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FORECASTING THE CRITICAL FREQUENCIES OF THE IONOSPHERE OVER BULGARIA IN 2022

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Abstract. The present study aims to illustrate the work in real time and in the conditions of geomagnetic storm of the developed empirical model for forecasting the critical frequencies of the ionosphere for the territory of Bulgaria. The task of creating a methodology for determining the critical frequencies is the main activity after the completion of the work of the "Plana" ionospheric station for the vertical sounding. For this purpose, a team from Department of Geophysics at the National Institute of Geophysics, Geodesy and Geography (NIGGG) – Bulgarian Academy of Sciences developed a method for determining the critical frequencies of the ionosphere based on Total Electron Content (TEC) data. The methodology allows continuing the preparation and publication of forecasts for the radio wave propagation on the territory of Bulgaria, which are used by governmental institutions and are freely available to radio amateurs through the website of the NIGGG. In the present work, a comparison is made between the critical frequencies of the ionosphere obtained by TEC for Bulgaria and the data from the vertical sounding at Rome station (RO041, 41.9°N, 12.5°E). 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. The difference in local time is also reported. The comparison between the data of the Rome ionospheric station in and those determined according to the TEC data for Bulgaria shows that the deviations are close to those obtained in the comparison with the data of Plana ionospheric station for the period 1995-2014. The described results show that the created empirical model for reconstruction of the critical frequencies by TEC data on the basis of a previous period allows predicting the current state of the ionosphere even in the conditions of geomagnetic disturbances.

Key words: Geomagnetic activity, Ionosphere, Critical frequencies, Total Electron Content, Forecasting.

Introduction

One of the main tasks related to determining the parameters of a given radio path requires the knowledge of the most essential ionospheric characteristics obtained from the ionospheric stations by the vertical sounding of the ionosphere. Due to the absence of a station for vertical sounding of the ionosphere, an empirical model has been developed (Bojilova and Mukhtarov, 2021; Mukhtarov and Bojilova, 2021a), which allows to calculate estimated values of the critical frequency of the ionospheric F region (foF2) by TEC data (Mukhtarov et al., 2021b). The method published in (Bojilova and Mukhtarov, 2021) for determining the critical frequency of the ionosphere foF2 from TEC data is based on the linear-quadratic relationship between the two ionospheric characteristics established by regression analysis. The values of TEC (which is an integral of the electron concentration by height above a certain point on the Earth's surface) are formed predominantly at heights close to the height of the maximum electron density, which uniquely determines the critical frequency. This is the maximum radio frequency that is reflected by the ionosphere during vertical propagation of radio waves. For this reason, the relationship between TEC and foF2 values turns out to be sufficiently stable and allows the critical frequency of the F region to be calculated from the TEC data with accuracy acceptable for practical purposes. The features of the diurnal and seasonal variability of the values are reflected in the model.

By comparing the measured and modeled values for the period 1995-2014, it was found that the Root Mean Square Error (RMSE) of the model foF2 values is about 0.5 MHz (Mukhtarov and Bojilova, 2021a). It is well known that the main changes in the ionosphere are related to changes in solar extreme ultraviolet, ultraviolet radiation and geomagnetic activity. It is geomagnetic activity and geomagnetic storms that cause anomalies in the variations of the elements of the Earth‘s magnetic field (Metodiev and Trifonova, 2021). Also these effects cause anomalies both in the ULF RANGE (Chamati, 2020; Chamati 2021a; Chamati, 2021b) and not least in the ionosphere and the radio communication frequency range (Mukhtarov et al., 2011; Mukhtarov and Pancheva, 2012, Bojilova and Mukhtarov, 2020).

Everything described so far gives reason to make a comparative analysis, illustrating the reliability of the proposed methodology for reconstructing foF2 based on TEC data for Sofia and data from the vertical sounding of the ionosphere based on Rome data. 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 (Lakov et al., 2018; Ivanova et al., 2018, Syrakov et al., 2013; Gadzhev et al., 2015).

