INVESTIGATING THE INFLUENCE OF SOLAR ACTIVITY ON THE IONOSPHERIC CRITICAL FREQUENCIES OVER IRAQI REGION (A CASE STUDY)

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ABSTRACT: *The influence of solar activity on the annual behaviors of the ionospheric parameters on the critical frequency parameters for layers (foE.foF1,foF2) have been investigated over the ionospheric Iraqi region by data generated using International Reference Ionosphere (IRI-2016) model, the models result have been compared during years (1989,2001,2014) represents the maximum and years (1986,1996,2008)for the minimum of solar cycles (22,23, 24) respectively and for altitudes from 100-1000 km. The determinations have been made for fifty-five sites located within Iraq area; the capital Baghdad has been chosen to represent the transmitter station while the other communication points which are located on different distances and directions around the transmitter station have been represented as receiver stations. Also, a mathematical formula that describes the correlation between the ionospheric electron density and critical frequency parameters have been investigated for the annual times of the tested years. The mathematical correlation equation between the tested parameters has been found to be a polynomial equation of the third order. The result of the conducted study demonstrated that the critical frequency parameter is generally increased during noon time and the southern part of the studied zone showed higher values of electron density than the northern regions that may due to the solar radiation also the geographical location on the behavior of the foF2 parameters*

KEYWORDS: critical Frequency, IRI model, Solar Activity, Ionosphere layer.

INTRODUCTION

The ionosphere layer is located between 60 to 1000 km and more [1]. The ionosphere is the ionized component of the atmosphere, comprising of free electrons and positive ions ,the presence of the charged particles that brings about the possibility of radio communications over large distances by making use of one or more ionospheric reflections[2] Ionosphere is classified according to the density of the electrons and the ionization that divided into two main regions "topside region which extending upwards from about 500 km to 1000 km above the Earth's surface and the "*bottom-side region*" that textending from 60 km to 500 km above the Earth's surfaces. The bottom side region divided into three layers defined according to height and electron density: the D, E, and F layers. Each layer is subdivided into layers called the D, E, E_s, F_1, and F_2. The *D-layer* extending roughly from the height of (50 - 90) km being mainly responsible for the partial absorption of high-frequency radio waves [3]. The second layer, the *E-layer* extending form (90-150) km. These layers can only reflect radio waves that have frequencies below 5 MHz [4]. Also, there is an unexpected layer known as *E-Sporadic (Es)* with height 80 to 120 km [5]. The third layer is *F-layer* is considered to be one of the most ionized ionospheric layers, usually, range from about (140-500) km and above. The coming sunlight causes the division of this layer into two distinct layers *F1 layer* located at a height of (150-250) km and *F2 layer*, the highest layer of the ionosphere and is located at a height of (250-400) km [6].

CRITICAL FREQUENCY

The radio spectrum which represent a part of the electromagnetic spectrum from 3 Hz to 3000 GHz are extremely widely used in modern technology particularly in telecommunication [3]. The ionosphere can be described with different parameters. The most frequently used description called *Critical Frequency*. If an ionospheric layer possesses a distinct maximum in ionization, a radio frequency capable of just penetrating to this height is called the critical frequency of the layer. It is the greatest frequency that can be reflected vertically from the layer. In the strict sense of the word, radio waves transmitted at frequencies higher than the critical frequency of a given layer will pass through the layer and be lost in space. If this wave enters into an upper layer with a higher critical frequency, the wave will be refracted back to Earth. Radio waves of frequencies lower than the critical frequency will also be refracted back to Earth unless they are absorbed or have been refracted from a lower layer. The lower the frequency of a radio wave, the more rapidly the wave is refracted by a given degree of ionization [7]. The ordinary ray critical frequency for a given ionospheric layer is denoted by the symbol (f_o) plus the name of the layer (f_oD, f_oE, f_oF_1, and f_oF_2) respectively. Normally they are recorded in units of megahertz (MHz) [8]. When there is a standard daily layer division, the f_oF_2 values are one of the most important parameters to describe the status of ionosphere variation and known as the highest frequency signal that will be reflected directly to their transmitting location depending on the time from day to day. This relates to the maximum electron density of the F_2 layer (N_mF2) according to the following equation [9].

$$f_o F2 = 9 * \sqrt{Ne_{max}} \cdots \ldots\ldots (1)$$

Where: f_o: denotes critical frequency
N_e: denotes electron density

INTERNATIONAL REFERENCE IONOSPHERE (IRI)

The International Reference Ionosphere (IRI) project was initiated by the Commission for Space Research (COSPAR) and the International Union of Radio Science (URSI) in the late 1960s [10]. IRI was built as an empirical model representing the syntheses of most of the available ground and space measurements of ionospheric characteristics. IRI presents monthly averages of electron and ion densities and temperatures in the altitude range of (50–2000 km). It also provides the vertical Total Electron Content (TEC) from the lower boundary (60–80 km) to a user-specified upper boundary [11]. The latest version of the IRI model is the IRI-2016 model which was selected in this paper because this model represents one of the best model and solution in the ionosphere [12].

