

The Effect of Sunspots Number on Critical Frequencies f_oF_2 for the Ionospheric Layer- F_2 Over Kirkuk City During the Ascending Phase of Solar Cycle 24

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Abstract

The study of the F_2 -layer properties and the critical frequency (f_oF_2) is necessary to understand the dynamic features and thus more accurately predict the behavior of the F layer, and this research aims to find the relationship (correlation) and interdependence between the critical frequency (f_oF_2) of Ionospheric layer F_2 and Sunspot number. In this study the characteristics and behavior of F_2 layer during Solar cycle 24 were studied, the effect of Sunspots number (Ri) on the critical frequency (f_oF_2), were investigated for the years (2012, 2013, 2014) which represents the ascending phase and 2014 represent the peak phase of the solar cycle 24 over Kirkuk city (35° N, 44° E) by finding the critical frequency (f_oF_2) values, the layer's impression times are determined for the days of solstice as well as equinox, where the solar activity was examined for the days of the winter and summer solstice and the days of the spring and autumn equinoxes for a period of 24 hours by applied the International Reference Ionosphere model IRI (2016). The output data for f_oF_2 were verified by using the IRI-Ne- Quick option by specifying the time, date and Sunspot number parameters. Statistical analysis was carried out through the application of the Minitab (version 2018) in order to find the correlation between the critical frequency (f_oF_2) of Ionospheric layer F_2 and Sunspot number. It was concluded that the correlation is strong and positive, this indicate that critical frequency (f_oF_2) increase with increasing Sunspots number (Ri) for solar cycle 24.

1. Introduction:

The ionosphere is a layer of the Earth's atmosphere that extend from the upper part, and it extends about (60-1000) km above the earth's surface. It was characterized by certain electrical and magnetic properties because it contains ions and electrons so that it can cause radio waves to be combined or even completely reflected towards the earth, and this feature allows long-range wireless communications [1]. Without the ionospheric layer Radio waves would have penetrated into outer space without return.

The ionosphere consists of layers that have been divided

according to their electronic density into four diurnal regions, and they are D, E, F_1 , and F_2 [2][3] which are important for the propagation of waves due to their ionization by cosmic and solar radiation.

Understand the behavior of this region's parameters during Solar activity and Solar cycle phases may be useful for investigations of solar variability and its terrestrial impacts. The behavior of the ionosphere have highlighted the variability of its critical frequency f_oF_2 profiles during various seasons, day, time, solar events and latitude [4][5][6].

The proportion of production of ions in these layers depends on the zenith angle (x). Sunset is also the angle value varies depending on the time of days, year and location. The F_2 layer is the top layer of the ionospheric F region, and it is 250 km above sea level. It has a high electron density and

thus plays an important role in shortwave communications. The variations of the critical frequency of the F_2 layer (f_oF_2) offer clues regarding the events happening within the entire F_2 layer, and f_oF_2 analysis is essential for stable shortwave communications [7][8].

The ionospheric layer F_2 has been selected for its importance in HF radio communications such as refraction, absorption, global positioning system (GPS), interference and phase delay.

There is a lot of research for the Ionosphere study, and Solar activity that dealt with several topics and themes, Among them:

In 2020, researcher Rwziah Mahmood Mohammed, et. al [9] compared the measurements of the total electronic content over Kirkuk station in Iraq with the IRI2016 data in the period for the years (2008, 2014, 2018) which represents the rising phase, the peak and the down phase of the Solar cycle 24. It was found that the expected values from IRI the measured values in all hours, days and seasons, and concluded there is a strong correlation between the total electron Content (TEC) of Ionospheric layer E and Sunspot number for solar cycle 24.

In 2015, researcher Wafaa A. Zaki, et. al [10] presented a study of the highest position in the rising phase of solar cycle 24 had been studied by analyzing the photometric observations of coronal mass ejection (CME) for the year 2013 for the months 2,3,4,5 that were derived from Large Angle and Spectrometric Coronagraph Experiment (LASCO). It had been found that the event increased gradually with adopted months (2, 3, 4, 5). Also it has been noticed that most of solar events have multi eruption phenomena.

In 2010, researcher Omar Tareq Ali [11] studied the effects of long-term solar activity on the critical frequencies of the ionosphere layer F_1 over the city of Baghdad during the 22nd solar cycle (1988-1995). It was found that the critical frequency of this layer is closely related to the number of Sunspots during the 22 years of the solar cycle, in the mid-latitudes of the world. The study also discussed the effect of the number of sunspots and the sun on the electron density of the F_1 layer, which is the most important ionospheric parameter.

