

Comparison of GPS TEC with modelled values from IRI 2016 and IRI-PLAS over Istanbul, Turkey

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Abstract The Total Electron Content (TEC) prediction performances of the empirical IRI model and IRI-PLAS model were investigated by comparing the GPS-based TEC values provided by the IONOLAB group. TEC values were obtained on equinox (March 21 and September 23) and solstice (June 21, and December 21) days in low (2009), medium (2012) and high (2015) solar activity periods at Istanbul, Turkey. The prediction performances of the models were statistically analyzed based on the differences between the GPS-TEC and the empirical models, considering the maximum and minimum deviations, the correlation analysis and the root mean square error (RMSE). As a result of the investigation, it is seen that the empirical models have similar predictive performances when the plasmaspheric effects are neglected, and the IRI-PLAS estimations are generally a little closer to the observed GPS-TEC values than all options of IRI-2016 model. Also, it can be said that “IRI2001”, one of the IRI-2016’s “topside” options, can make better predictions than other options and “IG” solar proxy option of IRI-PLAS model is a more appropriate option than the others in TEC calculations over Istanbul, Turkey.

Keywords IRI model · IRI-PLAS model · Mid-latitude ionosphere · IONOLAB-TEC

1 Introduction

The ionosphere, which is a partially ionized region of the upper atmosphere located at a height of ~50 km and

~1000 km from the surface of the Earth, is a natural plasma that undergoes the action of various forces resulting from above effects, such as solar-generated ionizing precipitations (Amin 2015; Basu et al. 2001; Laštovička 2006; Yiğit et al. 2016; Yiğit and Medvedev 2015), energetic particles and solar wind, the electric field generated by the interaction of magnetosphere and ionosphere, and from below effects, such as, internal atmospheric waves, lightning discharges, earthquake, etc. (Atıcı et al. 2016; Atıcı and Sağır 2017; Bittencourt 2013; Çetin et al. 2017; Laštovička 2006; Pasko et al. 1997; Pulnits et al. 2000; Sağır et al. 2015). Since the ionosphere has significant effects on long-range radio waves, it is necessary to constantly observe the uncertainties in the ionosphere for ionospheric-based applications; such as communication, navigation, and surveillance systems to work more efficiently. The most basic parameter to observe these irregularities in the ionosphere is the electron density. TEC value, which provides important information about the structure of the electron density in the ionosphere and which used in ionospheric studies in recent years, represents the sum of the electrons in the ray path between the satellite and the receiver. TEC value has great importance for many areas, including space-based observation systems, communication systems, navigation and space weather investigations (Alçay et al. 2017; Doherty et al. 2004; Fagundes et al. 2016; Karatay et al. 2017).

TEC values can be obtained through GPS-based measurement methods as well as empirical models. Among these empirical models, IRI, which is the most extensive and intensively used model, provides many ionospheric parameters such as the ion density (O^+ , H^+ , He^+ , N^+ , NO^+ , O^{+2} , Cluster ions), equatorial vertical ion drift, vertical ionospheric electron content (VTEC) (Bilitza 2001; Bilitza et al. 2017, 2012, 2011). Since IRI-model provides the ionospheric parameters up to 2000 km, it will not accurately

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predict the TEC up to GPS satellites located in altitude of 20,200 km. To solve this problem it is necessary to extrapolate the ionosphere up to the GPS satellite height of IRI-model (Alçay et al. 2017; Gulyaeva 2003). For this purpose, IRI-PLAS model has been proposed to expand IRI model to the plasmaspheric heights (Gulyaeva 2003). IRI-PLAS model provides many ionospheric parameters, also including TEC, with an internet interface offered by the IOBOLAB-group at www.ionolab.org.

