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ASSIMILATION CAPABILITIES OF THE IRI-PLAS MODEL

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Summary. Climatological models of the ionosphere are median and, when used in real time, should adapt to the parameters of current diagnostics. Modern ionospheric models IRI and IRI-plas allow for assimilation to the main parameters of the ionosphere (critical frequency foF2 and maximum height hmF2). The IRI-plas model additionally allows for assimilation to the total electron content TEC. In this paper, this assimilation is used to plot the latitudinal dependence of foF2 during the disturbances in March 2012 at the meridian 15˚ E in the range 30˚- 80˚ N because TEC bears the information on the disturbed condition. The results are compared with foF2(IRI) and with frequencies reconstructed using observational TEC values and an equivalent slab thickness τ, for which a polynomial latitudinal dependence was plotted using data from five ionosondes located along the meridian. IRI-Plas always gives better results than IRI. For latitudes exceeding 45° N, deviation |ΔfoF2(Plas)| varies from 0.6 MHz to 0.2 MHz with increasing latitude, for IRI, it is almost constant (~0.5 MHz), the relative deviations for foF2(Plas) decrease from 10% to 5%, for foF2(IRI), they are almost constant around 10%. A noticeable increase is observed at low latitudes. The constructed successive latitudinal dependences of foF2(Plas) show day-to-day variations that are in good agreement with the behavior of foF2 in individual latitudinal zones noted in separate papers. The advantage of the IRI-plas model is that it takes into account the plasmaspheric part of the TEC. Estimates of the topside and plasmaspheric parts are given for different latitudes, showing the conditions under which the plasmaspheric part cannot be neglected.

1 INTRODUCTION

In studies of the ionosphere, empirical models play no less a role than experimental data. The most common is the IRI model [1], which describes well the behavior of such parameters as the critical frequency foF2 and the maximum height hmF2. The model allows assimilation of these parameters while adapting to the data of the current diagnostics. But in connection with the appearance of navigation satellites and the measurement of the total electron content TEC, the IRI-Plas model has appeared, which allows the assimilation for the TEC [2]. This can provide great advantages in studying the behavior of the ionosphere, in particular, of the parameter foF2, during disturbances along the meridians. One of the possible approaches is assimilation of the IRI-Plas model to the latitudinal dependence of TEC. To test this approach, it is proposed to use the network of ionosondes along the meridian. The ionosonde data at each point is used to calculate the equivalent slab thickness τ of the ionosphere, and from its values at these points, a polynomial latitudinal dependence of τ is constructed. This latitudinal dependence of τ is used to calculate the reconstructed foF2(rec) values which serve to compare with the foF2(Plas) values obtained by assimilation of the TEC into the IRI-Plas model. An additional comparison is made with the reference IRI model.

The main concept of the paper is: the climatological ionospheric IRI-Plas model is adopted for the instantaneous observational TEC values to obtain the latitudinal behavior of foF2 during disturbances along the meridian unlike other works.