In 2007, researcher Ahmed Hassan Abdullah [12] conducted a study of the effect of the Sunspot rate on the monthly critical frequencies of the F_1 layer of the city of Baghdad and found that the ionosphere suffers from daily and seasonal changes and is affected by changes in solar activity and in turn affects the performance of the radio communication system (HF) that transmits Its signal through the layers of the ionosphere. The study showed that there is a direct relationship between the critical frequencies and the number of sunspots for the twenty-four hours for the month of March, June and September, and the relationship varies between one month and another, and between night and day, and the relationship is inverse for the month of December, it is inverse during the

day hours and direct during the night hours.

The main goal of this study is to know and analyze the behavior of the F_2 ionosphere layer which is very important at High-frequency (HF) radio communications, as well as to determine the nature of the relationship between the Sunspots number with the critical frequency of Ionospheric layer F_2 , over Kirkuk station during the Solar cycle 24 using the International Reference Ionosphere model IRI. The geographical location of this study station are shown in Figure 1.

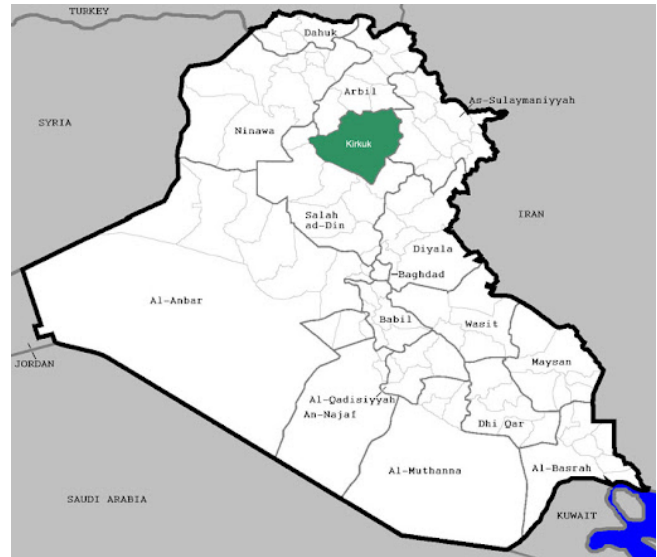


Figure 1. Kirkuk City in Iraq [13].

2. Theoretical approach:

The most important recent studies are describing about the high and middle latitude ionospheric variation with different solar indices like Coronal Mass Ejection (CME) and Sunspot Number (Ri). These all parameters depends on short and long term solar activities and they are shows the correlations with each other. The investigation of the characteristics of the F_2 -layer and the critical frequency (f_oF_2) of an ionospheric layer is the maximum frequency that can be radiated vertically upwards by a radio transmitter and be returned to earth. This condition corresponds to a wave that travels to the top of the layer is necessary to understand and describe the dynamic features and therefore to more accurately predict the behavior of the F layer more accurately, which is the main layer for High-Frequency (HF) long-distance communication and navigation [14][15].

In this investigation the ionospheric variabilities in F_2 region are better demonstrated using International Reference Ionosphere 2016 (IRI 2016) program was adopted to find the value of the critical frequency. This program (IRI 2016) is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). These organizations formed a Working

Group (members list) in the late sixties to produce an empirical standard model of the ionosphere, based on all available data sources (Charter). For given location, time and date, IRI provides monthly averages of the electron density, electron temperature, ion temperature, and ion composition in the ionospheric altitude range [16]. And provides the values of (f_oF_2) critical frequency at altitudes ranging from 50 to 2000 km at any date or time and anywhere [17],[18].

The IRI 2016 modeled values were estimated by employing the International Union of Radio Science (URSI) coefficients. In order to evaluate the performance of the model of critical frequency. The simulated monthly values were calculated for critical frequency (f_oF_2) for a seasonal basis (Spring, Summer, Autumn, Winter) and for the months (21 March, 21 June, 23 September, 21 December) for both day and night hours. In this study the individual behavior of the average monthly and daily value of the critical frequency and the entire number of Sunspots during the Solar cycle 24 were presented. As well as the output data were analyzed in order to find the type of correlation between the critical frequency (f_oF_2) and Sunspots number (Ri) in this study.

Regression method was used to investigate the dependence of Sunspots numbers (Ri) on the critical frequency (f_oF_2) of the ionospheric F_2 - layer over Kirkuk. Regression analysis makes it possible to find the line which best describes the association between two variables [19].