The accuracy of estimates of empirical models in each region depends on the availability of reliable data for that region. Because of the lack of experimental data measurement on Turkey, located in the mid-latitudes, the prediction ability of empirical models about ionospheric environment in this region can be low. Recently, the performance of empirical models has been studied by some researchers. Zakharenkova et al. (2015) compared the TEC data derived from the mid-latitude GPS station with the IRI-2012 and IRI-PLAS TEC data (Zakharenkova et al. 2015). As a result, they found that IRI-PLAS model overestimated the TEC values, especially during low and medium solar activity years. They also stated that the reason for the differences in estimations of IRI-2012 and IRI-PLAS is related to the representation of the topside of the ionosphere used in these models. Arikan et al. (2015) reviewed the performance of IRI-PLAS maps by comparing it with the Global Ionospheric Maps (GIM) on a magnetically active day. As a result of the investigation, they observed that the global distribution of TEC is very different due to the effects of geomagnetic disturbances (Arikan et al. 2015). Maltseva et al. (2015) compared the performance of IRI-PLAS and Neustreliz Global Model (NGM) in VTEC estimation at different geographical regions. They found that VTECNGM and VTECIRIPLAS provided better results than VTECIRI at medium and high latitude regions. In addition, their results show that IRI-PLAS model predicts better than NGM in the winter months (Maltseva et al. 2015). Ezquer et al. (2018) compared the TEC estimations of NeQuick 2 and IRI-PLAS models with TEC values obtained by GPS over low-latitude and South American region. The predictive performances of IRI-PLAS and IRI-2007 models are also compared. Ezquer et al. (2018) stated that, at low latitudes, IRI-PLAS model made better predictions, on the other hand, at high latitudes, NeQuick model made better predictions (Ezquer et al. 2018). Alçay et al. (2017) compared the TEC estimation performance of IRI-2012 and IRI-PLAS models at different parts of the world, and they showed that there is good correlation between GPS-TEC and Model TEC on quiet days (Alçay et al. 2017). Ansari et al. (2017) studied ionospheric TEC changes obtained from the International GNSS System (IGS) and from the Turkey' Permanent GNSS Network (TPGN) during 2015. As a conclusion of their observations, the seasonal ionospheric VTEC pattern at all stations indicated a slight

increase in March equinox compared to September equinox. They also noted that a relatively higher VTEC was obtained on solstice of December, in compared to the solstice of June (Ansari et al. 2017). Especially in recent studies investigating the ionospheric disturbances on Turkey (Karatay et al. 2017), ionospheric changes were examined by using TEC forecast obtained from regional GPS network during periods of equinox and solstice. They were stated that the reduction in TEC distributions occurs at noon due to the mid-latitude winter anomaly in the central region of Turkey, in which charge diversity exhibits during the winter months for a minimum of SSN. They were also stated that TEC values and ionospheric changes show more significant increases on solstice days than equinox periods.

The aim of this study is to compare the IRI-PLAS and IRI-2016 models in terms of their topside performances on equinox (March 21 and September 23) and solstice (June 21 and December 21) days of three years, namely 2009, 2012 and 2015, using the GPS-TEC values obtained over Istanbul, Turkey.

2 Materials and methods

2.1 Obtaining TEC values from IRI model

The IRI model is a joint initiative undertaken by the Space Research Committee [COSPAR] and the International Radio Science Association [URSI] to develop an international standard for parameters in the world ionosphere (Bilitza et al. 2014). This effort was initiated because of the need for an ionosphere for satellite / experiment design and satellite data analysis [COSPAR] and radio propagation studies [URSI], but at the same time it has found a much wider range of users with respect to space weather (Bilitza et al. 2017). The IRI model has three different topside options for TEC estimations: NeQuick, IRI01-corr and IRI2001. NeQuick is the standard IRI option in these options and automatically used in the internet interface. In this study, TEC values for the three topside options of IRI-2016, the latest version of the IRI, were obtained during the equinox and the solstice days in low, middle and high solar activity years of 24th the solar cycle. When the TEC values were obtained from the IRI-2016 web site at https://omniweb.gsfc.nasa.gov/vitmo/iri2016_vitmo.html, the Ne topside option was only changed from the options in the internet interface. Other options were stable in the case of IRI-2016 as the standard.

2.2 Obtaining TEC values from IRI-PLAS model

Many approaches have been proposed for extending IRI to the plasmasphere, including The Global Core Plasma

Model (GCPM-2000), the Global Plasmasphere Ionosphere Density (GPID), the IMAGE/RPI plasmasphere model and the IZMIRAN plasmasphere model (Gulyaeva and Bilitza 2012). The IRI-PLAS model is an expanded version of the IRI, proposed by the International Organization for Standardization (ISO) to extend the IRI model up to plasmaspherical altitudes (Gulyaeva and Bilitza 2012; Gulyaeva et al. 2002). It can find the software of the IRI-PLAS model and the source code at <ftp://ftp.izmiran.ru/pub/izmiran/SPIM/>. In addition, the IONOLAB working group offers an online data acquisition service that can obtain many ionospheric parameters including TEC from the <http://www.ionolab.org/iriplasonline/index.php> web address. In the present study, TEC values were obtained by IRI-PLAS from the above web address for the same conditions as IRI-2016.

2.3 Obtaining GPS TEC data by IONOLAB-TEC model

IONOLAB-TEC provides accurate, reliable and robust GPS-TEC estimation at high latitude, medium latitude or equatorial GPS stations with the same reliability and accuracy on both quiet and active days (www.ionolab.org) (Arikan et al. 2008; Nayir et al. 2007; Sezen et al. 2013). The current version of IONOLAB-TEC, which can be used online or downloaded as *.exe from www.ionolab.org, can estimate the GPS-TEC at the temporal resolution of any RINEX file. Therefore, if the data in the RINEX file is 1 s or 30 s, IONOLAB-TEC can produce the same temporal resolution. However, in order to reduce the computational burden in the analyzes, time period of 2.5 minute was used because this temporal resolution was sufficient to indicate the temporal change in the TEC (Karatay et al. 2017). In this study, GPS-TEC values were obtained from the internet site www.ionolab.org provided by the IONOLAB group.

