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Seasonal Variations of the Optimum Reliable Frequencies during Maximum and Minimum Periods of Solar Cycle 24

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ABSTRACT

In this research, the seasonal Optimal Reliable Frequency (ORF) variations between different transmitter/receiver stations have been determined. Mosul, Baghdad, and Basra have been chosen as tested transmitting stations that located in the northern, center, and southern of Iraqi zone. In this research, the minimum and maximum years (2009 and 2014) of solar cycle 24 have been chosen to examine the effect of solar activity on the determined seasonal ORF parameter. Mathematical model has been proposed which leads to generate the Optimal Reliable Frequency that can maintain the seasonal connection links for different path lengths and bearings. The suggested ORF parameter represented by a different orders polynomial equation. The polynomial equation has been determined depending on different selected parameters (path length, bearing, time (day), months and BUF values). The suggested seasonal ORF parameter was examined for the three stations of the adopted years. The value of the seasonal ORF ionospheric parameter increased with the increase of path length and varies with the bearing between the transmitting and receiving stations also, the seasonal ORF values were higher at maximum solar cycle (2014) than the minimum solar cycle (2009).

KEYWORDS: Ionospheric Parameters, BUF, HF Communication, seasonal ORF.

الخلاصة

في هذا البحث، تم تحديد التغيرات الموسمية للتردد الموثوق الامثل (ORF) بين محطات الإرسال والاستقبال المختلفة. وقد تم اختيار الموصل وبغداد والبصرة كمحطات إرسال تم اختبارها تقع في شمال ووسط وجنوب المنطقة العراقية. في هذا البحث، تم اختيار الحد الأدنى والأقصى للسنوات (2009 و 2014) للدورة الشمسية 24 لفحص تأثير النشاط الشمسي على معامل ORF الموسمي. تم اقتراح نموذج رياضي يؤدي إلى توليد التردد الموثوق الأمثل الذي يمكنه الحفاظ على روابط التوصيل الموسمية لأطوال ومسارات مختلفة. معامل ORF المقترح و المتمثل بمعادلة متعددة الحدود ذات اسس مختلفة. تم تحديد المعادلة متعددة الحدود اعتماداً على المعاملات المختارة المختلفة (طول المسار والزاوية والوقت (اليوم) والأشهر وقيم BUF). تم فحص معامل ORF الموسمي المقترح للمحطات الثلاث للسنوات المعتمدة. زادت قيمة المعامل الموسمي الأيونوسفيري ORF مع زيادة طول المسير وتختلف باختلاف الاتجاه بين محطات الإرسال والاستقبال أيضاً، وكانت قيم ORF الموسمية أعلى عند الحد الأقصى للدورة الشمسية (2014) من الحد الأدنى للدورة الشمسية (2009).

INTRODUCTION

Ionosphere is created due to the ionization of the upper atmosphere by the electromagnetic radiation coming from the sun; due to its ionization state it is gradually bends the HF radio waves coming from earth. In general, radio wave leaves the transmitting antenna and hit the ionosphere obliquely [1]. Ionosphere composed of mixed particles molecules, electrons and positive ions and remains electrically neutral since the numbers of positive and negative charges are equal overall the charged particles are produced primarily by ionizing solar radiation [2]. The ionosphere composed of several defined layers, D layer, E layer, and F layer [3]. Figure 1 shows the structure of the ionosphere layers at night and day time [4]. The ionosphere affects the radio wave in different ways depending on their frequencies. Radio waves with frequencies above 30 MHz can usually penetrate the ionosphere. The ionosphere act as an efficient reflector for radio waves with frequencies below 30 MHz as high frequencies (HF) allowing radio communication to distance of kilometers. (HF) band is usually defined as being between (3-30) MHz [5].

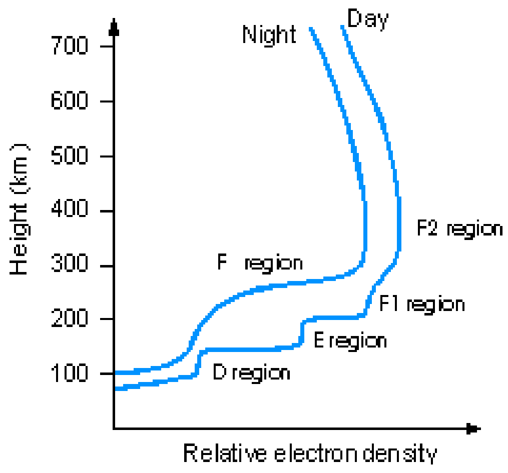

Figure 1. Structure of Ionosphere [4].

HF Communication Parameters

High Frequency communication parameters have an important role determining the best range of reliable frequencies that are reflected from the ionospheric layers between two terminals at a specific time [6]. The ionospheric communication parameters can be defined as follow:

1. **The Maximum Usable Frequency (MUF):** The highest frequency at which radio wave is 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 [7].
2. **The Optimum Working Frequency (OWF):** Is also called the Optimum Traffic Frequency (FOT), the most practical operating frequency is one that you can rely on to have the least number of problems, the OWF is about 85% of the MUF and time for 90% of the days of the month [7].
3. **The Lowest Usable Frequency (LUF):** The lower frequency that allows reliable long-range HF radio communication between two stations by ionospheric refraction, it is exceeded by the operational MUF on 10% of the specified period [7].
4. **Best Usable Frequency (BUF):** BUF is defined as frequency from the specified set with the maximum signal to noise ratio (S/N), which also satisfies the specified minimum take-off angle required S/N ratio and probability level [8].