THE RESULTS

In this work, the impact of solar activity on the behavior of the ionosphere layers has been studied over Iraqi region during the minimum and maximum years of the solar cycles (22, 23 and 24). The minimum tested years of the three solar cycles are (1986, 1996 and 2008) and the maximum years are (1989, 2001, and 2014) respectively. In order to study the behavior of the ionosphere layers (E, F1, and F2), critical frequency parameter (f_oF2, f_oF1, and f_oE) have been calculated using IRI-2016 international ionospheric model. The execution of the IRI -2016 model needs different input parameters like the monthly adjusted values of the solar flux (F10.7) and the monthly Smoothed Sunspot Number (SSN) of the selected years.The monthly sunspot numbers and the monthly values of the adjusted solar flux ($F_{10.7}$) of the selected year are shown in the table (1).

Table (1) Monthly sunspot number and adjusted solar flux (F10.7) values of the min. and max. years of solar cycle 24 [13].

Smoothed Sunspot Number (SSN)						
Month	**1986**	**1989**	**1996**	**2001**	**2008**	**2014**
Jan	15.2	210.1	16.8	158.3	6.6	109.3
Feb	14.3	208.7	16.2	152.5	5.6	110.5
Mar	14.3	170.4	15.4	155.1	5.1	114.3
Apr	15.1	166.3	13.6	160.7	5.1	116.4
May	15.8	195.4	12.9	163.7	5.3	115.0
Jun	15.2	284.5	13.5	167.4	4.8	114.1
Jul	15.1	180.5	13.4	172.0	4.0	112.6
Aug	14.4	232.0	13.1	175.8	3.8	108.3
Sep	13.5	225.1	13.3	177.1	3.2	101.9
Oct	14.7	212.2	14.0	177.3	2.4	97.7
Nov	16.6	238.2	15.4	180.3	2.3	94.7
Dec	18.3	211.4	16.2	179.1	2.2	92.2

Solar Flux ($F_{10.7}$ cm)						
Month	**1986**	**1989**	**1996**	**2001**	**2008**	**2014**
Jan	73.25	235.38	74.52	167.50	74.02	162.69
Feb	83.58	222.39	71.83	146.72	71.03	170.13
Mar	77.02	205.07	70.67	178.14	72.99	150.50
Apr	75.06	189.56	69.42	192.46	70.15	143.94
May	72.61	190.14	70.13	147.52	68.32	130.11
Jun	67.59	239.58	69.86	174.11	65.85	122.37
Jul	70.21	181.86	71.36	131.72	65.67	137.90
Aug	68.37	217.09	72.48	166.85	66.17	124.56
Sep	68.71	225.90	69.45	134.08	67.00	146.57
Oct	82.95	208.68	69.23	210.54	68.21	154.99
Nov	77.14	235.13	79.06	214.57	68.53	155.74
Dec	72.64	213.00	75.69	241.16	69.05	159.02

In this study, Baghdad city (44.37^o E, 33.35^o N) has been picked to represent as a transmitting station with other fifty-five different selected receiving stations laid within the Iraqi region. The behavior of the annual variations of the ionospheric critical frequency parameter for the twelve months of the selected years (1989, 2001, 2014) at maximum solar cycles (22, 23 and 24) and the years (198, 1996, 2008) of the minimum same solar cycles have been determined.

The calculations have been conducted using the (IRI-2016 model). The adopted model have been tested for the selected locations; the predicted values of the ionospheric parameter have been calculated for the altitudes (100, 200, 300 …1000) km. A statistical analytical study has been made on the generated datasets of the predicted values from the international model by taking into consideration the local time (LT) for the city of Baghdad (transmitter station). Table (2) shows a sample of the statistical analysis results that illustrate the annual variations of the critical frequency parameter for the (E, F1, and F2) layers (f_oE, f_oF1, and f_oF2) for the height (100, 200, 300… 1000) km for Baghdad location for the year (1989).

Table (2) show the values of the critical frequency parameter for the heights (100-1000) km of Baghdad city for the year (1989)

Critical Frequency (F_oE) for Baghdad location at height (100-1000)km for year (1989)

