Iraqi Journal of Science
ISSN: 0067-2904

The Suggested Mutual Correlation between Ionospheric Parameters for Long Distance Radio Wave Communications

Marwa D. Abdulkareem*, Khalid A. Hadi
Department of Astronomy and Space, College of Science, University of Baghdad, Baghdad, Iraq

Abstract:
In this research, the mutual correlations between ionospheric parameters (MUF, OWF and LUF) have been suggested. The datasets of the MUF and OWF parameters have been generated using ASAPS international communication model, while the LUF parameter has been calculated using the REC533 model. The calculations have been made for the connection links between the capital Baghdad and many other locations that spread over the studied zone (Middle East region). The annual time of the years (2009 & 2014) of solar cycle 24 has been adopted to make the investigation in order to get the mutual correlation between ionospheric parameters. The test results of the annual correlation between ionospheric parameters showed that the mutual correlation between MUF & OWF is simple and can be represented by a linear regression equation, while the mutual correlations between (MUF & LUF), (OWF & LUF) can be represented by a fourth order polynomial equation (Quartic Polynomial Equation). The results of the conducted study showed that there was a good fit between ionospheric parameter values that have been generated using the suggested mutual correlation equation and the results generated from the international communication models and the international recommended criterion.

Keywords: Optimum Working Frequency (OWF), Ionospheric Parameters, Lowest Usable Frequency (LUF), Radio Wave Propagation.

أقتراح علاقة تبادلية بين المعاملات الأيونوسفيرية للأتصالات الراديوية بعيدة المدى

مروة داود عبد الكريم*، خالد عبد الكريم هادي
قسم الفلك والفضاء، كلية العلوم، جامعة بغداد، بغداد، العراق

الخــلاصة
تم في هذا البحث أقتراح العلاقة التبادلية بين المعاملات الايونوسفيرية (MUF, OWF و LUF) لطبقة الايونوسفير فوق منطقة الشرق الاوسط. مجموعة البيانات الخاصة بالمعاملات الايونوسفيرية (MUF, OWF) تم توليدها باستخدام النموذج العالمي ASAPS الذي يعتبر احد اكثر نماذج الاتصالات العالمية دقة وتقدماً في مجال دراسة انتقال الموجات الراديوية ذات الترددات العالية. بينما تم حساب قيم معامل الـ (LUF) باستخدام النموذج REC533 الذي يعتبر احد أصدارات منظمة الأتصالات العالمية الحديثة للبث الاذاعي. تم أجراء الحسابات لوصلات الأتصال بين العاصمة بغداد والعديد من المواقع الأخرى المنتشرة فوق نطاق منطقة الدراسة (منطقة الشرق الأوسط). للفترة السنوية للعاميين 2009 و 2014 من الدورة الشمسية 24 والتي تم أختيارها لأجراء الدراسة من أجل الحصول والتوصل الى العلاقة التبادلية بين المعاملات الأيونوسفيرية. اظهرت نتائج الأختبارات السنوية أن العلاقة التبادلية بين المعاملات الأيونوسفيرية الـ MUF وOWF هي علاقة بسيطة يمكن تمثيلها بمعادلة الأنحدار الخطي، اما العلاقة التبادلية بين معاملات الـ MUF وOWF مع معامل الـ LUF فيمكن تمثيلها بعلاقة متعددة الحدود للمرتبة الرابعة. بينت نتائج الدراسة الحالية أن هنالك

*Email: marwa_falak@yahoo.com

تطابق جيد بين قيم المعاملات الأيونوسفيرية المحسوبة من معادلة العلاقة التبادلية المقترحة وتلك النتائج التي
تم حسابها من تنفيذ نماذج الأتصالات العالمية والمعيار العالمي المعتمد.

Introduction

Radio technology is concerned with the lower (in frequency) part of the electromagnetic spectrum. As a matter of convenience, the radio part of the electromagnetic spectrum is further subdivided into a series of bands. The range of these bands extended from Extremely Low Frequency (ELF) at 3 Hz (Long Wave) to Extremely High Frequency (EHF) at 300 GHz (Short Wave). The high frequency (3-30 MHz) is the important band in the long distance communications, the high frequency is travels in three case by ground, direct and sky wave. The sky wave propagation is radiated in an upward direction and returned to Earth. Sky wave propagation depends on the different layers of the ionosphere, and therefore goes through diurnal, seasonal and sunspot cycles, as well as being affected by latitude [1]. Several frequency parameters have been introduced to describe the optimum radio frequency values. Among these frequencies are the Lowest Useable Frequency (LUF), the Optimum Working Frequency (OWF), and the Maximum Usable Frequency (MUF).

High Frequency Communication Ionospheric Parameters

The ionospheric parameters are represented an important parameters in HF communications to determine the best range of reliable frequencies that are reflected from the ionospheric layers between two terminals at specific time, The MUF, LUF, and OWF parameters are representing the main ionospheric parameters that can determine the best communication frequencies [2]. These parameters, as show in Figure-1.

- **The Maximum usable Frequency (MUF):** is the highest frequency at which radio waves are returned to Earth by reflected from the ionosphere and which can be used to transmit over a particular path under given ionospheric conditions at a specific time, the median value of MUF working 50% of the time [3].
- **The Optimum working Frequency (OWF):** The most practical operating frequency is one that you can rely onto have the least number of problems. It should be high enough to avoid the problems of multipath fading, absorption, and noise encountered at the lower frequencies; but not so high as to be affected by the adverse effects of rapid changes in the ionosphere, A frequency that meets the above criteria is known as the "OPTIMUM WORKING FREQUENCY" It is abbreviated “OWF”, The OWF is roughly about 85% of the MUF [4].
- **The Lowest usable Frequency (LUF):** is the lower frequency that allows reliable long-range HF radio communication between two points by ionospheric refraction [5]. The accepted working LUF is the lower frequency predicted to occur via a normal reflection from the F2-layer (F-region at night) on 10% of the days of the month at a given time of day on a specified path.

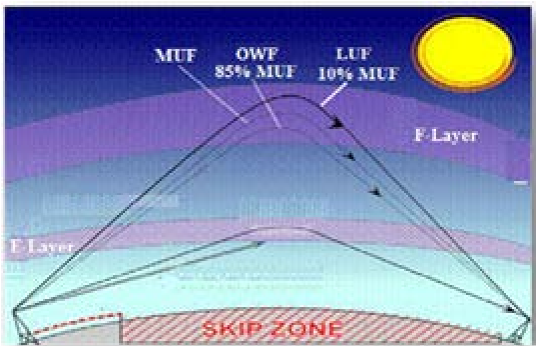


Figure 1-The ionospheric communication parameters [2]

The Adopted High Frequency Models

In this work, Advanced Stand Alone Prediction System (ASAPS) model and REC533 international model have been adopted to get the dataset of the required ionospheric parameters over the Middle East region in the frequency range 3 to 30 MHz. ASAPS model which considered as one of the most accurate and advanced HF sky wave propagation models allow the prediction of Sky Wave communication conditions in the HF radio spectrum or Short Wave Band (1 to 45 MHz) that based on an Ionospheric model, developed by IPS Radio and Space Services of the Australian Bureau of Meteorology, and ITU-R / CCIR models. The REC533 propagation prediction model which used for estimating the reliability and compatibility between frequencies of about 3 and 30 MHz, The propagation program was made available to the ITU in July 1993 by Working Party 6A (WP6A). This implementation was simultaneously developed by the U.S. Department of Commerce NTIA/ITS under contract from the Voice of America (VOA). It includes the following point-to-point and area coverage models. This implementation represents one of the modern radio broadcasting versions of ITU [6].