Data and methods

Due to the lack of vertical sounding data on the territory of Bulgaria, in the present study a comparison was made between the modeled values of foF2 over Bulgaria with those measured at the Rome station (RO041, 41.9°N, 12.5°E). A comparison of the coordinates of this station with the coordinates of the Plana station (SQ143, 42.6°N, 23.4°E) shows that the two stations have practically the same geographic latitude with a difference in longitude 10.9°. This means that the local times at these two stations differ by 44 minutes. When comparing hourly values, this difference can be taken as one hour. The data for the ionospheric station Rome (Station Code: RO041, 41.9°N, 12.5°E) are taken from the GLOBAL IONOSPHERE RADIO OBSERVATORY (GIRO) freely available to users at the following link: https://giro.uml.edu/didbase/scaled.php. Data from GPS satellite navigation has wide application in geophysics and geodesy (Vassileva and Atanasova, 2016; Василева и Атанасова, 2016; Atanasova et al., 2021). The data for the critical frequencies over Bulgaria are calculated by an empirical model from TEC (Bojilova and Mukhtarov, 2021; Mukhtarov and Bojilova, 2021a). To solve the task of forecasting foF2 according to TEC were used data from Center for Orbit Determination in Europe (CODE) - ftp://ftp.unibe.ch/aiub/CODE/. In the examples of geomagnetic storms shown, the Kp-index is received from: Goddard Space Flight Center: https://omniweb.gsfc.nasa.gov/.

Results

In the next few examples, various comparisons are made between the data for Rome and the reconstructed data for Sofia. The purpose of this analysis is to show that the proposed methodology for reconstructing critical frequencies based on TEC data for a given past period is sufficiently good and reliable for forecasting the ionosphere over Bulgaria in real time and during geomagnetic storms.

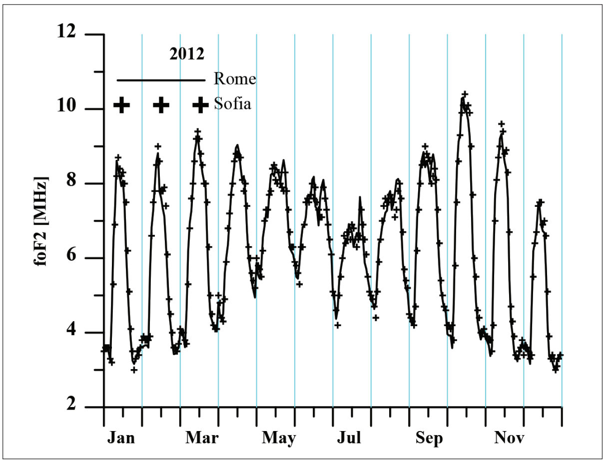

Fig. 1. Monthly medians of the critical frequency foF2 at stations SQ143 and RO041 for 2012.

Fig. 1 shows a comparison between the monthly hourly medians of the two stations for 2012. For the selected year, there are measured values from Rome- Italy and Sofia-Bulgaria. In the figure the data from Rome has been shifted by one hour, which approximately compensates for the difference in local times.

The year 2012 occupies approximately the same place in 24th Solar Cycle as 2022 occupies in the next one. As can be seen from Fig.1 the medians of the two stations are sufficiently close in value to justify the use of the Rome station data to estimate the prediction during 2022.

