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SEMI-EMPIRICAL MATHEMATICAL MODEL FOR TRANS-IONOSPHERIC PARAMETERS OVER MIDDLE EAST REGION

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ABSTRACT

In this paper, the variation of the ionospheric parameters (Maximum Usable Frequency (MUF) and Optimum Traffic Frequency (FOT)) has been investigated between the transmitter station (Baghdad) and numerous receiving stations that laid on different directions over Middle East zone. The values of the ionospheric parameters have been determined using ICEPAC international model for the seasonal and annual times of the current solar cycle (2009-2011). In this work, a mathematical model has been suggested to calculate the ionospheric parameters of the studied area for the tested years of the current solar cycle. According to the statistical analysis results that have been made between the geographical locations coordinates (longitudes & Latitudes) of receiver stations and the dataset of the MUF and FOT parameters, the empirical formula can be presented as a linear surface equation. The predicated ionospheric parameters results that have been evaluated using the suggested mathematical model showed a good fitting with the theoretical results that have been obtained from the HF international communication models.

KEYWORDS: Trans-Ionospheric Parameters, HF Radio Propagation, Maximum Usable Frequency, Optimum Traffic Frequency

INTRODUCTION

The ionosphere is defined as the highest part of the earth's atmosphere which contains the enough amounts of free electrons that have large effect on radio waves propagation. The existence of ionosphere was discovered when observed radio waves can propagate for large distances [1]. The height of ionosphere region is ranged from about 60 km to 1000 km above the surface of the earth and the concentration of free electrons is greatly varies from about 10^7 particles per m^3 to a maximum of 10^{12} particles per m^3 [2]. As indicated above, the ionosphere is conventionally described in terms of layers, so these layers were called (D, E, F, topside layers). The ionospheric layers are formed by extreme ultraviolet (EUV) and x-ray radiation that is come from the sun, and have big variation with solar activity, time of day and geographical location [3].

Basically, the propagation of radio range signals for long distances is limited by the band of high frequency (HF) (2 - 30 MHz), although significant propagation can take place at other frequencies in unusual circumstances [4].

IONOSPHERIC COMMUNICATION PARAMETERS

The ionospheric parameters or trans- ionospheric parameters are represented an essential role for determination the ionospheric variability and physical mechanism of propagation of HF radio signals and are defined as the best operational usable frequencies that are maintained successful communication link for specific path between two points on the earth [5], so these parameters are explain as follows:

- **Maximum Usable Frequency (MUF)** is the highest frequency which is allowed an acceptable operation of HF radio wave propagation only 50 percent of the time.

- **Optimum Traffic Frequency (FOT)** is define as best working frequency that is reflected from ionosphere layer for long time (about 90 % of the time) between two ground terminals.
- **Lowest Usable Frequency (LUF)** is the lower limit of frequency that can be used for HF propagation through ionosphere layer over specific path only 10 % of the time [6].

For many years, several researchers have been worked to developing ionospheric parameter models, for instance, [Singer and Dvinskikh, 1991] [7], [Daniell *et al*., 1995] [8], [Zolesi and Cander, 2000] [9], [Tsagouri *et al.*, 2006] [10], [Bilitza and Reinisch, 2008] [11], LiBo *et al*. [2011] [12], Sardar *et al.* [2012] [13]. The ionospheric parameters have widely variations with time, geographical location, orientation, and other effects that resulted from the changes of solar activity [14].

INTERNATIONAL IONOSPHERIC COMMUNICATION MODEL

Many radio operating systems during the past years have been developed military and humanitarian organizations to predict the propagation characteristics of HF signals which are an important aspect of ionosphere variability [15]. Various computer codes have been design by a number of organizations for this purpose like REC533, VOACAP, ICEPAC and others which are developed by Institute of Telecommunication Sciences (ITS) of the National Telecommunication and Information Administration (NTIA)/ITS software in the United States of America for prediction of communications and coverage by HF signals [16]. For this work, the ICEPAC model has been adopted to calculate ionospheric parameters, because this model represents the best and modern HF international communication models and applicable for investigating the performance of HF band [17].

The ICEPAC propagation program is a statistical model of the large-scale properties of the ionosphere which is considered an extension of IONCAP model. It is used primarily to predict long term frequency management and circuit planning and contain different algorithms for the subauroral trough, the equator-ward portion of the auroral zone, the polar-ward region of the auroral zone, and the polar cap [18]. This program have ability to predicts the long-term operational parameter, like maximum usable frequency (MUF), optimum traffic frequency (FOT), lowest usable frequency (LUF), propagation modes take-off angles, height of ionosphere layer, signal to noise ratio and more in terms of the probability of successful transmission for a particular circuit [19].

TEST AND RESULTS

The main idea of this research is to suggest a simplified forecasting mathematical model that enable to predict the best ionospheric operational frequencies (MUF and FOT) for connection links between the province Baghdad (transmitter station) and fifty six receiving station that are distributed over Middle East zone, as shown in figure 1.

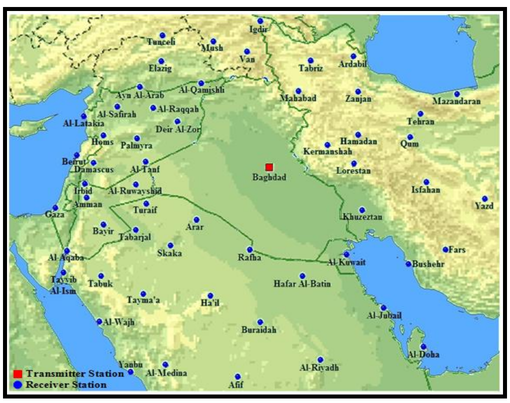


Figure 1: Distribution of Geographical Locations of Transmitter and Receiver Stations over Middle East Zone

Table 1 show the values of geographical location coordinates of receiving stations and the calculated bearing values of the transmitter to receiver stations.

Table 1: Values of Geographical Locations Coordinates for Receiver Stations and Bearing Transmitter to Receiver

Station Name	Geographical Location		Bearing
	Lon (^{0}E)	Lat (^{0}N)	(T_x to R_x) (Deg)
Elazig	39.36	38.67	323.28
Igdir	44.00	39.90	357.00
Mush	41.83	39.00	340.13
Tunceli	39.47	39.22	326.63
Van	43.38	38.49	350.84
Ardabil	48.30	38.25	32.010
Bushehr	50.84	28.92	127.80
Fars	52.53	29.62	117.03
Hamadan	48.46	34.80	65.610
Isfahan	51.67	32.66	95.160
Kermanshah	47.09	34.32	65.420
Khuzestan	48.69	31.33	118.26
Mahabad	48.49	31.33	17.000
Mazandaran	53.06	34.65	64.17
Qum	50.88	38.07	78.59
Tabriz	46.30	35.71	17.53
Tehran	51.41	31.90	66.53
Yazd	54.36	36.68	98.23
Zanjan	48.49	34.65	44.24
Lorestan	48.53	33.49	86.54
Al-Kuwait	47.97	29.37	141.98
Al-Doha	51.53	25.29	141.40
Afif	42.92	23.91	188.10
Al-Jubail	49.67	27.00	143.61
Al-Wajh	36.42	26.28	225.66
Arar	41.02	30.98	231.38
Buraidah	43.97	26.33	183.14
Hafar Al-Batin	45.96	28.44	164.63
Ha'il	41.68	27.52	202.51
Al-Medina	39.60	24.47	206.12
Rafha	43.50	29.64	192.09
Al-Riyadh	46.73	24.71	166.47
Skaka	39.85	29.80	228.54
Tabarjal	38.22	30.50	242.68
Tabuk	36.58	28.38	234.79
Tayma'a	38.55	27.63	222.44
Tayyib Al-Ism	34.83	28.57	241.30
Turaif	38.65	31.68	252.20
Yanbu	38.00	24.08	212.19
Al-Ruwayshid	38.21	32.51	262.06
Amman	35.93	31.95	260.35
Al-Aqaba	35.00	29.52	245.99
Bayir	36.68	30.78	249.92
Irbid	35.85	32.55	265.11
Gaza	34.45	31.52	259.32
Al-Qamishli	41.22	37.05	325.38
Al-Raqqah	39.02	35.95	300.48
Al-Safirah	37.37	36.07	296.33
Al-Tanf	38.68	33.48	272.66
Ayn Al-Arab	38.37	36.89	306.63
Damascus	36.29	33.51	273.44

Table 1: Contd.,

Deir Al-Zor	40.15	35.33	300.24
Homs	36.71	34.73	283.47
Al-Latakia	35.78	35.52	288.32
Palamyra	38.27	34.56	284.47
Beriut	35.51	33.89	275.58

The datasets of the calculated MUF and FOT parameters has been generated using ICEPAC communication model for the twenty four solar cycle years (2009-2011). Figure 2 illustrates the behavior of the monthly observed sunspots numbers of the adopted years [12].

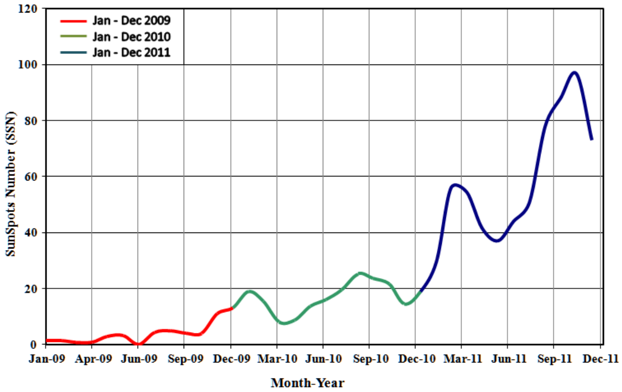


Figure 2: Variability of Observed Sunspots Values for Years (2009-2011)

The statistical analysis results that have been made on the generated MUF and FOT parameters datasets which obtained from execution of the ICEPAC model are shown in table 2 for the seasonal and annual times of the studied years and for all connection links.