Time	100	200	300	400	500	600	700	800	900	1000
0	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581
1	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581
2	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581
3	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581
4	0.588	0.588	0.588	0.588	0.588	0.588	0.588	0.588	0.588	0.588
5	0.870	0.870	0.870	0.870	0.870	0.870	0.870	0.870	0.870	0.870
6	1.578	1.578	1.578	1.578	1.578	1.578	1.578	1.578	1.578	1.578
7	2.475	2.475	2.475	2.475	2.475	2.475	2.475	2.475	2.475	2.475
8	3.110	3.110	3.110	3.110	3.110	3.110	3.110	3.110	3.110	3.110
9	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481
10	3.709	3.709	3.709	3.709	3.709	3.709	3.709	3.709	3.709	3.709
11	3.837	3.837	3.837	3.837	3.837	3.837	3.837	3.837	3.837	3.837
12	3.878	3.878	3.878	3.878	3.878	3.878	3.878	3.878	3.878	3.878
13	3.836	3.836	3.836	3.836	3.836	3.836	3.836	3.836	3.836	3.836
14	3.708	3.708	3.708	3.708	3.708	3.708	3.708	3.708	3.708	3.708
15	3.479	3.479	3.479	3.479	3.479	3.479	3.479	3.479	3.479	3.479
16	3.104	3.104	3.104	3.104	3.104	3.104	3.104	3.104	3.104	3.104
17	2.463	2.463	2.463	2.463	2.463	2.463	2.463	2.463	2.463	2.463
18	1.588	1.588	1.588	1.588	1.588	1.588	1.588	1.588	1.588	1.588
19	0.886	0.886	0.886	0.886	0.886	0.886	0.886	0.886	0.886	0.886
20	0.594	0.594	0.594	0.594	0.594	0.594	0.594	0.594	0.594	0.594
21	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581
22	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581
23	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581	0.581

Critical Frequency (F_oF1) for Baghdad location at height (100-1000)km for year (1989)

Time	100	200	300	400	500	600	700	800	900	1000
0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
11	2.722	2.722	2.722	2.722	2.722	2.722	2.722	2.722	2.722	2.722
12	2.742	2.742	2.742	2.742	2.742	2.742	2.742	2.742	2.742	2.742
13	2.724	2.724	2.724	2.724	2.724	2.724	2.724	2.724	2.724	2.724
14	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0

Critical Frequency (F_oF2) for Baghdad location at height (100-1000)km for year (1989)

Time	100	200	300	400	500	600	700	800	900	1000
0	7.440	7.440	7.440	7.440	7.440	7.440	7.440	7.440	7.440	7.440
1	7.317	7.317	7.317	7.317	7.317	7.317	7.317	7.317	7.317	7.317
2	7.111	7.111	7.111	7.111	7.111	7.111	7.111	7.111	7.111	7.111
3	6.629	6.629	6.629	6.629	6.629	6.629	6.629	6.629	6.629	6.629
4	6.174	6.174	6.174	6.174	6.174	6.174	6.174	6.174	6.174	6.174
5	6.380	6.380	6.380	6.380	6.380	6.380	6.380	6.380	6.380	6.380
6	7.625	7.625	7.625	7.625	7.625	7.625	7.625	7.625	7.625	7.625
7	9.477	9.477	9.477	9.477	9.477	9.477	9.477	9.477	9.477	9.477
8	11.150	11.150	11.150	11.150	11.150	11.150	11.150	11.150	11.150	11.150
9	12.269	12.269	12.269	12.269	12.269	12.269	12.269	12.269	12.269	12.269
10	12.960	12.960	12.960	12.960	12.960	12.960	12.960	12.960	12.960	12.960
11	13.377	13.377	13.377	13.377	13.377	13.377	13.377	13.377	13.377	13.377
12	13.538	13.538	13.538	13.538	13.538	13.538	13.538	13.538	13.538	13.538
13	13.502	13.502	13.502	13.502	13.502	13.502	13.502	13.502	13.502	13.502
14	13.396	13.396	13.396	13.396	13.396	13.396	13.396	13.396	13.396	13.396
15	13.230	13.230	13.230	13.230	13.230	13.230	13.230	13.230	13.230	13.230
16	12.918	12.918	12.918	12.918	12.918	12.918	12.918	12.918	12.918	12.918
17	12.412	12.412	12.412	12.412	12.412	12.412	12.412	12.412	12.412	12.412
18	11.702	11.702	11.702	11.702	11.702	11.702	11.702	11.702	11.702	11.702
19	10.761	10.761	10.761	10.761	10.761	10.761	10.761	10.761	10.761	10.761
20	9.673	9.673	9.673	9.673	9.673	9.673	9.673	9.673	9.673	9.673
21	8.691	8.691	8.691	8.691	8.691	8.691	8.691	8.691	8.691	8.691
22	8.024	8.024	8.024	8.024	8.024	8.024	8.024	8.024	8.024	8.024
23	7.646	7.646	7.646	7.646	7.646	7.646	7.646	7.646	7.646	7.646

Figures (1) and (2) show samples of the statistical analysis results of the annual time variations for the critical frequency parameter of the (E, F1, and F2) layers (f_oE, f_oF2, and f_oF2) parameters for the height (100 km) of the maximum years (1989, 2001, and 2014) and the minimum years (1986, 1996, and 2008) respectively