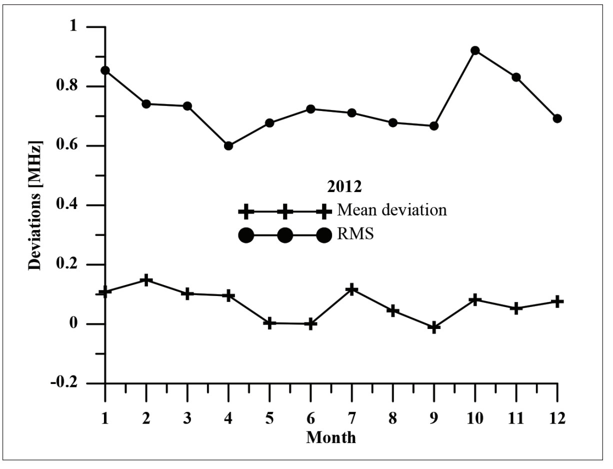

Fig. 2. Means and standard deviations between the data of stations SQ143 and RO041 for 2012.

Fig. 2 shows the mean deviation and RMSE between the SQ143 data and RO041 for each calendar month for 2012. It can be seen from Fig.2 that the mean deviation of the data from Bulgaria compared to the data from Rome for 2012 is 0.068 MHz and RMSE is 0.742 MHz. These deviations are calculated based on all hourly values for that year.

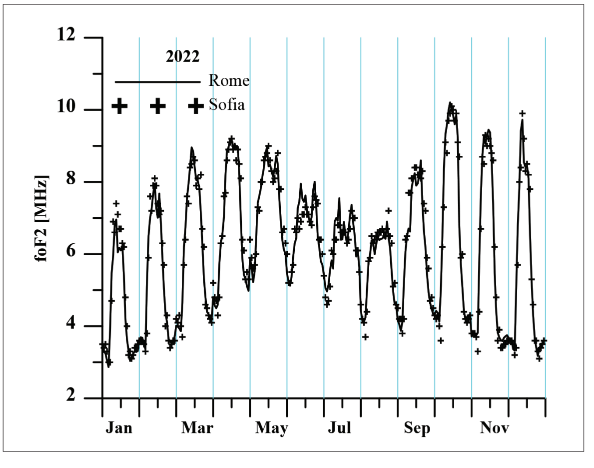

Fig. 3. Monthly medians of reconstructed critical frequency foF2 for Bulgaria and RO041 data for 2022.

Fig. 3 shows the behavior of the monthly hourly medians from the Rome ionospheric station and the reconstructed values for Sofia in 2012. The figure shows the good coincidence between the two data types. The monthly medians also show a distinct seasonal variability of foF2 characterized by lower values of critical frequencies in summer and their increase in winter conditions. The physical explanation of the obtained result is due to the so-call winter anomaly in the ionosphere. In particular, the winter anomaly is a phenomenon consisting in the fact that mid-latitude hourly median daytime foF2 value is greater in winter than in summer conditions at approximately the same solar activity level (Yasyukevich, et al., 2018).

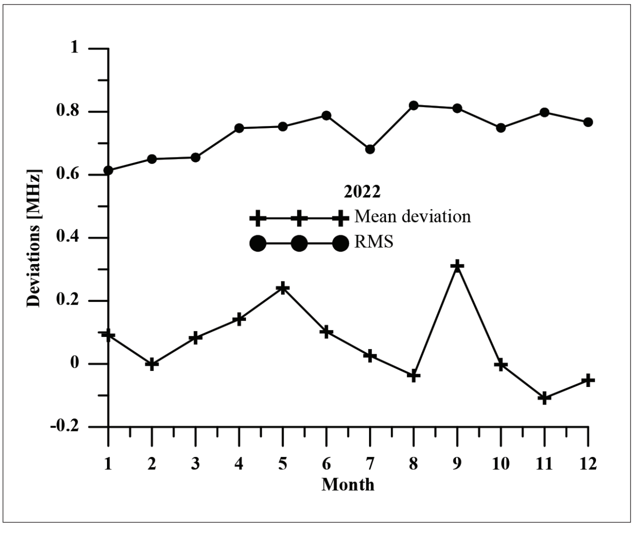

Fig. 4. Means and standard deviations between reconstructed critical frequency foF2 for Bulgaria and the measured data of RO041 for 2022.