Test and Result

The aim of this research is to make an analytical study to investigate the behavior of ionospheric parameters in order to get the mutual correlation between these parameters for the annual time of the years 2009 & 2014. The dataset values of the MUF & OWF ionospheric parameters have been calculated using the ASAPS international communication model, while the LUF parameter has been calculated using the REC533 communication model. The Middle East area that located within the mid-latitude region has been picked up to become the tested region. Baghdad city (44.42^{O}E, 33.32^{O}N) the capital of Iraq has been considered as a transmitter station and many communication locations (sixty five) that are speared over studied zone have been considered as receiver stations, as shown in Figure-2.

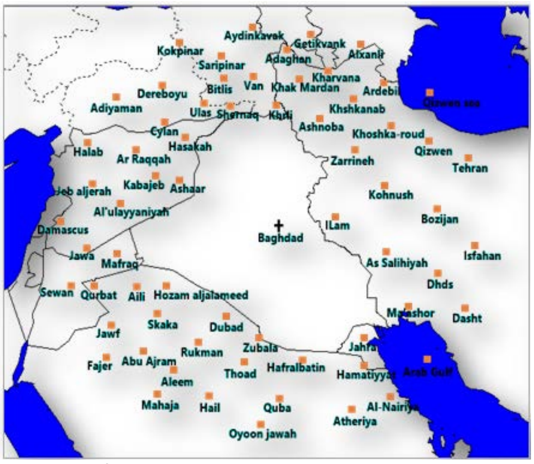


Figure 2- The location of transmitter and receiver station over Middle East zone

The monthly-observed sunspot number (SSN) for the years of 2009 and 2014 which have been chosen to be the studied time period, because these years represent the beginning and the peak of solar cycle 24. Table-1 shows the values of the observed sunspot number for each month of the selected years of solar cycle 24.

Table 1- Observed Monthly Sunspot Number of Solar Cycle 24 [7]

Months Name	**Sunspot number**					
	2009	**2010**	**2011**	**2012**	**2013**	**2014**
January	1.3	13.2	18.8	58.3	62.9	81.8
February	1.4	18.8	29.6	32.9	38.1	102.3
March	0.7	15.3	55.8	64.3	57.9	91.9
April	0.8	8.0	54.4	55.2	72.4	84.7
May	2.9	8.7	41.5	69.0	78.7	75.2
June	2.9	13.6	37.0	64.5	52.5	71.0
July	3.2	16.1	43.8	66.5	57.0	72.5
August	0.0	19.6	50.6	63.0	66.0	74.7
September	4.3	25.2	78.0	61.4	37.0	87.6
October	4.8	23.5	88.0	53.3	85.6	60.6
November	4.1	21.5	96.7	61.8	77.6	70.1
December	10.8	14.4	73.0	40.8	90.3	78.0
Annual	**3.1**	**16.5**	**55.7**	**57.6**	**64.7**	**79.3**

The geodesic parameters [Distance, Path length and Bearing (transmitter to receiver and receiver to transmitter)] for the tested connection links between transmitter and receiver station have been determined. Table-2 shows a list of geographical location coordinates (longitude and latitude), spherical geodesic parameters (path length - bearing transmitter to receiver (Tx to Rx) and bearing receiver to transmitter (Rx to Tx)) and distance for connection links over the Middle East Region.

Table 2- Geographical location coordinates and spherical geodesic parameters for the connection links over Middle East Region

Receiver Station		Location		Distance (Km.)	Path length (Rad.)	Bearing (Deg.)					
						T_x to R_x			R_x to T_x		
		Long. (E)	Lat. (N)			Method (1)	Method (2)	Average	Method (1)	Method (2)	Average
Ilam		46.240	33.380	169.170	0.027	88.110	88.240	88.180	271.890	272.760	272.320
Kharvana		46.100	38.400	584.770	0.091	198.280	195.500	196.890	341.720	345.480	343.600
Zarrineh		47.100	36.400	420.760	0.066	143.810	143.800	143.800	323.810	323.800	323.800
Ashnoba		45.510	37.200	442.630	0.069	166.530	166.520	166.520	346.530	346.520	346.520
Kohnush		48.160	34.430	366.640	0.058	73.460	69.290	71.370	253.460	251.370	252.420
Qizwen		49.590	36.160	568.090	0.089	123.290	123.280	123.280	303.290	303.280	303.280
Tehran		51.250	35.410	668.400	0.105	109.970	109.960	109.960	289.970	289.960	289.960
Ardebil		48.160	38.150	634.200	0.099	147.430	147.410	147.420	327.430	327.410	327.420
As Salihiyah		48.210	32.270	372.970	0.059	108.540	108.540	108.540	288.540	288.540	288.540
Ma'ashor	Iran	49.110	30.330	553.850	0.087	126.930	126.920	126.920	306.930	306.920	306.920
Isfahan		51.400	32.390	660.010	0.104	99.240	99.240	99.240	279.250	279.240	279.240
Dasht		51.160	30.320	718.660	0.113	114.000	115.830	114.910	294.000	299.390	296.690
Bozijan		50.140	33.550	531.320	0.083	92.380	92.380	92.380	272.380	272.380	272.380
Dhds		50.170	31.420	579.760	0.091	111.540	111.540	111.540	291.540	291.540	291.540
Khoshka-roud		48.310	36.480	499.220	0.078	134.170	134.160	134.160	314.170	314.160	314.160
Adaghan		44.360	39.240	658.290	0.102	180.150	180.150	180.150	359.840	360.150	359.990
Khshkanab		47.700	37.420	544.230	0.085	146.380	146.370	146.370	326.380	326.370	326.370
KhakMardan		45.400	38.230	553.060	0.086	170.380	170.370	170.370	350.380	350.370	350.370
Van		43.220	38.290	563.110	0.087	169.220	169.210	169.210	349.220	349.210	349.210
Khrli		44.150	37.290	442.120	0.068	177.270	177.270	177.270	357.270	357.270	357.270
Saripinar		42.800	39.120	661.060	0.103	167.550	167.540	167.540	347.550	347.540	347.540
Kokpinar		40.340	39.390	767.270	0.120	146.120	150.330	148.230	326.120	332.760	329.450
Ceylan		40.400	36.550	513.000	0.079	134.450	134.440	134.440	314.450	314.440	314.440
Adiyaman	Turkey	38.120	37.460	733.200	0.114	128.870	128.850	128.860	308.870	308.850	308.860
Shernaq		42.270	37.300	483.600	0.076	151.630	155.580	153.610	331.630	336.820	334.230
Ulas		41.320	37.340	528.020	0.083	142.370	146.910	144.640	322.370	328.710	325.550
Bitlis		42.150	38.250	585.120	0.091	159.750	159.740	159.740	339.750	339.740	339.740
Dereboyu		39.560	38.100	689.000	0.107	140.540	140.510	140.520	320.540	320.510	320.520
Getikvank		45.300	39.560	698.290	0.110	171.980	173.260	172.620	351.980	353.780	352.890
Aydinkavak		43.190	40.110	762.900	0.119	171.980	171.960	171.970	351.980	351.960	351.970
Al Hasakah		40.470	36.240	485.260	0.076	131.990	131.980	131.980	311.990	311.980	311.980
Ashaar		40.330	34.550	401.300	0.062	109.650	109.650	109.650	289.650	289.650	289.650
Halab		37.800	36.120	680.220	0.107	117.130	117.120	117.120	297.130	297.120	297.120
ArRaqqah		38.590	35.570	590.110	0.093	114.940	114.930	114.930	294.940	294.930	294.930
Damascus	Syria	36.170	33.300	766.450	0.119	89.580	90.410	89.990	269.580	270.410	269.990
Jeb aljerah		37.180	34.480	680.370	0.106	100.710	100.700	100.700	280.710	280.700	280.700
Al'ulayyaniyah		38.350	33.500	563.690	0.088	91.700	91.700	91.700	271.700	271.700	271.700
Kabajeb		39.400	35.400	515.480	0.081	112.510	115.220	113.860	292.510	298.050	295.280
Jawa		37.900	32.350	618.520	0.096	100.410	100.400	100.400	280.410	280.400	280.400
AL-Qurbat		37.220	31.190	717.080	0.112	109.640	109.630	109.630	289.640	289.630	289.630
Hozamjalamed		40.600	31.160	432.100	0.067	124.410	124.410	124.410	304.410	304.410	304.410
Al Jawf		38.100	29.570	730.030	0.114	125.220	125.200	125.210	305.220	305.200	305.210
AL-Dubad		42.180	30.140	412.170	0.064	149.770	149.760	149.760	329.770	329.760	329.760
Hail		41.410	27.300	728.980	0.114	157.050	157.030	157.040	337.050	337.030	337.040
Abu Ajram		39.140	29.100	687.050	0.107	133.500	133.480	133.490	313.500	313.480	313.490
Hafr Al Batin		45.120	28.430	547.820	0.086	188.130	187.180	187.660	351.860	353.170	352.520
Quba		44.200	27.240	676.390	0.106	177.930	178.150	178.040	272.060	268.260	270.170
Al-Hamatiyyat		47.350	28.360	618.320	0.097	149.450	152.340	150.890	239.450	243.840	241.650
Al-Nairiya	KSA	48.290	27.280	767.350	0.120	147.380	150.050	148.710	237.380	242.000	239.700
AL-Rukman		41.160	29.200	552.990	0.086	146.460	146.440	146.450	326.460	326.440	326.450
Skaka		39.440	30.280	579.310	0.090	126.180	126.170	126.170	306.180	306.170	306.170
Mahaja		39.450	27.340	818.060	0.128	144.730	144.700	144.710	324.730	324.700	324.710
Oyoonjawah		43.370	26.370	779.390	0.122	172.850	172.840	172.840	352.850	352.840	352.840
Fajer		37.510	28.490	849.940	0.133	129.530	129.500	129.510	309.530	309.500	309.510
Zubala		43.320	29.320	456.870	0.072	167.340	167.330	167.330	347.340	347.330	347.330
AL-Thoad		43.000	28.400	563.590	0.088	163.910	165.710	163.810	253.910	256.440	255.180
AL-Aleem		40.230	28.240	692.140	0.108	145.110	145.090	145.100	325.110	325.090	325.100
Al-Atheriya		47.200	27.200	730.920	0.115	155.600	157.860	156.730	335.600	339.260	337.430
AL-Aili		38.590	31.150	598.960	0.093	114.190	114.190	114.190	294.190	294.190	294.190
Jahra- Kuwait		47.360	29.300	527.020	0.083	147.860	147.840	147.850	327.860	327.840	327.850
Mafraq- Jordan		38.180	32.250	595.230	0.092	101.920	101.910	101.910	281.920	281.910	281.910
Sewan- Jordan		36.340	31.160	796.710	0.124	107.850	107.850	107.850	287.860	287.850	287.850
Alxanli-Azerbajan		39.350	27.230	833.730	0.130	144.660	144.630	144.640	324.660	324.630	324.640
Arab Gulf		49.510	28.470	725.520	0.114	133.640	136.650	135.140	223.640	229.270	226.460
Qizwen sea		49.550	37.560	661.790	0.103	135.010	134.990	135.000	315.010	314.990	315.000