2.4 Statistical analysis

The relationship between the TEC values obtained by the above-mentioned models and the GPS-TEC values was investigated by means of a correlation analysis. In addition to the correlation analysis, the maximum and minimum deviations of the data obtained by subtracting the model TEC values from the GPS-TEC were also examined.

Besides, error calculation was performed to determine how much the TEC values, obtained from the models, differed from the GPS-TEC values. The following equation was used to calculate this deviation:

$$\text{Error}\% = \frac{(\text{TEC}_{\text{Model}} - \text{TEC}_{\text{GPS}})}{\text{TEC}_{\text{GPS}}} \times 100 \quad (1)$$

Here $\text{TEC}_{\text{Model}}$ expresses both the TEC values obtained by three different topside options of IRI-2016 and TEC values obtained by IRI-PLAS. TEC_{GPS} shows GPS based TEC

values obtained by IONOLAB TEC estimation method. To compare statistically models' prediction errors and evaluate this observation, it is calculated the Root Mean Square Error (RMSE) of the variables using the following expression:

$$\text{RMSE} = \left[\sum_i^N (\text{TEC}_{\text{Model}_i} - \text{TEC}_{\text{GPS}_i})^2 / N \right]^{1/2} \quad (2)$$

3 Results

In the present study, the relationship between both TEC values obtained by empirical models (IRI-2016 and IRI-PLAS) and the TEC values obtained by GPS was statistically investigated. Examination was performed for Turkey' Istanbul geocentric coordinates (40.91°N, 29.01°E), called as "ista" station in International GNSS System (IGS) network. This study was conducted during the equinox and solstice days, where solar activity is low, medium and high. The GPS-TEC value refers to the sum of the electron contents of the two regions, being the ionospheric total electron content (IEC) and the plasmaspheric total electron content (PEC), namely $\text{GPS-TEC} = \text{TEC}_{\text{IEC}} + \text{TEC}_{\text{PEC}}$. To make a more accurate comparison of the obtained TEC values, it is necessary to subtract the plasmaspheric effects from the GPS-TEC data. In this context, the PEC values (from 1336 km to 20,200 km) obtained by the IRI-PLAS model were subtracted from the GPS-TEC values and the plasmaspheric effects in GPS-TEC were neglected. Similarly, the TEC values obtained by IRI-2016 model were also calculated up to 1336 km. Thus, a comparison of both empirical and experimental TEC values was made more accurately. TEC values were obtained at time intervals of 15 minutes on each day of data received.

The changes of TEC values obtained during equinox days in three solar activity periods (low, medium and high) were shown in (a)–(f) panel of Fig. 1. The daytime distribution of IRI-2016's three different topside options, IRI-PLAS and GPS-derived TEC values are generally similar. The lowest TEC values for equinox days were obtained at low solar activity, as expected, while the highest TEC values were obtained at high solar activity. It is seen that the TEC values obtained by both IRI-2016 and IRI-PLAS are larger in March equinox than in September equinox. In addition, the GPS-TEC values in March equinox are also greater in September equinox, excluding September 23, 2012. It can be said that the TEC estimations of IRI-PLAS model are generally higher than GPS-TEC for low and medium solar activity years on equinox days, except for September 2012. The TEC values obtained by the three different topside options of the IRI-2016 model are close to the GPS-TEC values on both equinox days in 2009. However, the TEC predictions of IRI-2016 model are higher than GPS-TEC on the March equinox and are lower than GPS-TEC on the September equinox in