THE ADOPTED INTERNATIONAL COMMUNICATION MODEL

For many years, many organizations have developed HF ionospheric communication models in order to provide more accurate usable frequencies that are maintains between transmitter and receiver stations over long distance [9]. Different propagation prediction models exist in the form of software to predict the ionospheric parameters such as (MUF, LUF, FOT … etc.). Typical input parameters for such prediction programs include time of day, month, frequency, sunspot number, transmitter and receiver position and possibly a geomagnetic index [10]. In this research, Advanced Stand Alone Prediction System (ASAPS) model has been adopted to calculate the datasets of the required ionospheric parameter. The ASAPS is one of the international HF communication models developed by the Ionospheric Prediction of Australian government IPS Radio and Space Services, ASAPS model allows the predictions of the sky wave communications condition in the HF radio spectrum (3-30) MHz. ASAPS model based on an ionospheric model developed by Space Weather Services within the Australian Bureau of Meteorology and ITU-R/CCIR models [11].

TEST AND RESULT

In this research, the ORF has been estimated for three different transmitter locations Mosul (43.119° E, 36.335° N), Baghdad (44.401° E, 33.341° N) and Basra (47.780° E, 30.508° N) and more receiving stations distributed over Iraq and neighboring regional countries. The calculation of geographical coordinates was made by implementing a program using a Matlab programming language. The calculations were made depending on the values of the geodesic parameters which were adopted in this research: path length (100, 200, 300, … , 1000) Km and bearing (0, 45, 90, …, 315) degree that were calculated using Equations (1) and (2). The adopted locations (receiver stations) for each of the three transmitting station were (80) locations (8 bearings and 10 path length), so the total adopted receiving stations for the three transmitting stations were (240) locations. Table 1 presents sample of the geographical coordinates of receiving stations, path length and bearing distributed over the studied zone.

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$$\lambda = \frac{\Delta x}{\Delta \text{long.}} + \lambda_\circ \quad (1)$$

$$\varphi = \frac{\Delta y}{\Delta \text{Lat.}} + \varphi_\circ \quad (2)$$

$$\Delta y = \text{Path length} * \cos(B) \quad (3)$$

$$\Delta x = \text{Path length} * \sin(B) \quad (4)$$

$$\Delta \text{Lat} = \frac{2\pi R}{360} \quad (5)$$

$$\Delta \text{Long} = \frac{2\pi R}{360}\cos(\varphi_\circ) \quad (6)$$

Where, λ, λ°: longitude of the receiving and transmitting stations, φ, φ° : latitude of the receiving and transmitting stations, Δy : the distance along vertical between two points, Δx : the distance along the parallel between two points, B: Bearing, R: Radius of Earth.

The datasets of the BUF has been calculated using the adopted ASAPS communication model for the years (2009 and 2014) that represent the minimum and maximum activity of solar cycle 24. Table 2 illustrates the monthly T-Index values of the years (2009, 2014) of solar cycle 24.

In this research, the values of the BUF has been studied statistically by analyzing the generated dataset from the ASAPS model for seasonal time period of the selected two years of solar cycle 24.

The relation between the analyzed seasonal BUF parameter dataset with the path length, bearing and time parameters were studied to get an approximate mathematical representation.

Depending on the results that have been achieved from the statistical analysis study of the seasonal BUF parameter, and by taking into consideration the effects of path length (100-1000) Km, bearing (00-315^o), day time (0-23) and month (1-12) parameters a mathematical formula has been suggested using simplified mathematical model as a polynomial equation to determine the ORF seasonal parameter values.

The suggested seasonal equation presents a correlation between the ORF parameter with the path length, bearing, time and month factors. The suggested mathematical polynomial equation can be presented as follows:

$$ORF_{Seasonal}(d.B.t.M) = \left(\sum_{i=0}^{n1} a_i d^i\right) \times$$

$$\left(b_0 + \sum_{k=1}^{n2} b_{2k-1}\cos\left(\frac{2\pi kB}{360}\right) + b_{2k}\sin\left(\frac{2\pi kB}{360}\right)\right) \times$$

$$\left(c_0 + \sum_{j=1}^{n3} c_{2j-1}\cos\left(\frac{2\pi jt}{24}\right) + c_{2j}\sin\left(\frac{2\pi jt}{24}\right)\right) \times$$

$$\left(e_0 + \sum_{z=1}^{n4} e_{2z-1}\cos\left(\frac{2\pi zM}{365}\right) + e_{2z}\sin\left(\frac{2\pi zM}{365}\right)\right) \quad (7)$$

where, *d:* Path Length (Km), *t:* Universal Time (UT), *B:* Bearing (Degree), *M:* Month, and n_i: is the polynomial order, a, b, c, and e polynomial coefficients.

Based on Equation (7), the variation of seasonal ionospheric ORF parameters was estimate for the minimum and maximum years of the solar cycle 24. The estimation was made by implementing a program using visual basic programing language (VB6).

Many tests have been performed to determine the coefficients order (n_1, n_2, n_3, and n_4) of the Equation (7), these tests include the calculations of squared correlation coefficient (R^2), Mean Difference (MD), Mean Square Deviation (MSD); and Mean Absolute Deviation (MAD) between the ORF and BUF ionospheric parameters. Depending on the tests results, the suitable set of coefficients that reflects a closer behavior of ORF parameter to BUF parameter was attained when the polynomial orders were (n_1=2, n_2=2, n_3=10, n_4=2). Table 3 presents sample of the polynomial coefficients of Equation (7) for Baghdad transmitting station.

Figures (2-7) present samples of the calculated ORF results compared to BUF for all seasons of the years (2009 and 2014) for Mosul, Baghdad, and Basra transmitting stations. Table 4 present the values of the squared correlation coefficient (R^2) that calculated between seasonal ORF and BUF for different path length and bearing values.

