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The Accuracy of Prediction for the Models IRI- 2012 and VOACAP in Measurements foF2 Over Iraq during High Solar Activity Level

Fahmi A. Mohammed*

Department of Space Environment, Atmosphere and Space Science Center, Directorate of Space and Communications, Ministry of Science and Technology, Baghdad, Iraq

Abstract

The accuracy of IRI- 2012 and VOACAP models during high solar activity level have been tested to know which of them is more accurate in predicting hourly foF2 values for three Iraqi cities (Baghdad, Mosul and Basrah). The results indicated that the accuracy of them increases for all hours during Spring and Summer and decreases during Winter and Autumn especially at hours near to sunrise; i.e., both of two models have the same accuracy. And that the foF2 values predicted by VOACAP model are higher than that predicted by IRI- 2012 model for all seasons.

Keywords: accuracy, IRI- 2012 model, VOACAP model, foF2, high solar activity level.

دقة تنبؤ موديلي 2012 –IRI وVOACAP في قياسات foF2 فوق العراق خلال مستوي النشاط الشمسي العالي

فهمي عبد الرحمن محمد*

قسم بيئة الفضاء، مركز علوم الجو والفضاء، دائرة الفضاء والاتصالات، وزارة العلوم والتكنولوجيا، بغداد، العراق

الخلاصة:

تم اختبار دقة موديلي 2012 –IRI وVOACAP خلال مستوي النشاط الشمسي العالي، لمعرفة اي منهما هو اكثر دقة في تنبؤ قيم foF2 الساعية لثلاث مدن عراقية (بغداد، الموصل والبصرة) . بينت النتائج بأن الدقة لهما تزداد لجميع الساعات خلال فصلي الربيع والصيف، وتقل خلال فصلي الشتاء والخريف خصوصا عند ساعات قريبة من شروق الشمس؛ بمعنى ان كلا الموديلين لهما نفس الدقة. وان قيم foF2 المتنبأ بها بأستخدام موديل VOACAP تكون اعلى من تلك المتنبأ بها بأستخدام موديل 2012 –IRI ولجميع الفصول.

Introduction:

The Voice of America Coverage Analysis Program (VOACAP):

VOACAP predicts the expected performance of high frequency (HF) broadcast systems, and in doing so is useful in the planning and operation of HF transmissions for the four seasons, different sunspot activities, hours of the day and geographic location.

The software program will be taken (actually a suite of software programs) from the Voice of America (VOA) of the US Department of Commerce. The name of the program is VOACAP and there are two versions: The earlier version, which is now frozen in development and will not be further revised, is a DOS- based program. VOA also released a Windows- based program equally called VOACAP. Development of this software is an ongoing project and new versions of the program are released from time to time.

There are many good reasons to take a good look at VOACAP. One good reason is the price of the program - which is free. A second reason is that VOACAP is one of several software packages that are

*Email:fahmibeg@yahoo.com

based on a program called IONCAP developed in the late 1970's by the Institute for Telecommunication Sciences (ITS) of the Department of Commerce.

Since the late thirties, many different organizations have been involved in the study of HF spectrum radio wave communications. A worldwide effort to measure ionospheric parameters, including noise, was established and detailed records have been obtained for variations in system performance over various paths. All of this research has shown that HF system performance is related, in a very complex manner, to solar activity, time of the day, day of the year, and the details of the radio wave path. In 1978, ITS released a FORTRAN program called the Ionospheric Communications Analysis and Prediction Program (IONCAP). Prior to the release of IONCAP, much of the path analysis that was done, had to be handled manually - a very time consuming process.

There are separate subroutines in the IONCAP program for antenna analysis. For any path, the gain of the antenna in the direction of the path and at the elevation angle of the specific signal needs to be considered. In the earliest versions of IONCAP only simple antenna geometries were included but, since it is fairly easy to extend a modular program, VOACAP and other software offer more complex antenna geometries, or the opportunity for you to quantify your own particular antenna system. IONCAP is designed around the 12- month running average of the sunspot number, not the day-to-day measured solar flux. During sunspot lows, which is the present situation, this doesn't matter much but near sunspot peaks the differences can be large. IONCAP also does not include geomagnetic effects related to the A- or K- indices [1].

The operation and use of the Ionospheric Communications Analysis and Prediction Program (IONCAP), are described by the report [2]. The computer program is an integrated system of subroutines designed to predict high- frequency (HF) sky wave system performance and analyze ionospheric parameters. These computer- aided predictions may be used in the planning and operation of high- frequency communication systems using sky waves. This report contains instructions for the use of IONCAP. A description of the input data requirements, including data definition, organization, and instructions for setup of the various analysis tasks, is presented. Procedures and formats are given for preparing the input data and executing the program. The various outputs are presented and described with an interpretation of the analysis results [2].