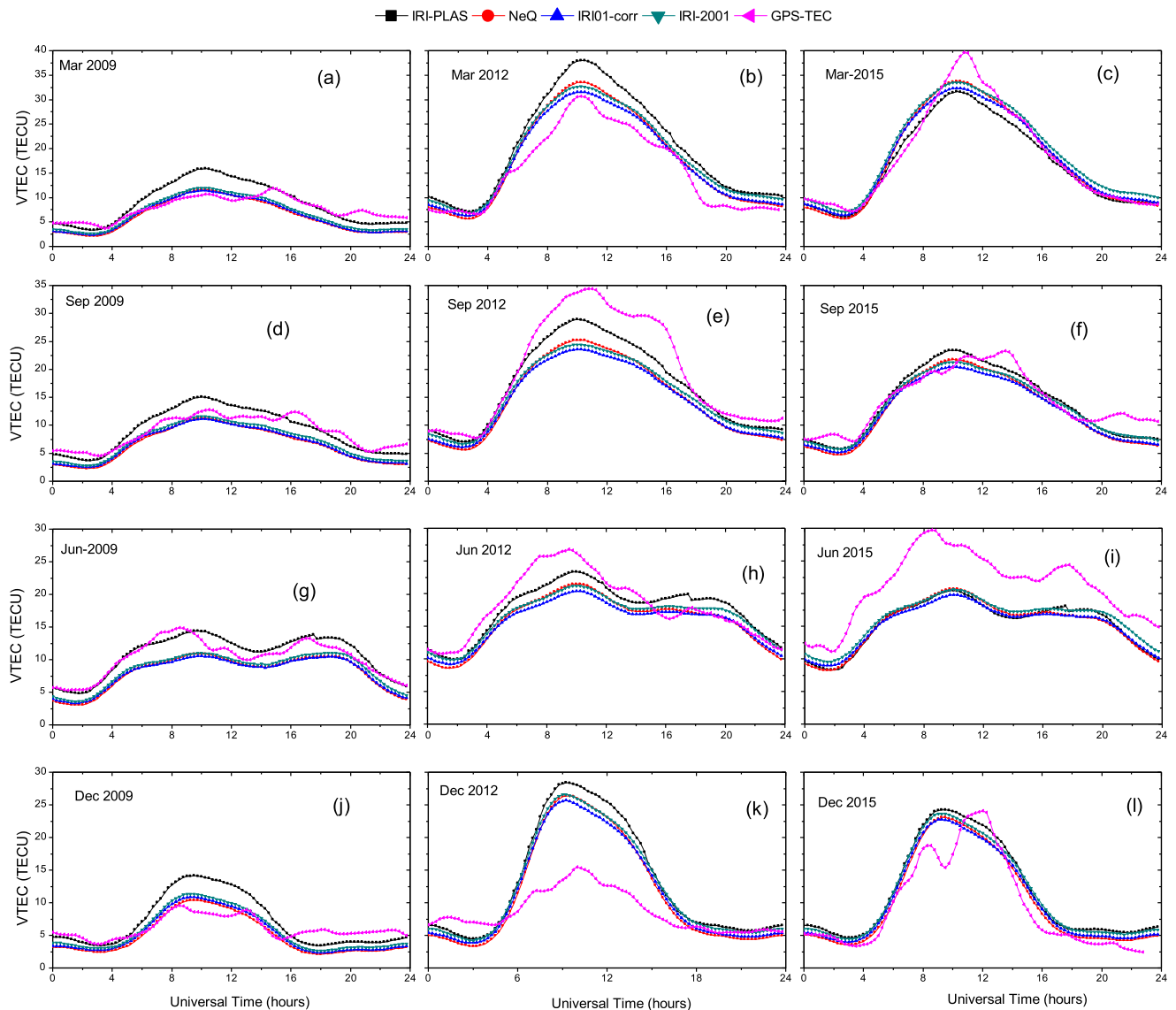


Fig. 1 Daily changes on equinox and solstice days of TEC values obtained by GPS and by the empirical models for low, medium and high solar activity periods. (a)–(f) panels of the figure illustrate the TEC

changes on equinox days, while (g)–(l) panels of the figure show the TEC changes on solstice days

the time periods of about 06–18 UT in 2012. In 2015, both IRI-2016 and IRI-PLAS model TEC estimations are close to GPS-TEC values. The greatest difference (11.24 TECU) between GPS-TEC and model calculations on equinox days for the reviewed years was obtained by the IRI01-corr topside option of the IRI-2016 model on September 23, 2012.

The TEC values estimated by IRI-2016 and IRI-PLAS and measured by GPS for the 2009, 2012 and 2015 solstice (21 June and 21 December) were shown in (g)–(l) panels of Fig. 1. It is seen that the TEC values obtained by the IRI-2016 model for three different topside options are generally lower than the GPS-TEC values on the June solstice in every three years. TEC values obtained by IRI-PLAS model are similar to GPS-TEC values in low and medium solar activity

years. It is seen that the GPS-TEC values are higher than the TEC values obtained by both models at every hour in June 2015. TEC values obtained by IRI-2016 model are close to GPS-TEC values on December solstice in 2009 and 2015. On December 21, 2012, the models seem to overestimate TEC values between ~06–17 UT.