Fig. 4 shows the behavior of the mean deviations and RMSE for each calendar month from 2022 for data from Rome and Sofia. The data for Sofia are model values derived from TEC. The mean deviation calculated on the basis of the hourly values is 0.069MHz, and RMSE is 0.741MHz. These values practically coincide with the analogous ones in 2012, which means that the deviations between the foF2 values for the two stations in both cases are dominated by the natural heterogeneity of the ionosphere and not by the inaccuracy of the reconstruction. The obtained acceptable errors give reason to analyze cases of geomagnetic storms as an additional conformation about the validity and significance of the proposed methodology for reconstructing the critical frequencies based on TEC data for the territory of Bulgaria.

The behavior of the reconstructed critical frequencies for Bulgaria compared to the critical frequencies measured in Rome during ionospheric disturbances from geomagnetic origin is shown in Fig. 5 and Fig. 6. The two disturbances in March 2022 (see Fig. 5)

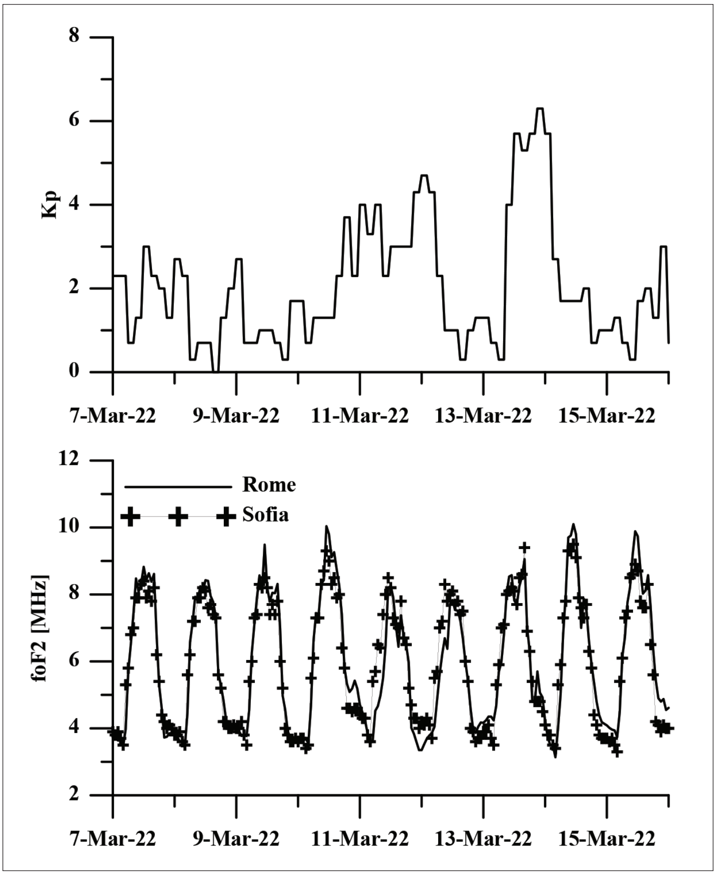

Fig. 5. Course of the reconstructed critical frequencies for Bulgaria and measured in Rome station from 7 to 15 March 2022.

and May 2022 (see Fig. 6) are relatively weak. During the first geomagnetic storm, the geomagnetic activity index Kp reaches 4 on 11 March and reached to 6 on 13 March (see Fig. 5 top panel). All this indicates that the considered geomagnetic storm is of Minor type. From Fig. 5 it follows that during the anomalies the deviation between the two types of ionospheric data increased. This phenomenon is explained in the first place by the different character of the variations in TEC and foF2 during such type of anomalies. As an integral quantity, TEC also depends on the behavior of the electron density above the maximum, which is inaccessible for vertical sounding of the ionosphere and where physical processes differ from those at lower heights (Mukhtarov and Pancheva, 2012). The different local time has an additional influence on the differences. It is well known that the ionospheric response to geomagnetic disturbances has a significant dependence on the local time (Mukhtarov et al., 2013).