International Reference Ionosphere model (IRI- 2012):

For successful radio communication, it is essential to predict the behavior of the ionospheric region that will affect a given radio communication circuit. Such a prediction will identify the time periods, the path regions and the sections of high frequency bands that will allow or disrupt the use of the selected high frequency communication circuit. The need for predicting the behavior of the ionosphere leads to modelling of that atmospheric region. Several models were developed to predict the behavior of the ionospheric parameters. Empirical models are widespread tools to describe ionospheric conditions. These models are used not only for the long- term prediction, but also for the real- time description of the ionospheric conditions. One of the most widely used new empirical models, is the IRI- 2012. IRI- 2012 model is actively used in a great variety of applied and research projects. In particular, IRI provides a basis for the simulation and prediction of the ionospheric radio wave propagation. The model takes into account daily and seasonal variations, perturbed and quiet conditions as well as the impact of the solar activity on the ionospheric plasma. The IRI- 2012 model uses an ionospheric- effective solar index that is based on ionosonde measurements, the IG12 index, to obtain NmF2. Ionospheric measurements are essential to know the behavior of the ionosphere and also to check the validity of the ionospheric models [3]. The references [4- 7] give more information about IRI model.

In this paper, the accuracy of IRI- 2012 and VOACAP models in predicting foF2 for Baghdad, Mosul and Basrah during high solar activity level, have been compared.

Materials and Methods:

Predicted hourly foF2 values for Baghdad, Mosul and Basrah were deduced from IRI- 2012 and VOACAP models, by inputting the geographical coordinates for these cities and the monthly smoothed sunspot number of 2000 (high solar activity level). The hourly seasonal averages of foF2 were calculated and the results were listed in Tables (1- 4). Also, the results obtained, were drown as shown in Figures (1- 4).

Input system parameters in VOACAP were:

1. Man- made noise level at 3 MHz (- dBW/ Hz) in a 1 Hz bandwidth = - 145 dBW/ Hz (residential).

Man- made noise level at 3 MHz in – dBW/ Hz (dB below a watt)

1= 140.4= industrial= - 27.7 Log (F) + 76.8 (1)

2= 144.7= residential= - 27.7 Log (F) + 72.5 (2)

3= 150= rural= - 27.7 Log (F) + 67.2 (3)

4= 164.1= remote= - 28.6 Log (F) + 53.6 (4)

5= 138.7= noisy= - 37.5 Log (F) + 83.2 (5)

6= 152.7= quiet= - 29.1 Log (F) + 65.2 (6)

Other values are specified in the range of (100- 200).

Default= - 145 dBW/Hz.

The external noise factor (fa) defined as:

$$f_a = \frac{p_n}{kT_0 b} \quad (7)$$

Fa is the external noise figure, defined as:

$$F_a = 10 log f_a \qquad dB \quad (8)$$

Where:

Pn = available noise power from an equivalent lossless antenna.

k= Boltzmann's constant = 1.38* 10^{-23} J/K.

To= reference temperature (K) taken as 290 K.

b= noise power bandwidth of the receiving system (Hz).

Eq. (7) can be written as:

$$P_n = F_a + B - 204 \ dBW \quad (9)$$

Where:

P_n (available power, W) = 10 log p_n (10)

B = 10 log b (11)

b = 1 Hz, then B = 0

-204 = 10 log k To (12)

Eq. (9) becomes:

$$P_n = F_a - 204 \ dBW \quad (13)$$

Fa deduced from the Figure below at a frequency of 3 MHz and for residential environment (line B):