2 OBSERAVATIONAL DATA AND MODELS

In the present paper, data of foF2 for five stations was taken on the SPIDR website. These stations have coordinates: Longyearbyen (78.2°N, 15.9°E), Tromso (69.7° N, 19° E), Juliusruh (54.6°N, 13.4°E), Pruhonice (50°N, 14.6°E), Rome (41.9°N, 12.5°E). The foF2(IRI) values of the IRI model were calculated online by using the website (http://omniweb.gsfc.nasa.gov/vitmo/iri2016_vitmo.html). The original and assimilated values of the IRI-Plas model were calculated online by using the website (http://www.ionolab.org/index.php?language=en). The TEC values were calculated for the global GIM JPL map from the IONEX files on the website (ftp://cddis.gsfc.nasa.gov/pub/gps/products/ionex/) with a step of 2 hours in the range from 30° N up to 80° N with step 2.5°. These values are substituted into the IRI-Plas model and the foF2(Plas) values are calculated. To assess the efficiency of assimilation, two coefficients are introduced: η(TEC) = TEC(obs)/TEC(Plas) and η(foF2) = foF2(rec)/foF2(Plas). In the latitudinal course, the relative error can be defined as (1-1/η)*100%. The IRI-Plas model allows calculating different parts of TEC: the bottom side ECbot, the topside ECtop and the plasmaspheric ECpl. The observational values TEC(obs) and foF2(obs) of five ionosondes were used to calculate values of a median τ(med) which serve to construct a latitudinal dependence of τ in the form of a polynomial for all latitudes in the chosen range. Then the observational values TEC (obs) in all points of a meridian were used to calculate a latitudinal dependence of the reconstructed frequencies foF2(rec). As the time period, the March 2012, containing some magnetic storms was chosen. One period (on March, 7-17th) has been recommended by SCOSTEP [3]. The second (on March, 21-31) was added for comparison because it represents an interesting case of a magnetic storm against amplified TEC.

3 ASSIMILATION OF TEC FOR THE IRI-PLAS MODEL

First of all, the reconstructed frequencies foF2(rec) are calculated for comparison with observational frequencies and frequencies of the IRI model. To calculate foF2(rec), the equivalent slab thickness of the ionosphere τ=TEC/NmF2 is used. Unlike other works using τ(IRI) of the IRI model (e.g. [4]), in the present paper the median of an observational thickness τ(med) is used [5]. Using τ(med) for five ionosondes, the latitudinal dependence of τ(med) is constructed by means of a polynomial. Differences between dependences for two approaches are shown in Figure 1 for several UT hours (0, 6, 12, 18). The local time is UT+1.

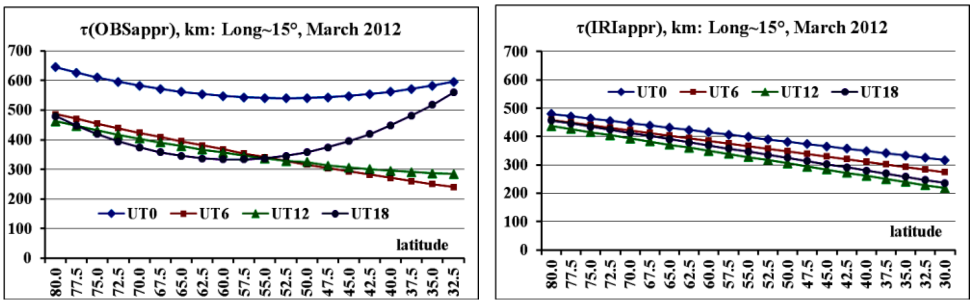

Figure 1: Latitudinal dependences of τ(obs) and τ(IRI) for Longitude ~ 15˚ E

The differences are noticeable at night and in the evening. Further, these dependences are used to reconstruct values foF2(rec). Correspondence of foF2(IRI) and foF2(rec) with the observational values is resulted in the Table 1.

station	Longyear	Tromso	Julius	Pruhon	Rome	mean
|ΔIRI|	0.6	1.1	1.05	0.99	0.96	0.95
|Δrec|	0.44	0.7	0.36	0.32	0.34	0.43

Table 1: Correspondence between calculated and observational values of foF2

The Table shows, that the reconstructed values foF2(rec) can be used as an equivalent reference between stations along a meridian. However, meridians along which are located ionosondes, are very little and it is necessary to have a method of foF2 definition from observational TEC on meridians where are not present ionosondes. For this purpose, it is proposed to use assimilation of TEC in the IRI-Plas model. Efficiency of assimilation is estimated by two coefficients η(TEC)=TEC(obs)/TEC(Plas) и η(foF2)= foF2(rec)/foF2(Plas), where TEC(Plas) and foF2(Plas) are values after assimilation for each hour of each day. Examples are given in Figure 2 for low-latitude, middle-latitude and high-altitude points along a meridian. The first plots show conformity between observational and model TEC after the assimilation, the second plots give relations of η of parameters, the third - conformity of foF2 values.