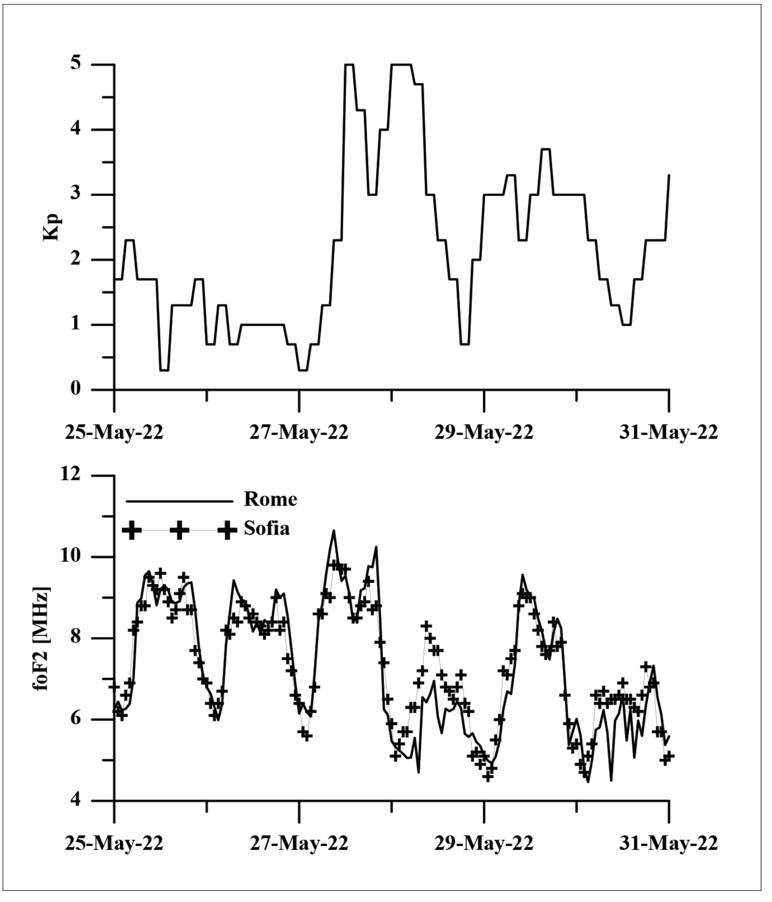

Fig. 6. Course of the reconstructed critical frequencies for Bulgaria and measured in Rome station from 25 to 30 May 2022.

In Fig. 6 shows a comparison of the behavior of the ionosphere based on data from Rome and reconstructed values for Sofia. The one shown in Fig. 6 critical frequency response illustrates the behavior of the two types of ionospheric data during the weak geomagnetic disturbance in summer conditions. From the top panel of Fig 6 it can be seen that the Kp index reaches to 5 on 27 and 28 May 2022. At the moment of the first maximum during 27 May, the critical frequencies begin to increase relative to the average, but subsequently there is a sharp decrease, which is essential for radio communications. In general, the response is predominantly negative, which is characteristic of the season during which the storm occurs. Analogous to Fig. 5 during the anomalies the deviations of both types of data increase.