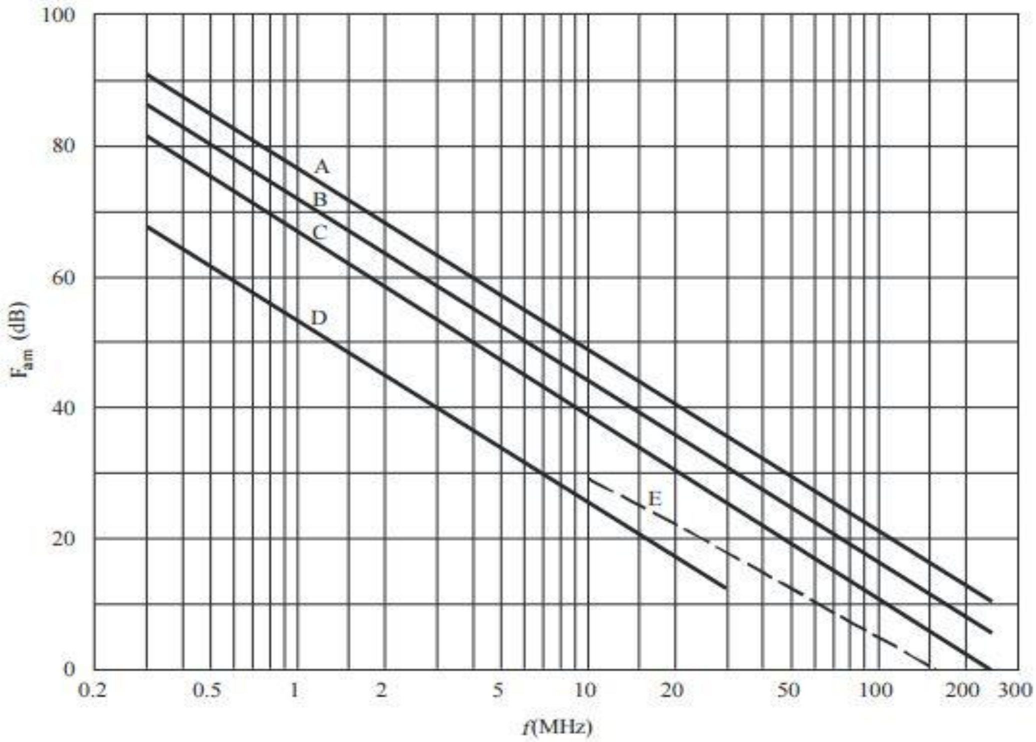

Figure 1- Median values of man- made noise power for a short vertical lossless grounded monopole antenna.

Environment category: Lines A: city, B: residential, C: rural, D: quiet rural and E: galactic [8].

Fam = 59 dB **(14)**

Substitute (14) in (13) gives:

P_n = - 145 dBW/ Hz

2. Minimum takeoff angle of main lobe = 0.1 degrees.

The value is normally very small unless antenna performance is expected to be so poor at low angles that these angles should not be used in the estimation of upper useful frequencies. Or if the horizon is so obstructed that low takeoff and reception angles appear unlikely. Range = (0.01- 40 degrees, default = 0.1 degrees).

3. Require circuit reliability = 90%

The required circuit reliability which is an estimate of the percent of days within the month that the signal quality will be acceptable and should be specified for LUF calculations or time availability for service probability. Range = (1- 99%), default = 90%.

4. Required signal to noise ratio = 73 dB.

The required signal to noise ratio of the hourly median signal power relative to the hourly median noise in a 1 Hz bandwidth which is necessary to provide the type and quality of service required. Range = (-30 to 99 dB), default = 73 dB.

5. Multipath power tolerance = 3 dB.

The maximum difference in signal power between sky- wave modes to permit satisfactory system performance in the presence of multiple signals. Modes weaker than this level below the MRM are not considered multipath problems. (0 = multipath not considered). Range = (0- 40 dB), default = 3 dB.

6. Maximum tolerance time delay = 0.1 milliseconds.

The maximum tolerable difference in delay times between sky- wave modes to permit satisfactory system performance in the presence of multiple signals. Modes within this time delay are not considered multipath problems. (0 = multipath not considered). Range = (0- 99.99 msec), default = 0.1 milliseconds.

7. Absorption model = normal.

Tx antenna (transmitter antenna parameters):

Tx power (transmit power = 0.001 to 9999.99 Kw) = 500 Kw.

Main beam (transmit antenna main beam azimuth (deg. from North = 0- 360 deg.)) = 0 deg.

Rx antenna (receiver antenna parameters):

Receiver bearing (receive antenna direction (degrees from North = 0- 360)) = 0 degree.

Gain (receiver gain (for isotrope only = -90 to 90 dBi)) = 0 dBi.

Table 1- Seasonal hourly averages of foF2 for Baghdad, Mosul and Basrah during Winter- 2000. The yellow's values represent the abnormal predicted foF2 values using two models

(Seasonal average of smoothed sunspot number, Ri= 166.9)/ Winter- 2000						
	IRI- 2012			VOACAP		
Time(LT)	Baghdad	Mosul	Basrah	Baghdad	Mosul	Basrah
0	4.873	4.571	5.269	6.1	5.733	6.567
1	4.889	4.727	5.093	6.1	5.9	6.267
2	4.961	4.874	5.011	5.667	5.6	5.667
3	4.646	4.615	4.571	4.833	4.867	4.667
4	3.908	3.969	3.733	4.433	4.5	4.2
5	3.552	3.658	3.341	5.433	5.333	5.333
6	4.473	4.446	4.412	7.867	7.533	8.1
7	6.677	6.395	6.885	10.8	10.333	11.2
8	9.23	8.798	9.613	13.033	12.6	13.433
9	11.121	10.763	11.492	14.033	13.767	14.367
10	11.986	11.805	12.265	14.133	13.967	14.4
11	12.078	12.004	12.324	13.867	13.733	14.267
12	11.858	11.774	12.163	13.7	13.467	14.233
13	11.671	11.504	12.098	13.7	13.267	14.367
14	11.591	11.306	12.174	13.567	13	14.433
15	11.447	11.042	12.152	13.167	12.533	14.067
16	10.992	10.504	11.747	12.367	11.633	13.367