Table 1. Geographical coordinates (latitude and longitude), Path length, Bearing, for the distributed receiving stations around transmitting stations.

Path length (Km)	Bearing (Degree)	Latitude (Degree)	Longitude (Degree)	R_x Station Name
Mosul (T_x)				
100	0	37.234	43.119	Duhok, Zakho
	45	36.971	43.908	Duhok, Aqrah
	90	36.335	44.235	Erbil, Shaqlawa
	135	35.699	43.908	Kirkuk, Makhmur
	180	35.436	43.119	Saladin, Al-Shirqat
	225	35.699	42.330	Nineveh, Hatra
	270	36.335	42.003	Nineveh, Sinjar
	315	36.971	42.330	Nineveh, Tel Afar
200	0	38.134	43.119	Turkey, Çatak Van
	45	37.607	44.698	Iran, West Azerbaijan, Urmia
	90	36.335	45.352	Iran, West Azerbaijan
	135	35.063	44.698	Sulaymaniyah, Chamchamal
	180	34.536	43.119	Saladin, Baiji
	225	35.063	41.540	Nineveh, Al-Ba'aj
	270	36.335	40.886	Syria, Al-Hasakah
	315	37.607	41.54	Turkey, Ardıç Köyü
Baghdad (T_x)				
100	0	34.240	44.401	Saladin, Al-Daur
	45	33.977	45.162	Diyala, Muqdadiyah
	90	33.341	45.477	Diyala, Baladrooz
	135	32.705	45.162	Wasit, Al-Suwaira
	180	32.442	44.401	Babylon, Hilla
	225	32.705	43.640	Al Anbar, Razazza Lake
	270	33.341	43.325	Al Anbar, Ramadi
	315	33.977	43.640	Saladin, Samarra
200	0	35.140	44.401	Kirkuk, Daquq
	45	34.613	45.923	Iran, Kermanshah
	90	33.341	46.554	Iran, Ilam
	135	32.069	45.923	Wasit, Al-Hayy
	180	31.542	44.401	AlQadisiya, Hamza
	225	32.069	42.879	Al Anbar, Ar Rutba
	270	33.341	42.248	Al Anbar, Ar Rutba
	315	34.613	42.879	Saladin, Baiji
Basra (T_x)				
100	0	31.407	47.780	Iran
	45	31.144	48.518	Iran, Khuzestan
	90	30.508	48.824	Iran, Khuzestan
	135	29.872	48.518	Arabian Gulf
	180	29.609	47.780	Kuwait, Al Jahra
	225	29.872	47.042	Basra, Al-Zubair
	270	30.508	46.736	Basra, Al-Zubair
	315	31.144	47.042	Thi Qar, GIBAYSH
200	0	32.307	47.780	Iran, Khuzestan
	45	31.780	49.256	Iran, Khuzestan
	90	30.508	49.868	Iran, Omidiyeh
	135	29.236	49.256	Arabian Gulf
	180	28.709	47.780	Kuwait
	225	29.236	46.304	Al Muthanna, Al-Salman
	270	30.508	45.692	Al Muthanna, Al-Salman
	315	31.780	46.304	Thi Qar, Rifai

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Table 2. T-Index for the years 2009 and 2014.

Month	2009	2014
January	-2	91
February	-1	108
March	-2	130
April	0	114
May	2	96
June	-3	84
July	-4	86
August	-7	81
September	-2	90
October	-3	94
November	-3	98
December	-2	103

Table 3. Polynomial equation coefficients for Baghdad Station for the years 2009 and 2014.

2009	2014
4.236738	6.337359
0.745787	0.321386
1.258299	2.186499
-0.114454	-0.009249
0.094696	-0.365271
-0.258122	-0.316314
-0.043855	0.009930
0.196372	-0.029776
-0.139028	0.019776
-1.639541	-1.777431

Table 4. samples of the squared correlation coefficients for seasonal BUF and ORF of the years 2009 and 2014.

Mosul (200 km)	Bearing			
	90 degree		270 degree	
	2009	2014	2009	2014
Winter	0.980	0.981	0.985	0.973
Spring	0.969	0.924	0.976	0.933
Samar	0.988	0.958	1	0.929
Autumn	0.965	0.984	0.970	0.982
Baghdad (400 km)	**Bearing**			
	0 degree		**180 degree**	
	2009	**2014**	**2009**	**2014**
Winter	0.972	0.890	0.941	0.890
Spring	0.963	0.906	0.966	0.910
Samar	0.980	0.949	0.938	0.934
Autumn	0.962	0.957	0.964	0.973
Basra (500 km)	**Bearing**			
	45 degree		**225 degree**	
	2009	**2014**	**2009**	**2014**
Winter	0.980	0.963	0.967	0.946
Spring	0.980	0.949	0.972	0.941
Samar	0.987	0.930	0.976	0.924
Autumn	0.974	0.984	0.977	0.977