One can see latitudinal dependences of both the values themselves and the correspondence between the model and experimental values. All η decrease with increasing latitude. The IRI model showed good agreement, but the IRI-Plas model better reflects the nature of the disturbances. These results show that the assimilated IRI-Plas model can be used for an estimation and studying of behavior of the ionosphere during disturbances.

Figure 3 presents statistical estimations for TEC and foF2. The first plot gives the averaged over all hours and all days, the absolute deviation of the assimilated TEC in TECU units and the relative deviation in % depending on latitude. The second graphs give the averaged over the same days absolute deviation of the parameter η from 1. The lower graphs compare the absolute and relative deviations of the calculated foF2 from the experimental values.

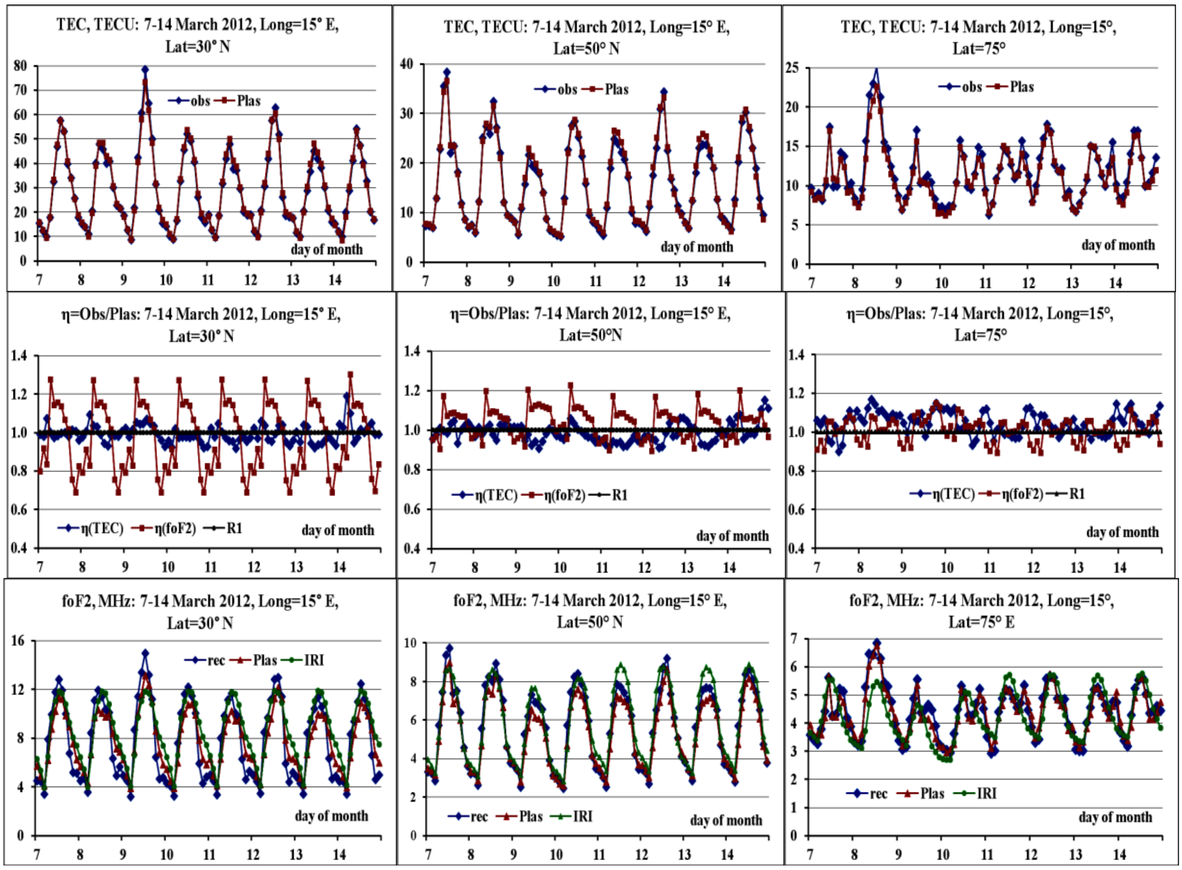

Figure 2: Results of the TEC assimilation for the IRI-Plas model

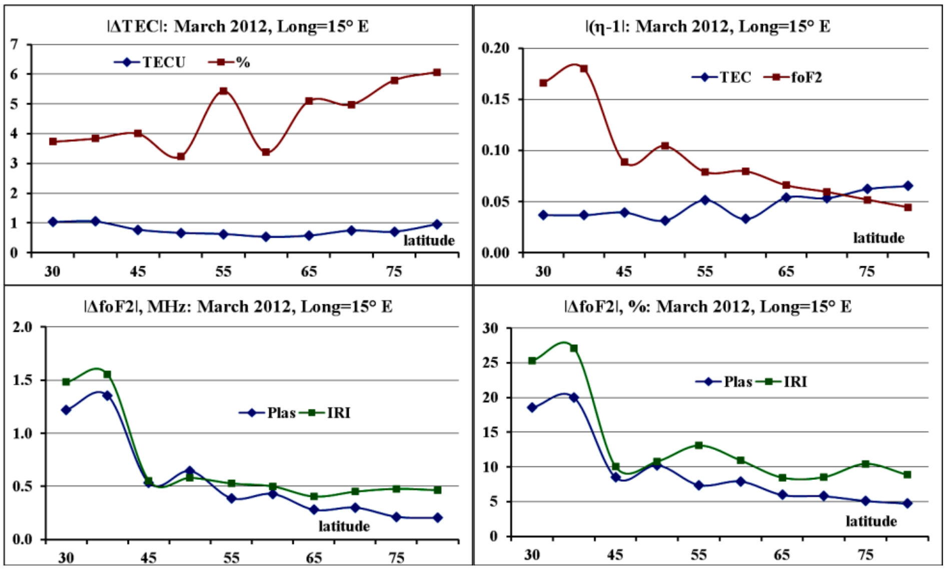

Figure 3: Statistics of the TEC assimilation for the IRI-Plas model

Results show that the IRI-Plas model yields satisfactory results at middle and high latitudes. For the zone of low latitudes, an additional study of the reasons for the discrepancies is necessary, although it is quite obvious that they can be related to the shape of the N(h) - profile in the topside ionosphere.

4 LATITUDINAL DEPENDENCE OF PARAMETERS

Figure 4 shows the latitudinal dependences of TEC and the critical frequencies calculated from them for all days of the selected disturbances.