The annual variation of the ionospheric parameters for the years (2009 & 2014) has been studied for the tested link stations over the Middle East zone. The analytical study of the annual variations of the MUF, LUF and OWF parameters have been achieved for the twelve months of the studied years. Figures-3 and 4 show samples of the annual behavior of ionospheric parameters for the tested receiving stations over regional area.

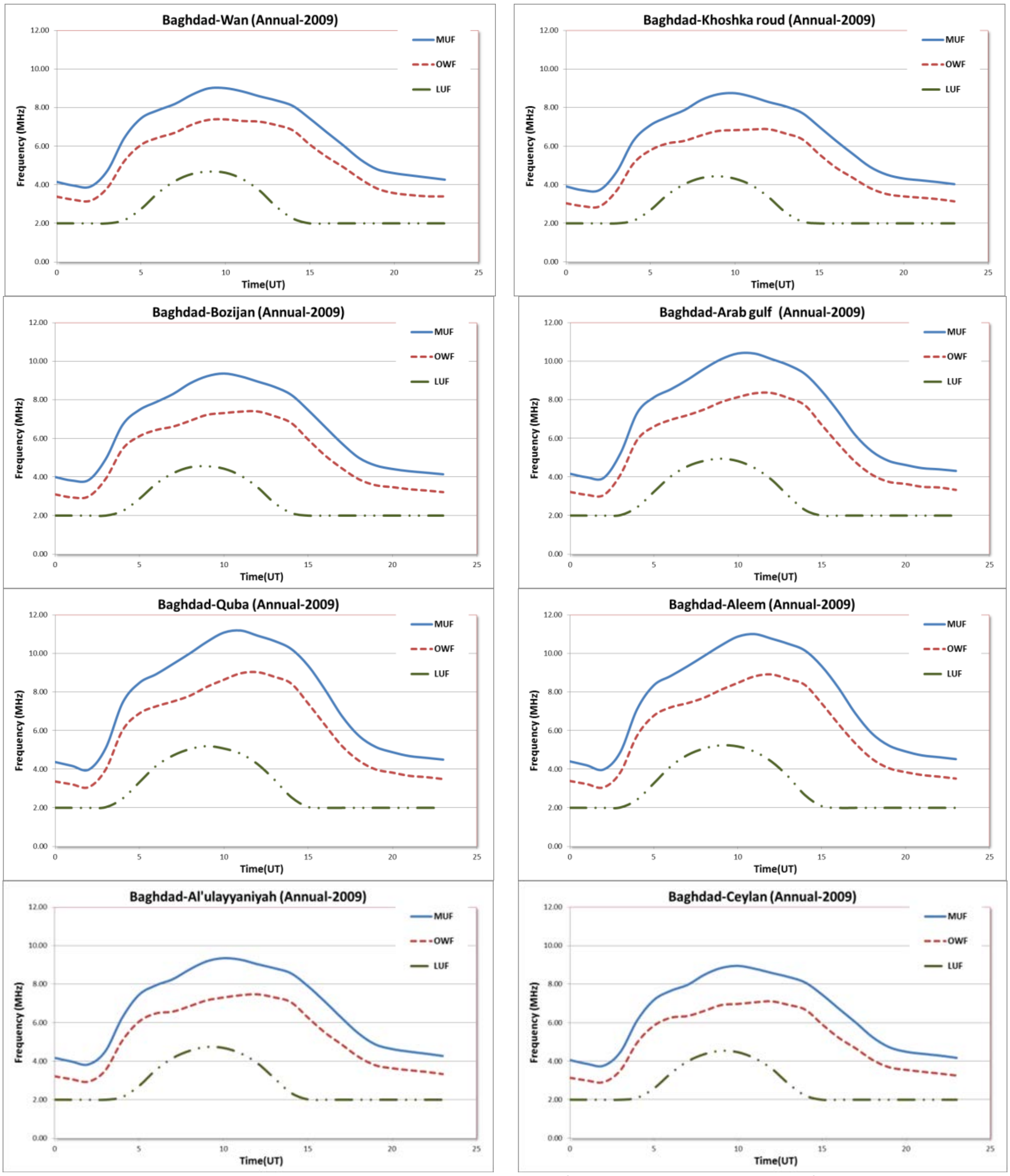


Figure 3-The Annual ionospheric parameters variation for some connection links of the year 2009