(Seasonal average of smoothed sunspot number, Ri= 166.9)/ Winter- 2000						
IRI- 2012				IRI- 2012		
Time(LT)	Time(LT)	Time(LT)	Time(LT)	Time(LT)	Time(LT)	Time(LT)
17	10.114	9.57	10.906	11.167	10.3	12.333
18	8.901	8.288	9.787	9.733	8.733	11.1
19	7.611	6.927	8.574	8.5	7.4	9.8
20	6.549	5.844	7.465	7.6	6.567	8.8
21	5.87	5.211	6.636	7.033	6.133	8.067
22	5.452	4.876	6.09	6.567	5.8	7.467
23	5.107	4.649	5.647	6.233	5.667	6.9

Table 2- Seasonal hourly averages of foF2 for Baghdad, Mosul and Basrah during Spring- 2000

(Seasonal average of smoothed sunspot number, Ri= 174.1)/ Spring- 2000						
IRI- 2012				VOACAP		
Time(LT)	Baghdad	Mosul	Basrah	Baghdad	Mosul	Basrah
0	8.014	7.361	8.659	10.333	9.533	11.033
1	7.76	7.202	8.271	9.833	9.167	10.4
2	7.435	6.978	7.833	9.133	8.667	9.567
3	6.835	6.508	7.158	8.533	8.2	8.733
4	6.231	6.04	6.311	8.433	8.233	8.467
5	6.113	6.003	6.09	9.3	9.1	9.333
6	6.986	6.851	7.007	10.9	10.633	11.033
7	8.657	8.438	8.802	12.5	12.2	12.733
8	10.343	10.066	10.586	13.567	13.233	13.867
9	11.474	11.175	11.787	14.267	13.9	14.667
10	12.16	11.811	12.558	14.967	14.433	15.5
11	12.745	12.292	13.258	15.6	14.933	16.233
12	13.223	12.659	13.849	15.733	15.033	16.533
13	13.343	12.721	14.055	15.4	14.7	16.167
14	13.09	12.47	13.838	14.9	14.267	15.6
15	12.72	12.12	13.455	14.433	13.867	15.167
16	12.358	11.765	13.078	13.9	13.267	14.7
17	11.831	11.242	12.571	13.067	12.467	13.9
18	10.985	10.425	11.737	12.133	11.6	12.9
19	9.983	9.47	10.675	11.467	10.9	12.167
20	9.167	8.659	9.771	11.167	10.433	11.933
21	8.705	8.125	9.313	11.1	10.233	11.967
22	8.474	7.797	9.171	11	10.067	11.9
23	8.265	7.556	8.998	10.733	9.867	11.567

Table 3- Seasonal hourly averages of foF2 for Baghdad, Mosul and Basrah during Summer- 2000

(Seasonal average of smoothed sunspot number, Ri= 173.2)/ Summer- 2000						
IRI- 2012				VOACAP		
Time(LT)	Baghdad	Mosul	Basrah	Baghdad	Mosul	Basrah
0	8.683	8.334	8.828	9.933	9.433	10.1
1	8.462	8.041	8.673	9.5	9.1	9.733
2	8.103	7.678	8.381	9.033	8.6	9.233
3	7.626	7.256	7.897	8.667	8.333	8.8
4	7.266	6.992	7.436	8.767	8.567	8.8
5	7.395	7.22	7.438	9.367	9.233	9.333
6	8.033	7.921	8.045	10	9.9	10.033
7	8.729	8.633	8.803	10.333	10.267	10.467
8	9.08	8.981	9.217	10.467	10.367	10.667
9	9.204	9.099	9.377	10.867	10.7	11.1
10	9.51	9.348	9.756	11.567	11.267	11.967
11	10.139	9.824	10.529	12.367	11.8	12.933
12	10.803	10.284	11.374	12.733	12	13.533
13	11.144	10.471	11.87	12.633	11.833	13.5

(Seasonal average of smoothed sunspot number, Ri= 173.2)/ Summer- 2000						
	IRI- 2012			IRI- 2012		
Time(LT)	Time(LT)	Time(LT)	Time(LT)	Time(LT)	Time(LT)	Time(LT)
14	11.058	10.321	11.893	12.267	11.467	13.167
15	10.722	9.966	11.607	11.9	11.1	12.8
16	10.375	9.62	11.247	11.567	10.833	12.367
17	10.108	9.407	10.893	11.167	10.6	11.833
18	9.814	9.249	10.437	10.7	10.3	11.1
19	9.405	9.016	9.792	10.3	10	10.467
20	8.991	8.751	9.144	10.067	9.833	10.133
21	8.774	8.611	8.795	10.067	9.833	10.133
22	8.763	8.595	8.788	10.167	9.867	10.267
23	8.78	8.535	8.866	10.067	9.7	10.233

