Comparison of Ionospheric Total Electron Content Measurements with IRI-2012 Model Predictions Over Athens

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Abstract
Total Electron Content measurements derived from Athens station ionograms (ITEC), located near Iraq, during the ascending phase of solar cycle 24 (July 2009- April 2010), according to availability of data, are compared with the latest version of the International Reference Ionosphere model, IRI-2012 (IRI TEC), using two options (NeQuick, IRI01-Corr) for topside electron density.
The results obtained from both (ITEC and IRI TEC) techniques were similar, where correlation coefficients between them are very high. Generally, the IRI predictions overestimate the ITEC values.

Keywords: Comparison, total electron content, IRI - 2012 model.

مقارنة قياسات المحتوى الالكتروني الكلي للايونوسفير مع تنبؤات موديل IRI-2012 فوق مدينة اثينا

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الخلا صة
تم مقارنة قياسات المحتوى الالكتروني الكلي المستخرجة من ايونوكرامات محطة اثينا (ITEC) ، الواقعة بالقرب من العراق، خلال الطور المرتفع من الدورة الشمسية 24 (لاشهر تموز2009 – نيسان 2010)، وبحسب ما متوفر من بيانات، مع موديل المرجعية العالمية للايونوسفير IRI-2012 (IRI TEC) بأستخدام خياري الكثافة الالكترونية للجانب العلوي من الايونوسفيرtopside ionosphere وهما (NeQuick, IRI01- Corr).
اعطت النتائج المستحصلة من تطبيق تقنية الايونوكرام تقارب جيد مع تلك المستحصلة من تطبيق النموذج الرياضي. حيث كانت قيم معاملات الترابط بينهما عالية جدا. بصورة عامة، ان تنبؤات قيم المحتوى الالكتروني الكلي بأستخدام موديل IRI كانت اعلى من قيمها المقاسة من جهاز الايونوسوند .

Introduction

The Total Electron Content TEC is the ionospheric parameter that has the largest effect on radio waves that pass through the ionosphere. Historically, most TEC measurements have used the Faraday rotation technique, incoherent scatter radar measurements, and TOPEX surface reflections. Recently, Huang and

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Reinisch introduced a new technique for estimating the total electron content from ground- based ionosonde data [1].

Since an ionosonde cannot measure the topside electron density profile, it is modeled by an α-Chapman function with a constant scale height that is derived from the bottom side shape around the F_2 peak. Vertical electron density profiles for the bottom side ionosphere are the one output of ionosondes that is equally important for geophysics and for radio wave propagation applications [2]. Advanced digital ionosondes like the Digisonde 256 and the Digisonde Portable Sounder generate electron density profiles in real time at some 50 stations worldwide. ITEC is calculated by integrating over the entire height profile, and is given by:

$$\textbf{ITEC}= \int_0^{\infty} N(h)dh = \int_0^{h_mF_2} N_B(h)dh + \int_{h_mF_2}^{\infty} N_T(h)dh \qquad (1)$$

where, N is the vertical electron density profile, N_B is the vertical electron density profile up to F_2 layer peak (bottom side profile) calculated using the inversion program proposed by Huang and Reinisch and N_T is vertical electron density profile above the F_2 layer peak (topside profile). $N_B(h)$ is calculated from the measured $h'(f)$ traces in the ionogram (information directly provided from the ionograms). For Athens region, N_T (h) is calculated from Topside Sounder Model Profiler (TSMP) -assisted Digisonde(TaD) model[3].

TEC measurements have been carried out at a number of stations, the data for continuous TEC measurements are not always available for all latitudes around the globe. For this purpose, some models are used like IRI , SLIM , PRISM , SUPIM , NeQuick , and USA-GAIM. Out of these models, International Reference Ionosphere (IRI) is being used widely. The IRI is an international project sponsored by the COmmittee on SPAce Research (COSPAR) and International Union of Radio Science (URSI). The IRI provides the electron density and TEC at altitudes ranging from about 50 to 2000 km at any specific given location, time and date, based on various ground and space measurements. The IRI model obtains TEC by integrating the electron density profile from the lower boundary to a user- specified upper boundary. This model is continuously updated and improved during COSPAR-IRI sessions and/or IRI workshops. The latest version is the IRI-2012 which is accessible on internet from the website at http://omniweb.gsfc.nasa.gov/vitmo/iri-2012_vitmo.html. This model provides three different options for the topside electron density distribution. The first one is the IRI-2001 model that was based primarily on Alouette 1 topside sounder data with some AE-C, AEROS, and DE-2 in situ data . The second option is the correction factor (IRI01- Corr), which is a correction of the 2001 model with the help of Alouette 2, ISIS 1 and 2 topside sounder data . The third option is the NeQuick, the model developed by Radicella *et al.*, using Intercosmos 19 topside sounder data in addition to the ISIS 1 and 2 data; and two options for bottom side thickness B0, B1 that are the most important parameters controlling TEC. The bottom side thickness B0 is the height difference between the F peak height h_mF_2 and the height where the electron density profile has dropped down to half the F peak value ($N_mF_2/2$), and B1 is a parameter describing the bottom side profile shape[4].