Table 2: Statistical Analysis of Ionospheric Parameters for Seasonal and Annual Times of Selected Years

MUF (Baghdad – Amman) (2011)					
Time	**Winter**	**Spring**	**Summer**	**Autumn**	**Annual**
0	5.1	8.5	8.8	8.2	7.7
1	5.3	8.4	8.5	8.1	7.6
2	5.7	8.1	8.1	7.9	7.5
3	5.7	7.6	7.6	7.5	7.1
4	5.0	7.1	7.1	6.7	6.5
5	4.4	7.2	7.3	6.6	6.4
6	4.9	8.2	8.4	8.2	7.4
7	6.9	10.1	9.8	11.1	9.5
8	9.4	11.6	10.2	13.9	11.3
9	11.7	12.3	10.0	15.6	12.4
10	12.4	12.6	10.0	15.8	12.7
11	12.6	13.2	10.4	15.7	13.0
12	12.4	14.0	11.1	15.6	13.3
13	12.1	14.6	11.7	15.6	13.5
14	12.0	14.7	11.9	15.7	13.6
15	12.5	14.6	11.8	16.0	13.7
16	12.3	14.6	11.6	15.9	13.6
17	11.2	14.4	11.7	15.2	13.1
18	9.5	13.6	11.9	13.9	12.2
19	7.8	12.3	11.6	12.3	11.0
20	6.6	10.9	10.9	10.8	9.8
21	5.8	9.8	9.9	9.7	8.8
22	5.5	9.0	9.3	9.0	8.2
23	5.2	8.7	9.0	8.6	7.9

Table 2: Contd.,

FOT (Baghdad – Amman) (2011)					
Time	**Winter**	**Spring**	**Summer**	**Autumn**	**Annual**
0	4.1	6.6	6.9	6.3	6.0
1	4.3	6.5	6.7	6.2	5.9
2	4.6	6.3	6.4	6.1	5.8
3	4.2	5.9	6.0	5.7	5.4
4	3.7	5.5	5.6	5.1	5.0
5	3.2	5.6	5.8	5.0	4.9
6	3.6	6.4	6.6	6.2	5.7
7	5.9	8.3	7.5	9.1	7.7
8	8.1	9.5	7.8	11.4	9.2
9	10.0	10.1	7.7	12.8	10.2
10	10.6	10.3	8.2	13.0	10.5
11	10.4	10.8	8.8	13.0	10.7
12	10.2	11.4	9.2	13.0	10.9
13	10.0	11.9	9.3	12.9	11.0
14	9.9	12.0	9.5	13.0	11.1
15	10.6	11.5	9.4	12.5	11.0
16	10.4	11.5	9.2	12.4	10.9
17	9.5	11.4	9.3	11.9	10.5
18	8.1	10.7	9.5	10.9	9.8
19	6.1	9.0	9.0	8.9	8.2
20	5.1	7.9	8.5	7.8	7.3
21	4.5	7.1	7.8	7.0	6.6
22	4.3	6.5	7.2	6.5	6.1
23	4.2	6.7	7.0	6.6	6.1

In this work, an empirical mathematical model has been designed. The suggested model has been constructed depending on the statistical analysis results that have been made between the geographical locations coordinates (longitudes & Latitudes) of receiver stations and the dataset of the MUF and FOT parameters that have been evaluated using ICEPAC model for seasonal and annual times of the selected years.

The construction of a simplified model encountered some complications due to the orientational variability of the ionospheric parameter values around the transmitter station.

According to the analytical tests that have been achieved, the behavior of MUF and FOT parameters was essentially depends on the bearing parameter. Therefore, the studied area (Middle East zone) has been divided into four sectors depending on the values of the bearing parameter, as shown in figure 3.

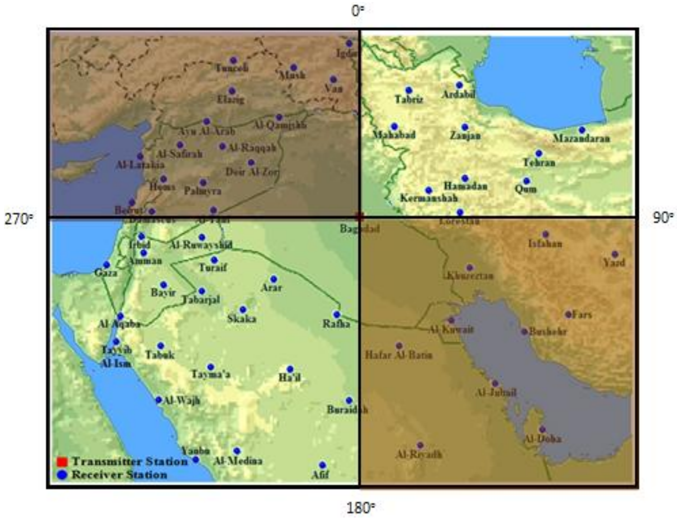


Figure 3: Classification of the Tested Area into Four Tested Sectors According to the Value of Bearing Parameter

Consequently, the results of the correlation tests showed that the mathematical description of the suggested simplified model between the geographical location coordinates of respecting stations and ionospheric parameters is simple and can be represented by a linear surface equation which can be illustrated by the following formula:

$$I_P = a_0 + a_1 G_{lat} + a_2 G_{lon}$$

Where

I_p **:** is the ionospheric parameter (MUF or FOT).

G_{lat} **:** is the latitude of receiving station.

G_{lon} **:** is the longitude of receiving station.

a_0, a_1, a_2 **:** are the constant coefficients.

Table 3 shows sample of the constant coefficient values (a_0, a_1, a_2) and correlation parameter (R^2) for the first sector that have been made for seasonal and annual times of the year 2011.

Table 3: Samples of the a's Correlation Coefficients of the MUF & FOT Parameters for Year 2011

MUF (First Sector - Winter Time - 2011)				
Time	a_0	a_1	a_2	R^2
0	-11.81	0.2003	0.183	0.9761
1	-13.84	0.2256	0.2113	0.9781
2	-14.83	0.2443	0.2233	0.9781
3	-14.00	0.2444	0.2028	0.9761
4	-13.06	0.2342	0.1788	0.9781
5	-14.21	0.2378	0.1939	0.9801
6	-18.55	0.2605	0.2811	0.9801
7	-25.92	0.321	0.4228	0.9801
8	-33.11	0.4357	0.523	0.9781
9	-38.78	0.5357	0.5944	0.9781
10	-36.97	0.5222	0.5729	0.9761
11	-36.65	0.5318	0.5638	0.9761
12	-34.95	0.5225	0.533	0.9761
13	-32.54	0.4872	0.5042	0.9742
14	-32.77	0.4697	0.5192	0.9742
15	-33.82	0.4837	0.5324	0.9742
16	-31.52	0.4592	0.4937	0.9742
17	-27.70	0.419	0.4257	0.9722
18	-22.09	0.3471	0.3372	0.9722
19	-16.77	0.2674	0.2637	0.9702
20	-12.94	0.2089	0.2119	0.9722
21	-10.82	0.1813	0.1808	0.9702
22	-9.85	0.1726	0.1637	0.9722
23	-10.10	0.1782	0.163	0.9742

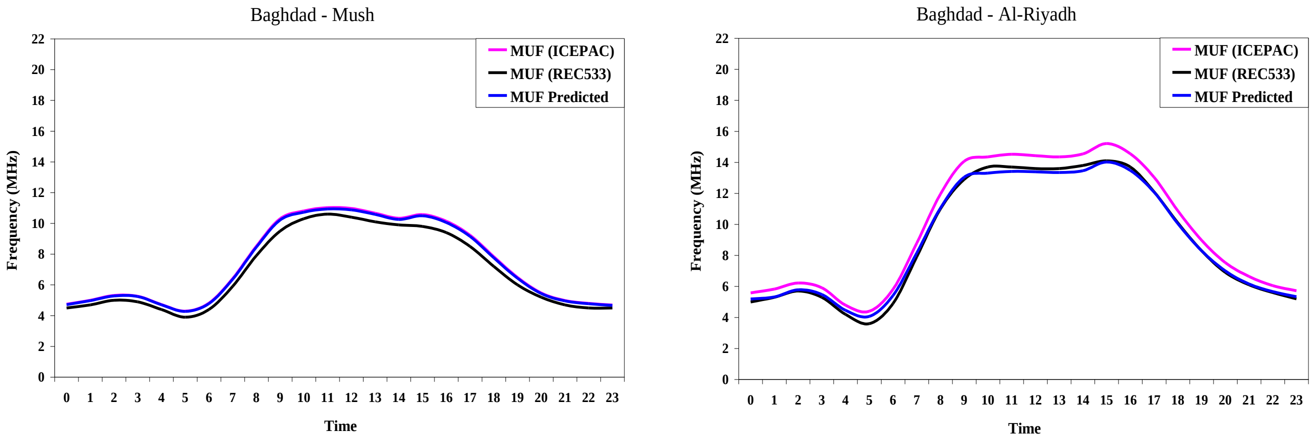
FOT (First Sector - Winter Time - 2011)				
Time	a_0	a_1	a_2	R^2
0	-9.558	0.162	0.1483	0.9742
1	-11.18	0.182	0.1711	0.9781
2	-13.62	0.254	0.168	0.9604
3	-12.98	0.252	0.1537	0.9604
4	-12	0.2375	0.1352	0.9624
5	-12.72	0.2347	0.1475	0.9663
6	-15.41	0.2101	0.2405	0.9801
7	-21.55	0.2561	0.3623	0.9801