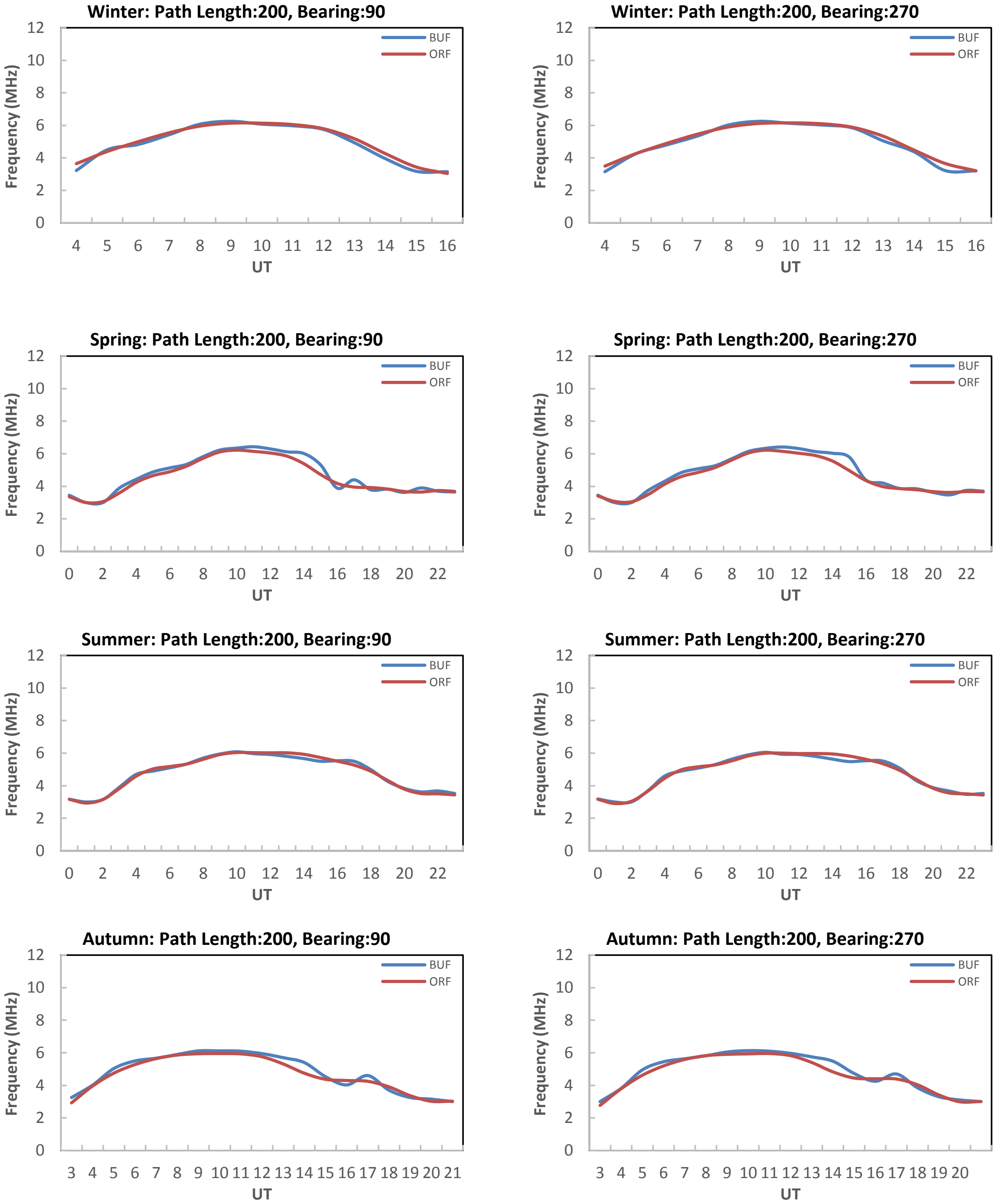

Figure 2. . Seasonal variation of the ORF and BUF parameters for 200 Km Path lengths and different bearings of Baghdad for the year 2014.

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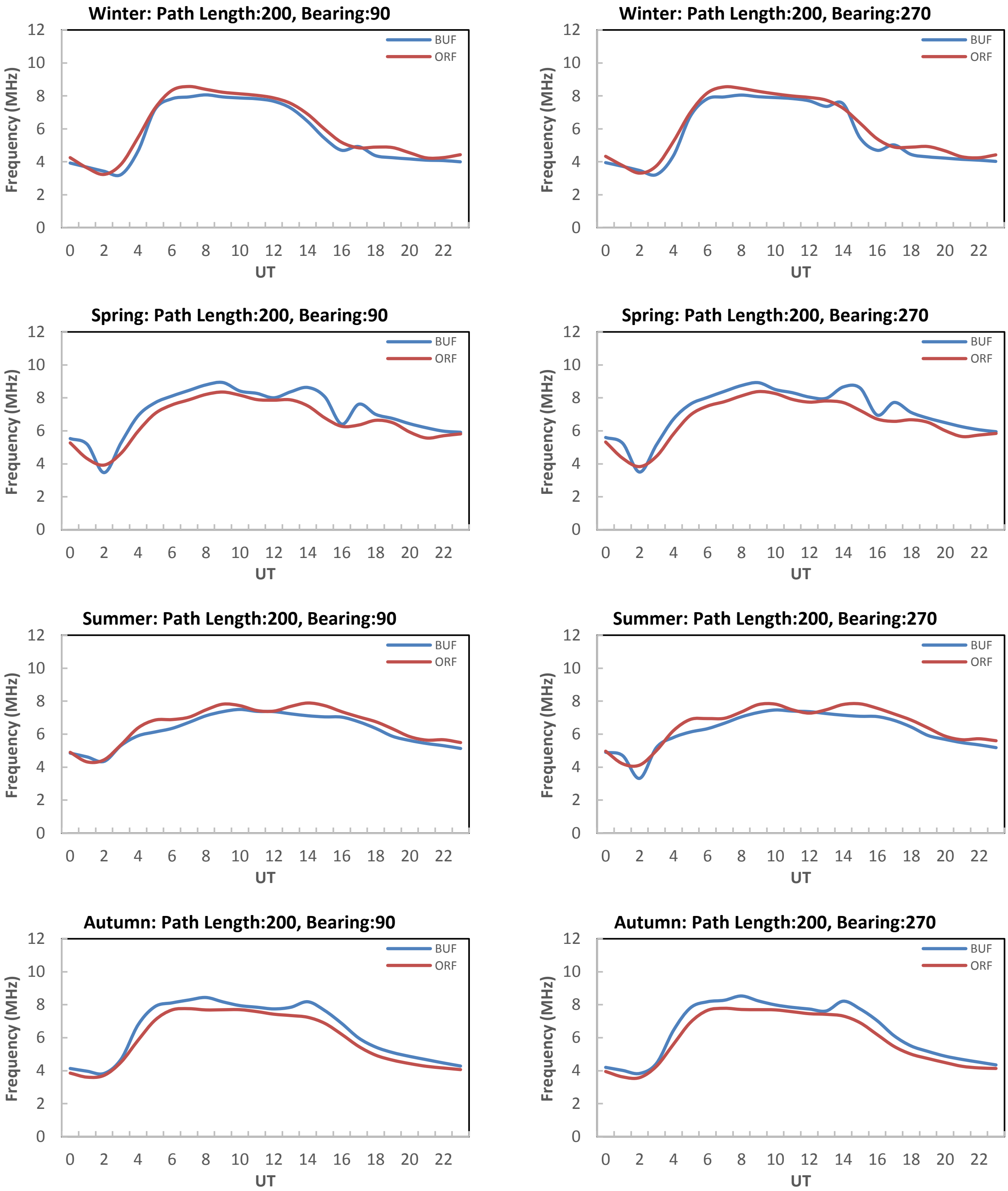