Alouette and ISIS topside sounder data:

The Alouette 1, 2 and ISIS 1, 2 satellites were ionospheric observatories designed and operated jointly by the USA and Canada.

The primary instrument was the topside sounder for recording the electron density profile from the satellite down to the F peak. But other instruments were included as well. ISIS-2, for example, carried a sweep- and a fixed-frequency ionosonde, a VLF receiver, energetic and soft particle detectors, an ion mass spectrometer, an electrostatic probe, a retarding potential analyzer, a beacon transmitter, a cosmic noise experiment, and two photometers. NASA support of the ISIS project was terminated on October 1, 1979. Partial operations were continued by the Canadian project team until March 9, 1984 and were then resumed in even more limited form by the Japanese Radio Research Laboratories (Kashima ground station) from August 1984 to January 24, 1990. These satellites have accumulated a large volume of data for the topside ionosphere [5].

NeQuick topside:

NeQuick topside mathematical representation is an Epstein layer with a height-dependent thickness parameter (scale height H_T):

$$N_T = N_mF_2.exp\left[\frac{1}{2}(1 - z - e^{-z})\right] \quad (2)$$

and

$$z = \frac{h - h_mF_2}{H_T} \quad (3)$$

$$H_T = H_o\left[1 + \frac{rg(h - h_mF_2)}{rH_0 + g(h - h_mF_2)}\right] \quad (4)$$

Where N_mF_2 (m^3) is the maximum electron density of the F_2 layer, h_mF_2 (km) is the height of this maximum, r = 100 and g = 0.25 are constant factors. The thickness at the F_2 peak height, H_0, is linked to the thickness of NeQuick bottom side:

$$H_O = k.B2_{bot} \quad (5)$$

$$k = 3.22 - 0.0538f_oF_2 - 0.00664h_mF_2 + 0.113\frac{h_mF_2}{B2_{bot}} + 0.00257R12 \quad (6)$$

in which f_oF_2 (MHz) is the critical frequency of the F_2 layer, $B2_{bot}$ (km) is NeQuick bottom side thickness parameter and R12 is the twelve-month running-mean relative sunspot number. The empirical relation (6) is based on ISIS-2 TOPIST (TOPside Ionogram Scaler with True Height Algorithm program developed at the University of Massachusetts Lowell) topside electron density profiles . The inflection point of the

Epstein layer representing NeQuick bottom side defines $B2_{bot}$:

$$B2_{bot} = \frac{0.385N_mF_2}{(dN/dh)_{max}} \quad (7)$$

In IRI, the bottom side electron density profile is given by:

$$N(h) = \frac{N_mF_2exp(-x^{B1})}{cosh(x)} \quad (8)$$

$$x = \frac{(h_mF_2 - h)}{B0} \quad (9)$$

$$\mathbf{k_{B0T} = 0.6288 - 0.0109f_oF_2 - 0.00149hmF2 + 0.152h_mF_2 / B0 + 0.00074R12} \quad (10)$$

$$\mathbf{k_{B0G} = 0.5446 - 0.0086f_oF_2 - 0.00158h_mF_2 + 0.188h_mF_2 / B0 + 0.00077R12} \quad (11)$$

Where B0 (km) is the thickness parameter of IRI bottom side, f_oF_2 (MHz) is the critical frequency of the F_2 layer, h_mF_2 (km) its height. Eq. (10) has been derived using the IRI B0 Table option, whereas Eq. (11) has been obtained using the B0 Gulyaeva model option [6].

Many studies are found in the literature that report comparisons of total electron content measurements and predictions of models, such as, the IRI model at different locations: Mosert *et al.* [7] studied comparisons of IRI TEC predictions with digisonde measurements at Ebro station (40.8 N, 0.5 E) recorded during two years of high solar activity 2000 (R12 = 117) and 2001 (R12 = 111), and found that the IRI predictions generally overestimate the ITEC values. Jodogne *et al.* [8] studied comparisons of ITEC from digisonde data at the Dourbes station with NeQuick model in 2001, and found that the median's data from January and March are always below the model's values while they are higher in June during day's hours. In September, the agreement between model and experimental values is very good, especially during the first half of the day.