Table 4- Seasonal hourly averages of foF2 for Baghdad, Mosul and Basrah during Autumn- 2000

(Seasonal average of smoothed sunspot number, Ri= 165.7)/ Autumn- 2000						
	IRI- 2012			VOACAP		
Time(LT)	Baghdad	Mosul	Basrah	Baghdad	Mosul	Basrah
0	6.957	6.484	7.408	7.8	7.333	8.2
1	6.783	6.414	7.092	7.467	7.167	7.633
2	6.55	6.273	6.725	6.833	6.7	6.867
3	6.035	5.851	6.102	6.133	6.133	6.033
4	5.471	5.41	5.426	6.3	6.333	6.133
5	5.616	5.622	5.501	7.8	7.767	7.733
6	6.92	6.852	6.88	10.233	9.967	10.333
7	8.862	8.65	9	12.3	12	12.667
8	10.475	10.198	10.744	13.567	13.233	13.9
9	11.365	11.127	11.651	14.067	13.833	14.433
10	11.827	11.608	12.126	14.3	14	14.733
11	12.174	11.869	12.592	14.4	14	15
12	12.398	11.953	13.014	14.467	13.933	15.267
13	12.454	11.899	13.232	14.433	13.833	15.367
14	12.39	11.779	13.264	14.267	13.6	15.267
15	12.202	11.574	13.105	13.833	13.133	14.833
16	11.775	11.159	12.661	13.067	12.3	14.067
17	11.068	10.469	11.916	12	11.2	13.067
18	10.18	9.587	10.98	10.867	10.033	11.9
19	9.244	8.663	9.974	9.9	9.033	10.9
20	8.417	7.864	9.031	9.267	8.433	10.133
21	7.833	7.296	8.35	8.833	8	9.633
22	7.477	6.927	7.977	8.467	7.667	9.233
23	7.203	6.659	7.716	8.067	7.433	8.733

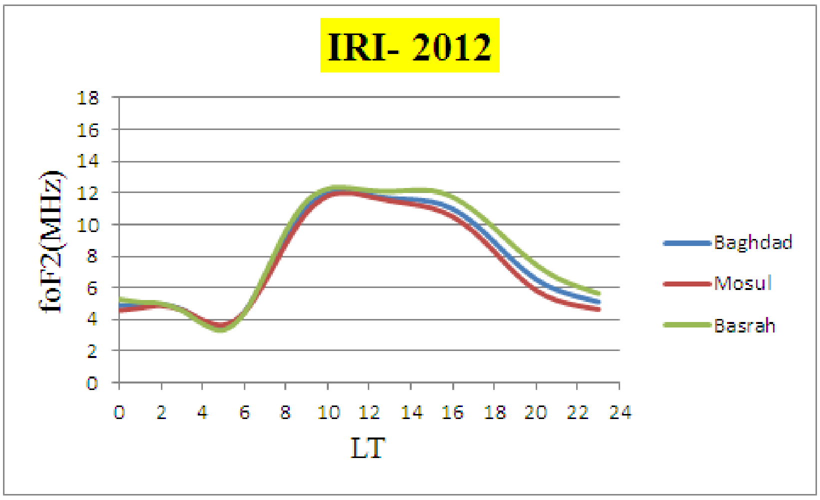

Figure 2- Hourly variation of predicted foF2 for Baghdad, Mosul and Basrah during Winter 2000.

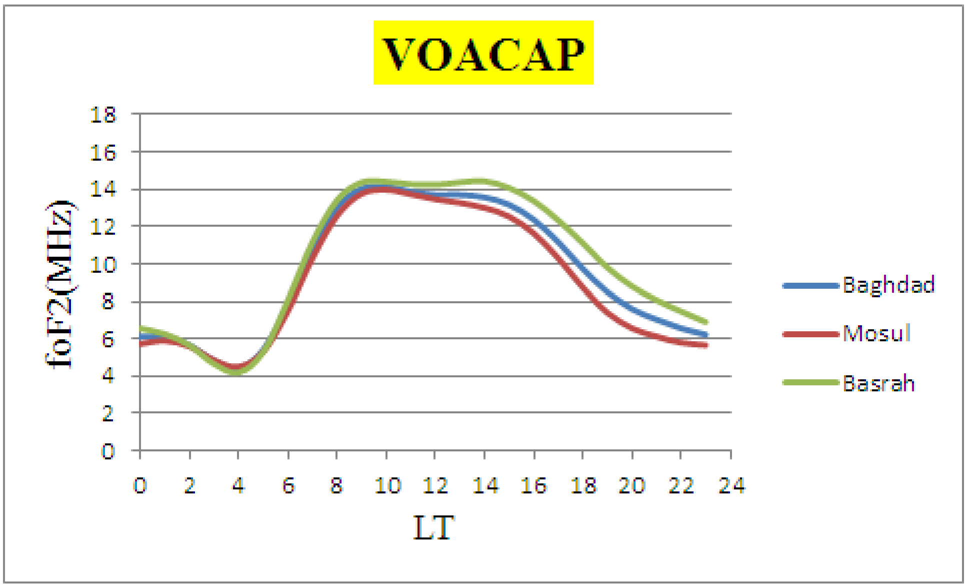

Figure 3- Hourly variation of predicted foF2 for Baghdad, Mosul and Basrah during Winter 2000.