Figure 3. Seasonal variation of the ORF and BUF parameters for 200 Km Path lengths and different bearings of Mosul for the year 2014.

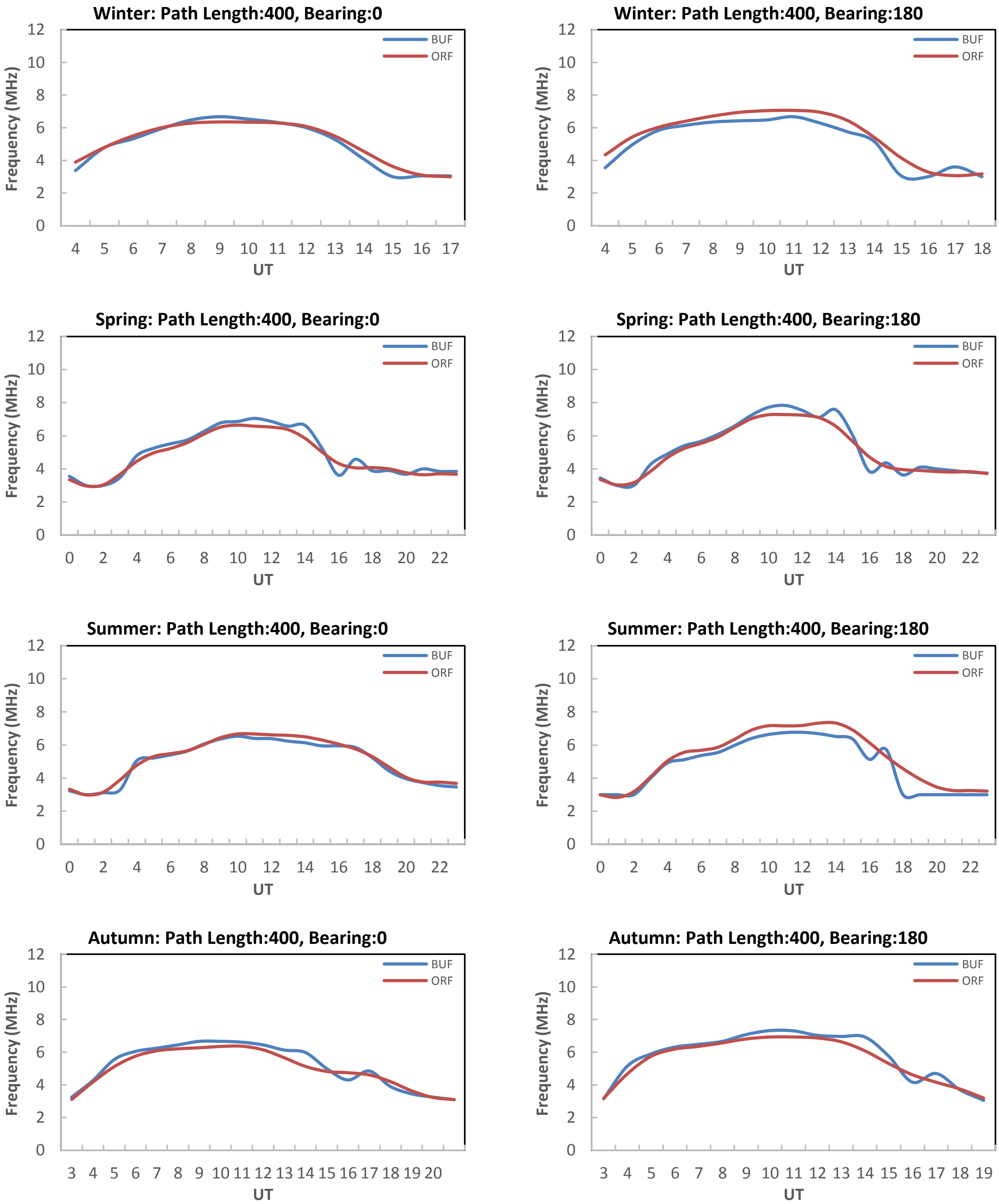

Figure 4. Seasonal variation of the ORF and BUF parameters for 400 Km Path lengths and different bearings of Baghdad for the year 2009.