Wang *et al.*[9] studied comparisons of ionogram- derived with IRI TEC in Hainan, and found that the total electron contents produced by ITEC and IRI TEC, have similar variation trends and that the IRI predictions greatly overestimate TEC values in the daytime and there is small deviation at nighttime.

The objective of this paper is to compare the IRI-2012 TEC predictions with ITEC measurements at Athens (38 N, 24 E).

Material and Methods

Vertical incidence ionograms from Athens recorded by a DPS-4 during two years of ascending solar activity (2009 and 2010) were used to calculate the integrated total electron content, ITEC(bottom side TEC values), and topside TEC values are calculated from Topside Sounder Model Profiler (TSMP) - assisted Digisonde(TaD) model[10]. The database includes hourly ionograms obtained during the representative months of July, August, September, October, November and December 2009 and January, February, March and April 2010. The corresponding IRI TEC predictions were calculated with the last version of the model, (IRI-2012).

The monthly hourly averages of ITEC are derived from hourly ITEC data of Athens station and compared with the corresponding ones of IRI-2012 model during 2009 and 2010.

Statistical analysis is used to calculate standard deviation (SDV) for monthly averages of ITEC according to equation (12):

$$\mathbf{SDV} = \sqrt{\frac{\sum[\mathbf{ITECmeans}-\overline{\mathbf{ITECmeans}}]^2}{(\mathbf{n}-\mathbf{1})}} \quad \mathbf{(12)}$$

Where $ITEC_{means}$ is TEC from ionosonde ionograms, $\overline{ITEC_{means}}$ is the average and (n) is the number of data. The relative deviation ΔTEC (%) is defined as:

$$\Delta\mathbf{TEC}(\%) = \left[\frac{(\mathbf{NeQuick_{IRI}} - \mathbf{ITEC_{means}})}{\mathbf{ITEC_{means}}}\right] * \mathbf{100} \quad (\mathbf{13})$$

and

$$\Delta\mathbf{TEC}(\%) = \left[\frac{(\mathbf{IRI01} - \mathbf{Corr_{IRI}} - \mathbf{ITEC_{means}})}{\mathbf{ITEC_{means}}}\right] * \mathbf{100} \quad (\mathbf{14})$$

Equation (13) and (14) are applied on seasonal hourly averages of TEC obtained from IRI-2012 model and Athens station measurements.

Results and Discussions

Tables 1, 2, 3 & 4 illustrate the Seasonal hourly variations of observed ITEC and predicted TEC using IRI-2012 (NeQuick & IRI01-corr) and R.D% (ITEC- NeQuick, ITEC- IRI01-corr) for different seasons above Athens.

Table 1- Seasonal hourly variations of observed ITEC and predicted TEC using IRI-2012(NeQuick & IRI01-corr) and R.D%(ITEC- NeQuick, ITEC- IRI01-corr) for Winter 2009-2010 above Athens.

Time	Winter(Dec., Jan., Feb.) 2009-2010				
UT	OBS. ITEC($*10^{16}$ e/m^2)	NeQuick	IRI01-corr	R.D%	R.D%
0	1.636	1.600	1.633	-2.240	-0.205
1	1.559	1.670	1.700	6.880	9.015
2	1.683	1.500	1.500	-10.920	-10.923
3	1.287	1.200	1.266	-6.830	-1.648
4	1.242	1.270	1.333	1.940	7.307
5	1.678	2.030	2.100	21.150	25.117
6	3.281	3.670	3.866	11.730	17.828
7	4.838	5.600	5.966	15.740	23.314
8	5.763	7.130	7.533	23.770	30.706
9	7.405	7.830	8.233	5.780	11.185
10	8.347	7.900	8.200	-5.360	-1.761
11	7.532	7.700	7.900	2.230	4.880
12	6.846	7.400	7.633	8.080	11.486
13	7.104	6.930	7.233	-2.400	1.818
14	5.488	6.100	6.366	11.150	16.010
15	3.946	4.700	4.933	19.090	25.001
16	2.458	3.130	3.266	27.430	32.852
17	1.842	2.100	2.166	13.950	17.571
18	1.825	1.600	1.633	-12.340	-10.518
19	1.746	1.470	1.500	-16.020	-14.106
20	1.698	1.430	1.433	-15.630	-15.629
21	1.697	1.330	1.333	-21.460	-21.463
22	1.736	1.270	1.300	-27.070	-25.150
23	1.716	1.430	1.433	-16.480	-16.480

Table 2- Seasonal hourly variations of observed ITEC and predicted TEC using IRI-2012(NeQuick & IRI01-corr) and R.D%(ITEC- NeQuick, ITEC- IRI01-corr) for Spring 2010 above Athens.