The global Sunspot count is calculated Through (Ri) (International Sunspot number) represents in the following relationship [20][21].

$$Ri = K(10G + I) \tag{1}$$

Where K represents a constant quantity approximately equal to one. The difference in observatories' monitoring devices, G is number a visible total Sunspots, and I is the number of individual spots. The number of these spots expresses the degree of Solar activity that changes Periodically every 11 years and this change is known as the Solar cycle, which basically takes 22 years to complete Changing the polarity of the Sunspot's magnetic field [22][23].

The behavior of the F_2 layer is completely different from that of other ionospheric layers. The critical frequency (f_oF_2) changes directly with the increase in solar activity, represented by the number of Sunspots (Ri), but there is no convincing relationship between these two variables [24]. With the increase in solar activity, the critical frequencies (f_oF_2) increase, as the relationship between them is almost linear the critical frequency at noon for a given latitude and month is subject to the following relationship [25].

$$(f_oF_2)^2 \alpha 1 + 0.02Ri \tag{2}$$

$$InSummer f_oF_2 = 5.55(1 + 0.02Ri)^{1/2} \tag{3}$$

$$InWinter f_oF_2 = 6.55(1 + 0.02Ri)^{1/2} \tag{4}$$

The height of the F_2 layer depends on the sunspot cycle as well, as the height is higher during the Sunspot cycle the maximum elevation during the minimum sunspot cycle. And over the course of the cycle, from the lower end to the great end the lower edge of the layer rises slightly during the night only. On the other hand, the height of the center increases the layer is continuous, and accordingly the layer becomes thicker during the great Sunspot Cycle [26].

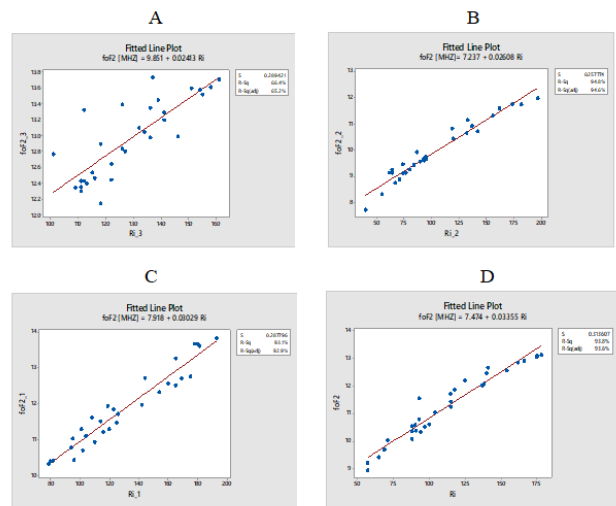


Figure 2. Relationship between Critical frequency f_oF_2 (MHz) And Sunspots number (Ri) at maximum height of the layer F_2 h= 400 km for the year 2014, represents A-March, B-June, C-September and D-December.

3. Application and Discussion:

3.1 - Temporal Analysis of Data

In the present study, the critical frequency (f_oF_2) values were obtained from the International Reference Ionosphere IRI 2016 model for Kirkuk city (35.449699 o N 44.381119 o E), for the days of spring equinox and autumn equinox and winter summer solstices days for the years (2012, 2013, 2014) with high Solar activity represented by the ascending phase, were compared with the total number of Sunspots that were obtained on it from the site Silso [27]. The value of the critical frequency (f_oF_2) was obtained by the international reference ionosphere model from option (Ne - Quick), at a maximum height of 400 km of the F_2 ionosphere layer for solar cycle 24. Figure3represents the solar cycle 24 and the deflection rates

of critical frequencies f_oF_2 for solstice days and equinoxes for years (2012, 2013, 2014) for solar cycle 24 as shown in Tables 1.

Table 1 The critical frequency (f_oF_2) value from IRI2016 at altitude 400 km (F_2 layer) for the years (2012, 2013, 2014) for days of solstice and equinox over Kirkuk station.

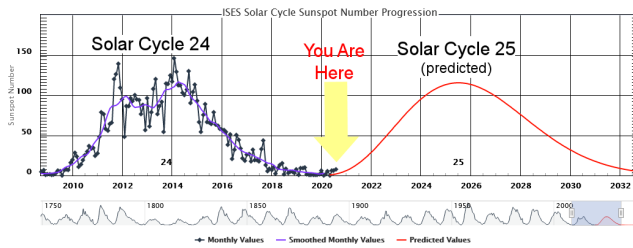


Figure 3. Solar cycle 24 [27].