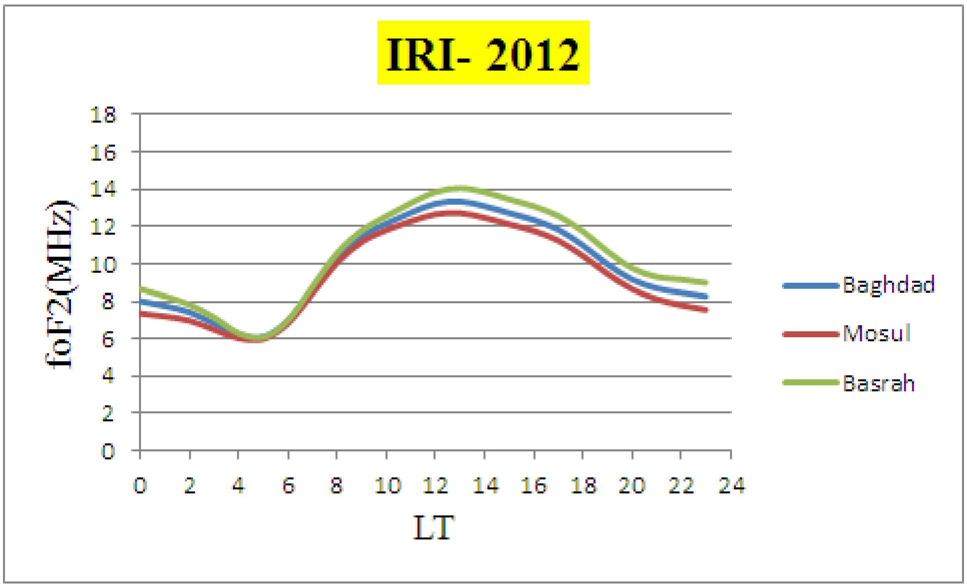

Figure 4- Hourly variation of predicted foF2 for Baghdad, Mosul and Basrah during Spring 2000.

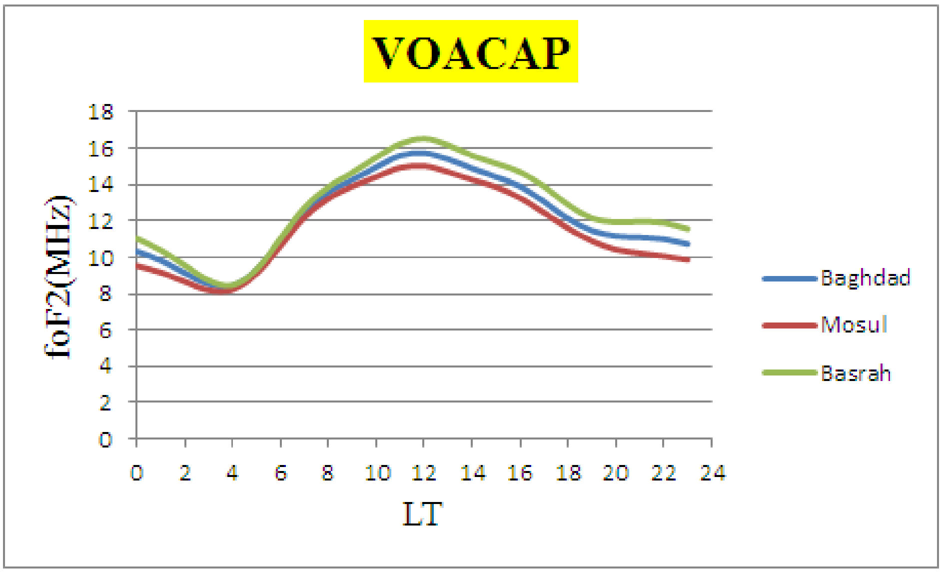

Figure 5- Hourly variation of predicted foF2 for Baghdad, Mosul and Basrah during Spring 2000.