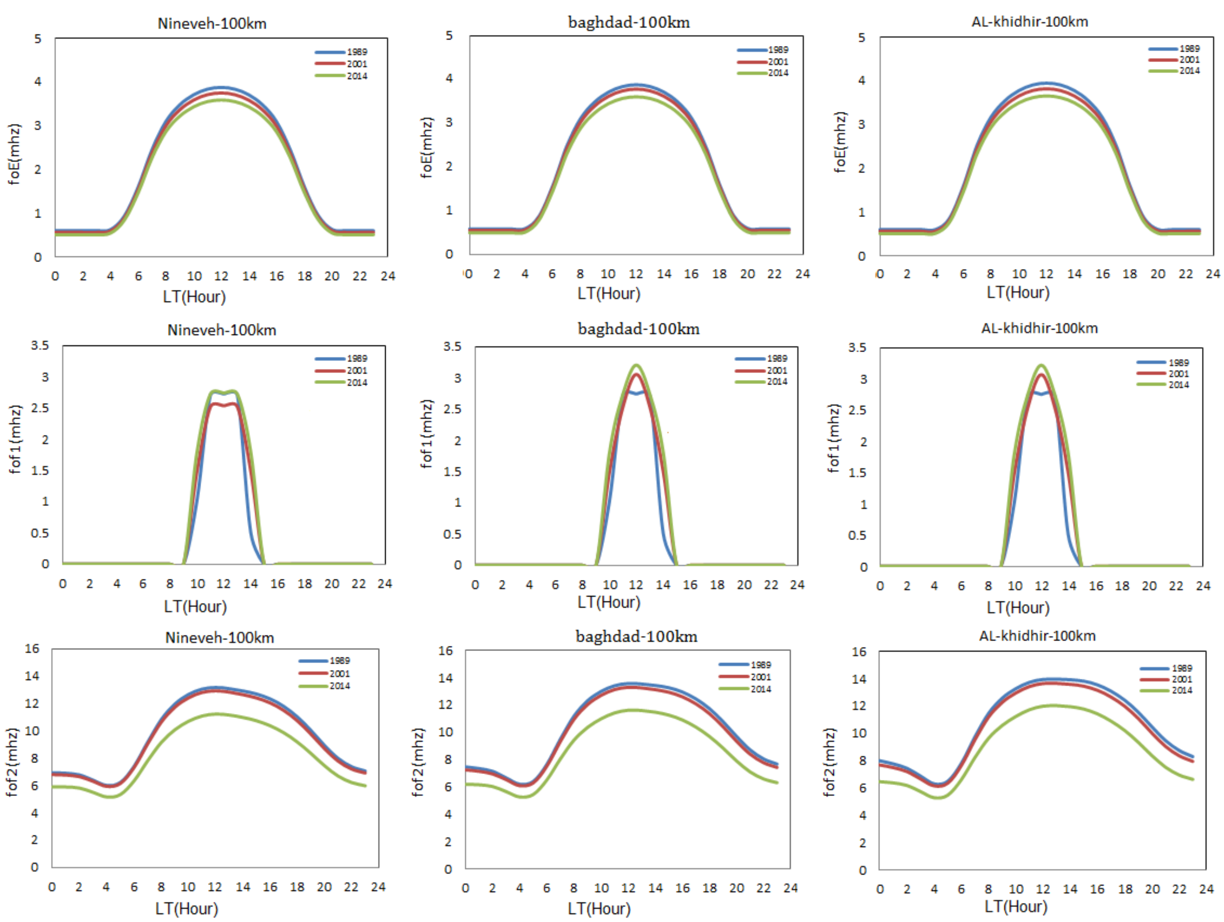

Figure (1) show samples of the annual critical frequency variation (f_oE, f_oF_2, and f_oF_2) parameters for the height (100 km) of the maximum years (1989, 2001, and 2014).