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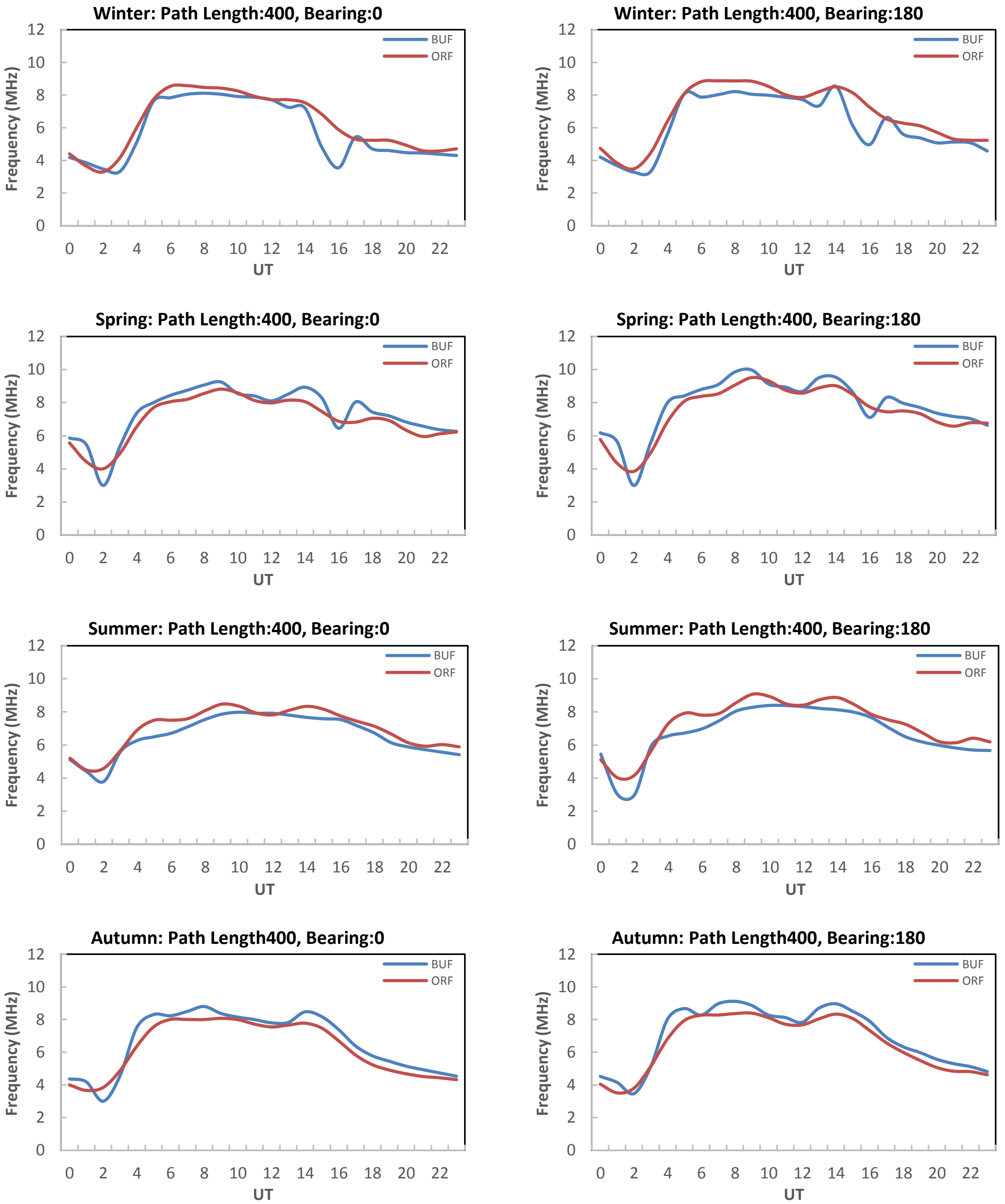

Figure 5. Seasonal variation of the ORF and BUF parameters for 400 Km Path lengths and different bearings of Baghdad for the year 2014.