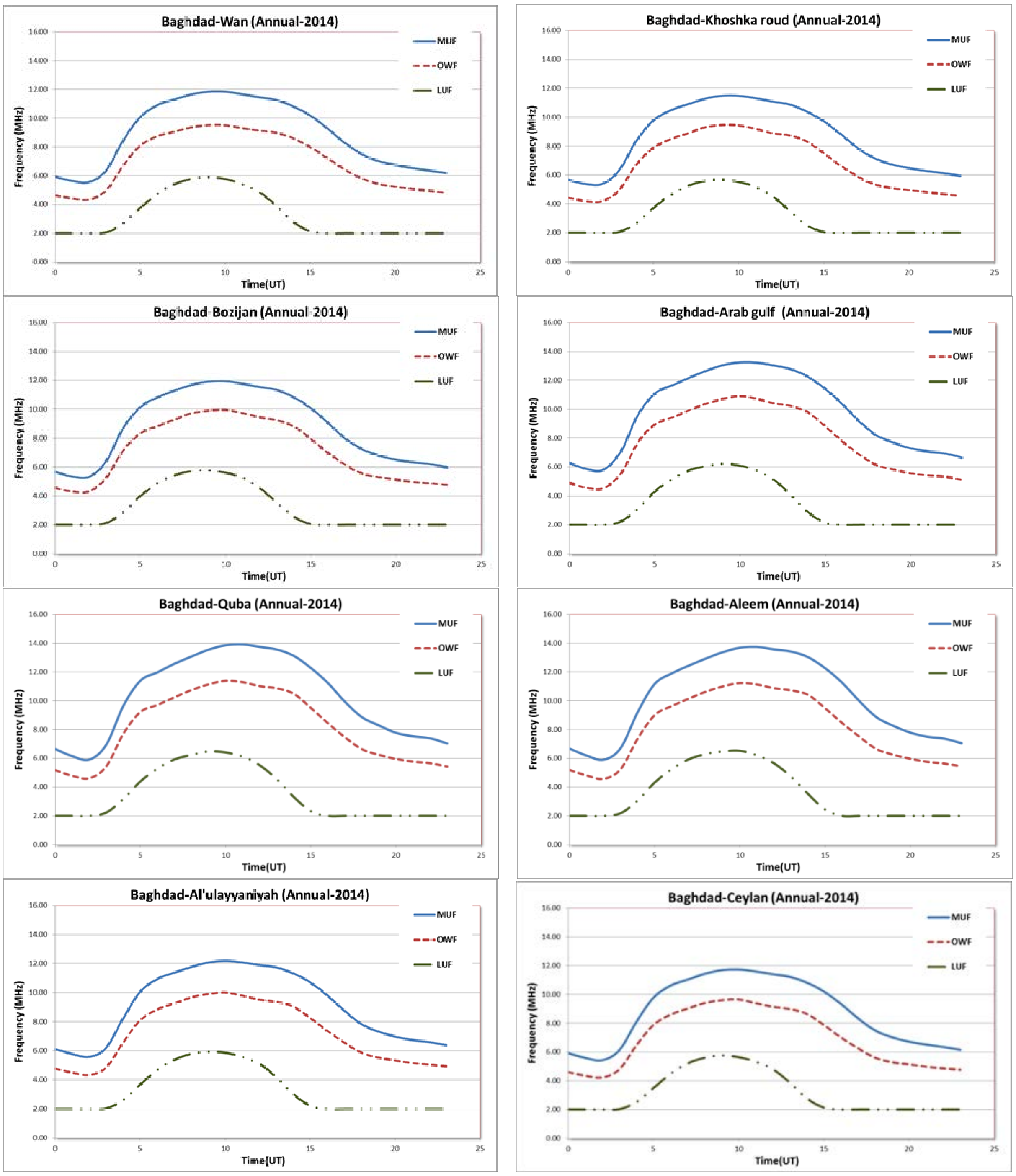


Figure 4-The Annual ionospheric parameters variation for some connection links of the year 2014

The main goal of this research is to get a mutual correlation between the ionospheric parameters. In order to investigate the capability of getting a mutual correlation between the MUF, OWF and LUF parameters, the analytical study of these parameters has been conducted. Figures-5 and 6 illustrate samples of the annual correlation between the ionospheric parameters for the years 2009 and 2014 respectively.

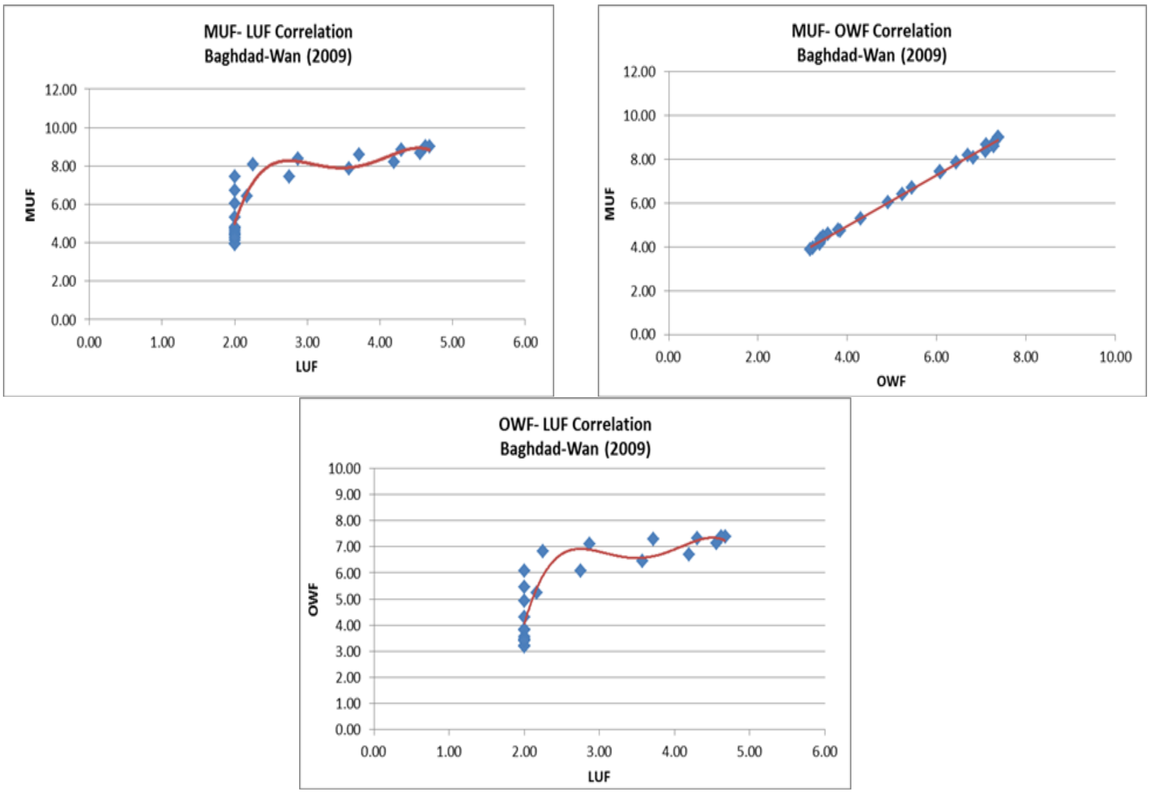


Figure 5- Correlation relationship between MUF, OWF and LUF (Annual - 2009)

