behavior. After revealing the brackets, the empirical dependence takes the form of a multi-linear regression, which allows the constants of the model to be calculated by the method of least squares. Synthesis of the model is performed according to the following formula:

$$hmF2 = (a_0 + a_1 F107)\left(b_0 + \sum_{k=1}^{4}\left(b_{ck}\cos\left(k\frac{2\pi}{12}(month-1)\right) + b_{sk}\sin\left(k\frac{2\pi}{12}(month-1)\right)\right)\right)\times$$

$$\left(c_0 + \sum_{k=1}^{4}\left(c_{ck}\cos\left(k\frac{2\pi}{24}ut\right) + c_{sk}\sin\left(k\frac{2\pi}{24}ut\right)\right)\right)$$

6. Comparison between model and data

The following example shows a comparison that can show whether the created empirical model succeeds in generating the hmF2 values with good enough accuracy. Figure 4 shows a comparison between the medians, derived from measurements at ionospheric station Rome (RO041) and the obtained analogous values according to the proposed methodology for two years of high and low solar activity. The plots show that there is a satisfactory fit between data and model. Seasonal changes are clearly visible, as well as the influence of solar activity.

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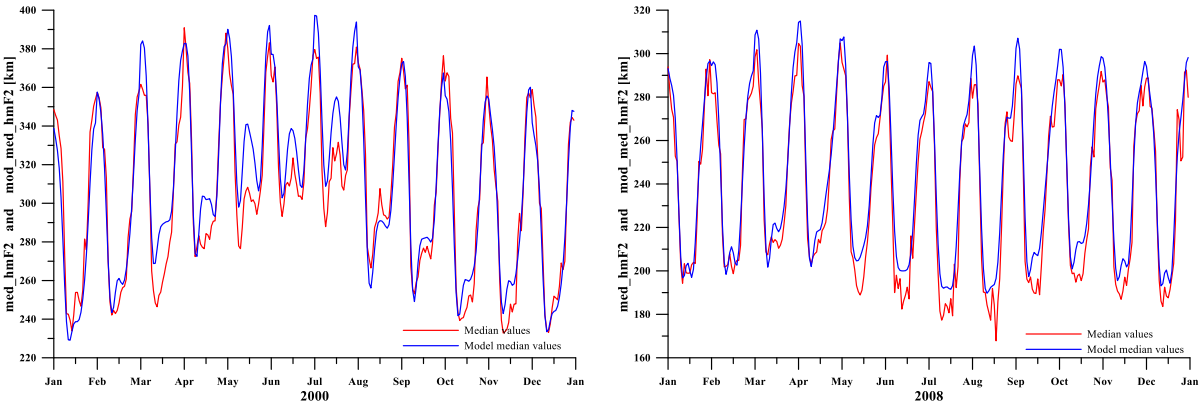


Figure 4. Comparison between measured and model-generated median values.

Conclusion

The methodology proposed in the present work for preparing an empirical model for forecasting the height of the peak electron density applies to any mid-latitude ionospheric station that has a sufficiently long series of measurements of the hmF2 quantity. For the specific station Rome-RO041, the model allows to predict hmF2 with an accuracy of about 11km. The measured values range from 180 to about 400 km, so the error has a negligible relative value. The choice of the Rome ionospheric station is related to the fact that it is located at a latitude coinciding with the latitude of Sofia, which supposes similar characteristics of the ionosphere and applicability of the results for the territory of Bulgaria. Using the presented empirical model, the currently offered forecast on the website of the National Institute of Geophysics, Geodesy and Geography can be improved [6-8]. The obtained results confirm that the proposed dependency sufficiently accurately manages to solve the tasks set by the Ministry of Defense and the practical needs of environmental technologies [9,10].

Acknowledgments Present work is supported by Contract No D01-164/28.07.2022 (Project "National Geoinformation Center (NGIC)" financed by the National Roadmap for Scientific Infrastructure 2020-2027 of Bulgaria. This work was partially supported by the Bulgarian Ministry of Education and Science under the National Research Programme “Young scientists and postdoctoral students - 2” approved by DCM № 206 /07.04.2022.

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