Table 3: Contd.,

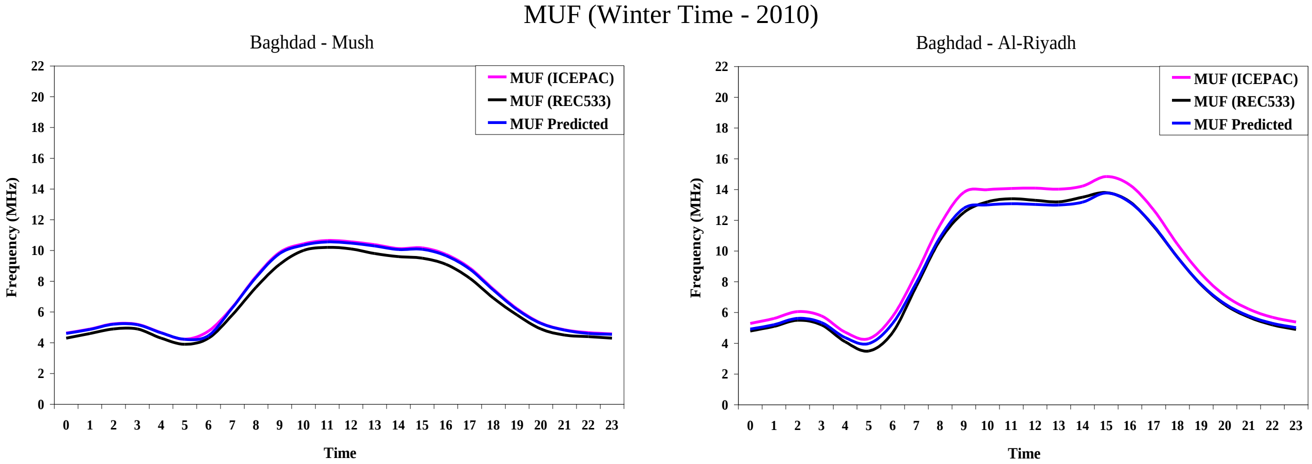
8	-27.57	0.3498	0.4488	0.9781
9	-32.22	0.431	0.5089	0.9761
10	-36.03	0.5785	0.4815	0.9663
11	-35.84	0.5885	0.4741	0.9663
12	-34.29	0.5801	0.4461	0.9663
13	-32.07	0.5446	0.4221	0.9624
14	-32.18	0.5138	0.4497	0.9683
15	-33.15	0.528	0.4609	0.9702
16	-30.95	0.5016	0.4267	0.9683
17	-27.25	0.4557	0.3678	0.9702
18	-16.49	0.2498	0.2625	0.9702
19	-12.44	0.1906	0.2052	0.9683
20	-9.62	0.149	0.1655	0.9702
21	4.8571	0.0538	-0.0822	0.937
22	4.8771	0.0538	-0.0822	0.937
23	4.4492	0.0585	-0.0777	0.9545

The accuracy of the predicted results that are calculated using the suggested empirical model has been verified by comparing them with other theoretical values evaluated from the ICEPAC, REC533 and VOACAP international HF-models. Figures 4 & 5 show samples of the predicted seasonal values of the MUF and FOT parameters and other theoretical values that determined using ICEPAC, REC533, VOACAP international models between Baghdad city and receiving pointes that laid within the Middle East zone.

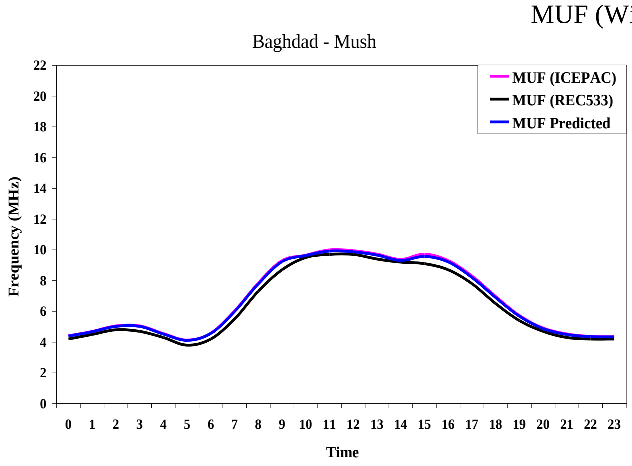
MUF (Winter Time - 2011)

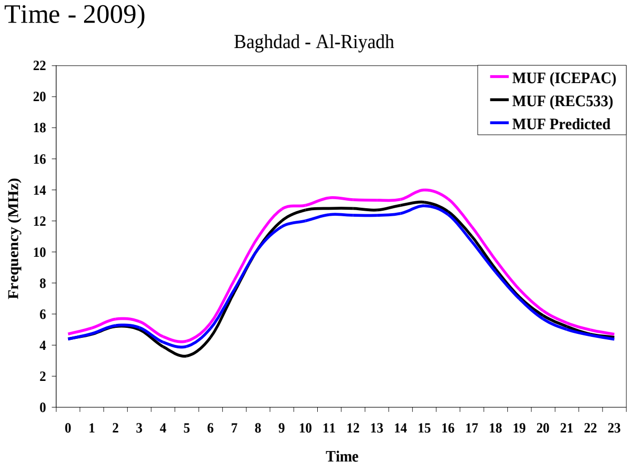


MUF (Winter Time - 2010)

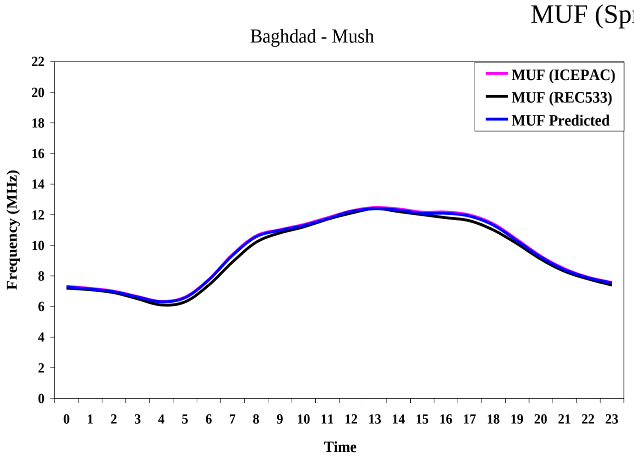


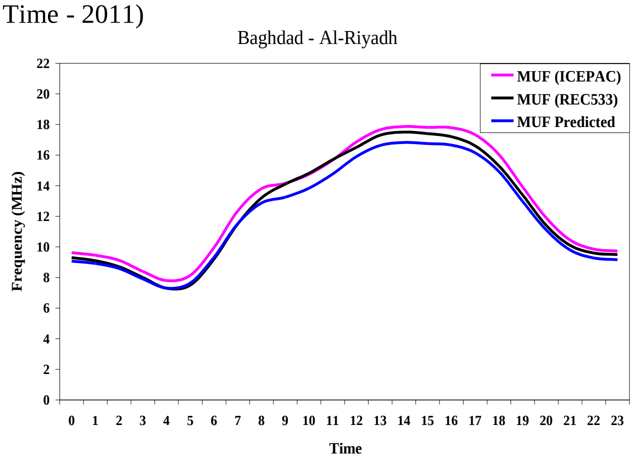
MUF (Winter Time - 2009)



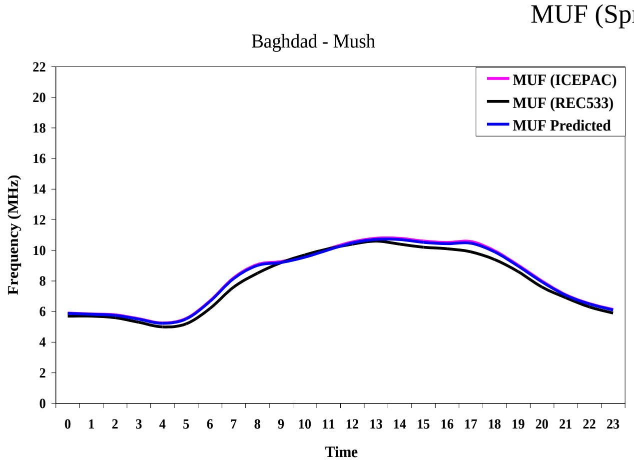


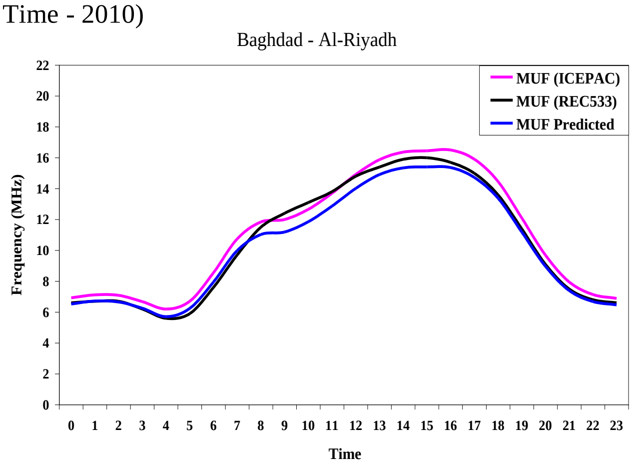
MUF (Spring Time - 2011)