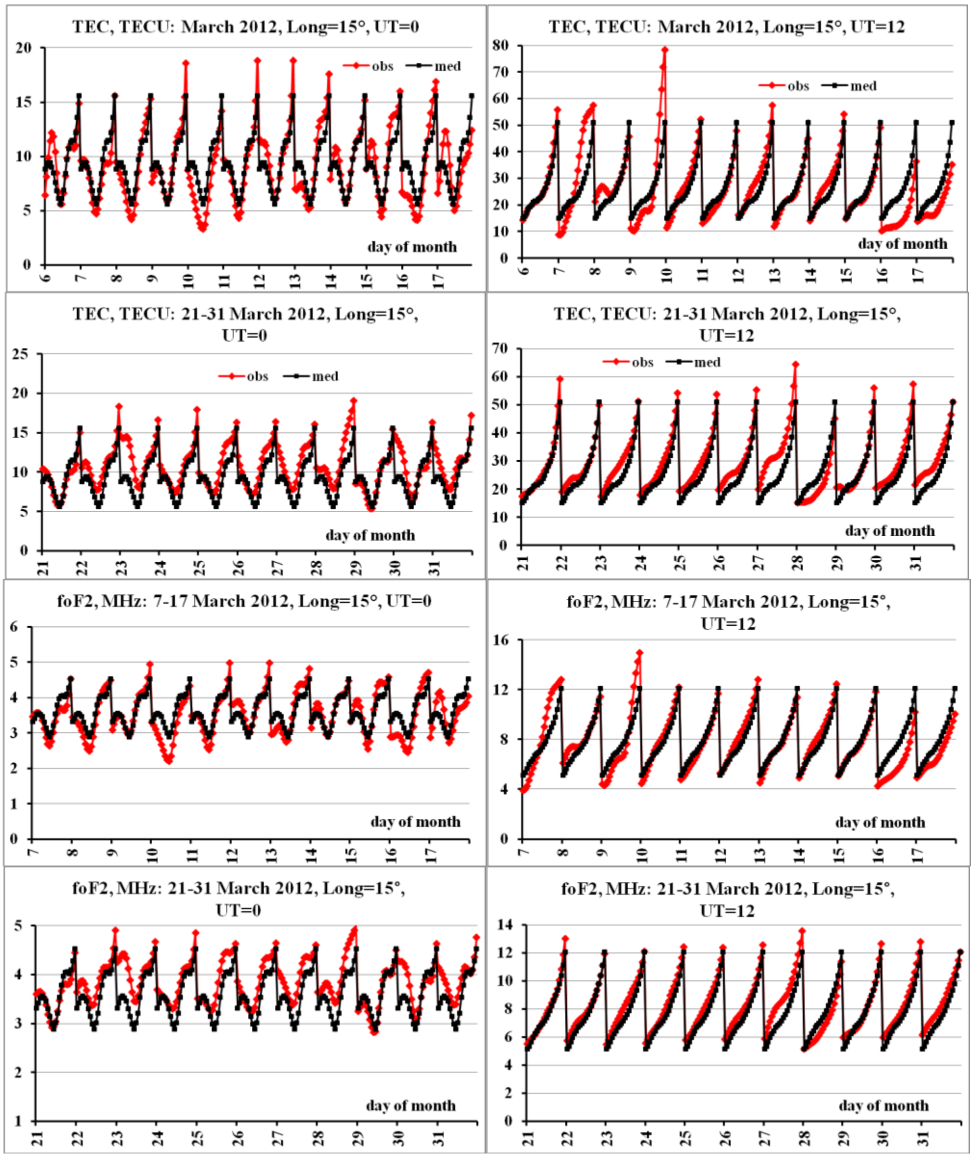

Figure 4: Behavior of TEC and foF2 during two disturbed period

The red curves show the frequency behavior on any given day compared to the black curves that represent monthly medians. Each curve contains 21 points, each of which refers to a particular latitude in order from high to low latitudes: 80° N to 30° N. Each set consists of nighttime and daytime latitudinal dependences of TEC and foF2 for the first period on March 6-17, 2012 and the second period on March 21-31, 2012. In the first period, one can see such behavior features as the expansion and deepening of the ionization trough, the transition from the negative phase of the disturbance at high latitudes to the positive phase at low latitudes, and a long recovery phase. In the second period, at all times, positive disturbances are observed. A careful study of each curve should make it possible to concretize the mechanisms of perturbations using the results of other observations that prevail at the particular latitudinal zones.

5 ADDITIONAL POSSIBILITIES OF THE IRI-PLAS MODEL: THE PLASMASPHERIC CONTRIBUTION

Advantage of the IRI-Plas model is the account of the plasmaspheric part of N(h) -profile as in it the profile is integrated to height of GPS satellites (an order of 20,000 km) whereas the profile into the IRI model is integrated only to 2000 km. However traditional practice of comparison and studying TEC is connected with the IRI model in the private assumption, that the contribution of the plasmaspheric part is small. The IRI-Plas model allows one to define this contribution. Plots of Figure 5 give contributions of the basic topside part and the plasmaspheric part for several latitudes in % to the total TEC.