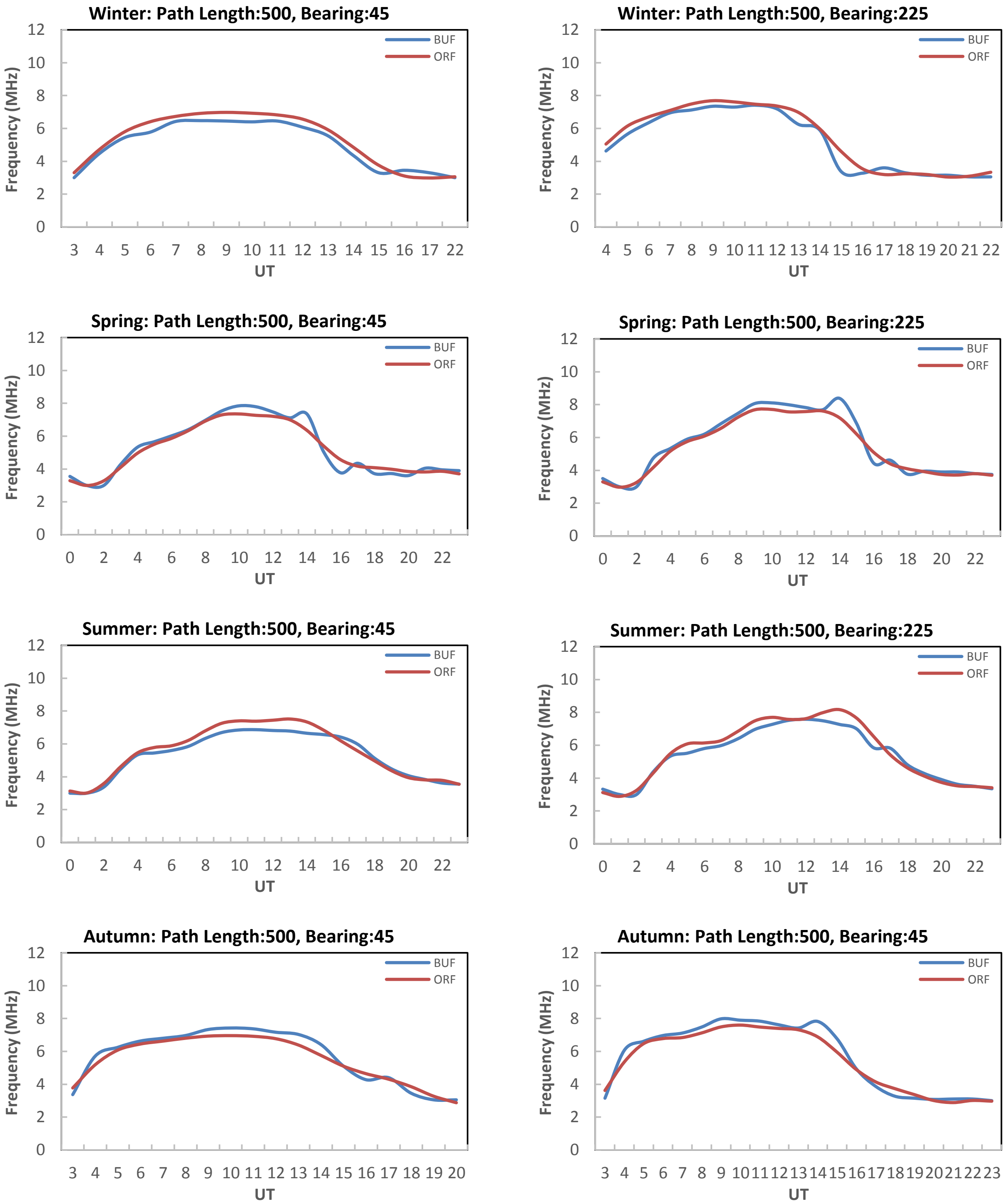

Figure 6. Seasonal variation of the ORF and BUF parameters for 500 Km Path lengths and different bearings of Basra for the year 2009.

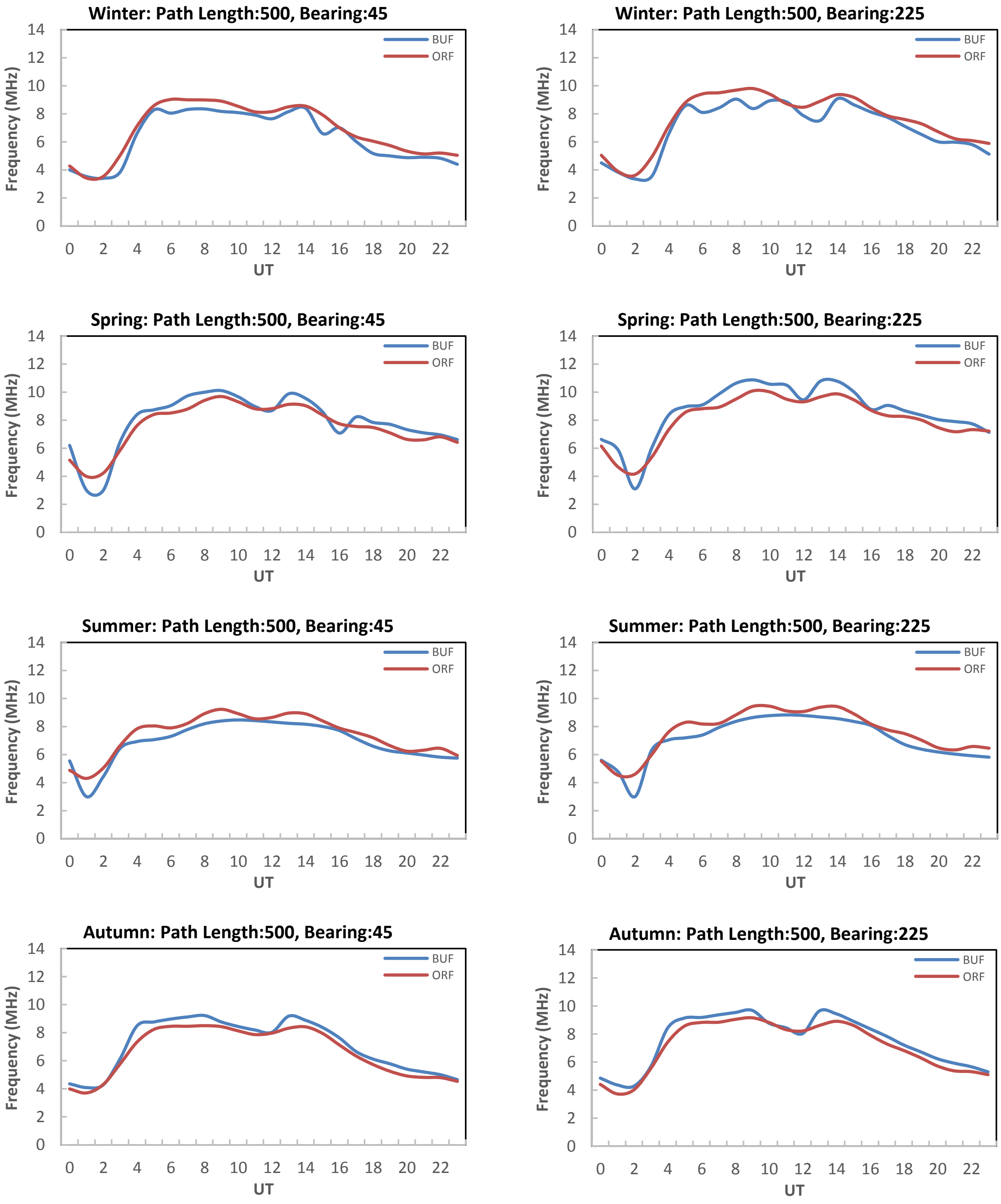

Figure 7. Seasonal variation of the ORF and BUF parameters for 500 Km Path lengths and different bearings of Basra for the year 2014.