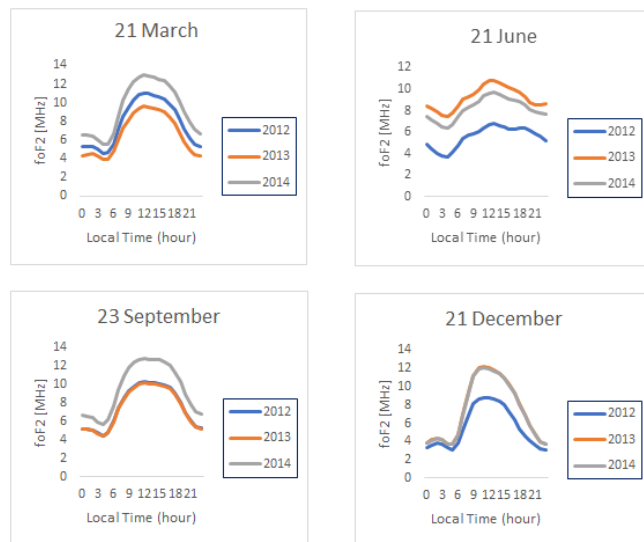


Figure 4. Daily changes on equinox and solstice days of f_oF_2 values obtained by International Reference Ionosphere models IRI2016 over Kirkuk city for ascending phase (2012, 2013, 2014) (solar activity periods).

Figure 4: represents the relationship between f_oF_2 values and local time for solstice and equinoxes days of months (March, June, September, December) at a height $h=400$ km (maximum height of layer F_2) over Kirkuk city. In the year of the ascending phase (2012, 2013, 2014) the f_oF_2 in March and September were the highest value at 07.00 Am to 12.00 Pm. In June and December the f_oF_2 were the highest value at 07.00 Am to 13.00 Pm. It was found that the critical frequencies of the F_2 layer increase in the times of sunrise and sunset and for all seasons when the solar activity increases. This is consistent with the researcher Haider Al-Sheikhly [28]. In this study, the empirical values of f_oF_2 for the Ionospheric layer F_2 were obtained from IRI2016 program option Ne Quick [29]. As well as the values of Sunspot number for solar cycle 24

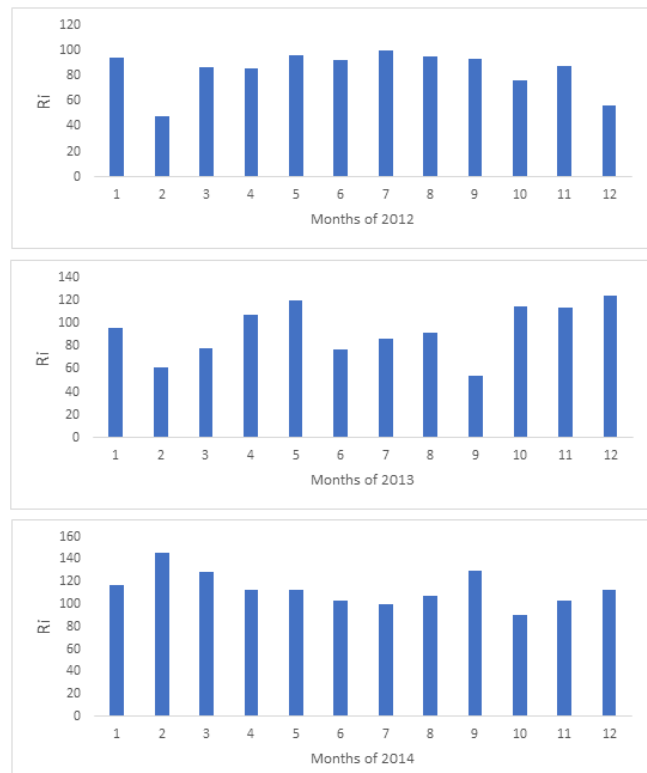


Figure 5. The monthly mean Sunspot numbers in 2012, 2013, 2014.

were applied in this program. Figure 5 represents the monthly Sunspot numbers (Ri) for years (2012, 2013, 2014).

3.2 Statistical investigation

Through data processing using the statistical program Minitab version 2018, the impact of Solar activity (Sunspots) on the critical frequency f_oF_2 at maximum height of layer F_2 was investigated in the four months (March, June, September and December) for the Years (2012, 2013, 2014) which is represents (ascending phase) of the Solar cycle 24 over Kirkuk city as shown in Figures 5, 6 and 7.