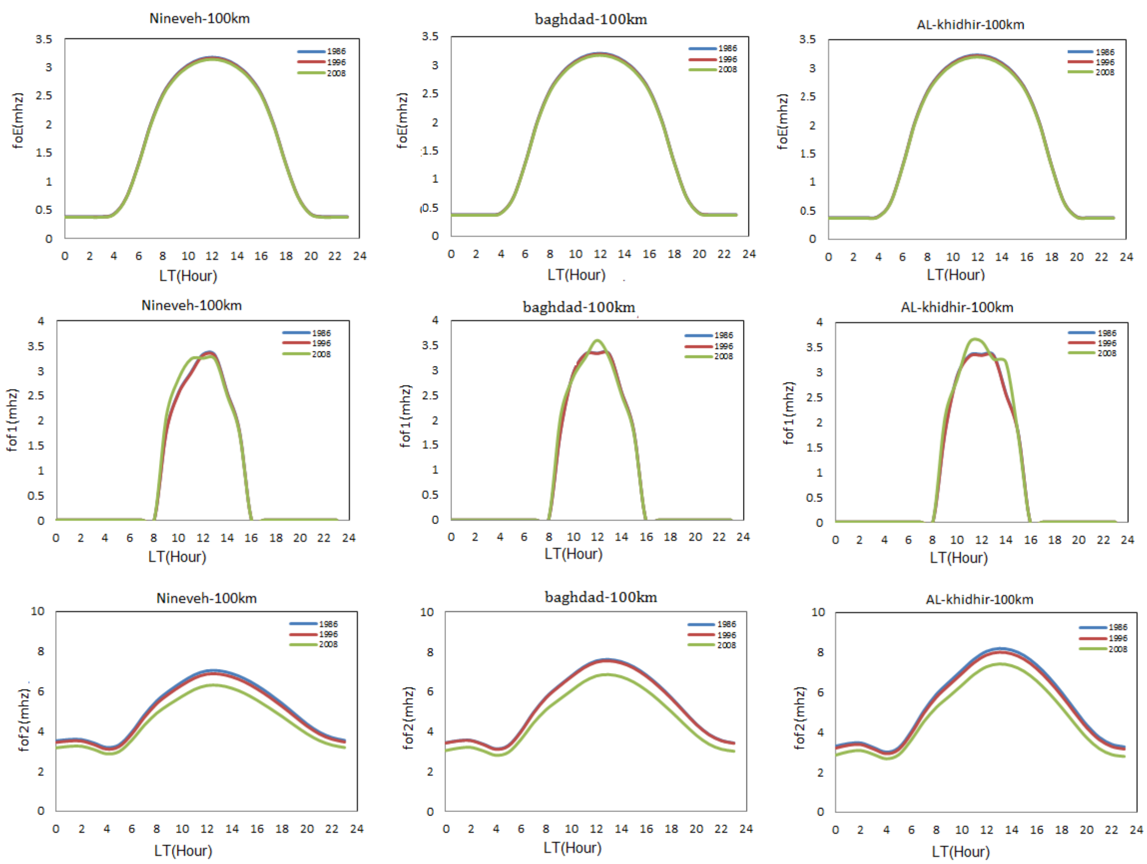

Figure (2) show samples of the annual critical frequency variation (f_oE, f_oF_2, and f_oF_2) parameters for the height (100 km) of the minimum years (1986, 1996, and 2008).

The relationship between the ionospheric electron density and critical frequency parameters have been investigated to get a suitable mathematical correlation equation for these parameters that can give predictable values. Depending on the results of the annual statistical analysis study that have been made on the generated datasets using the IRI-2016 model for the maximum and minimum years of the studied solar cycles, the mathematical correlation equation between the tested parameters have been found to be expressed as a polynomial formula, so the suggested mathematical correlation equation between the studied parameters can be presented by the following equations:

$$y = \sum_{k=0}^{n} a_k \; x^k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

$$Y = a_o + a_1 x^1 + a_2 x^2 + \cdots + a_n x^n \quad \ldots\ldots\ldots\ldots\ (3)$$

So, the suggested correlation formulas can be presented as follow:

$$f_o F2 = a_o + a_1 (N_e) + a_2 (N_e)^2 + \cdots + a_n (N_e)^n \ \ldots\ldots\ldots\ (4)$$

According to the result of the statistical analytical study, the correlation formula has been found to be a polynomial equation of "*Third Order*". The theoretical values of the ionospheric critical frequency have been calculated using equation (1).

Table (3) shows a sample of the correlation coefficients (a_o, a_1, a_2 and a_3), the correlation parameter (R^2) and the calculated values of the Root Mean Square Error (RMSE) which have been calculated using the following equation:

$$\text{RMSE}=\sqrt{\frac{\sum_{i=0}^{n}(X_i - Y_i)^2}{n}} \quad \ldots\ldots\ldots\ (5)$$

Where:

Xi = present values,

Yi = Predict or Theoretical Values.

Table (3) shows sample for the correlation coefficients of the f_oF_2 parameter for the annual times of Baghdad city for the heights (100-1000) Km of the year 2014.

baghdad-2014							
Equation: foF2=a3*(Ne)^3 - a2*(Ne)^2 + a1*(Ne) - ao							
Hieght =100km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0-4	15.082	-317.890			0.8143	0.0883	6.95232
5_13	4.755	7.679	3.559	1.145	0.9992		
14-19	8.551	4.096	-1.454		0.9923		
20-23	-616.2	40966	-671069		0.9999		
Hieght =200km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0_3	-671.830	20441	-153940.000		0.3745	0.20844	4.78159
4_10	5.209	1.156	-0.630		0.9949		
11_17	2.593	3.231	-0.293		0.9729		
18_23	6.6292	1.8724	-0.2932		0.912		
Hieght =300km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²		RMSE
0_4	1.994	1.439			0.608	0.11193	0.696575
5_13	3.455	-515.000	0.015	-0.001	0.9997		
14_23	5.105	0.423	-0.010	0.001	0.9993		
Hieght =400km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0_4	3.055	-0.636			0.9887	0.06574	1.49848
5_13	-3.218	3.642	-0.319	0.010	0.9999		
14_23	-5.987	3.547	0.241	0.060	0.9973		
Hieght =500km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0_4	3.033	1.273			0.9937	0.07425	3.5588
5_13	-1.031	7.810	-1.397	0.089	0.9999		
14_23	-15.186	13.040	-2.221	0.132	0.9988		
Hieght =600km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0_4	2.868	2.644			0.9969	0.05871	4.99616
5_13	-2.482	12.016	-3.638	0.399	0.9999		
14_23	-5.831	12.236	-2.551	0.130	0.9978		
Hieght =700km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0_4	2.729	4.947			0.9982	0.419	5.89817
5_13	-1.016	16.200	-7.074	1.111	0.9999		
14_23	-0.129	8.272	1.662	-1.495	0.9989		
Hieght =800km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0_4	2.633	5.257			0.999	0.02913	6.4809
5_13	-0.019	20.800	-11.811	2.258	0.9999		
14_23	2.304	5.045	12.111	-5.335	0.9995		
Hieght =900km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0_4	2.568	12.568			0.9994	0.01219	6.8765
5_13	0.614	26.212	-18.492	3.940	0.9999		
14_23	3.343	3.126	30.250	-25.302	0.9993		
Hieght =1000km	Correlation Coefficients						
LT	ao	a1	a2	a3	R²	RMSE-pred	RMSE-theo
0_4	2.525	17.516			0.9995	0.01763	7.15763
5_13	1.013	37.645	-28.400	6.986	0.9999		
14_23	3.801	2.464	27.111	-66.305	0.9999		