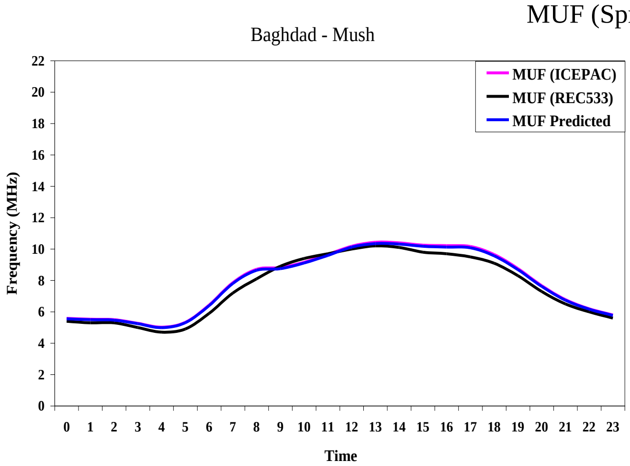


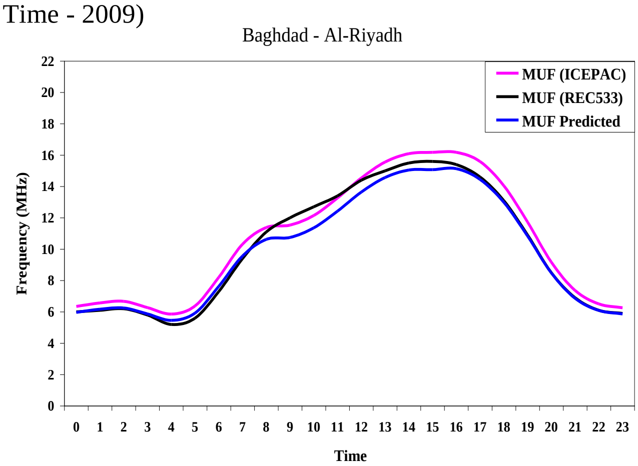
MUF (Spring Time - 2010)



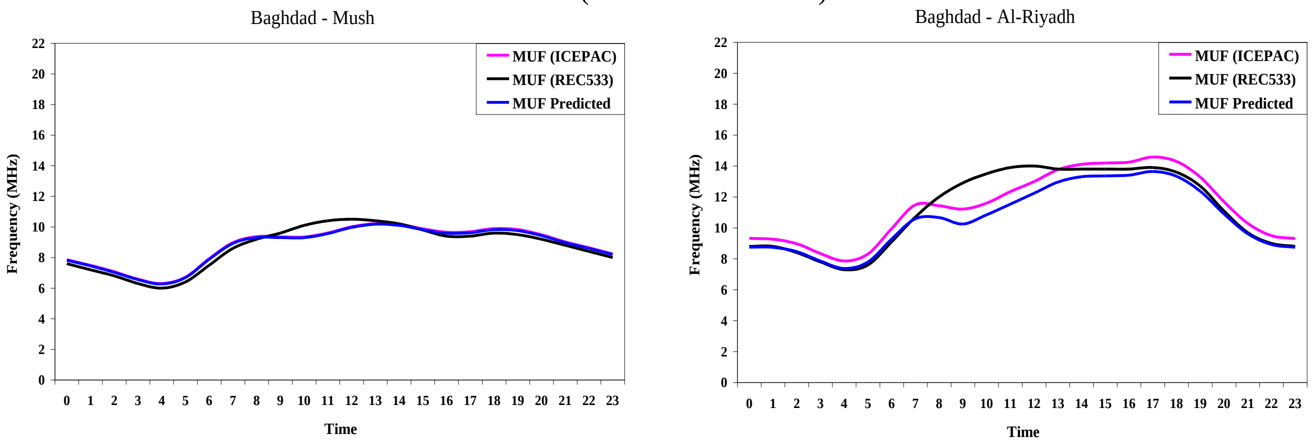


MUF (Spring Time - 2009)

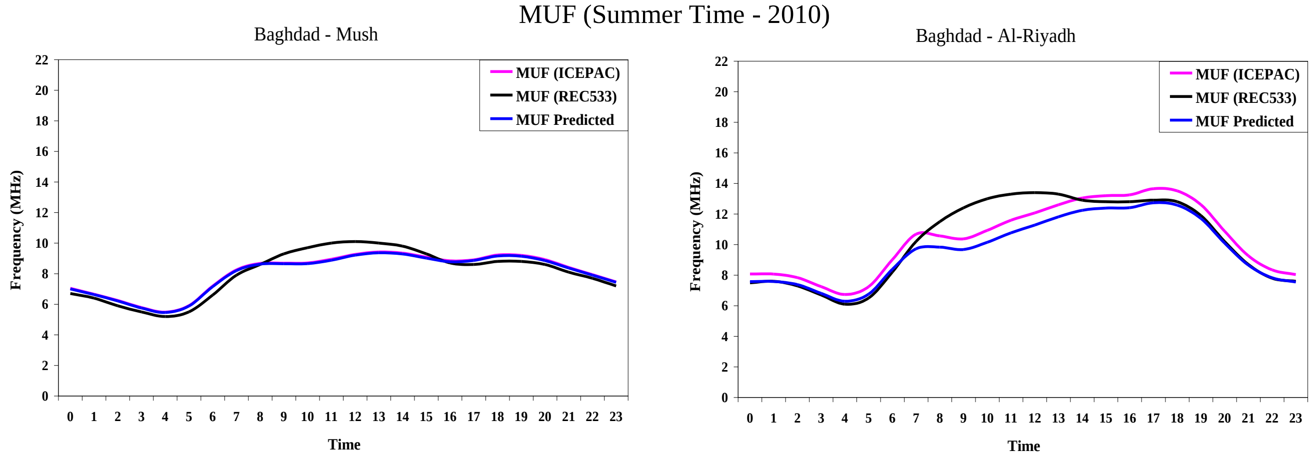




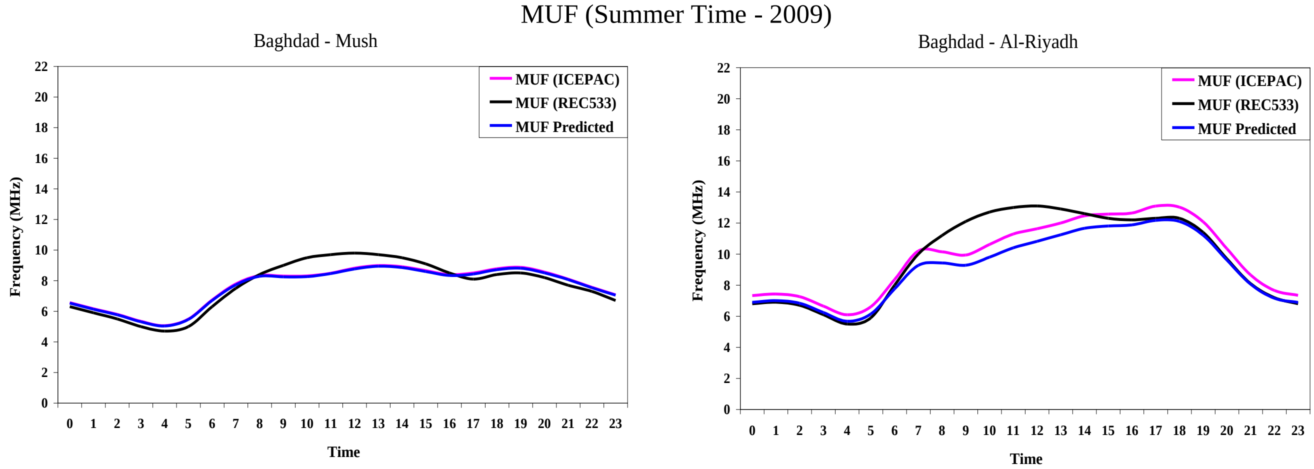
MUF (Summer Time - 2011)



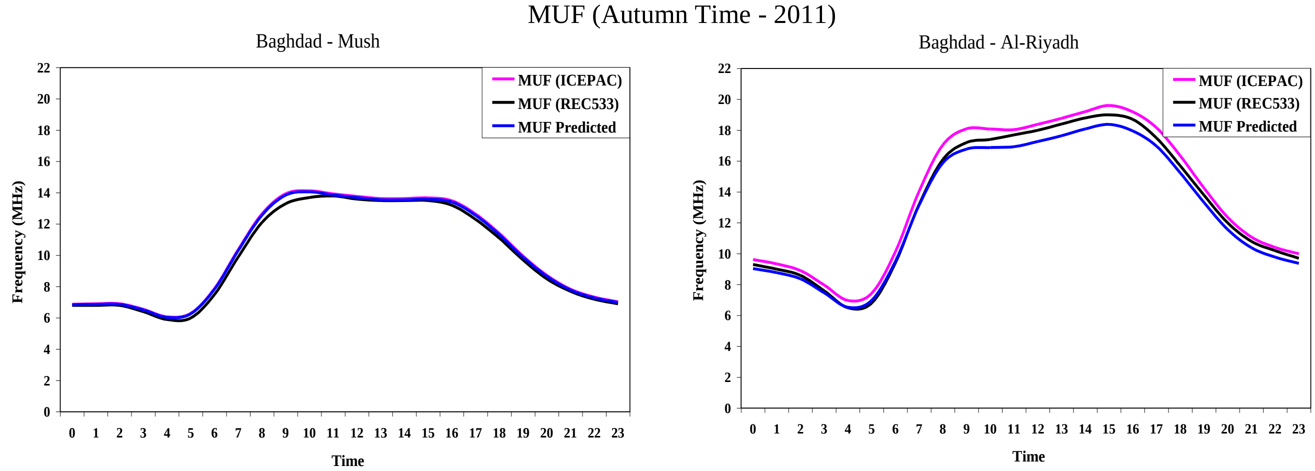
MUF (Summer Time - 2010)



MUF (Summer Time - 2009)



MUF (Autumn Time - 2011)