Summary

In the present investigation, a comparison of the obtained model values of the critical frequency of the ionospheric F region for Bulgaria and the data of vertical sounding from the Rome ionospheric station is presented. The use of data from the Rome ionospheric station for control the forecasting of the ionosphere over Bulgaria is due to the fact that Rome station is the only nearby working station at geographic latitude coinciding with the territory of Bulgaria. The detailed analysis presented in the article of the values of the critical frequency foF2 reconstructed by TEC data for Bulgaria in 2022 shows that in the absence of data from vertical sounding of the ionosphere, the use of the empirical model for preparing radio wave propagation forecasts by TEC data is justified due to the accuracy sufficient for practical needs. A comparison of the resulting mean and RMSE errors shows that the values are of sufficiently good accuracy for practical purposes. From the comparison of the reconstructed data in 2022 with the data from the same type (by geographic location) station Rome. It is found that the differences are the same compared to the differences between the data from the vertical sounding in Sofia and Rome in 2012. The created model based on regression analysis between data from the vertical sounding and TEC for the period 1995-2014 turns out to be sufficiently accurate during the next 11-year cycle of solar activity. In addition, the behavior of foF2 during two geomagnetic storms in 2022 is considered. The presented comparison between the Rome data and the reconstructed Sofia data shows the good similarity and the clearly expressed seasonal response of the ionosphere under conditions of geomagnetic disturbances. All the obtained results show that the model created and published on the website of the National Institute of Geophysics, Geodesy and Geography for forecasting the critical frequencies based on TEC data for the territory of Bulgaria sufficiently accurately and satisfactorily manages to reconstruct and describe the behavior of the ionosphere above the country.

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References

Bojilova, R., and Mukhtarov, P., 2021. RECONSTRUCTION OF IONOSPHERIC CRITICAL FREQUENCIES BASED ON THE TOTAL ELECTRON CONTENT OVER BULGARIA. COMPTES RENDUS DE L ACADEMIE BULGARE DES SCIENCES, 74(1), 110-119.

Mukhtarov, P., and Bojilova, R., 2021a. Accuracy Assessment of the Ionospheric Critical Frequencies Reconstructed by TEC over Bulgaria. COMPTES RENDUS DE L ACADEMIE BULGARE DES SCIENCES, 74(2), 250-259.

Mukhtarov, P., Bojilova, R., and Andonov, B., 2021b. THE SECOND G3 (STRONG) GEOMAGNETIC STORM IN 25TH SOLAR CYCLE ON 3-4 NOVEMBER 2021. Bulgarian Academy of Sciences, 44, 43-52.

Metodiev, M., and Trifonova P., 2021. Geomagnetic Events Recorded in PAG Observatory During the First Year of Solar Cycle 25. 11th Congress of the Balkan Geophysical Society, Vol. 2021, 1, 1-5.

Chamati, M., 2020. ULF geomagnetic observation at Panagjurishte, Bulgaria as a tool for investigation of the magnetosphere-ionosphere-lithosphere system. Bulgarian Geophysical Journal, 43, 89-97.

Chamati, M., 2021a. SPECTRAL CHARACTERISTICS IN ULF RANGE OF GEOMAGNETIC STORM OBSERVED AT PANAGJURISTE, BULGARIA ON 27-28 SEPTEMBER 2017. Bulgarian Geophysical Journal, 44, 109-116.

Chamati, M., 2021b. ULF GEOMAGNETIC DISTURBANCES DUE TO MODERATE GEOMAGNETIC STORM AT PANAGJURISTE, BULGARIA. Bulgarian Geophysical Journal, 44, 53-59.

Mukhtarov, P., Pancheva, D., and Trifonova, P., 2011. Geomagnetic and Ionospheric Response to Recurrent Geomagnetic Activity at Middle Latitudes. Comptes rendus de l'Académie bulgare des Sciences, 64(10).

Mukhtarov, P., and Pancheva, D., 2012. Thermosphere–ionosphere coupling in response to recurrent geomagnetic activity. Journal of atmospheric and solar-terrestrial physics, 90, 132-145.

Bojilova, R., and Mukhtarov, P., 2020. Relationship between the Critical Frequencies of the Ionosphere over Bulgaria and Geomagnetic Activity. COMPTES RENDUS DE L ACADEMIE BULGARE DES SCIENCES, 73(8), 1113-1122.

Lakov, L., Jivov, B., Aleksandrova, M., Ivanova, Y., and Toncheva, K., 2018. AN INNOVATIVE COMPOSITE MATERIAL BASED ON SINTERED GLASS FOAM GRANULES. Journal of Chemical Technology & Metallurgy, 53(6).