The comparison between the annual values of the (f_oF2) ionospheric parameter that have been calculated using the suggested formula (4) "predicted" with the ionospheric values that have been generated using the international model (IRI) and the theoretical values which have been calculated using equation (1) have been shown in figures (3) and (4), that show samples for this comparison between the annual values of the (f_oF2) parameter for the maximum tested years (1989, 2001, and 2014) and the minimum years (1986, 1996 and 2008) of the three solar cycles (22, 23 and 24) respectively for Al-Khidhir location and for the heights (100, 200, 300…1000) km.

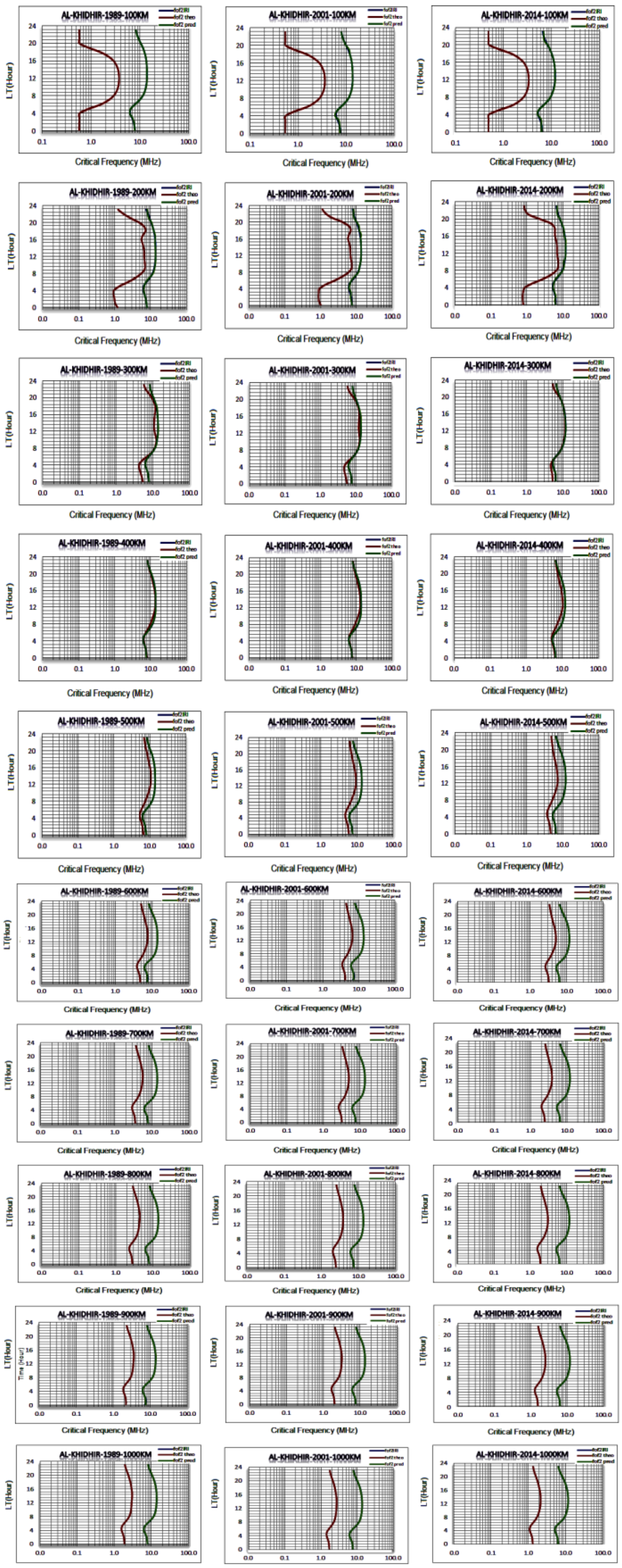

Figure (3) Comparison between the (IRI, predicted and theoretical) values of the (f_oF2) parameter for Al-Khidhir city for the heights (100-1000) km for the years (1989, 2001and 2014)