It can be said that the TEC estimations of IRI-2016 model are close to GPS-TEC values while IRI-PLAS model overestimates the TEC values in 2009, when the solar activity was low, especially up to 16:00 UT, except for June 21. In March 2012, it can be said that IRI-PLAS model estimates generally higher than GPS-TEC values, except for between 00:00–05:00 UT, whereas IRI-2016 model predicts generally closer to GPS-TEC values. Model estimations between

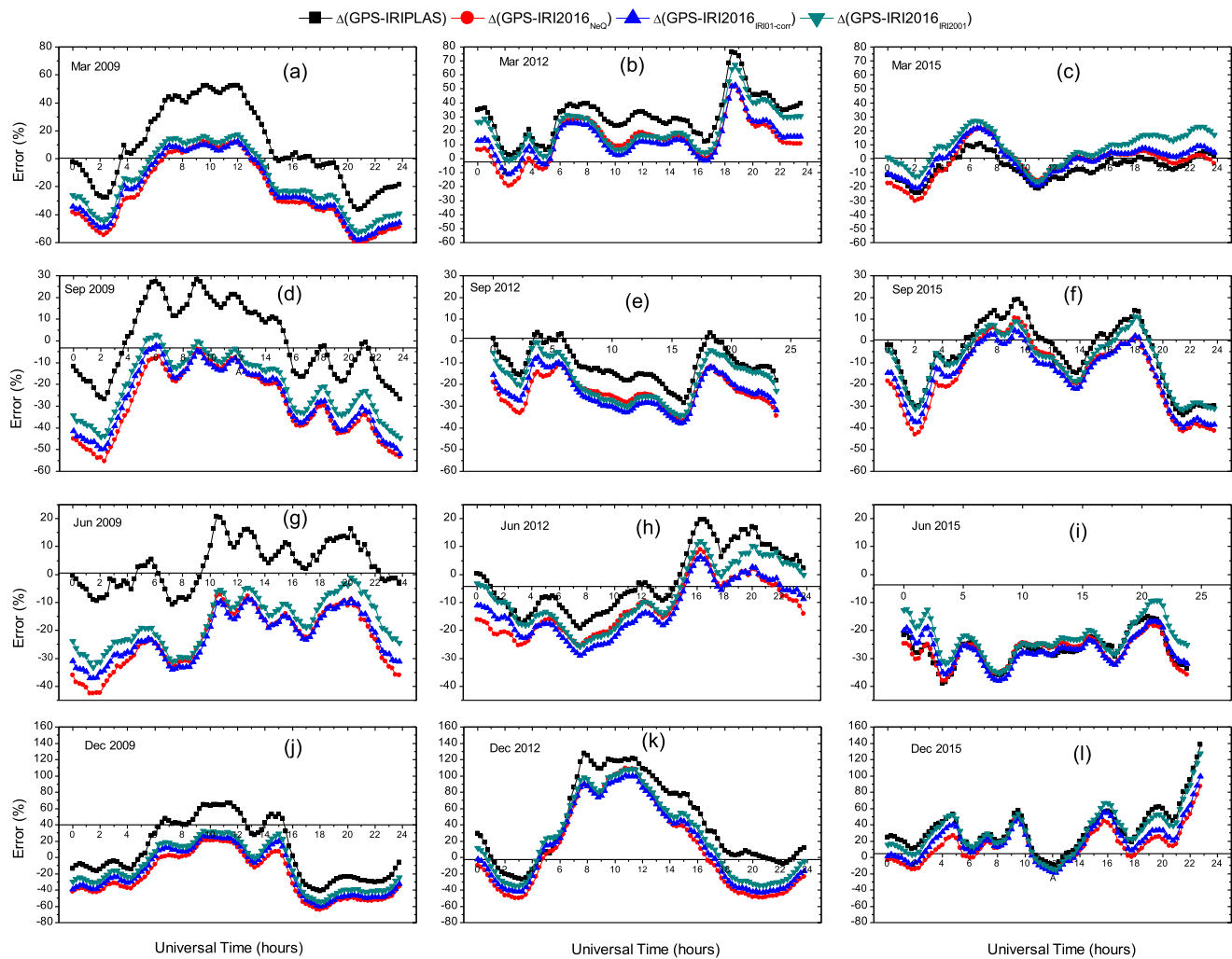


Fig. 2 Error representation of estimated TEC values by empirical model. (a)–(f) panels show the errors percentages on March and September equinox, while (g)–(l) panels demonstrate on June and December solstice for the same solar situation as the one in Fig. 1

06:00–18:00 UT time period in September 2012 are lower than GPS-TEC values, but models' predictions are similar in other time periods in 2012. While the TEC estimations of the models until midnight on 21 June 2012 are lower than the GPS-TEC values, the changes in both model and GPS-TEC values after noon are almost the same. In December 2012, except for between 00:00–06:00 and 18:00–24:00 UT, both models overestimate to the TEC values. In 2015, when high solar activity takes place, TEC estimations of the models on all days, except June 21, are close to the GPS-TEC values. TEC values obtained by the models are smaller than the GPS-TEC values at each hour of the day on June 21, 2015.