Time	Spring(Mar., Apr.) 2010				
UT	OBS. ITEC($*10^{16}$ e/m^2)	NeQuick	IRI01-corr		
0	2.493	3.400	3.500	36.358	40.369
1	2.452	3.200	3.300	30.486	34.564
2	2.217	2.700	2.850	21.771	28.536
3	2.206	2.300	2.450	4.245	11.044
4	2.837	2.750	3.000	-3.081	5.729
5	4.793	4.600	4.850	-4.032	1.183
6	7.280	7.150	7.400	-1.798	1.635
7	7.923	9.400	9.700	18.631	22.417
8	9.301	11.200	11.350	20.404	22.016
9	11.089	12.900	12.850	16.326	15.875
10	13.477	14.100	13.850	4.618	2.763
11	14.724	14.150	13.950	-3.903	-5.261
12	12.810	13.500	13.350	5.381	4.210
13	11.258	12.800	12.750	13.691	13.247
14	10.093	12.000	12.100	18.884	19.874
15	9.586	10.900	11.000	13.702	14.745
16	9.402	9.250	9.400	-1.625	-0.030
17	6.690	7.500	7.650	12.095	14.337
18	4.519	6.100	6.200	34.969	37.181
19	3.890	4.950	5.050	27.220	29.790
20	3.277	4.050	4.100	23.588	25.114
21	2.898	3.550	3.650	22.479	25.929
22	2.933	3.350	3.450	14.197	17.605
23	2.851	3.350	3.450	17.496	21.004

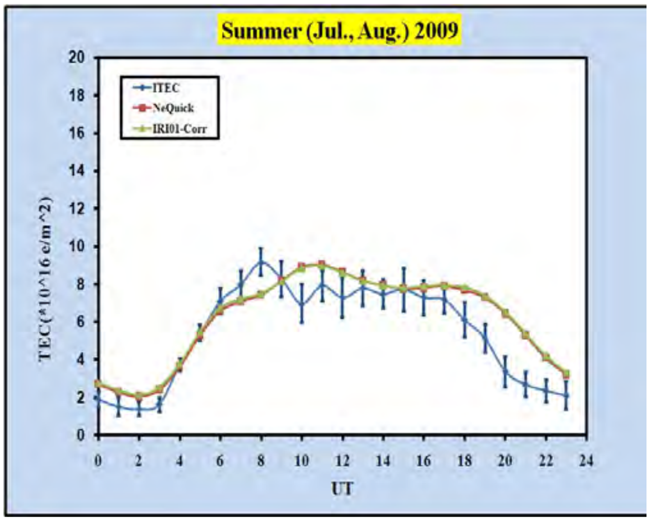
Table 3- Seasonal hourly variations of observed ITEC and predicted TEC using IRI-2012(NeQuick & IRI01-corr) and R.D%(ITEC- NeQuick, ITEC- IRI01-corr) for Summer 2009 above Athens.

Time UT	Summer(Jul., Aug.) 2009				
	OBS. ITEC($*10^{16}$ e/m^2)	NeQuick	IRI01-corr		
0	1.884	2.700	2.800	43.280	48.585
1	1.510	2.300	2.400	52.250	58.867
2	1.382	2.050	2.150	48.320	55.555
3	1.627	2.400	2.550	47.460	56.678
4	3.727	3.650	3.800	-2.090	1.933
5	5.407	5.300	5.500	-1.980	1.717
6	7.105	6.600	6.750	-7.120	-5.006
7	7.996	7.100	7.200	-11.210	-9.963
8	9.173	7.450	7.500	-18.790	-18.246
9	8.279	8.200	8.150	-0.960	-1.560
10	6.981	8.900	8.850	27.470	26.755
11	7.923	9.050	9.000	14.220	13.591
12	7.297	8.650	8.600	18.540	17.849
13	7.796	8.200	8.200	5.170	5.170
14	7.483	7.950	7.950	6.230	6.228
15	7.713	7.750	7.800	0.470	1.115
16	7.289	7.800	7.900	7.000	8.369
17	7.196	7.900	7.950	9.780	10.471
18	6.139	7.700	7.850	25.410	27.850
19	5.143	7.300	7.400	41.940	43.882
20	3.359	6.450	6.550	92.010	94.991
21	2.689	5.300	5.400	97.050	100.764
22	2.343	4.100	4.200	74.980	79.243
23	2.090	3.200	3.350	53.050	60.221