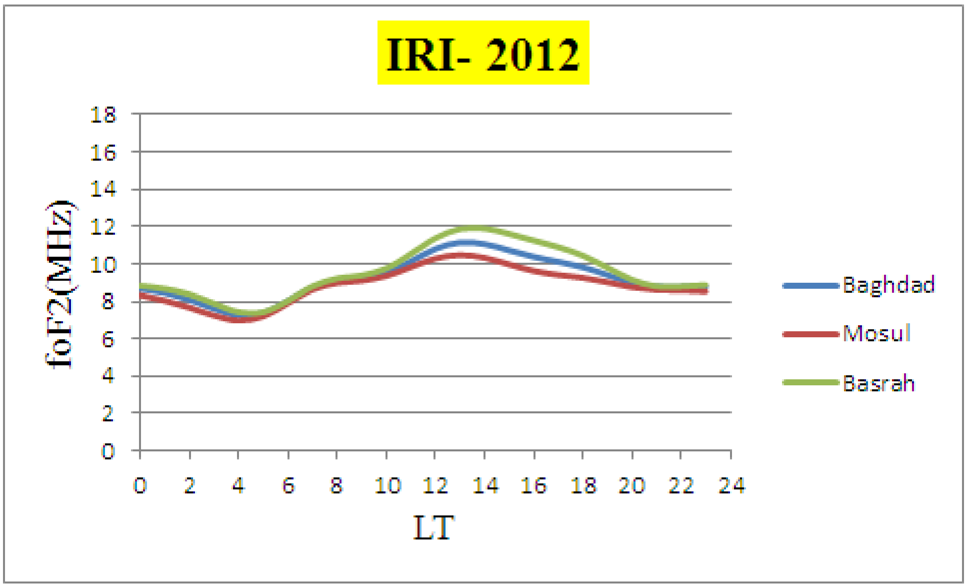

Figure 6- Hourly variation of predicted foF2 for Baghdad, Mosul and Basrah during Summer 2000.

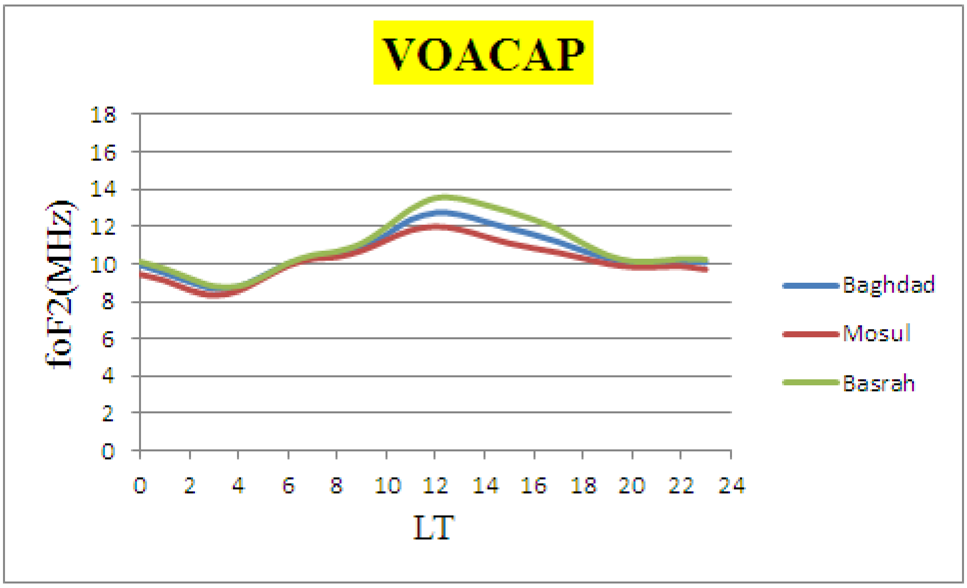

Figure 7- Hourly variation of predicted foF2 for Baghdad, Mosul and Basrah during Summer 2000.