Figure 6 represents the relationship between f_oF_2 values and Ri at a Height, $h=400$ km (F_2 layer) for year 2012 over Kirkuk city at 12 Pm o'clock in A- March, B- June, C- September, D-December. According to the statistical output data is a good agreement between critical frequencies (f_oF_2) and Sunspot number (Ri), for all months where Pearson correlation are ($R=0.984$ in March, and $R=0.992$ in June, and $R=0.941$ in September, and $R=0.972$ in December). And linear regression equations respectively as follows,

A- in March $f_oF_2[\text{MHz}]=7.078 + 0.04929\text{Ri}$

B- in June $f_oF_2[\text{MHz}]=6.150 + 0.03669\text{Ri}$

C- in September $f_oF_2[\text{MHz}]=7.796 + 0.03045\text{Ri}$

D- in December $f_oF_2[\text{MHz}]=6.052 + 0.04650\text{Ri}$

The relationship between f_oF_2 and Ri for 2012 is similar

Table 1. Maximum lengths of tracks for different alpha energies, and their saturation times by means of (D-L) calibration curves

Year	2012				2013				2014			
	21 LT(hour)	21 Mar	21 Jun	23 Sep	21 Dec	21 Mar	21 Jun	23 Sep	21 Dec	21 Mar	21 Jun	23 Sep
0	5.255	4.842	5.224	3.286	4.323	8.463	5.146	3.825	6.529	7.487	6.689	3.805
1	5.335	4.419	5.25	3.632	4.487	8.201	5.177	4.18	6.494	7.167	6.631	4.161
2	5.325	4.055	5.127	3.878	4.547	7.883	5.059	4.411	6.392	6.83	6.41	4.394
3	5.009	3.79	4.754	3.723	4.286	7.609	4.69	4.23	6	6.503	5.96	4.214
4	4.57	3.748	4.476	3.279	3.891	7.447	4.411	3.767	5.499	6.381	5.667	3.75
5	4.633	4.105	4.877	3.131	3.943	7.756	4.806	3.7	5.576	6.718	6.187	3.68
6	5.604	4.793	6.073	3.818	4.786	8.444	5.987	4.762	6.724	7.416	7.678	4.73
7	7.142	5.429	7.511	5.276	6.095	9.038	7.405	6.957	8.578	8.031	9.509	6.905
8	8.556	5.727	8.623	6.902	7.287	9.323	8.5	9.433	10.3	8.327	10.957	9.359
9	9.557	5.831	9.356	8.098	8.162	9.561	9.224	11.236	11.472	8.529	11.874	11.147
10	10.293	6.055	9.898	8.676	8.867	9.99	9.764	12.069	12.245	8.905	12.46	11.976
11	10.838	6.43	10.241	8.813	9.418	10.483	10.107	12.238	12.776	9.371	12.774	12.145
12	11.069	6.72	10.304	8.767	9.656	10.777	10.171	12.11	12.994	9.671	12.809	12.019
13	10.987	6.772	10.218	8.669	9.578	10.799	10.083	11.844	12.905	9.706	12.738	11.758
14	10.806	6.642	10.173	8.469	9.4	10.625	10.035	11.48	12.716	9.549	12.74	11.397
15	10.649	6.456	10.152	8.025	9.247	10.36	10.014	10.996	12.553	9.311	12.73	10.913
16	10.414	6.32	10.011	7.278	9.012	10.133	9.877	10.3	12.319	9.11	12.53	10.213
17	9.956	6.307	9.661	6.344	8.545	9.982	9.532	9.328	11.876	8.999	12.095	9.24
18	9.226	6.376	9.042	5.424	7.803	9.754	8.917	8.159	11.165	8.853	11.4	8.077
19	8.252	6.366	8.11	4.652	6.845	9.303	7.992	6.948	10.172	8.523	10.348	6.876
20	7.169	6.179	7.006	4.046	5.832	8.801	6.899	5.791	8.99	8.107	9.026	5.735
21	6.219	5.887	6.058	3.583	4.995	8.559	5.964	4.767	7.888	7.855	7.824	4.726
22	5.597	5.585	5.489	3.262	4.483	8.596	5.404	4.02	7.115	7.801	7.081	3.992
23	5.306	5.25	5.257	3.14	4.285	8.615	5.176	3.704	6.698	7.724	6.774	3.682

to (2013, 2014) at 400 km elevation due to the decrease in Solar activity for these years.

