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Comparison of TEC Prediction Methods in Low Latitudes with GIM Maps

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Abstract: For the high-latitude part of the low-latitude region, the errors in determining the TEC from the data of Rostov and Ankara stations in 2015 were estimated. The estimates obtained for the IRI-Plas model turned out to be better than for the NeQuick model, with an average absolute error in the range of 3-3.6 TECU, a relative RMS error in the range of 21-27% which is acceptable for use in positioning systems. For a short-term forecast, the best results were obtained by the Standard Persistence Model with an average absolute error in the range of 1.95-2.5 TECU, a relative RMS error in the range of 17-21%. For the proposed method, these estimates were 2.04–2.5 TECU and 12–14%.

Keywords: Ionosphere, Total electron content, Models, Prediction, Disturbance

Introduction

Low latitudes are one of the areas where there are few ionosondes that provide information on the state of the ionosphere necessary for the operation of various communication systems using a critical frequency. With the advent of GPS, GLONASS navigation satellites, on the one hand, it became possible to study the behavior of the total electron content TEC of the ionosphere, providing even more complete information, on the other hand, there is a need for modeling and prediction of TEC. There are a number of global models of ionospheric parameters, such as the International Reference Ionosphere IRI, IRI-Plas, NeQuick, and others that could be used in areas where there are no ionosondes and GPS receivers. But these models must be tested in each such local area. In this work, testing is carried out according to the data of Rostov and Ankara stations, which can be attributed to the high-latitude part of the low-latitude zone. This region needs testing, which is confirmed by a number of papers (e.g., Arikan et al., 2007). For testing, GIM maps are used (Hernandez et al., 2009), which are the most comprehensive database. A comparison is made for the IRI-Plas and NeQuick models. Despite the fact that the IRI model is the most used, no comparison is made for it. Firstly, there are a lot of papers on such a comparison, and secondly, such a comparison is not entirely correct due to the difference in the upper boundary of the TEC definition: for the IRI model, it is 2,000 km, for GPS satellites, 20,200 km. IRI-Plas and NeQuick models provide a long-term forecast. No less important role is played by short-term forecasting methods. For a short-term forecast, are compared the Standard Persistence Model (SPM), a 27 day median model, considered in (Badeke et al., 2018), and the proposed method for 1 day in advance, using data from 2015.

Experimental Data and Models

As experimental data the values of global maps JPL GIM-TEC calculated from IONEX files from steps of 2 hours (ftp://cddis.gsfc.nasa.gov/pub/gps/products/ionex/), for 2015 for stations Juliusruh (54.6 °N, 13.4 °E), Rostov (47.2 °N, 39.7 °E) and Ankara (39.89 °N, 32.76 °E) were used. Calculations of TEC with use of models IRI-Plas and NeQuick were carried out in online on websites: http://www.ionolab.org/index.php?language=en and https://t-ict4d.ictp.it/nequick2/nequick-2-web-model.

Comparison of Long-Term TEC Results for 2015

Figure 1 compares IRI-Plas and NeQuick for three stations and 2015 with global JPL maps for medians and deviations from them.

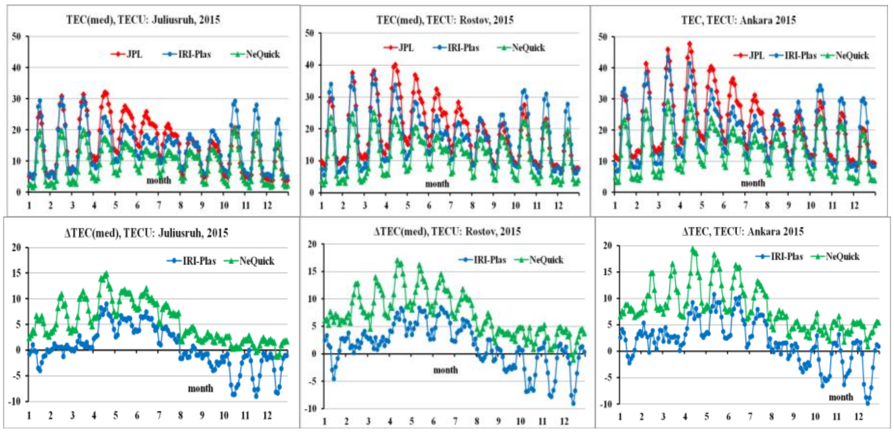

Figure 1. Comparison of TEC values calculated by different methods (upper part) and their deviations from observational medians (lower part) for three stations in 2015

One can see that values of TEC increase with decreasing latitude, however the seasonal variation of values is similar: maximum in March-May, minimum in August-September. The NeQuick model always underestimates values (ΔTEC> 0). The IRI-Plas model underestimates values in the first eight months, then starts to overestimate. Quantitative estimations are given in Table 1 for absolute and relative deviations.