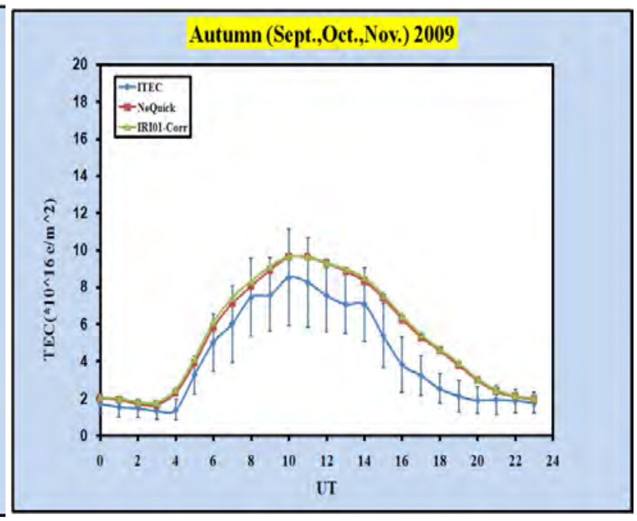
Table 4- Seasonal hourly variations of observed ITEC and predicted TEC using IRI-2012(NeQuick & IRI01-corr) and R.D%(ITEC- NeQuick, ITEC- IRI01-corr) for Autumn 2009 above Athens.

Time UT	Autumn(Sep., Oct., Nov.) 2009				
	OBS. ITEC($*10^{16}$ e/m^2)	NeQuick	IRI01-corr		
0	1.728	2.000	2.066	15.676	19.532
1	1.541	1.933	2.000	25.446	29.772
2	1.472	1.733	1.800	17.721	22.249
3	1.343	1.666	1.800	24.016	33.937
4	1.404	2.333	2.500	66.159	78.027
5	3.266	3.933	4.166	20.409	27.552
6	5.005	5.833	6.100	16.540	21.867
7	6.017	7.133	7.433	18.533	23.519
8	7.474	8.066	8.333	7.918	11.486
9	7.608	8.933	9.100	17.407	19.597
10	8.535	9.633	9.666	12.860	13.251
11	8.255	9.633	9.666	16.691	17.095
12	7.547	9.266	9.333	22.782	23.665
13	7.101	8.866	9.000	24.863	26.740
14	7.066	8.333	8.533	17.930	20.761
15	5.406	7.433	7.600	37.487	40.570
16	3.837	6.266	6.433	63.301	67.644
17	3.253	5.300	5.433	62.914	67.013
18	2.546	4.600	4.700	80.665	84.593
19	2.133	3.800	3.900	78.141	82.829
20	1.914	3.000	3.066	56.691	60.173
21	1.934	2.400	2.466	24.079	27.526
22	1.885	2.100	2.166	11.385	14.921
23	1.773	1.966	2.033	10.862	14.621

Figures 1-a, b, c and d, illustrate the seasonal hourly variation of ITEC along with IRI-201 predicted values using the two options provided in the IRI-2012 model for different seasons over Athens.



(a)



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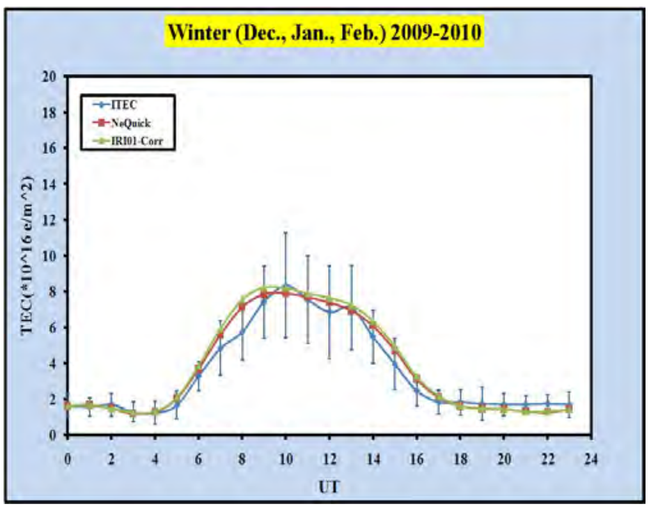