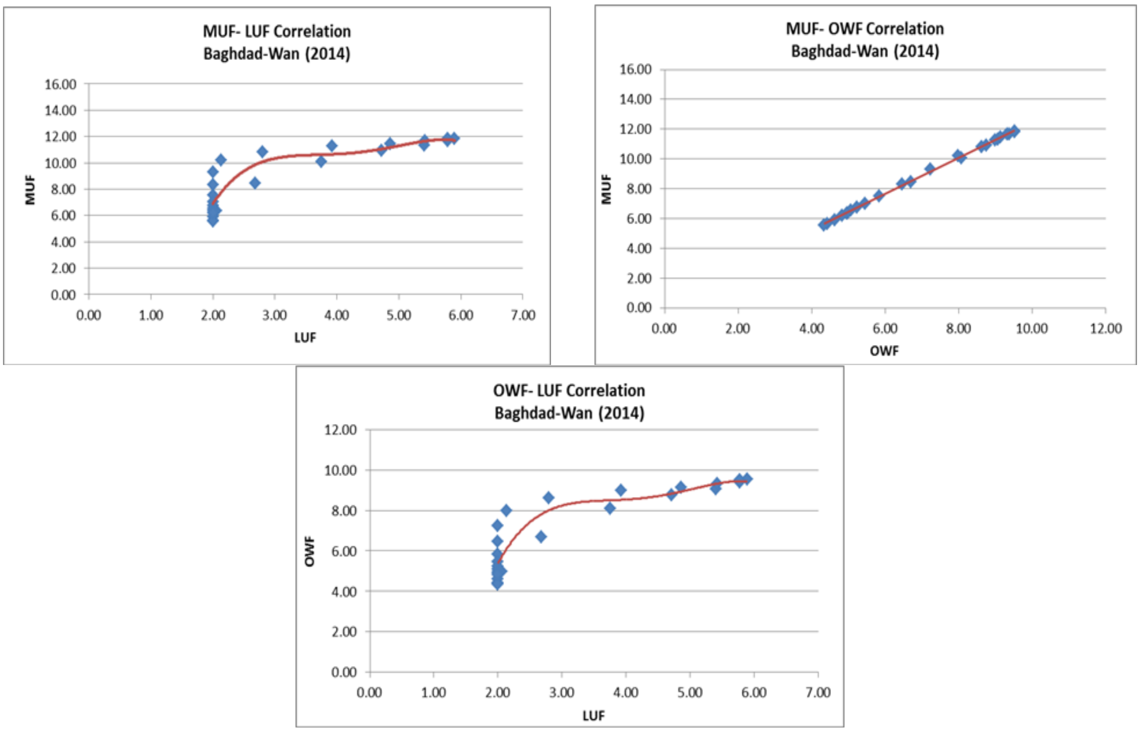


Figure 6-Correlation relationship between MUF, OWF and LUF (Annual - 2014)

The statistical analysis has been applied on the calculated datasets to assess the nature of correlation between these parameters. The results of the statistical analysis showed that the correlation between the ionospheric parameters could be expressed as a polynomial relationship, so the suggested mutual correlation equation between the studied parameters can be presented by the following equation:

$$\mathbf{Y = \sum_{i=0}^{n} a_i x^i} \quad \mathbf{(1)}$$

$$\mathbf{Y = a_0 + a_1x^1 + a_2x^2 + a_3x^3 + \cdots} \quad \mathbf{(2)}$$

So, the suggested mutual correlation equations can be expressed by the following set of equations:

$$\mathbf{MUF} = \sum_{i=0}^{n} \mathbf{a_i}\,(\mathbf{OWF})^{i} \qquad \textbf{(3a)}$$

$$\mathbf{MUF} = \sum_{i=0}^{n} \mathbf{a_i}\,(\mathbf{LUF})^{i} \qquad \textbf{(3b)}$$

$$\mathbf{OWF} = \sum_{i=0}^{n} \mathbf{a_i}\,(\mathbf{MUF})^{i} \qquad \textbf{(3c)}$$

$$\mathbf{OWF} = \sum_{i=0}^{n} \mathbf{a_i}\,(\mathbf{LUF})^{i} \qquad \textbf{(3d)}$$

$$\mathbf{LUF} = \sum_{i=0}^{n} \mathbf{a_i}\,(\mathbf{MUF})^{i} \qquad \textbf{(3e)}$$

$$\mathbf{LUF} = \sum_{i=0}^{n} \mathbf{a_i}\,(\mathbf{OWF})^{i} \qquad \textbf{(3f)}$$

The mutual correlation between MUF, OWF and LUF parameters have been determined for the annual time of the years 2009 and 2014. The determination has been conducted for all tested links that lay over the studied zone. According to the result of the statistical analytical study, the mutual correlation equation has been found to be a polynomial equation of the Fourth Order. Table-3 and 4 show samples of the correlation coefficients (a_o, a_1, a_2, a_3 & a_4) and correlation parameter (R^2) for different links and directions (N, S, E, W, NE, NW, SE, SW) over the Middle east zone of the annual time of the years 2009 and 2014 respectively.

Table 3- Samples of the correlation coefficients and correlation parameter for different links and directions over the Middle East zone of the annual time of the year 2009

Baghdad- Wan (North Direction)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.334	1.161	0.000	0.000	0.000	0.997
MUF (LUF)	- 142.990	179.320	- 78.244	14.865	-1.036	0.797
OWF (MUF)	- 0.272	0.858	0.000	0.000	0.000	0.997
OWF (LUF)	125.500	156.740	- 68.309	12.967	-0.904	0.794
LUF (MUF)	- 4.240	3.868	- 0.798	0.056	-0.000	0.869
LUF (OWF)	2.864	- 0.771	0.318	- 0.069	0.006	0.802
Baghdad- Quba (South Direction)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.299	1.209	0.000	0.000	0.000	0.995
MUF (LUF)	- 103.710	122.960	- 49.102	8.537	-0.544	0.763
OWF (MUF)	- 0.220	0.823	0.000	0.000	0.000	0.995
OWF (LUF)	- 89.890	105.980	- 42.346	7.386	-0.474	0.772
LUF (MUF)	3.135	- 0.080	- 0.129	0.024	-0.001	0.707
LUF (OWF)	- 12.987	12.901	- 3.972	0.512	-0.023	0.694
Baghdad- Bozijan (East Direction)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.253	1.208	0.000	0.000	0.000	0.995
MUF (LUF)	-19.150	247.070	-110.920	21.699	-1.560	0.784
OWF (MUF)	-0.183	0.823	0.000	0.000	0.000	0.995
OWF (LUF)	-167.650	212.350	-95.130	18.588	-1.337	0.786
LUF (MUF)	-0.592	1.954	-0.502	0.049	-0.001	0.784
LUF (OWF)	-22.896	22.493	-7.319	1.009	-0.049	0.710
Baghdad- Al'ulyyaniyah (West Direction)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.285	1.204	0.000	0.000	0.000	0.994
MUF (LUF)	-137.000	169.950	-73.046	13.668	-0.938	0.779
OWF (MUF)	-0.208	0.825	0.000	0.000	0.000	0.994
OWF (LUF)	-119.620	147.590	-63.355	11.860	-0.817	0.787
LUF (MUF)	0.968	0.681	-0.124	0.000	0.001	0.806
LUF (OWF)	-26.953	25.909	-8.357	1.143	-0.055	0.731

Table 4-Samples of the correlation coefficients and correlation parameter for different links and directions over the Middle East zone of the annual time of the year 2014