Table 1. Model accuracy comparison in 2015 for JPL map

	|ΔTEC|, TECU		σ, TECU		σ, %	
	IRI-Plas	NeQuick	IRI-Plas	NeQuick	IRI-Plas	NeQuick
Juliusruh	3.04	5.49	3.96	6.7	26.79	45.30
Rostov	3.39	7.14	4.16	8.15	22.02	43.17
Ankara	3.59	8.15	4.48	9.15	20.77	42.39

It can be seen that the deviations increase with decreasing latitude, although the relative deviations decrease with decreasing latitude due to large values. The results for the NeQuick model are almost 2 times worse than for the IRI-Plas model. This does not correspond to the global results of the work (Okoh et al., 2018), in which at low latitudes the best results were obtained for the NeQuick model.

Comparison of short-term TEC results for 2015

This section compares the results of methods such as SPM, Med, presented in (Badeke et al., 2018), with the results of the proposed method according to TEC for three stations in 2015. A brief description of the proposed method is as follows. The annual sequence of TEC contains values for every 2 hours (in accordance with the availability of experimental data) of each day for all months. This sequence is approximated on each 27-day interval by samples representing the decomposition for each day in accordance with the formula $y_{ij} = A_j * \sin(\omega_{i-1}\Delta t * (i-1)) + B_j$, where A_j is the harmonic amplitude and B_j is the constant component for every day. ω is selected based on the spectrum of the 27-day observation. The coefficients A_j and B_j are found by the least squares method. The first stage of the method work, the approximation of the TEC sequence, is illustrated by y_{ji} samples in Figure 2. The horizontal axis represents the day of the 27-day period. The blue rhombuses show the observational values, the red circles concern the approximation results.

The approximation accuracy depending on the period ranged from 0.5 TECU to 3.5 TECU with a relative RSME of 4 to 20%. The average annual accuracy was 1.49 TECU for Juliusruh station, 1.63 TECU for Rostov station, 1.63 TECU for Ankara station. The corresponding average RSMEs are 11.04, 9.66 and 8.36%.

Then, for each period, the decomposition spectra for each day are found, examples of which for the 10th 27-day period for three stations are shown in Figure 3.

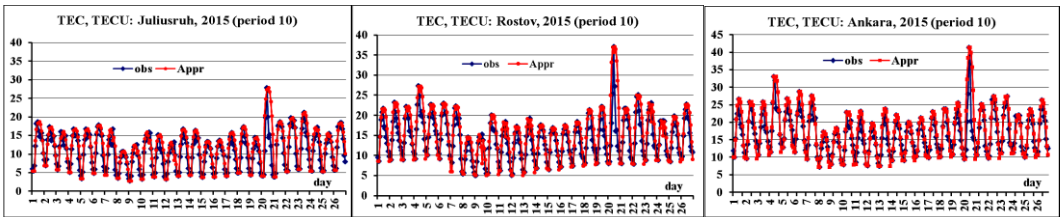

Figure 2. The results of the approximation of the TEC sequence for the 10th period

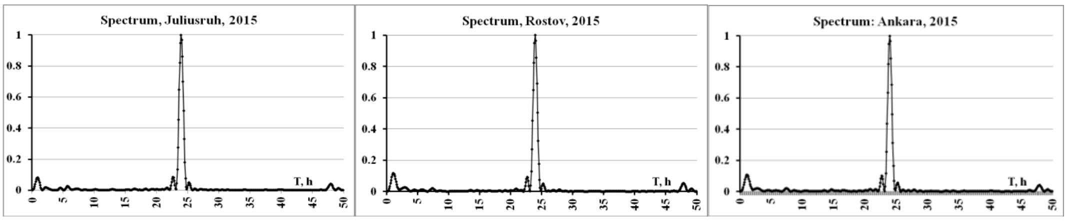

Figure 3. The decomposition spectra of the TEC sequence for the 10th 27-day period

The spectrum for Ankara is similar to two another. An example of a forecast is given in Figure 4. Observational TEC values (obs icon), 27-day medians (med icon), predicted values (pred icon), and forecast errors (Err) are presented.

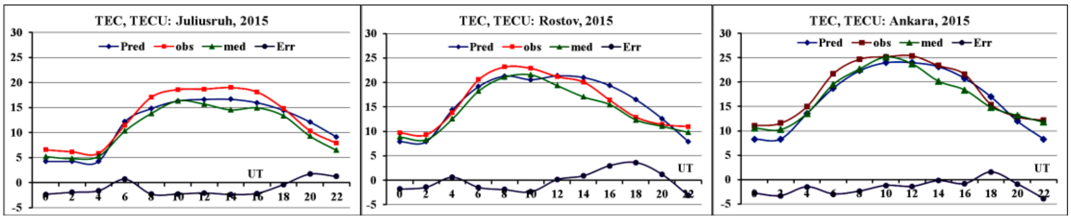

Figure 4. Example of forecast for the day following the 10th 27-day period

A comparison of the forecast accuracy for the three stations is given in Table 2 for the SPM method, for using the median (Med), and for the proposed method (Pred).

Table 2. Annual accuracy statistics of various forecast methods in 2015

	|ΔTEC|,TECU			σ, %		
2015	Pred	SPM	Med	Pred	SPM	Med
Julius	2.04	1.95	3.10	14.07	21.03	20.87
Rostov	2.19	2.14	3.38	12.01	17.80	17.54
Ankara	2.48	2.48	3.72	11.58	17.56	16.73

These results should be compared with data of (Badeke et al., 2018), which can be presented as Table 3.