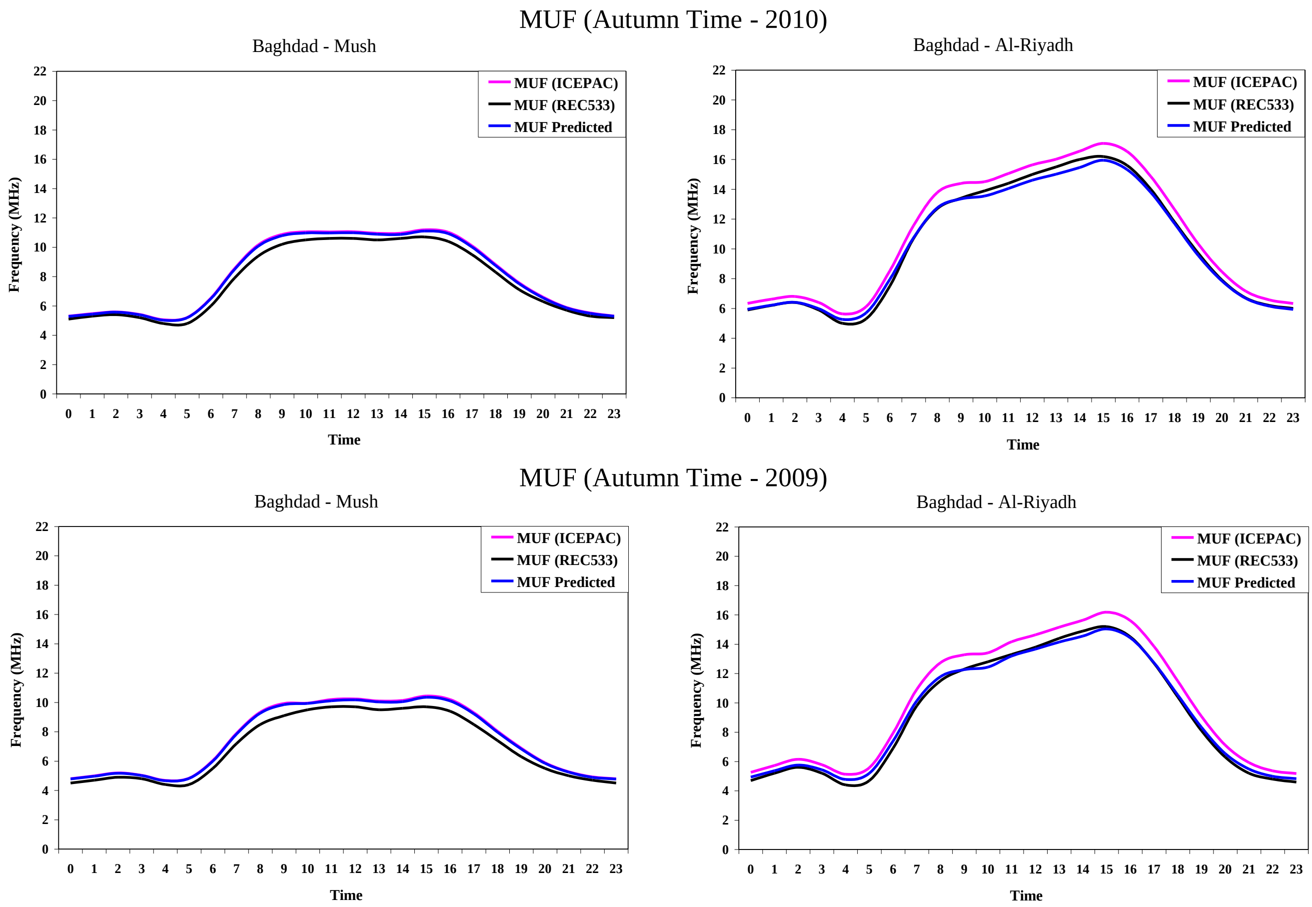
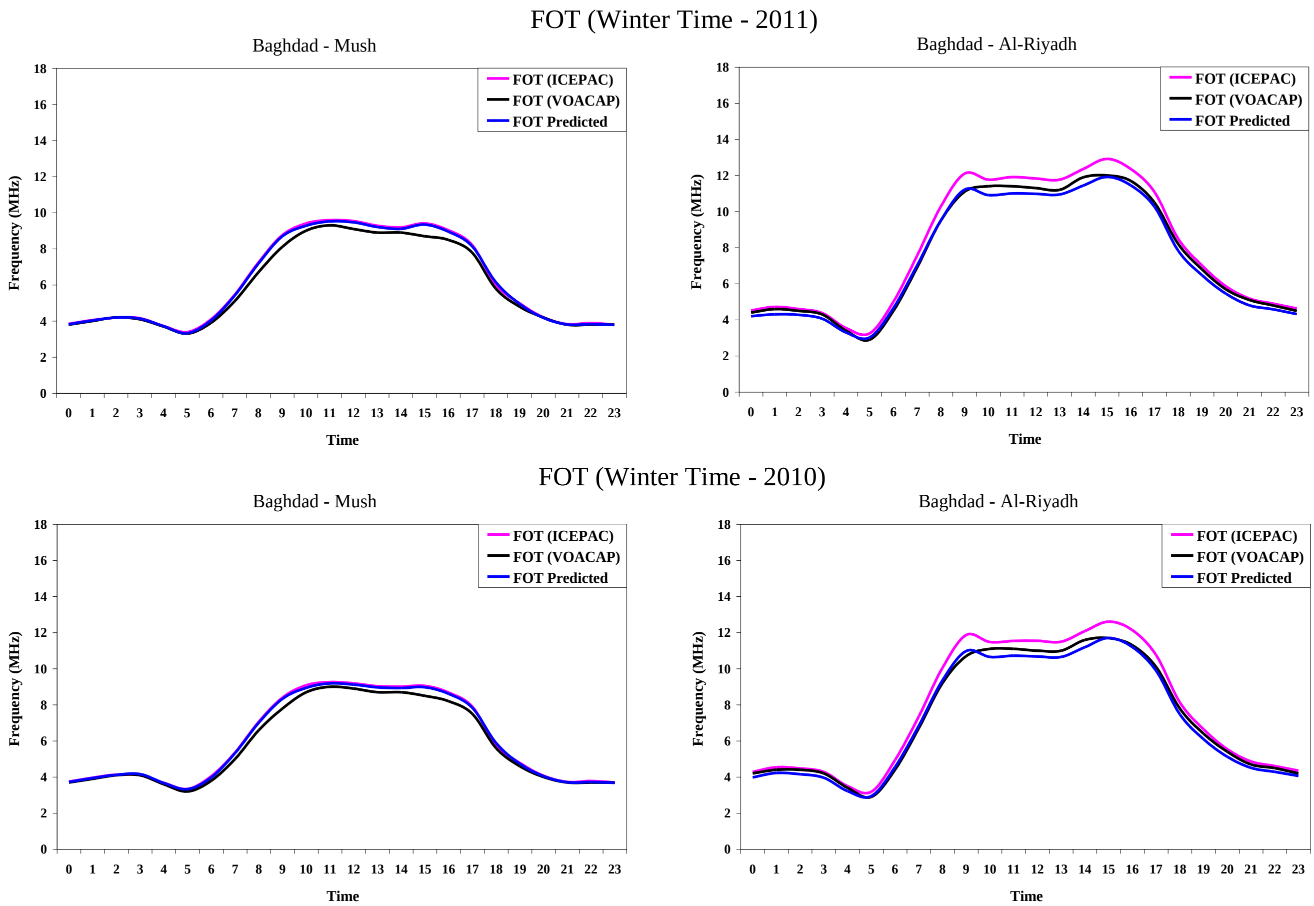
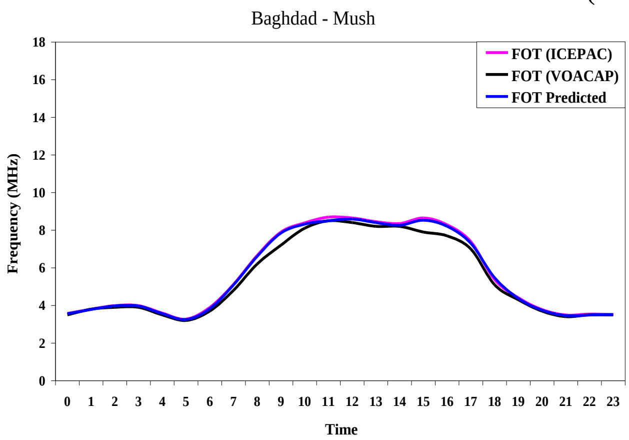
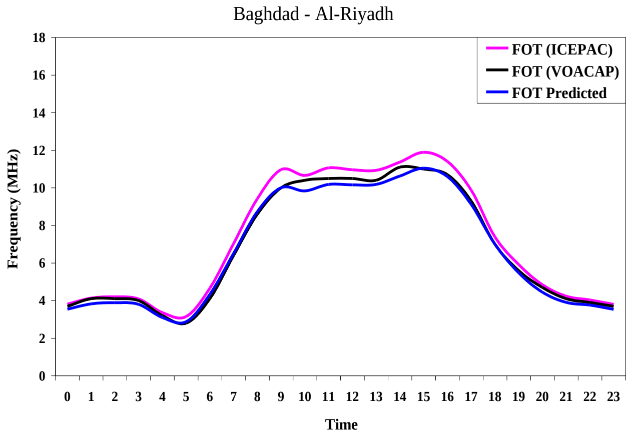


Figure 4: Analytical Studying of Theoretical and Predicted Values of MUF Parameter