Baghdad- Wan (North Direction)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.391	1.208	0.000	0.000	0.000	0.999
MUF (LUF)	- 42.648	51.364	- 18.400	2.886	-0.165	0.815
OWF (MUF)	- 0.317	0.826	0.000	0.000	0.000	0.999
OWF (LUF)	- 34.410	40.928	- 14.512	2.253	-0.128	0.836
LUF (MUF)	15.903	- 8.149	1.774	- 0.170	0.006	0.913
LUF (OWF)	1.959	- 1.104	0.603	- 0.108	0.006	0.927
Baghdad- Quba (South Direction)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.776	1.168	0.000	0.000	0.000	0.992
MUF (LUF)	- 24.335	30.441	- 9.530	1.315	-0.066	0.742
OWF (MUF)	- 0.602	0.849	0.000	0.000	0.000	0.992
OWF (LUF)	- 20.002	24.098	- 7.300	24.098	- 20.002	0.809
LUF (MUF)	- 7.362	4.651	- 0.823	0.060	-0.001	0.761
LUF (OWF)	- 4.716	4.328	- 0.985	0.091	-0.002	0.832
Baghdad- Bozijan (East Direction)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.499	1.166	0.000	0.000	0.000	0.995
MUF (LUF)	-45.990	54.833	-19.713	3.100	-0.178	0.792
OWF (MUF)	-0.392	0.853	0.000	0.000	0.000	0.995
OWF (LUF)	-42.486	49.759	-17.896	2.807	-0.160	0.839
LUF (MUF)	8.576	-3.861	0.854	-0.085	0.003	0.858
LUF (OWF)	-6.535	5.294	-1.154	0.100	-0.002	0.880
Baghdad- Al'ulyyaniyah (West Direction)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.739	1.162	0.000	0.000	0.000	0.992
MUF (LUF)	-40.643	49.170	-17.470	2.719	-0.155	0.792
OWF (MUF)	-0.580	0.853	0.000	0.000	0.000	0.992
OWF (LUF)	-34.029	40.15	-14.022	2.143	-0.119	0.853
LUF (MUF)	8.149	-3.775	0.861	-0.087	0.003	0.863
LUF (OWF)	-11.434	7.982	-1.675	0.142	-0.003	0.912

The comparison between the annual (MUF & OWF) ionospheric parameter values that have been calculated using the suggested mutual correlated equations (3a – 3d) (Present Work) with the ionospheric values that have been generated using the international model (ASAPS) (Predicted) and that values calculated depending on the international criterion equation (OWF = 0.85 x MUF) have been presented in Table-5. Also, The Mean Square Error (MSE) between the present values with the theoretical and predicted values have been calculated and presented in Table-5.

Table 5-The Theoretical, Predicted & Present value of the MUF & OWF parameters for the annual Time of the years 2009 and 2014

Baghdad- Wan (MUF- 2009)							Baghdad- Wan (MUF- 2014)					
UT	OWF	MUF					OWF	MUF				
		Predicted	Theoretical	Present	MSE			Predicted	Theoretical	Present	MSE	
					Theo.	Pred.					Theo.	Pred.
0	3.38	4.15	3.98	4.26	0.080	0.013	4.63	5.93	5.44	5.98	0.292	0.002
1	3.23	3.96	3.79	4.08	0.081	0.015	4.43	5.65	5.21	5.74	0.285	0.008
2	3.18	3.91	3.74	4.02	0.082	0.013	4.34	5.57	5.11	5.64	0.282	0.005
3	3.84	4.73	4.52	4.80	0.076	0.004	4.98	6.38	5.85	6.40	0.304	0.001
4	5.23	6.43	6.15	6.40	0.065	0.001	6.70	8.44	7.88	8.49	0.369	0.002
5	6.08	7.45	7.15	7.39	0.058	0.004	8.08	10.08	9.51	10.16	0.425	0.007
6	6.44	7.87	7.58	7.81	0.056	0.003	8.75	10.91	10.29	10.97	0.453	0.003
7	6.70	8.19	7.88	8.11	0.054	0.006	9.06	11.31	10.66	11.34	0.466	0.001
8	7.12	8.67	8.37	8.60	0.051	0.005	9.38	11.65	11.03	11.72	0.480	0.005
9	7.37	9.00	8.67	8.89	0.049	0.013	9.53	11.84	11.21	11.90	0.487	0.004
10	7.39	9.01	8.70	8.92	0.049	0.008	9.52	11.85	11.20	11.89	0.487	0.002
11	7.31	8.84	8.60	8.82	0.049	0.000	9.33	11.67	10.97	11.66	0.478	0.000
12	7.28	8.59	8.56	8.78	0.050	0.036	9.14	11.47	10.75	11.44	0.470	0.001
13	7.10	8.38	8.35	8.58	0.051	0.041	8.99	11.28	10.58	11.26	0.463	0.000
14	6.82	8.08	8.02	8.25	0.053	0.028	8.62	10.83	10.14	10.81	0.447	0.001
15	6.08	7.43	7.16	7.40	0.058	0.001	7.99	10.20	9.40	10.05	0.421	0.022
16	5.45	6.73	6.41	6.66	0.063	0.004	7.23	9.31	8.51	9.13	0.390	0.030
17	4.91	6.03	5.77	6.03	0.067	0.000	6.47	8.33	7.61	8.21	0.360	0.014
18	4.30	5.31	5.06	5.33	0.072	0.000	5.83	7.52	6.86	7.44	0.336	0.006
19	3.80	4.80	4.47	4.75	0.076	0.003	5.45	7.03	6.41	6.98	0.321	0.002
20	3.57	4.60	4.20	4.48	0.078	0.015	5.24	6.75	6.17	6.73	0.314	0.001
21	3.47	4.48	4.08	4.36	0.079	0.015	5.08	6.54	5.97	6.53	0.308	0.000
22	3.40	4.38	4.00	4.28	0.080	0.009	4.96	6.38	5.83	6.38	0.304	0.000
23	3.40	4.27	4.00	4.28	0.080	0.000	4.83	6.21	5.68	6.22	0.299	0.000
				Average MSE	**0.065**	**0.010**				**Average MSE**	**0.385**	**0.005**

The behavior of the present, theoretical, & predicted values of the MUF & OWF parameters for the annual time of the years 2009 and 2014 have been illustrated in Figure-7.