The error percentages from the GPS-TEC values of the TEC values obtained from the models in this study were obtained by Equation (1) and shown in Fig. 2. The models' TEC estimation performances were examined in three different solar activity periods. When Fig. 2 is examined, it

can be said that the models are estimated as low as 60% to the TEC values at certain times (00:00–06:00 UT and 15:00–23:00 UT) of day in the March equinox in 2009, while they predict as high as 50% at other times. In 2012 March equinox, the models generally estimate higher than GPS-TEC values. The maximum error is about 19:00 UT for all models. In 2015 March equinox, the error percentages of models' estimation from GPS-TEC values are less than the other years and the models' predictions are good. For all years, it appears that the models generally predict lower TEC values on September equinox. The error percentages obtained by the models on the September equinox, except for 2012, are generally higher at nighttime than daytime.

On June solstice, the TEC estimations of the models (except for 2009 in IRI-PLAS) are generally lower than GPS-TEC for three different solar activity periods. The error percentages on this day are lower than the other days.

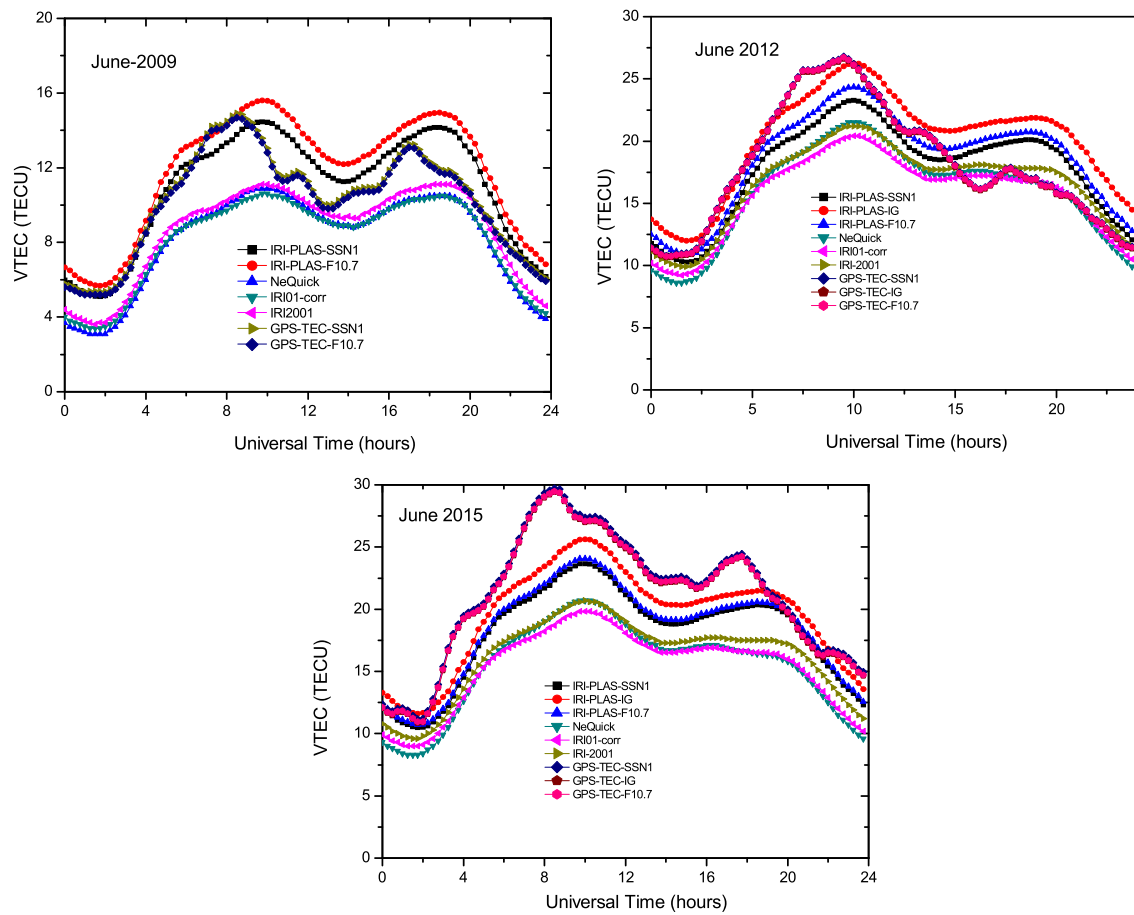


Fig. 3 The variation in time of TEC values predicted by different solar proxy options of IRI-PLAS model and by three different topside options of IRI-2016 model and of GPS-TEC values. (a), (b) and (c) indicate 2009, 2012 and 2015 years, respectively

In December 2009, it can be said that empirical models underestimated the TEC values at every hour of the day, except for between 0500–1500 UT for IRI-PLAS. In 2012, it can be said that the models underestimate the TEC values at nighttime, while the models overestimate the TEC values during the daytime on this day. The high error (around 130%) in December 2012 may be due to the fact that models can not include winter anomalies in their estimates. On December solstice in 2015, when the severe geomagnetic storm took place, the error percentage was the biggest. The percentage error rose to 140%.