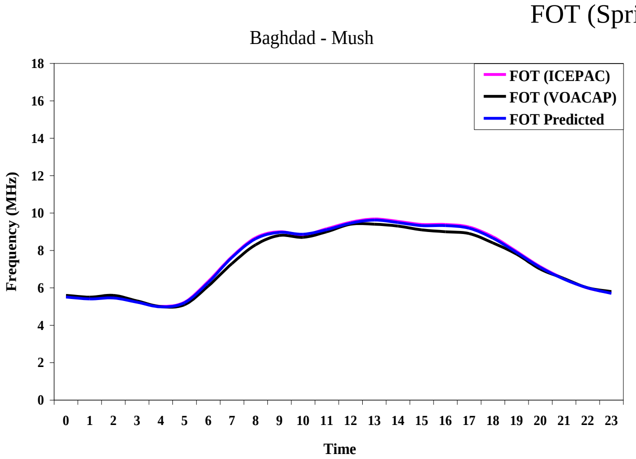


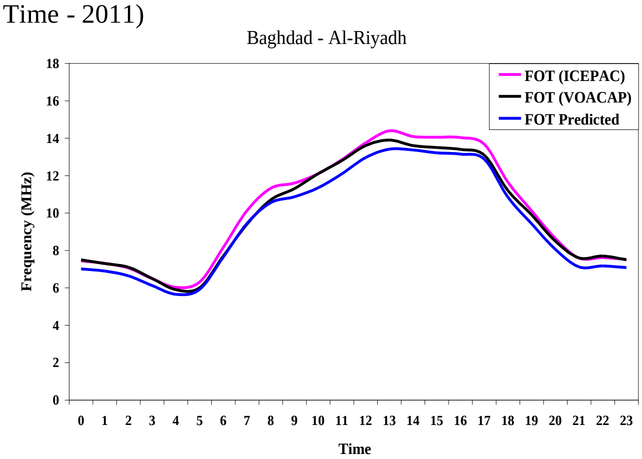
FOT (Winter Time - 2009)



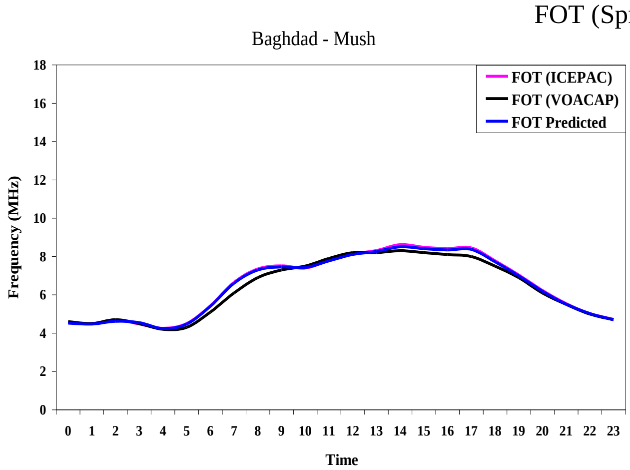


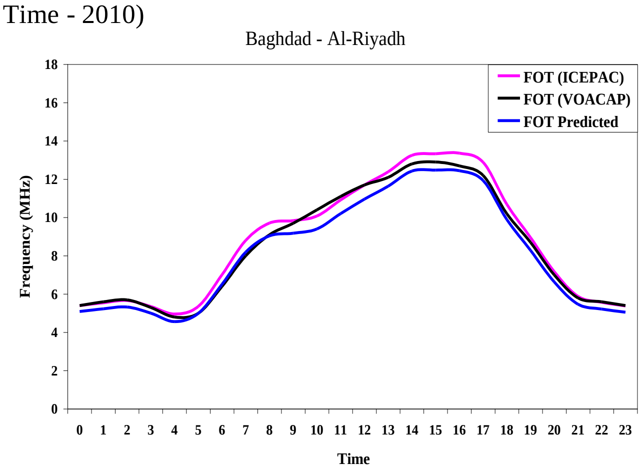
FOT (Spring Time - 2011)





FOT (Spring Time - 2010)





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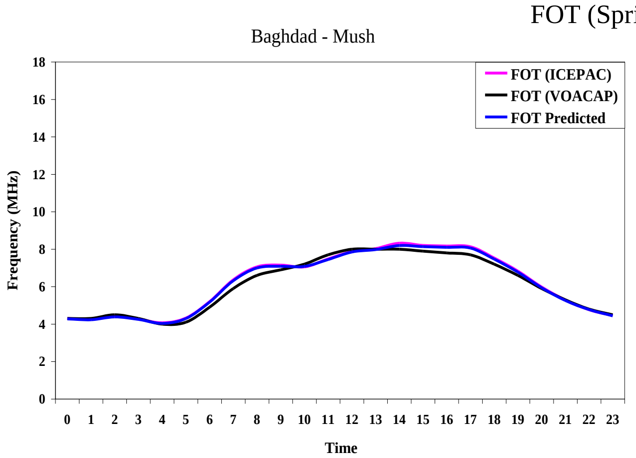
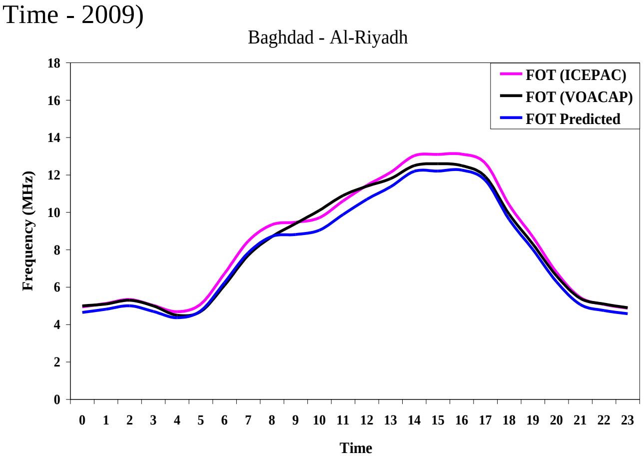
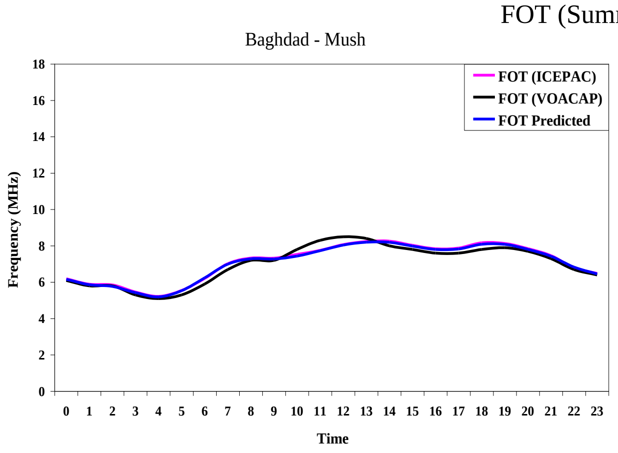
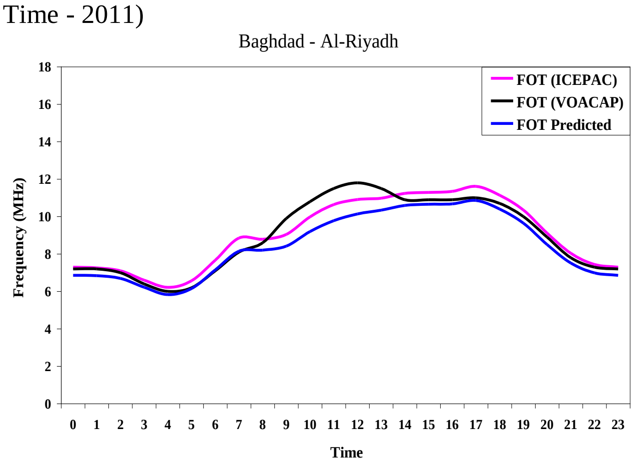




FOT (Summer Time - 2011)





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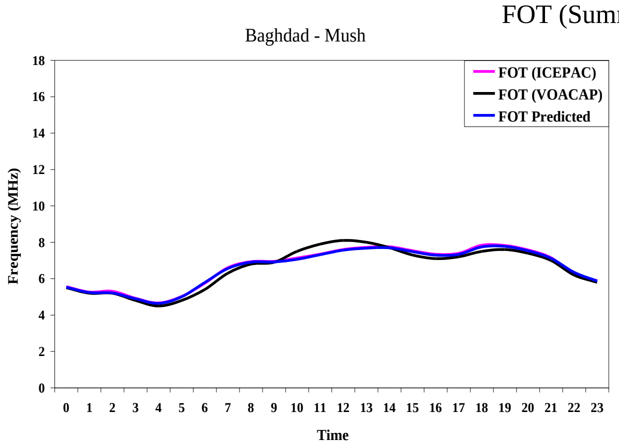