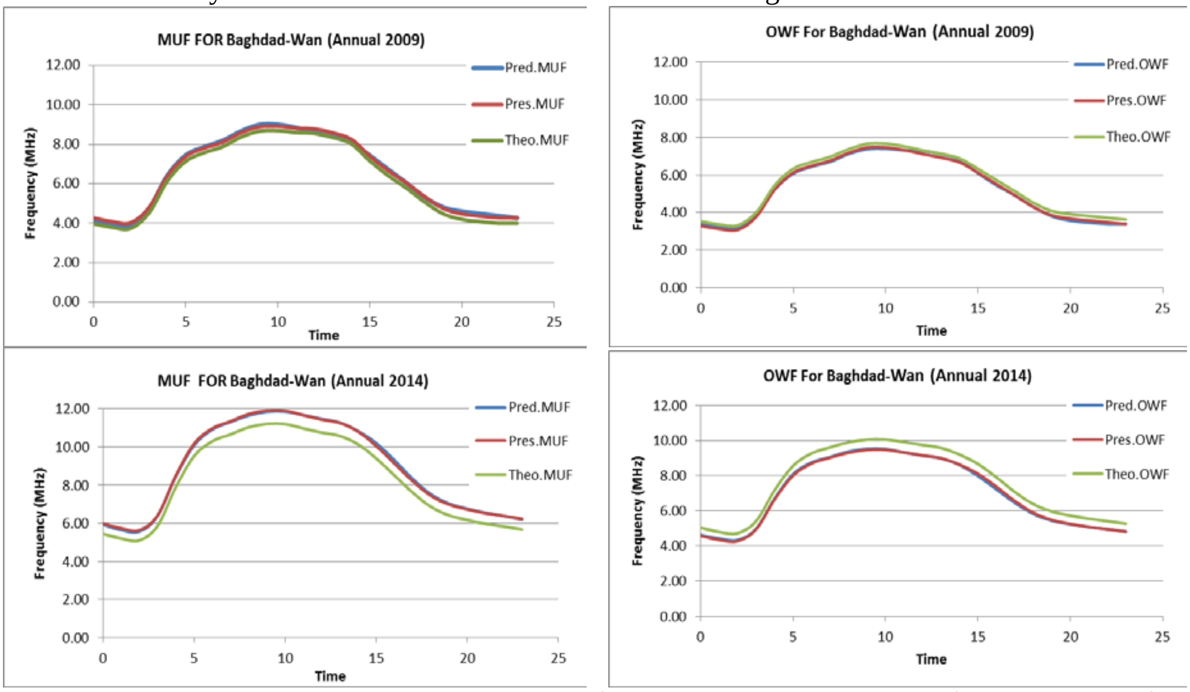
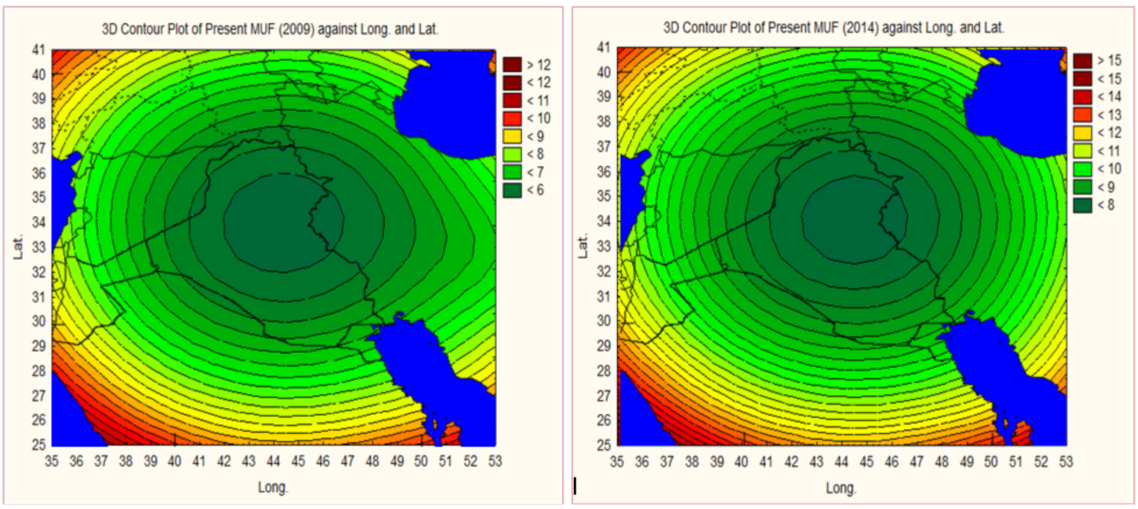
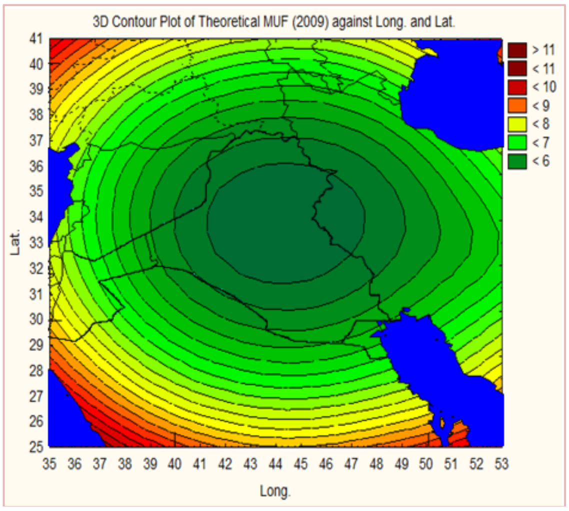
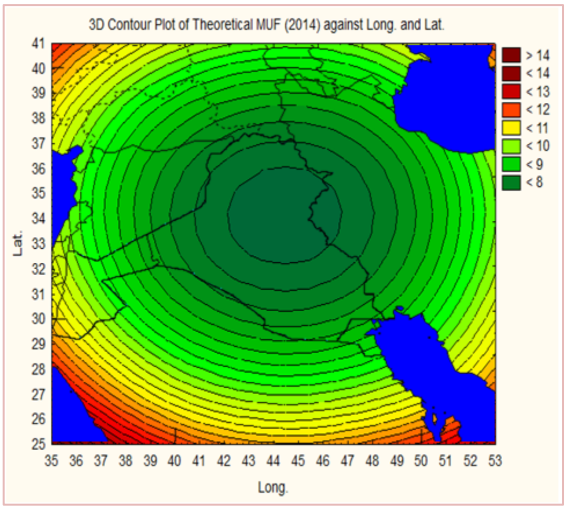


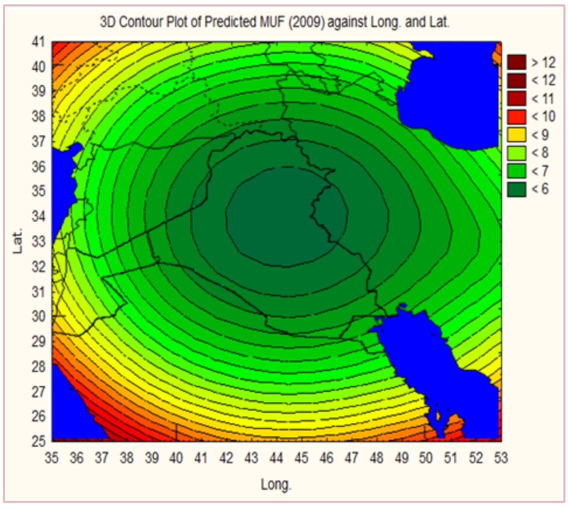
Figure 7-The present, theoretical, and predicted value of the MUF and OWF parameters for Sample Link of the annual time of the selected years

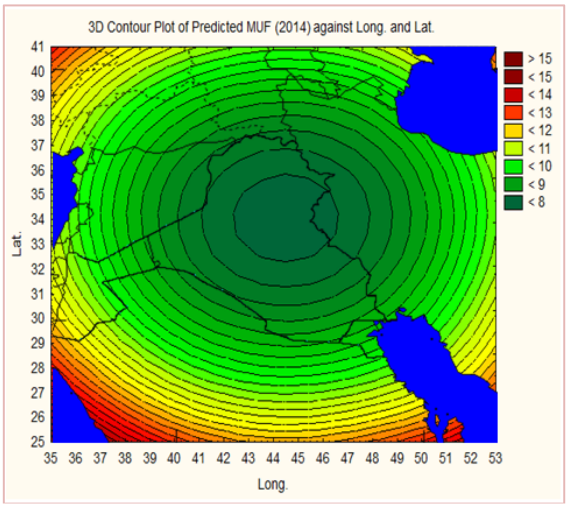
The contour and surface mesh distribution diagrams for the annual MUF & OWF parameters which have been presented using the graphical representation [geographical location coordinates (longitude & latitude)] of the receiving stations that cover the studied area of the Middle East zone for the years (2009 and 2014). Figure-8 show sample of contour and surface mesh distribution of theoretical, predicted and present values for MUF parameter.

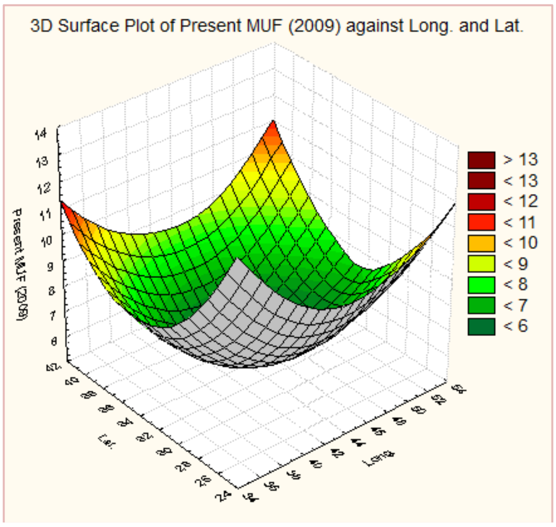


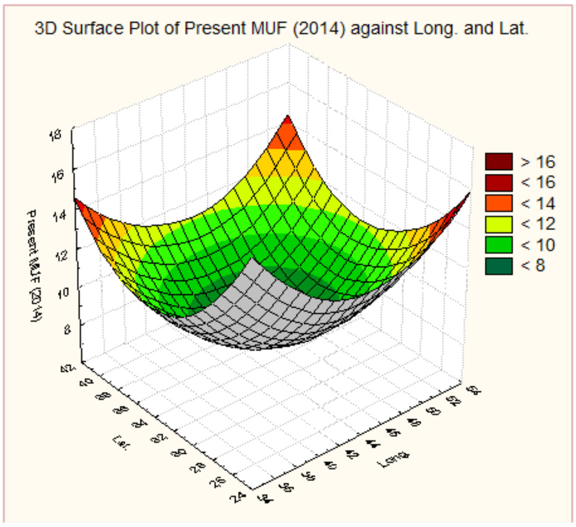

3D Contour Plot of Theoretical MUF (2009) against Long. and Lat.
Lat.
Long.
> 11
< 11
< 10
< 9
< 8
< 7
< 6