DISCUSSION AND CONCLUSIONS

In spring, it has been noticed that the values vary with the increase of path length parameter, and reaches the maximum values at (1000) km. The differences in the behavior of the ORF parameter at different bearing angles may be due to the sunrise and sunset phenomena, which may affect the parameter values due to the time differences caused by the two phenomena. This may cause differences in the frequency values due to the solar irradiance interaction with the components of the ionosphere layer the higher ORF value appears in the bearing (180^o) due to the effect of thermal and geographical equators. It has been noticed that maximum values of ORF parameter is at noon, while minimum values at the sunrise and sunset due to the loss of electron density. At the maximum solar cycle (i.e. 2014), it is almost the same behavior but with more fluctuations and higher values due to the effect of high solar activity.

Due to sun effects on the earth in summer season, the ionization is high. So, the behavior was smoother than spring season, the ORF increases with the increase of path length until it reaching the highest value at 1000 Km and the highest ORF value occur in south bearing direction due to the effect of thermal and geographical equators. Also, it has been noticed that maximum values of ORF parameter is at noon time, then the value begun to decline until it reaches the lowest values during the sunrise and sunset time due to the electron density concentration. In summer 2014, the behavior is more fluctuated with higher values due to the effect of high solar activity.

At the solar minimum 2009, virtually nonexistence to the winter anomaly and there is less ionization in the winter than in summer because of different solar zenith angle. In the winter and autumn seasons, the low ionization process causes the ORF parame ter to suffer from cut off at sunrise and sunset hours; this cut off disappear when the path length increase, due to the increase of the ORF parameter with path length parameter. The higher value of the ORF parameter was at noon time then a decline occurs at the sunset and sunrise time. At solar maximum 2014, the behavior of the cut off hours will disappear due to the winter anomaly and the values of the ORF parameter at the autumn and winter seasons will be higher due to the high solar activity. The seasonal variability of Basra Baghdad and Mosul transmitting stations showed a similar variation at the minimum and maximum years of the solar cycle 24 and the calculated seasonal ORF values for 2009 and 2014 years were higher in Basra, Baghdad and Mosul stations respectively. The difference in the ORF values can be explained by the proximity of the thermal equator to the Basra transmitting station. For Mosul, Baghdad and Basra sites, at minimum solar cycle 2009 the highest value were for Summer season due to the high ionization and there is virtually no winter anomaly, while at the maximum solar cycle 2014 the highest season was the Winter season due to the existence of winter anomaly. Based on the previous discussion, it has been notice that the year 2009 show more stable variation than that for year 2014, and the highest values of the seasonal ORF parameter appear in the southern region (i.e., Basra site) and decreases toward the northern region (i.e., Mosul site). Also, the higher ORF value in seasons (Winter, Spring, Summer, and Autumn) was also at the Basra site as shown in Tables 5 and 6.

Table 5. Seasonal ORF values for 2009.

Season	Mosul site	UT	Baghdad site	UT	Basra site	UT
Winter	8.607	9	8.819	9	9.144	9
Spring	8.805	10	9.198	14	10.251	13
Summer	9.753	14	10.138	14	10.663	14
Autumn	8.664	6	8.916	6	9.622	13

Table 6. Seasonal ORF values for 2014.

Season	Mosul site	UT	Baghdad site	UT	Basra site	UT
Winter	**12.858**	8	**13.253**	7	**13.459**	7
Spring	11.795	10	12.010	10	12.722	11
Summer	10.901	10	11.201	10	11.702	10
Autumn	11.432	9	12.033	9	12.374	9

According to the above discussion, the conclusions were summarized in the followings:

1. Radio wave communications depends on different parameters, path length and bearing angle between the transmitting and receiver stations, season of the year, time of the day, minimum and maximum of the solar cycle period.
2. The value of the seasonal ORF ionospheric parameter increased with the increase of path length (distance) between the transmitting and receiving stations.
3. The value of the seasonal ORF parameter vary with the bearing between the transmitting and

receiving stations this behavior may due to the geographical location and its closeness to the thermal and geographical equators.

4. Among the three transmitting stations (i.e., north, middle and south of Iraq), the highest frequencies were at south (i.e., Basra transmission station).
5. The seasonal ORF values were higher at maximum solar cycle (2014) than for the minimum solar cycle (2009) while the year 2009 (minimum solar cycle) showed more stable variation than the year 2014 (maximum solar cycle).
6. The results of the seasonal variation of the optimum reliable frequency parameter showed almost the same behavior with different values during various path lengths, bearing and solar activity.
7. The value of seasonal frequency parameter increased at morning time during the sunrise till reaching its highest values at noon time, then it starts to decline at sunset due to the behavior of electron density.
8. the year 2009 show more stable variation than that for year 2014, and the maximum values of the seasonal ORF parameter appear in the southern region (i.e., Basra site)

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