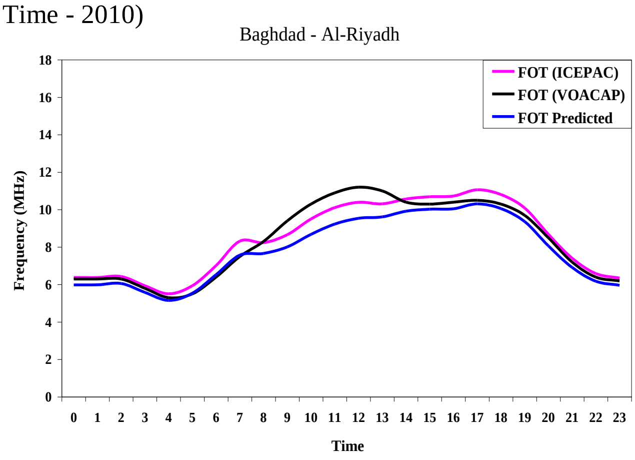

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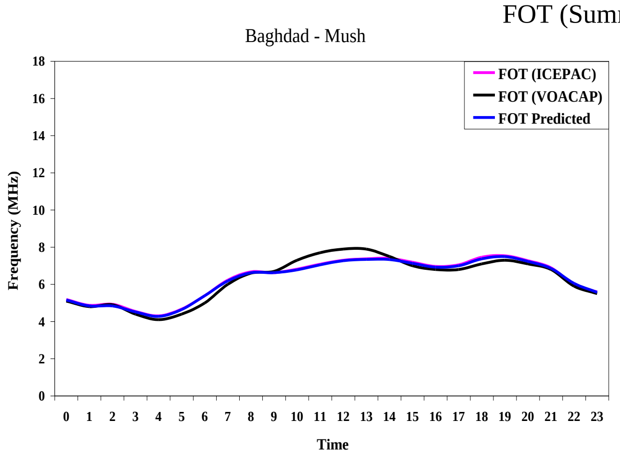
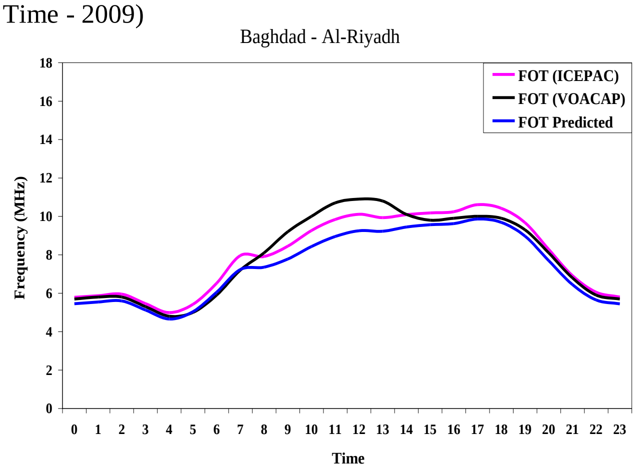
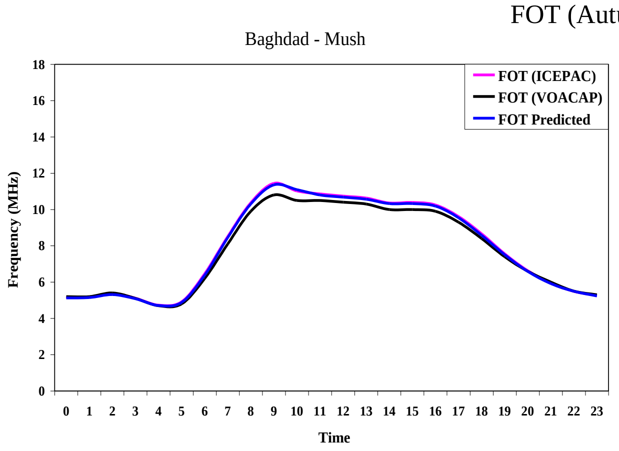
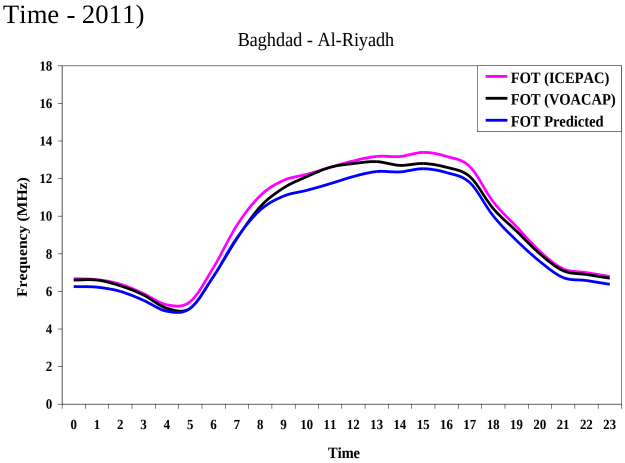




FOT (Autumn Time - 2011)





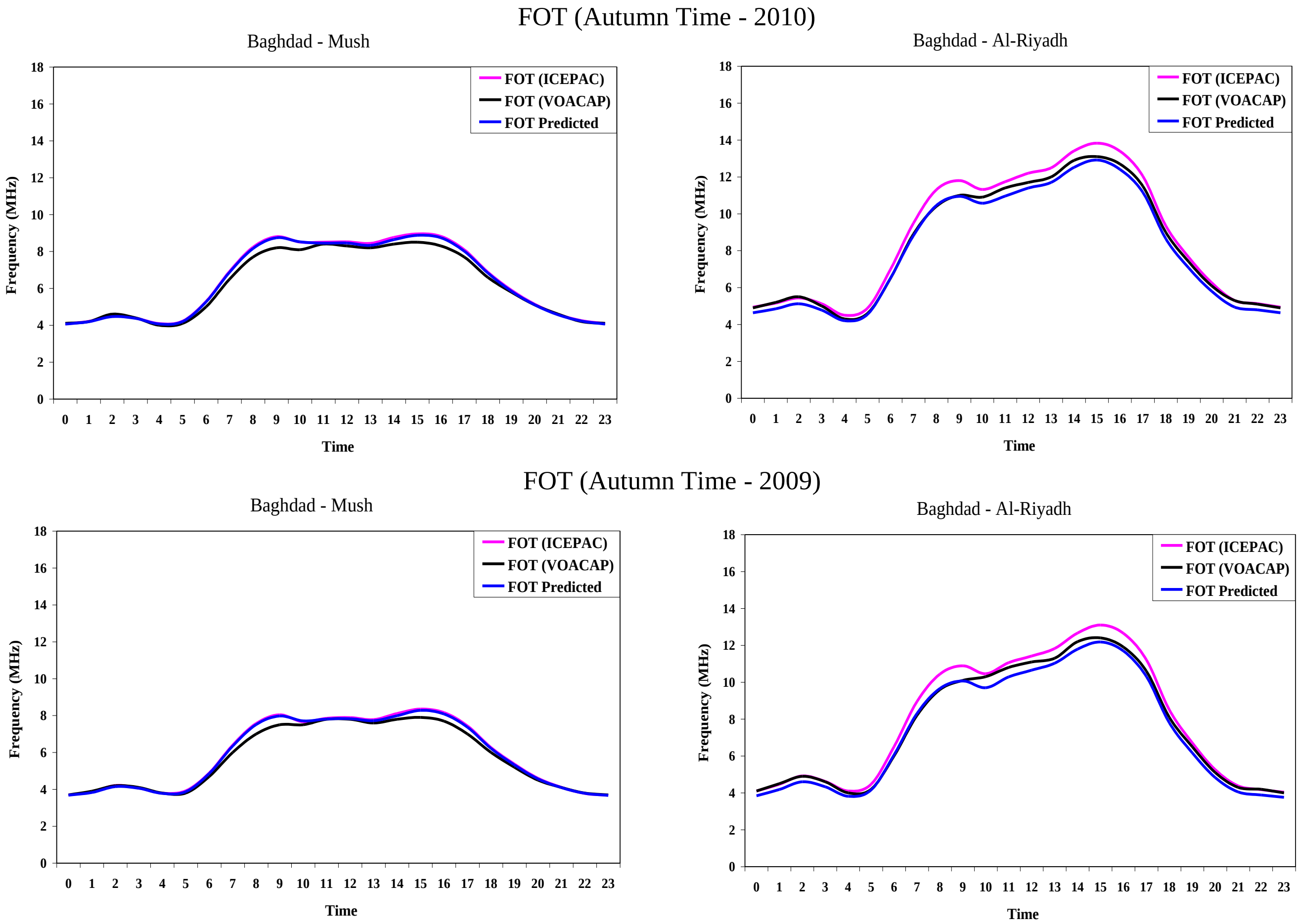


Figure 5: Analytical Studying of Theoretical and Predicted Values of FOT Parameter

Tables 4 present samples of the mean square error (MSE) for the seasonal MUF and FOT parameters between the predicted and theoretical values of the selected receiving stations over Middle East region.

Table 4: Samples of Seasonal Values of MSE of MUF & FOT Parameters for Year 2011

Winter Time (MUF – 2011)		
Station Name	**MSE (ICEPAC)**	**MSE (REC533)**
Akika	0.003	0.195
Ajlan	0.164	0.027
Kani Sakht	0.602	0.053
Tulaiha	0.217	0.051
Spring Time (MUF – 2011)		
Akika	0.003	0.042
Ajlan	0.192	0.062
Kani Sakht	0.699	0.24
Tulaiha	0.258	0.078
Summer Time (MUF – 2011)		
Akika	0.002	0.117
Ajlan	0.143	0.206
Kani Sakht	0.551	1.097
Tulaiha	0.2	0.591
Autumn Time (MUF – 2011)		
Akika	0.004	0.055
Ajlan	0.245	0.099
Kani Sakht	0.865	0.218
Tulaiha	0.297	0.054

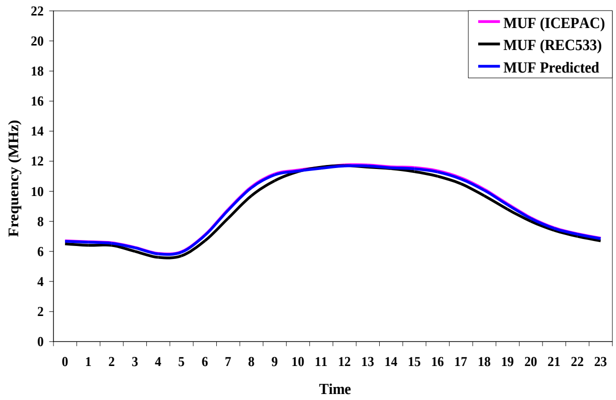
Table 4: Contd.