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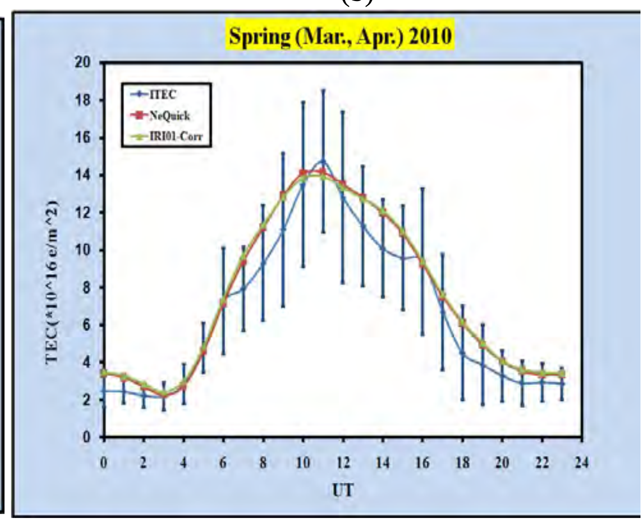

(d)

Figure 1- Hourly seasonal variation for the values of ITEC and IRI TEC (NeQuick and IRI01- Corr), in TEC units of 10^{16} m^2 = TECU, at Athens for (a) Winter (b) Spring (c) Summer and (d) Autumn during 2009 and 2010.

It can be noted from these figures that, both the ITEC and TEC generated by the IRI-2012 model with the two options, for different seasons over Athens reveal almost similar diurnal trend. There is, however, overestimation of TEC by IRI-2012 model for Autumn. The discrepancies between the TEC predicted by the IRI-2012 (in both NeQuick and IRI01- Corr options) and the ITEC are well obvious, almost, in all hours in winter.

Tables (5 & 6 illustrate the seasonal hourly variations of observed ITEC and predicted TEC using IRI-2012(NeQuick & IRI01-corr) for different seasons above Athens.

Table 5- Seasonal hourly variations of observed ITEC and predicted TEC using IRI-2012(NeQuick & IRI01-corr) for Winter 2009-2010 and Spring 2010 above Athens.

Time UT	Winter(Dec., Jan., Feb.) 2009-2010			Time UT	Spring(Mar., Apr.) 2010		
	Predicted	Predicted	OBS.		Predicted	Predicted	OBS.
0	1.600	1.633	1.636	0	3.400	3.500	2.493
1	1.670	1.700	1.559	1	3.200	3.300	2.452
2	1.500	1.500	1.683	2	2.700	2.850	2.217
3	1.200	1.266	1.287	3	2.300	2.450	2.206
4	1.270	1.333	1.242	4	2.750	3.000	2.837
5	2.030	2.100	1.678	5	4.600	4.850	4.793
6	3.670	3.866	3.281	6	7.150	7.400	7.280
7	5.600	5.966	4.838	7	9.400	9.700	7.923
8	7.130	7.533	5.763	8	11.200	11.350	9.301
9	7.830	8.233	7.405	9	12.900	12.850	11.089
10	7.900	8.200	8.347	10	14.100	13.850	13.477
11	7.700	7.900	7.532	11	14.150	13.950	14.724
12	7.400	7.633	6.846	12	13.500	13.350	12.810
13	6.930	7.233	7.104	13	12.800	12.750	11.258
14	6.100	6.366	5.488	14	12.000	12.100	10.093
15	4.700	4.933	3.946	15	10.900	11.000	9.586
16	3.130	3.266	2.458	16	9.250	9.400	9.402
17	2.100	2.166	1.842	17	7.500	7.650	6.690
18	1.600	1.633	1.825	18	6.100	6.200	4.519
19	1.470	1.500	1.746	19	4.950	5.050	3.890
20	1.430	1.433	1.698	20	4.050	4.100	3.277
21	1.330	1.333	1.697	21	3.550	3.650	2.898
22	1.270	1.300	1.736	22	3.350	3.450	2.933
23	1.430	1.433	1.716	23	3.350	3.450	2.851

Table 6- Seasonal hourly variations of observed ITEC and predicted TEC using IRI-2012(NeQuick & IRI01-corr) for Summer 2009 and Autumn 2009 above Athens.