Table 3. Statistical results of comparing short-term forecast methods

database	SPM	MediMod	Fourier	NTCM-GL
SWACI	2.75	2.86	2.81	4.0
UPC	2.66	3.15	3.28	4.73

It can be seen that in both tables the SPM model gives the best result, while the climatological model gives the worst result. This even coincides with the results of the paper (Lean, 2019), in which a statistical model for forecasting TEC at time scales Δt exceeding 1 day was developed. In (Lean, 2019), is shown that the SPM model gives better results than the new and climatological models, with Δt = 1. The average absolute error varies from 2.5 to 3.2 TECU with a relative RMSE error of 16 to 20%. In our case, the absolute and relative errors are less. Moreover, these deviations are smaller than those provided by the IRI-Plas and NeQuick models, shown in the Table 1. It should be noted that in contrast to (Badeke et al., 2018), quiet days were not selected. This allows us to reveal the dependence of the predicted values on the index Dst, which is chosen to characterize the disturbed conditions. Figure 5 shows the predicted values for Ankara station along with the Dst index, reduced by 10 times. Correlation coefficients for each period are also given.

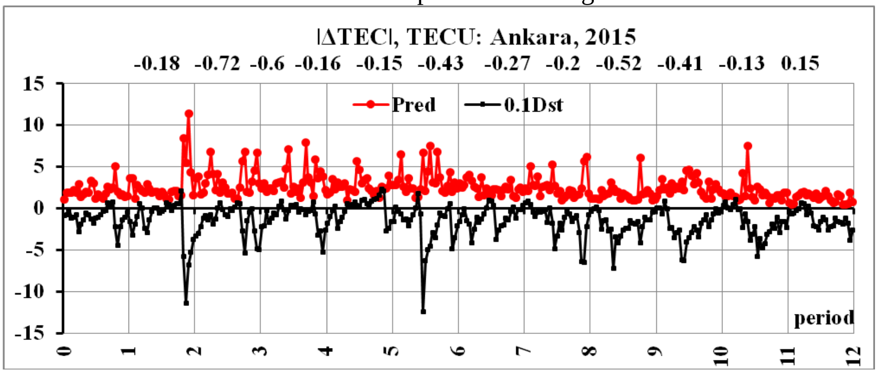

Figure. 5. The behavior of the predicted values of |ΔTEC| for all periods under consideration

For the Juliusruh station, the correlation coefficients for the periods were -0.13, -0.77, -0.47, -0.15, 0.14, -0.39, -0.1, -0.34, -0.1, -0.25, 0.02, 0.37, for Rostov -0.26, -0.8, - 0.47, -0.08, -0.02, -0.44, -0.38, -0.27, -0.57, -0.32, -0.09, 0.27. The values for Rostov and Ankara are close, also the graphs are similar. The average annual values of the correlation coefficients were -0.25, -0.36 and -0.34 for the stations Juliusruh, Rostov and Ankara, respectively. It can be seen that there are practically no quiet periods and the correlation is negative. The forecast for disturbed days is much worse than on quiet days. Apparently, in the future it will be necessary to switch to the forecasting scheme for the Dst index and, accordingly, adjusting the TEC values.

Conclusion

For the high-latitude part of the low-latitude region, the errors in determining the TEC from the data of Rostov and Ankara stations in 2015 were estimated. It is shown, that results of global model can differ from results in local area. The estimates obtained for the IRI-Plas model turned out to be better than for the NeQuick model, and are acceptable for use in positioning systems. TEC database for a specific receiver allows using the Standard Persistence Model as a short-term forecasting method. The proposed method provides the results no worse, while the relative errors are significantly reduced. It is important to notice, that accuracy of the forecast for this zone is close to results for the middle-latitude zone which are the etalon.

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References

Arikan, F., Arikan, O. & Erol, C. B. (2007). Regularized estimation of TEC from GPS data for certain midlatitude stations and comparison with the IRI model. *Advances in Space Research, 39, 867–874.*

Badeke, R., Borries, C., Hoque, M. M. & Minkwitz D. (2018). Empirical forecast of quiet time ionospheric Total Electron Content maps over Europe. *Advances in Space Research, 61, 2881-2890*.

Hernandez-Pajares, M., Juan, J. M., Sanz, J., Orus, R., Garcia-Rigo, A., Feltens, J., Komjathy, A., Schaer, S. C. & Krankowski, A. 2009. The IGS VTEC maps: a reliable source of ionospheric information since 1998. *Journal of Geodesy, 83, (3–4), 263–275*.

Lean, J. L. (2019). One-to 10-day forecasts of total electron content using a statistical model. *Space Weather, 17, 2, 313-338*.

Okoh, D., Onwuneme, S., Seemala, G., Shuanggen, J., Rabiu, B. Nava, B. & Uwamahoro J. (2018). Assessment of the NeQuick-2 and IRI-Plas 2017 models using global and long-term GNSS measurements. *Journal of Atmospheric and Solar-Terrestrial Physics, 170, 1–10*.

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