Station Name	MSE (ICEPAC)	MSE (VOACAP)
Winter Time (FOT – 2011)		
Akika	0.004	0.083
Ajlan	0.112	0.02
Kani Sakht	0.412	0.069
Tulaiha	0.147	0.019
Spring Time (FOT – 2011)		
Akika	0.002	0.033
Ajlan	0.122	0.018
Kani Sakht	0.427	0.175
Tulaiha	0.164	0.047
Summer Time (FOT – 2011)		
Akika	0.002	0.056
Ajlan	0.083	0.049
Kani Sakht	0.364	0.551
Tulaiha	0.13	0.294
Autumn Time (FOT – 2011)		
Akika	0.003	0.069
Ajlan	0.151	0.025
Kani Sakht	0.541	0.127
Tulaiha	0.191	0.028

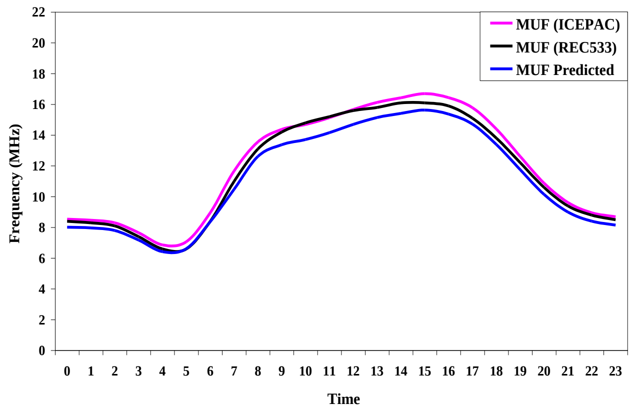
Figure 6 illustrate the annual calculation results of the predicted and theoretical MUF and FOT parameters values for the three studied years (2009, 2010, 2011) of the connection links between transmitting and receiving stations laid over Middle East region.

MUF (Annual Time - 2011)

Baghdad - Mush

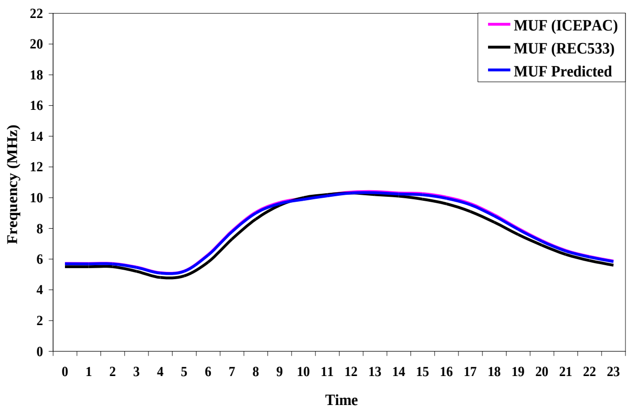


Baghdad - Al-Riyadh

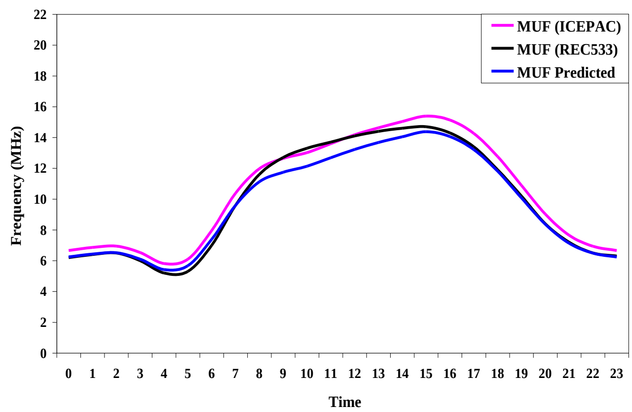


MUF (Annual Time - 2010)

Baghdad - Mush



Baghdad - Al-Riyadh



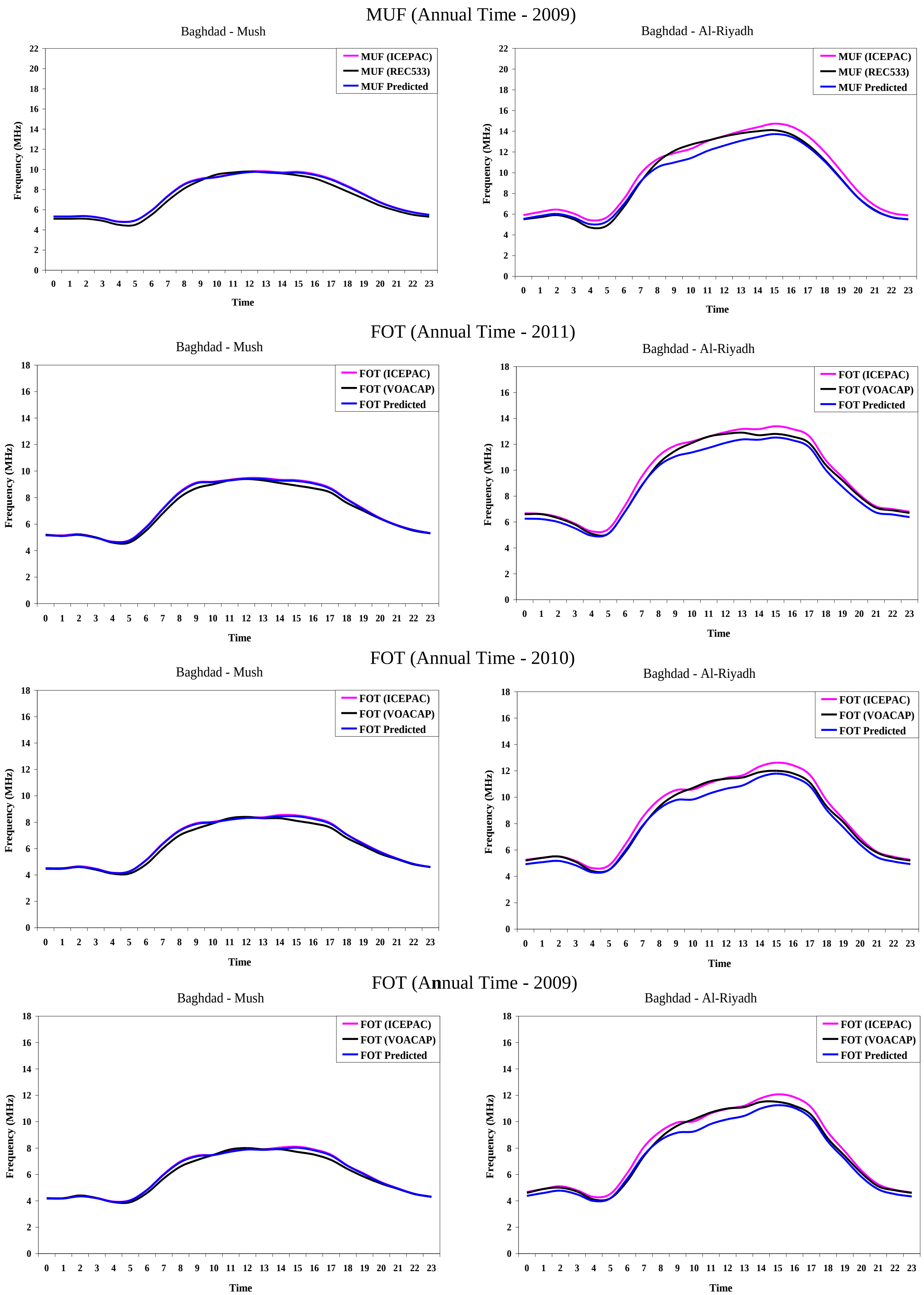


Figure 6: Annual Variation for Theoretical and Predicted Values of MUF & FOT Parameters for the Years (2009, 2010, 2011)

Table 5 shows the calculated MSE values for the annual MUF and FOT parameter values that are calculated for all receiver stations which are located over Middle East zone.

Table 5: Values of MSE of Annual Ionospheric Parameters for the Adopted Years

Annual Time (MUF – 2011)		
Station Name	**MSE (ICEPAC)**	**MSE (REC533)**
Akika	0.003	0.069
Ajlan	0.205	0.055
Kani Sakht	0.691	0.302
Tulaiha	0.239	0.085
Annual Time (MUF – 2010)		
Station Name	**MSE (ICEPAC)**	**MSE (VOACAP)**
Akika	0.003	0.079
Ajlan	0.159	0.051
Kani Sakht	0.578	0.237
Tulaiha	0.221	0.099
Annual Time (MUF – 2009)		
Akika	0.003	0.092
Ajlan	0.148	0.065
Kani Sakht	0.542	0.268
Tulaiha	0.165	0.12
Annual Time (FOT – 2011)		
Akika	0.002	0.039
Ajlan	0.115	0.015
Kani Sakht	0.437	0.168
Tulaiha	0.155	0.045
Annual Time (FOT – 2010)		
Akika	0.002	0.04
Ajlan	0.102	0.035
Kani Sakht	0.385	0.169
Tulaiha	0.117	0.051
Annual Time (FOT – 2009)		
Akika	0.002	0.034
Ajlan	0.095	0.036
Kani Sakht	0.365	0.174
Tulaiha	0.115	0.047

DISSCUSIONS AND CONCLUSIONS

In this research, the behavior of the ionospheric parameters has been tested for the communication links laid over Middle East region during the years (2009-2011) of the solar cycle 24.

According to the statistical analysis results that have been made between the geographical locations coordinates of receiver stations and the ionospheric parameters dataset generated using the ICEPAC international model, the empirical formula have been presented as a equation.

Due to the variational changes in the ionospheric parameters values the investigated area has been divided into four sectors according to the value of the bearing parameter (angle between the transmitter and receiver stations). The coefficients of the suggested equation have been evaluated separately for each studied communication sector.

The results of the seasonal and annual predictions [figures 4-6] that generated using the suggested model gave good results comparing to the theoretical outputs of the international models for all seasons and directions except there was a slight variation during a midday (noontime) between the predicted and theoretical values in the southern direction that might due to the impact of the thermal and geographical equators.

Depending on the analytical study that has made for ionospheric parameters over Middle East area, the following pointes can be concluded:-

- The correlation relationship between the ionospheric parameters and longitudes and latitudes of receiving stations can be expressed as linear surface formula.
- The prediction of the empirical suggested model for seasonal and annual times showed good results except there was a slight variation during midday between the predicted and theoretical values in the southern direction.

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