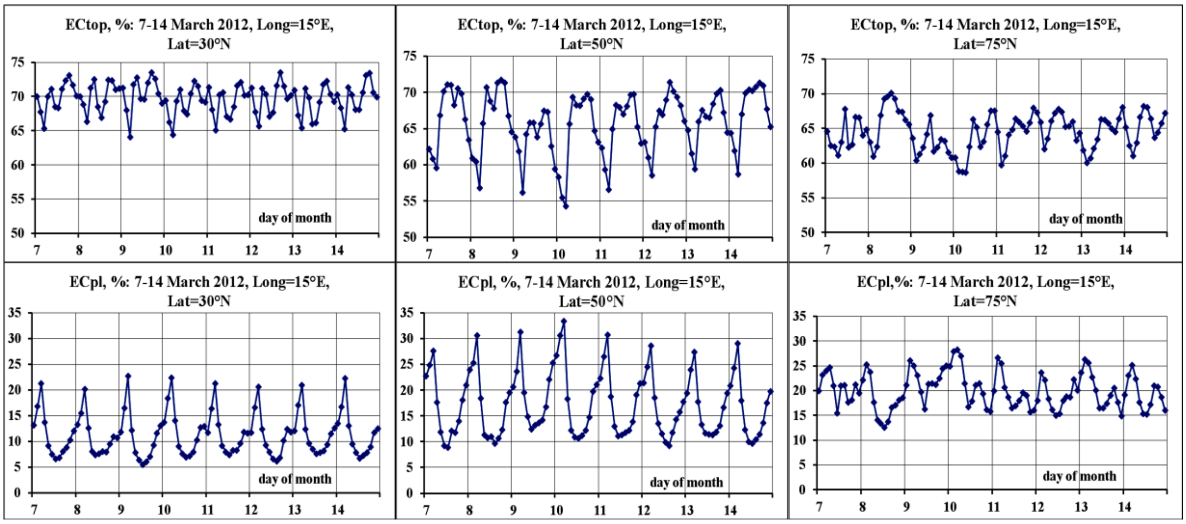

Figure 5: Contributions of the topside and plasmaspheric parts in % to the total TEC for several latitudes

Diurnal variations and variations associated with disturbances can be seen. Figure 2 showed how strongly the response of the ionosphere depends on latitude. In the first period, the maximum positive disturbance was observed on March 9 at 30° latitude, March 7 at 50° latitude, and March 8 at 75 ° latitude. Negative disturbances were observed on March 11, 9 and 10, respectively. That is, there is a constant redistribution of ionization. Figure 5 shows that the plasmaspheric part plays the maximum role at middle latitudes, but it cannot be neglected anywhere, although in the daytime at low latitudes it is small, but in the morning hours it can reach a quarter of the total content.

6 CONCLUSIONS

This paper presents the results of TEC assimilation into the IRI-Plas model. Quantitative estimates are as follows. The absolute TEC deviations were in the range of 0.5-1 TECU, the relative deviations were in the 3.5-6 % range and increased with increasing latitude. For foF2, an additional comparison with the IRI model is given. IRI-Plas always gives better results than IRI. For latitudes exceeding 45° N, |ΔfoF2(Plas)| varies from 0.6 MHz to 0.2 MHz with increasing latitude, |ΔfoF2(IRI)| is almost constant (~ 0.5 MHz), the relative deviations for foF2(Plas) decrease from 10% to 5%, for foF2(IRI), they are almost constant around 10%. A noticeable increase is observed at low latitudes. Despite the fact that the difference between the results of IRI-Plas and IRI is not great, it should be noted that IRI-Plas reflects the nature of disturbances much better because instantaneous TECs include the response of the ionosphere to disturbances. The constructed successive latitudinal dependences of foF2(Plas) show day-to-day variations that are in good agreement with the behavior of foF2 in individual latitudinal zones noted in separate papers. Thus, this approach can be used to study variations in foF2 during disturbances on the meridians not provided by ionosondes.

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