Time UT	Summer(Jul., Aug.) 2009			Time UT	Autumn(Sep., Oct., Nov.) 2009		
	Predicted	Predicted	OBS.		Predicted	Predicted	OBS.
0	2.700	2.800	1.884	0	2.000	2.066	1.728
1	2.300	2.400	1.510	1	1.933	2.000	1.541
2	2.050	2.150	1.382	2	1.733	1.800	1.472
3	2.400	2.550	1.627	3	1.666	1.800	1.343
4	3.650	3.800	3.727	4	2.333	2.500	1.404
5	5.300	5.500	5.407	5	3.933	4.166	3.266
6	6.600	6.750	7.105	6	5.833	6.100	5.005
7	7.100	7.200	7.996	7	7.133	7.433	6.017
8	7.450	7.500	9.173	8	8.066	8.333	7.474
9	8.200	8.150	8.279	9	8.933	9.100	7.608
10	8.900	8.850	6.981	10	9.633	9.666	8.535
11	9.050	9.000	7.923	11	9.633	9.666	8.255
12	8.650	8.600	7.297	12	9.266	9.333	7.547
13	8.200	8.200	7.796	13	8.866	9.000	7.101
14	7.950	7.950	7.483	14	8.333	8.533	7.066
15	7.750	7.800	7.713	15	7.433	7.600	5.406
16	7.800	7.900	7.289	16	6.266	6.433	3.837
17	7.900	7.950	7.196	17	5.300	5.433	3.253
18	7.700	7.850	6.139	18	4.600	4.700	2.546
19	7.300	7.400	5.143	19	3.800	3.900	2.133
20	6.450	6.550	3.359	20	3.000	3.066	1.914
21	5.300	5.400	2.689	21	2.400	2.466	1.934
22	4.100	4.200	2.343	22	2.100	2.166	1.885
23	3.200	3.350	2.090	23	1.966	2.033	1.773

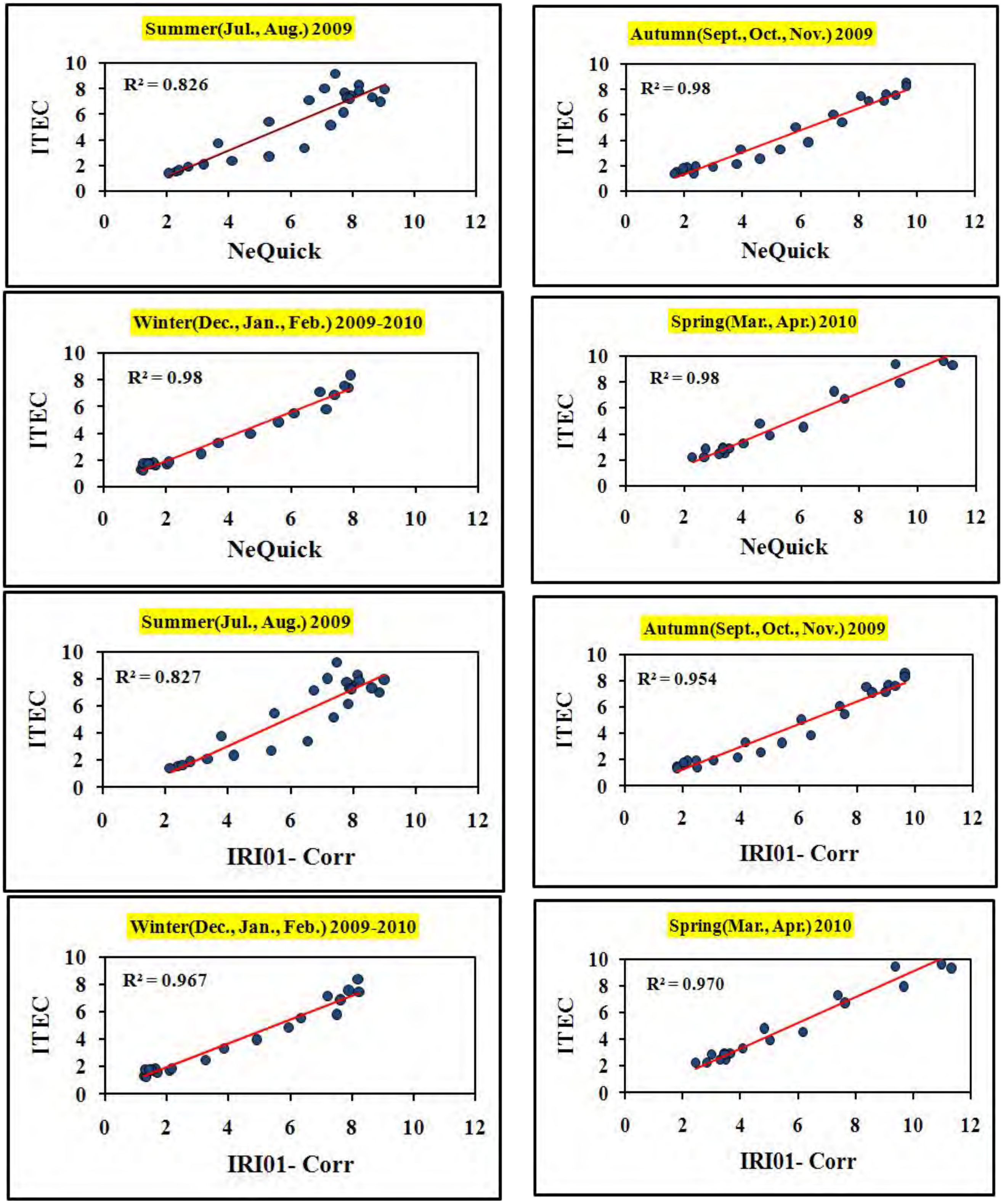

Figure 2- Scatter plots depicting the correlation between seasonal variations in IRI TEC (NeQuick, IRI01- Corr) and ITEC for Winter, Spring, Summer and Autumn. R^2, indicates the correlation coefficient for each season.