Since IRI-PLAS model was updated with several new solar proxy options to represent the solar activity (Gulyaeva et al. 2018; Sezen et al. 2018), it is necessary to determine whether the TEC estimation difference between IRI-PLAS and IRI-2016 model is due to the use of different solar indices of IRI-PLAS model. For this reason, the TEC values by IRI-PLAS model were obtained for SSN1, IG and F10.7 solar proxy options on June solstice of all years and the results obtained were shown in Fig. 3.

The solar proxies, used in IRI-PLAS model, can be listed as sunspot number (SSN1), SSN2, F10.7, global electron content (GEC), TEC, IG, Mg II, Lyman- α , and GEC_RZ (Sezen et al. 2018). The IRI model uses the solar indices (F10.7 daily, 81-day, and 12-month running mean; sunspot number 12-month running mean), ionospheric index (ionosonde-based IG index 12-month running mean), magnetic index (3-h ap, daily ap). The indices are found internally by IRI for the user-specified date and time. In the case of F10.7D, F10.7_81, F10.7_12, R_12, and IG_12 a user can input his/her own values (irimodel.org). In case the user does not choose to enter the index values, the IRI model uses the internal updated lists of indices from apf107.dat and igrz.dat files (Sezen et al. 2018).

The TEC value was not obtained with the IG solar proxy option in June 2009 when TEC values were obtained by IRI-PLAS model, so the IG solar proxy option in Fig. 3(a) was not shown. Figure 3 shows that the TEC values (IRI-PLAS-IG), obtained when the solar proxy option of IRI-PLAS model was IG, are higher than those with SSN1 (IRI-PLAS-SSN1) in both June 2012 and June 2015. In addition, it can be said that IRI-PLAS-IG TEC values are closer to

Table 1 The results of some statistical calculations between GPS_{TEC} values and MODEL_{TEC} values on equinox and solstice days in 2009, 2012 and 2015

		21 March				21 June				23 September				21 December			
		RMSE	Max	Min	R	RMSE	Max	Min	R	RMSE	Max	Min	R	RMSE	Max	Min	R
2009																	
IRI-2016	NeQ	2.33	4.48	-1.27	0.87	2.43	4.71	0.77	0.94	2.47	4.84	0.41	0.94	1.98	3.82	-1.82	0.90
	IRI01-corr	2.14	4.28	-1.18	0.88	2.44	4.93	0.87	0.93	2.31	4.64	0.16	0.94	1.88	3.52	-2.32	0.90
	IRI2001	1.92	3.88	-1.68	0.88	2.02	4.43	0.10	0.93	1.88	4.04	-0.24	0.94	1.78	3.22	-2.82	0.90
IRI-PLAS		2.65	2.68	-5.44	0.89	0.99	1.53	-2.43	0.96	1.53	2.02	-3.16	0.94	2.69	2.45	-5.56	0.91
2012																	
IRI-2016	NeQ	3.22	1.39	-8.20	0.99	3.05	6.62	-1.43	0.92	5.72	10.36	1.24	0.98	6.15	3.72	-12.89	0.96
	IRI01-corr	2.73	0.79	-8.60	0.98	3.43	7.42	-1.03	0.90	6.29	11.24	0.64	0.98	5.88	3.32	-12.49	0.96
	IRI2001	3.61	0.09	-9.70	0.98	2.93	6.62	-1.93	0.88	5.57	10.31	0.04	0.98	6.42	2.77	-13.49	0.95
IRI-PLAS		5.50	-0.16	-10.28	0.99	2.26	4.92	-3.21	0.89	3.55	7.75	-0.58	0.99	7.34	2.59	-14.99	0.96
2015																	
IRI-2016	NeQ	2.11	6.14	-4.37	0.98	6.13	10.32	2.80	0.96	2.54	5.03	-2.04	0.95	2.44	4.15	-7.68	0.96
	IRI01-corr	2.36	7.54	-4.28	0.97	6.33	11.12	2.10	0.96	2.49	5.05	-0.94	0.95	2.62	4.45	-7.28	0.95
	IRI2001	2.49	6.34	-5.28	0.97	5.55	10.32	1.40	0.95	1.96	4.25	-1.74	0.95	3.08	3.55	-8.28	0.95
IRI-PLAS		2.59	8.44	-2.12	0.98	6.10	10.54	2.51	0.95	2.05	4.15	-3.74	0.95	3.17	2.30	-8.87	0.96

GPS-TEC values in every two years, except for between 15:00–24:00 UT in 2012. This result confirms that one of the three best solar proxy options in the midlatitude regions for the IRI-PLAS model is the IG option (Sezen et al. 2018). But, IRI-PLAS-SSN1 TEC values are closer to IRI-2016 TEC values than IRI-PLAS-IG TEC values in both years. It is seen that the TEC values (IRI-PLAS-F10.7) obtained for F10.7 solar proxy option of IRI-PLAS model are higher than the TEC values obtained by SSN1 solar proxy option in every three years. However, IRI-PLAS-F10.7 TEC values are smaller than IRI-PLAS-IG TEC values. It is seen that the TEC values, obtained by the SSN1 option from three different solar proxy options (SSN1, IG and F10.7), are closer to the IRI-2016 TEC values.