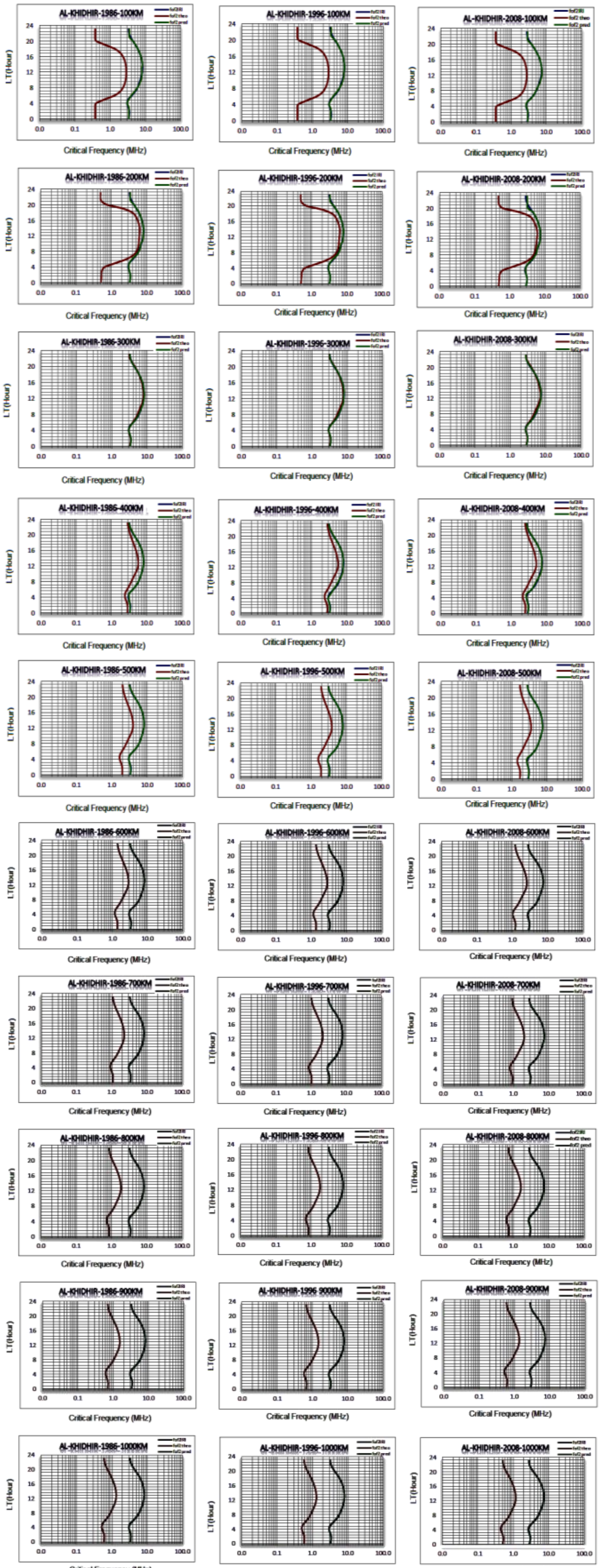

Figure (4) Comparison between the (IRI, predicted and theoretical) values of the (f_oF2) parameter for Al-Khidhir city for the heights (100-1000) km for the years (1986, 1996 and 2008)

DISCUSSION AND CONCLUSION

The results for the analytical study of the datasets that been generated using IRI-2016 model for the ionospheric parameters (f_oF2, f_oFl, f_oE) for the region over Iraqi zone have been conducted by considering a city of Baghdad as a transmitter station and many other sites that distributed around the transmitter station as receiving stations. The behavior of the critical frequency for the ionosphere layer has been studied during the minimum and maximum years of the solar cycles (22, 23 and 24). The maximum tested years of the three solar cycles are (1989, 2001 and 2014) and the minimum years are (1986, 1996 and 2008) respectively. Also, the calculations for all tested locations and years have been made for the heights (100,200,300 ..... 1000) km.

The study results of the annual variation of the critical frequency of the E layer (f_oE) for the years (1989, 2001, and 2014) showed that the values were almost invariant at all heights but it showed some differences in the southern regions which showed higher values than the mid and northern regions. So, the values in 1989 were higher than the values of 2001 and 2014, the highest value of (f_oE) during these years was (4.5) MHz, as shown in figure (1). Also, the variations for the years (1986, 1996, and 2008) present vary slight differences between them. The highest value of (f_oE) during these years was (3.5) MHz, as shown as in figure (2).

Form the study of the critical frequency behavior of F1-layer (f_oF1), it had been noticed that the values were invariant for all heights for each tested location. Also, it showed that the behavior of f_oF1 is varying from region to another and year to another that presented by a sharp peak at 2001 and 2014 in Al-khidhir location. The higher values of f_oF1 parameter during the maximum solar cycles were about (3.5) MHZ, as shown as in figure (1).