From the scatter plot shown in figure 2 there exists a high degree of correlation between ITEC and IRI TEC (NeQuick, IRI01- Corr) values for all the seasons, except for Summer, due to great lacking of data. This correlation indicated that, the model accurately predicts the seasonal trends over this region.

The contour diagrams figure 3-, a, b depicts the seasonal mean of relative deviation (rd %) between ITEC and NeQuick model, ITEC and IRI01- Corr model at each of the UT hours (0–23) in 2009 and 2010 at Athens.

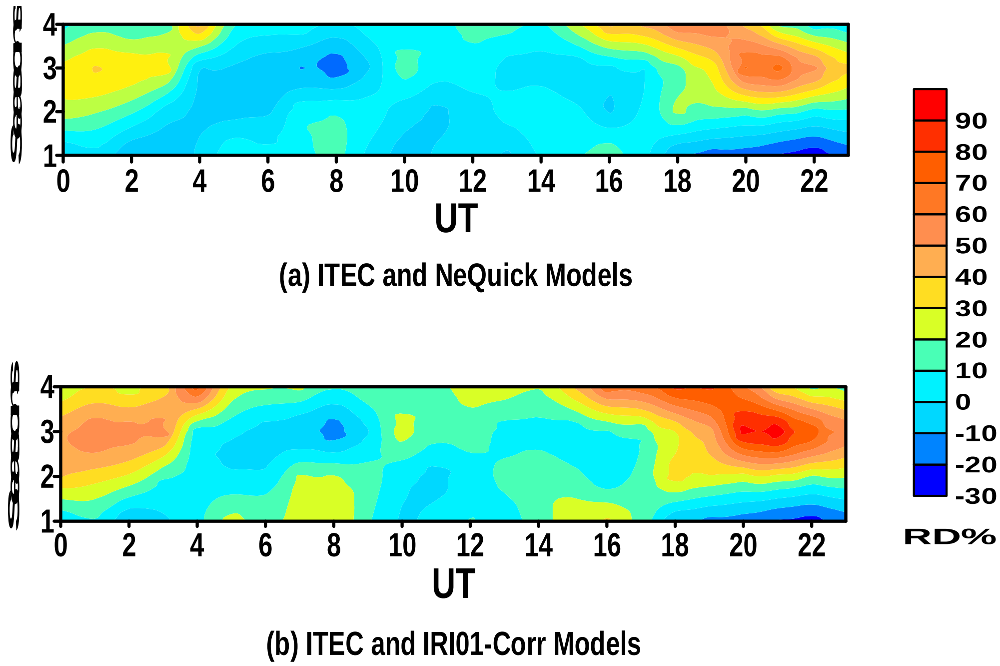

Figure 3- Contour plot of the relative deviations (rd%) between (a) ITEC and NeQuick model (b) ITEC and IRI01-Corr model during seasons (1=Winter, 2=Spring, 3=Summer, 4=Autumn) in 2009 and 2010 at Athens.

As seen from these figures, the relative deviation values were highest(80% in case of IRI01- Corr model, and 60% in case of NeQuick model) in Summer, than in other seasons and during night(21 UT); and lowest (-10% in case of IRI01- Corr model, -20% in case of NeQuick model) in Winter, than in other seasons during night too (22 UT). The relative deviation values were lowest by using of NeQuick model compared with IRI01- Corr model, i.e., a good agreement is found between the ITEC and IRI TEC using NeQuick model, compared with IRI01- Corr model.

Conclusions

Through the comparison between total electron content measurements and IRI-2012 model predictions**,** it is found that:

1. Predicted values of total electron content are higher than measured values at all hours of the day and for all seasons. The difference is smaller in winter compared with other seasons.
2. Correlation coefficient values, R^2, between measured TEC values and predicted one (using NeQuick & IRI01- Corr options) are very high (0.98, 0.97 & 0.827), and this refer to good relationship between them.
3. The relative deviation is highest in Summer and during night, compared with other seasons.
4. The relative deviation is lowest in Winter during night too, compared with other seasons.
5. Predicted TEC values by NeQuick model, are more accurate than it using IRI01- Corr model.

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