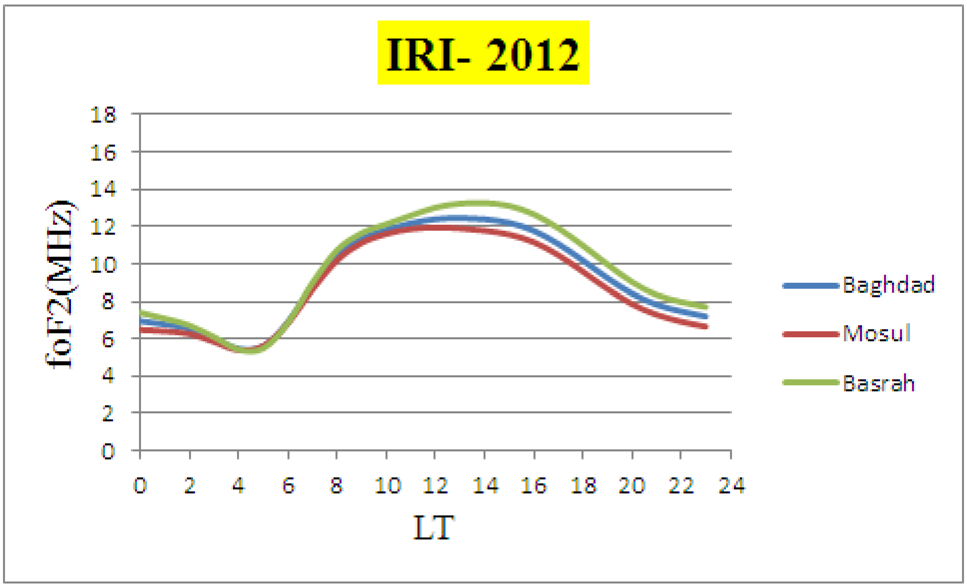

Figure 8- Hourly variation of predicted foF2 for Baghdad, Mosul and Basrah during Autumn 2000.

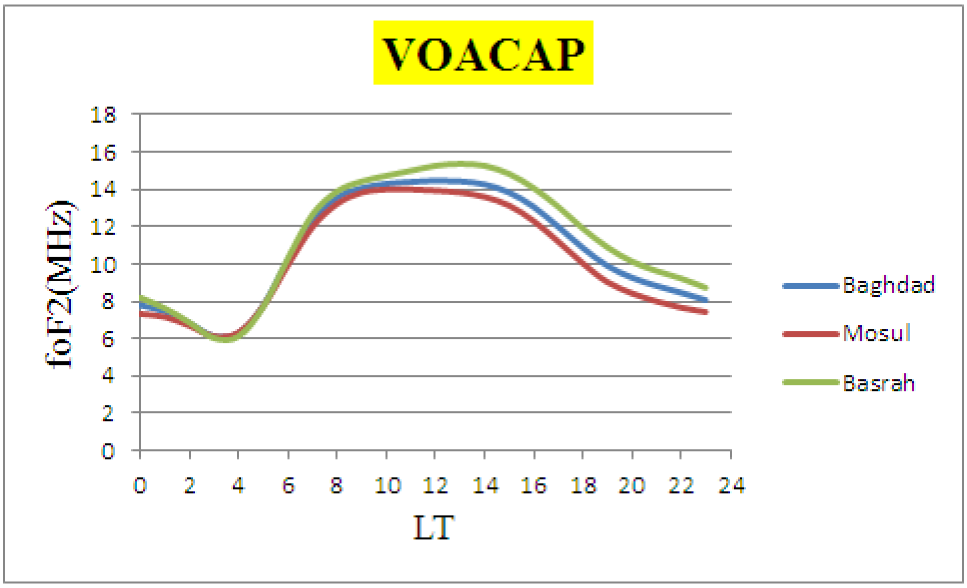

Figure 9- Hourly variation of predicted foF2 for Baghdad, Mosul and Basrah during Autumn 2000.

Discussion of results:

It is seen that, the predicted foF2 value for Basrah is smaller than that for Baghdad and Mosul at (3, 4, 5 and 6 LT), and for Mosul is greater than that for Baghdad at (4 and 5 LT); while for Basrah is smaller than that for Baghdad and Mosul at (3 and 4 LT), and for Basrah is equal to that for Baghdad at 2 LT and equal to that for Mosul and smaller than that for Baghdad at 5 LT (the yellow color, Table-1). The predicted foF2 value for Basrah using both of IRI- 2012 and VOACAP is greater than that for Baghdad and Mosul and for Baghdad is greater than that for Mosul, for the other hours. The same abnormal in predicted foF2 values at (3, 4, 5 and 6 LT) using two models is seen, as shown in the yellow color, Table-4.

The predicted foF2 values for Basrah are greater than that for Baghdad and Mosul, for Baghdad are greater than that for Mosul for all hours of the day Tables-2 and 3.

IRI- 2012 and VOACAP are accurate in predicting foF2 for Baghdad, Mosul and Basrah for all hours (day and night) during Summer and Spring of 2000, where seasonal values of smoothed sunspot number (during Summer and Spring) are greater than those during Winter and Autumn. Also, it is seen from Figures (2- 9) that the variation curve of predicted foF2 using both of IRI- 2012 and VOACAP is the same, and that the predicted hourly foF2 values for Baghdad, Mosul and Basrah, using VOACAP, are higher than those, using IRI- 2012 model, for all seasons of 2000, Tables (1- 4), probably because of input system and antenna parameters values in VOACAP are inaccurate which need to engineer deals with antennas and gives accurate information about antenna type used, signal to noise ratio, transmitted power, etc. And then the predicted values of foF2 using VOACAP are near to those using IRI- 2012 model.

Conclusions:

From the results obtained, we conclude that both of VOACAP and IRI- 2012 models have approximately the same accuracy and can be used any of them in predicting hourly foF2 values for Baghdad, Mosul and Basrah during high solar activity level.

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