The calculations of (f_oFl) for the minimum solar cycle years (1986, 1996 and 2008) present a clear anomaly behavior between selected regions. This anomaly it may due to the effect of sunrise and sunset and the differences in latitudes. The values of the (f_oFl) parameter vary from year to another with the highest value of about (4) MHz, as shown in figures (2).

The behavior study of (f_oF2) for ionospheric F2 layer shows that the values of (f_oF2) for the years (1989, 2001, and 2014) presented the same behavior at all regions for the maximum years of the studied solar cycles. The values of (f_oF2) for the tested year vary with altitude, so it showed the highest value in (1989) whereas the lowest value was at (2014). The highest value of (f_oF2) during the maximum years was about (16 MHz) as show as in figure (1). Also, the calculated results of the (f_oF2) parameter showed that their values in the southern region were more than the values of the mid and northern regions. As for the maximum years of the studied solar cycles, the behavior of (f_oF2) at the minimum solar cycles years (1986, 1996, and 2008) present the same behavior for the all selected regions and years with very slight differences in the values for the years and regions that showed highest value at Al-khidhir region. So, it showed the highest value at 1986 and lowest value at 2008 and the greatest value for these years was about (8 MHz), as shown as in figure (2).

The comparison results between the annual values of the (f_oF2) ionospheric parameter that have been calculated using the suggested formula "predicted values" with the ionospheric values that have been generated using the international model

(IRI-2016) and the theoretical values which have been calculated using a theoretical equation showed that the behavior of critical frequency values for the IRI-2016 model is similar to the predicted values while it difference from the values calculated using theoretical equation. The behavior of the foF2 parameter displayed kind of anomalies for the height (200, 300, and 400) km, then with increasing the height the values became more stable shown as in figure (3&4).

According to the previous discussion, the following conclusions can be recorded:

The variation of the critical frequency varies with the changes of the solar activity that associated with the sunspots number and strength of the solar flux. So, It has been noticed that the critical frequency values do not change with altitude, while it varies with daytime. So, it reaches its maximum value at 12 pm and then begins to decline within a sunset. Also, the comparison results between the annual values of the (f_of2) ionospheric parameter had different values for the same behavior during various altitudes, and also a kind of anomaly have been noticed in the behavior of the critical frequency in the altitudes 100, 200, 300 and 400 km.

REFERENCES

1. A. Belehaki, I. Stanislawska, and J. Lilensten, "An Overview of Ionosphere-Thermosphere Models Available for Space Weather Purposes", Space Science Reviews, Vol. 147, 2009.
2. K. A. Hadi ,"A study of the seasonal variation of ionosphere electron density over Baghdad", Science International (Lahore), ISSN 1013-5316; CODEN: SINTE 8, Vol. 28, No. 5, pp: (5087-5092), 2016.
3. A. D. Khudhur and K. A. Hadi,"Analytical Study for the Annual TEC Parameter Variations for the Solar Cycle 24 over Iraqi Zone", Iraqi Journal of Science, Vol 56, No.3C, pp: 2694-2703,2015.
4. T. R. Gilliland, G. W. Kenrick, and K. A. Norton, "Investigations of Kennelly-heaviside layer heights for frequencies between 1600 and 8650 kilocycles per second", Proceedings of the Institute of Radio Engineers, Vol. 20,1932.
5. Recommendation and Reports of the CCIR, Geneva, vol. VI, Rep.725-2, pp. 1-12, 1986.
6. N. M. Maslin, "HF communications: A system approach", Pitman Publishing, London, Britain, ISBN 0-273-02675-5, pp. 43, 2015.
7. "Principles of radio wave", subcourse edition SS0130 B US army signal center and fort Gordon, 2005
8. M. I. Mohammed, "Investigation of the variation of maximum usable frequency (MUF) to ensure a good communication link between two locations", M.Sc. Thesis, Department of Astronomy and Space, College of Science, University of Baghdad, 2011.
9. Z. Mosna, P. Sauli, and O. Santolkk, "Analysis of Critical Frequencies in the Ionosphere ", WDS'08 Proceedings of Contributed Papers, Part II, 2008.
10. D. Bilitza, L. McKinnell, B. Reinisch, "The international reference ionosphere today and in the future", Springer-Verlag, J Geod (2011) 85:909–920 DOI 10.1007/s00190-010-0427-x, 2010.
11. A. Komjathy, "Global Ionospheric Total Electron Content Mapping Using the Global Positioning System", Department of Geodesy and Geomatics Engineering Technical Report No. 188, University of New Brunswick, Fredericton, New Brunswick, Canada, (1997).
12. K. Rawer, D. Bilitza, S. Ramakrishnan, "International reference ionosphere 78. Special Report", International Union of Radio Science (URSI), Brussels, Belgium, 1978.
13. The Sunspot Cycle, Marshall Space Flight Center, NASA, USA, November 2018. http://solarscience.msfc.nasa.gov/Sun