The TEC values obtained by the SSN1 option, which is used as default in the online IRI-PLAS model, have shown the best fit with the IRI-2016 TEC values, as a result of examining the TEC values obtained for different solar proxy options. Therefore, it can be said that the difference between the TEC estimations of IRI-2016 and IRI-PLAS models in this study is not due to the different solar proxy options of the IRI-PLAS model.

For comparison and more quantitative interpretation of the results obtained, the results of some statistical procedures including the maximum and minimum deviation, correlation analysis and root mean square error (RMSE) test according to the differences between GPS-TEC and empirical models were presented in Table 1.

As seen on the table, the IRI-PLAS model overestimated the TEC values at certain times of the day and underesti-

mated at certain times of the day, except for June 21, 2015. Similarly, the IRI-2016 model overestimated the TEC values during at certain times of the day and underestimated at certain times of the day, except 21 June 2009, 23 September 2009, 23 September 2012 and 21 June 2015. Here, it can be said that when the deviation (GPS_{TEC}-MODEL_{TEC}) is positive, the model underestimates the TEC values, and when the deviation is negative, the model overestimates the TEC values..

Thus, the IRI-PLAS model overestimated the TEC values on all days of 2009, on March 21st and December 21st of 2012, and only on December 21st of 2015. This model underestimated the TEC values on 21 June and 23 September in 2012 and on 21 March, 21 June and 23 September in 2015. It can be said that the three topside options of the IRI-2016 model underestimated the TEC values for all days of 2009, for the period of 21 June and 23 September in 2012, and for all days, except December 21, in 2015. The IRI-2016 model overestimated the TEC values only on 21 March and 21 December in 2012 and on 21 December 2015.

The most overestimated day for IRI-PLAS and IRI-2016 models is December 21 in 2012 and the minimum deviation is -14.99 TECU and -13.49 TECU respectively. The most underestimated days for IRI-PLAS and IRI-2016 models are June 21 in 2015 and September 23 in 2012 and the maximum deviation is 10.54 TECU and 11.24 TECU respectively.

For the three topside options of the IRI-2016 model, it can be said that the IRI2001 option predicts better than the other topside options according to the RMSE values, except

for the 21 March and 21 December in 2012 and 2015. Moreover, according to the RMSE values, it can be said that IRI-PLAS model made better estimations than IRI-2016 model on 21 June and 23 September, and IRI-2016 model predicted better than IRI-PLAS on 21 March and 21 December in three different solar activity periods. The best estimation was made by the IRI-PLAS model on June 21 in 2009 (0.99 TECU) and the worst estimation was on December 21 in 2012 (7.34 TECU). The correlation coefficient between the GPS-TEC values and the MODEL-TEC values shows a good agreement in general over 0.90 for all solar conditions.

4 Discussion and conclusions

In this study, for coordinates of Turkey's Istanbul GPS station located in mid-latitude region, TEC values obtained by different empirical models and by GPS were compared and forecasting performance of the models was examined. The results obtained indicate that the predictive performances of the models in general are not superior to each other, when the plasmaspheric effects are neglected from the TEC values. As expressed in Alçay et al. (2017), IRI-2016 estimations are good on some days, just as IRI-PLAS estimations are good on some other days. However, it can be said that IRI-PLAS does not always exaggerate TEC values at mid-latitudes, especially during low and medium solar activity periods unlike (Zakharenkova et al. 2015). Especially in low and medium solar activity years, the TEC predictions of IRI-PLAS model are very close to the GPS-TEC values on June solstice and on September equinox days and does not overestimate.

As well as all empirical models, the predictive ability of the IRI model is strongly dependent on reaching the experimental data at the place, where the forecast is made. In times and regions where there are few or no data sources, the predictive power of IRI may be quite low (Bilitza et al. 2014). Although most of the data provided to IRI model is from mid-latitude regions, the actual data input to the IRI model over Turkey, as far as it is known, is not provided. Therefore, although IRI's estimation performance is high in the mid-latitudes, it may be low over Turkey. Additionally, it can be said that unlike previous studies (Okoh et al. 2012; Zakharenkova et al. 2015), the IRI2001 option of IRI's topside option made better predictions than the other options over Istanbul, Turkey.

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