3D Contour Plot of Theoretical MUF (2014) against Long. and Lat.
Lat.
Long.
> 14
< 14
< 13
< 12
< 11
< 10
< 9
< 8


3D Contour Plot of Predicted MUF (2009) against Long. and Lat.
Lat.
Long.
> 12
< 12
< 11
< 10
< 9
< 8
< 7
< 6


3D Contour Plot of Predicted MUF (2014) against Long. and Lat.
Lat.
Long.
> 15
< 15
< 14
< 13
< 12
< 11
< 10
< 9
< 8


3D Surface Plot of Present MUF (2009) against Long. and Lat.
Present MUF (2009)
Lat.
Long.
> 13
< 13
< 12
< 11
< 10
< 9
< 8
< 7
< 6


3D Surface Plot of Present MUF (2014) against Long. and Lat.
Present MUF (2014)
Lat.
Long.
> 16
< 16
< 14
< 12
< 10
< 8

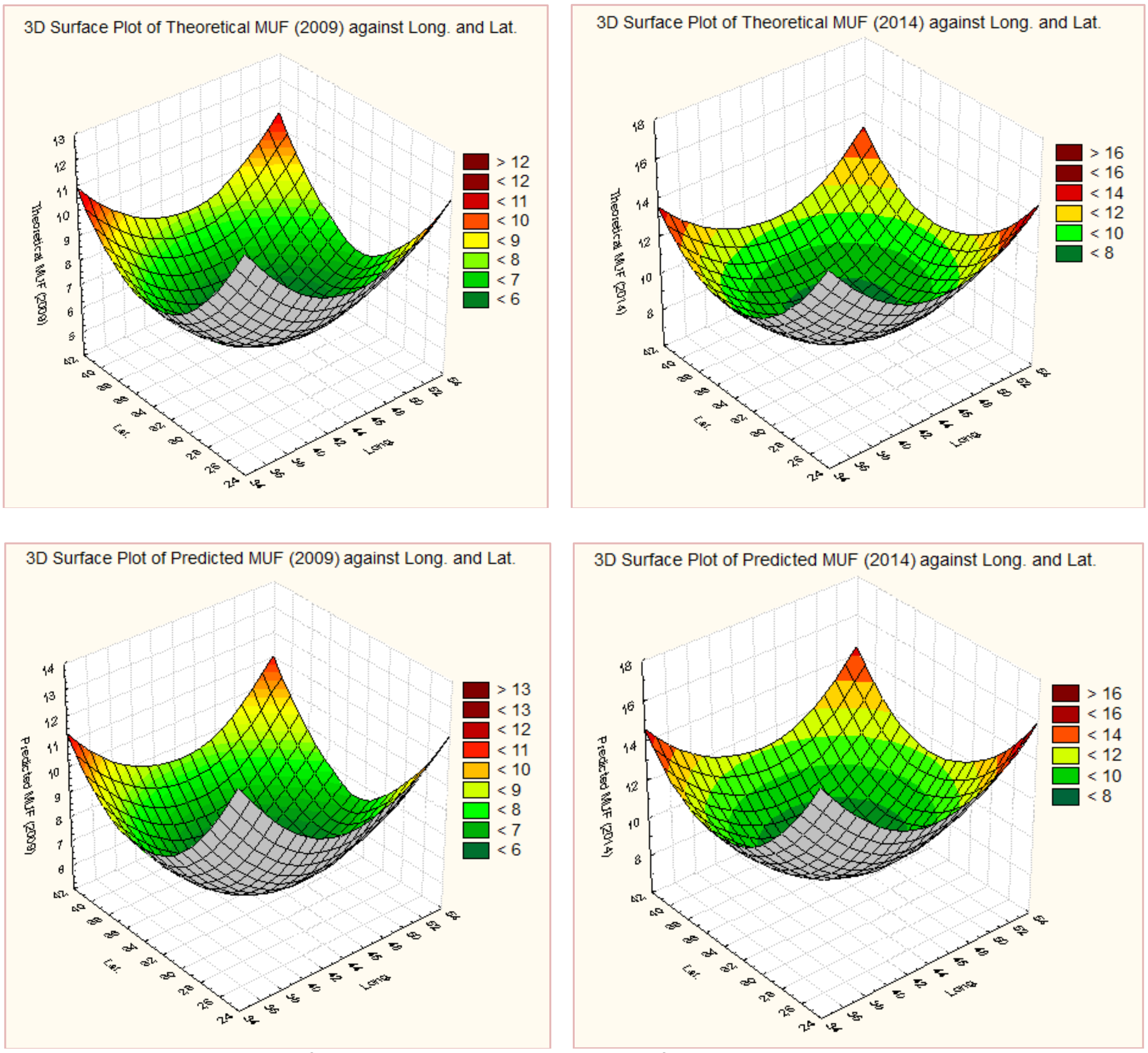


Figure 8- The contour and surface mesh distribution diagrams of the MUF parameter over the Middle East zone for selected years

Conclusion

1. For the determination of bearing parameter, the first method showed more accurate values than the second one.
2. The annual behavior of the ionospheric parameters shows a minor variation in the south direction, which may be resulted from the influence of the thermal and geographical equator.
3. The mutual correlation between MUF & OWF is simple and can be represented by a simple mathematical relationship "linear regression equation".
4. The values calculated from the suggested mutual correlation equation gave a good fit with the other values generated from the international model and criterion.
5. The correlated relationship between (MUF & LUF), (OWF & LUF) is a polynomial which represented by a fourth order polynomial equation (Quartic Polynomial Equation).
6. The datasets which have been generated from the suggested mutual correlation equation was closer to the values calculated from the international model than the values calculated depending on the international recommended criterion.
7. The results of the studied area (Middle East region) that presented by the contour and surface mesh distribution diagrams showed that the behavior of the MUF & OWF parameter faced some variations. So, the oval shape (semi-circular shape) of the MUF & OWF parameter presents the impact of the sunrise and sunset times on the behavior of these parameters

References

1. Les Barclay, IET. **2003**. Propagation of Radio Waves. Second Edition. The institution of Engineering and Technology, London, United Kingdom.
2. Lane, G. **2005**.Improved Guidelines for Automatic Link Establishment Operations, Preprint paper to 3B-4, *Ionospheric Effects Symposium, Alexandria VA USA*, May 3-5.
3. Bakshi, K.A. Bakshi, A.V. and Bakshi, U.A. **2009**. Antenna & Wave Propagation. First Edition.
4. ETC Larry D. Simmons and ETC Floyd L. **1995**. Electronics Technician Volume 7 Antennas and Wave Propagation.
5. John Douglas and David M. Boore.**2011.** High-frequency filtering of strong-motion records. *Springer Journal, Bull Earthquake Eng.*, pp: 395-409.
6. Australian Government. **2012**. Introduction to HF Radio Propagation, IPS Radio and Space Service.
7. NASA. **2015.** The Sunspot Cycle. Marshall Space Flight Center, USA, http://solarscience. msfc.nasa.gov/SunspotCycle.