Ivanova, Y., Partalin, T., Lakov, L., and Jivov, B., 2018. Airborne sound insulation of new composite wall structures. In MATEC Web of Conferences,145, 05013.

Syrakov D., Etropolska I., Prodanova, M., Slavov, K., Ganev, K., Miloshev, N., Ljubenov, T., 2013. Downscaling of Bulgarian Chemical Weather Forecast from Bulgaria region to Sofia city, American Institute of Physics, Conf. Proc. 1561, 120-132, http://dx.doi.org/10.1063/1.4827221

Gadzhev, G., Ganev, K., Miloshev, N., 2015. Numerical study of the atmospheric composition climate of Bulgaria – validation of the computer simulation results. Int. J. Environment and Pollution, 57, 3-4, Inderscience Enterprises Limited, DOI:10.1504/IJEP.2015.074503, 189-201.

Vassileva, K., and Atanasova, M., 2016. Earth Movements on the Territory of Bulgaria and Northern Greece from GPS Observations. Comptes rendus de l'Académie bulgare des Sciences, 69(11).

Василева, К., Атанасова, М., 2016. Определяне границите на тектонски зони за територията на България от GNSS данни. CD-VIII Национална конференция по геофизика, 25 Ноември 2016, 28-34

Atanasova, M., Nikolov, H., and Vassileva, K., 2021. APPLICATION OF GNSS AND SAR DATA IN LANDSLIDE MONITORING ALONG THE BLACK SEA COAST OF BULGARIA. Aerospace Research, 33, 87-100.

Yasyukevich, Y.V., Yasyukevich, A.S., Ratovsky, K.G., Klimenko, M.V., Klimenko, V.V. and Chirik, N.V., 2018. Winter anomaly in NmF2 and TEC: when and where it can occur. Journal of Space Weather and Space Climate, 8, A45.

Mukhtarov, P., Andonov, B., and Pancheva, D., 2013. Global empirical model of TEC response to geomagnetic activity. Journal of geophysical research: space physics, 118(10), 6666-6685.

Прогнозирането на критичните честоти на йоносферата над България през 2022

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Резюме: Настоящата работа има за цел да илюстрира работата в реално време и в условията на геомагнитни бури на разработения емпиричен модел за прогнозиране на критичните честоти на йоносферата за територията на България. Задачата за създаване на методика за определяне на критичните честоти е поставена след прекратяването на работата на йоносферната станция „Плана“ за вертикалното сондиране на йоносферата. За тази цел колектив от департамент „Геофизика“ при Националния институт по Геофизика, Геодезия и География (НИГГГ) към Българската академия на науките разроботи метод за определяне на критичните честоти на йоносферата по данни на тоталното електронно съдържание (TEC). Методиката позволява да бъде продължено изготвянето и публикуването на прогнози за разпространение на радиовълните на територията на България които се ползват от държавни органи и са достъпни за радиолюбители посредством Интернет страницата на НИГГГ. В настоящата работа е направено сравнение между определените посредством TEC критични честоти на йоносферата за България и данните от вертикалния сондаж в станция Rome (RO041, 41.9°N, 12.5°E). Изборът на тази йоносферна станция е свързан с това, че тя се намира на географска ширина съвпадаща с географската ширина на София, което предполага близки характеристики на йоносферата. Отчетена е и разликата в локалното време. Сравнението между данните на йоносферна станция Рим и определените по TEC данни за България показва, че отклоненията са близки до тези, получени при сравнението с данните на йоносферна станция Плана за периода 1995-2014 г. Описаните резултати показват, че създаденият емпиричен модел за реконструиране на критичните честоти по данни на TEC на базата на предходен период позволява да се прогнозира и актуалното състояние на йоносферата дори и в условията на геомагнитни смущения.