Figure 7 represents the relationship between f_oF_2 values and Ri at a Height, $h=400$ km (F_2 layer) for year 2013 over Kirkuk city at 12 Pm o'clock in A- March, B- June, C- September, D-December. According to the statistical output data is a good agreement between critical frequencies (f_oF_2) and Sunspot number (Ri), for all months where Pearson correlation are (R=0.997 in March, and R=0.966 in June, and R=0.967 in September, and R=0.955 in December). And linear regression equations respectively as follows,

A- in March f_oF_2 [MHz]=7.477 + 0.04418Ri

B- in June f_oF_2 [MHz]=6.628 + 0.03151Ri

C- in September f_oF_2 [MHz]=6.450 + 0.04869Ri

D- in December f_oF_2 [MHz]=7.653 + 0.03232Ri

Figure 2 represents the relationship between f_oF_2 values and Ri at a Height, $h=400$ km (F_2 layer) for year 2014 over Kirkuk city at 12 Pm o'clock in A- March, B- June, C- September, D-December. According to the statistical output

data is a good agreement between critical frequencies (f_oF_2) and Sunspot number (Ri), for all months where Pearson correlation are (R=0.815 in March, and R=0.974 in June, and R=0.965 in September, and R=0.969 in December). And linear regression equations respectively as follows,

A- in March f_oF_2 [MHz]=9.851 + 0.02413Ri

B- in June f_oF_2 [MHz]=7.237 + 0.0608Ri

C- in September f_oF_2 [MHz]=7.918 + 0.03029Ri

D- in December f_oF_2 [MHz]=7.474 + 0.03355Ri

The most important results that we reached were consistent with local and international results:

1-The values of f_oF_2 begin to increase from 7 am LT and reach the maximum value at 12 pm LT and peak appears at noon at 12 pm LT, this is consistent with the researcher H.A. Jawed [30].

2- In Winter f_oF_2 values increase as well as impressions hours in comparison to other seasons, this is consistent with the researcher Fahmy Abdel-Rahman [31].

3-The relationship between Sunspots and the critical fre-

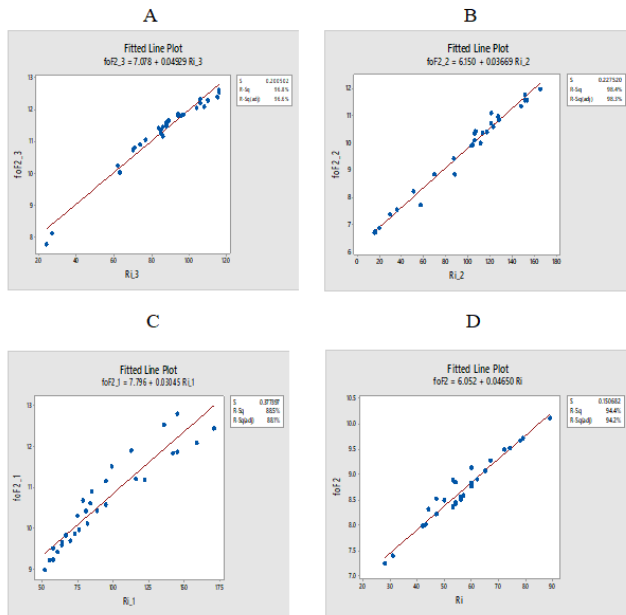


Figure 6. Relationship between Critical frequency f_oF_2 (MHz) And Sunspots number (Ri) at maximum height of the layer F_2 h= 400 km for the year 2012, represents A-March, B-June, C-September and D-December.

quency is linear positive relation and strong, this is consistent with the researcher S. Patric McIntosh and Murry Dryer [32]. 4- The values of critical frequencies f_oF_2 are higher in the morning than at night, this is consistent with the researcher Yonezawa [33].

4. Conclusions:

1. International Reference Ionosphere (IRI) extended to ionosphere is an important contribution in modeling ionosphere and its parameters such as critical frequency, electron density and peak ionization heights.
2. Differences over Kirkuk city reach their peak at noon so that the values of critical frequencies f_oF_2 are higher in the morning than at night because the low density of air makes the process of combining solid gas particles and atoms with free electrons again quite slow and difficult.
3. The values of the critical frequencies vary according to the seasonal change.
4. The values of critical frequency (f_oF_2) increase with increasing of Solar activity which represented by the Sunspots number (Ri).
5. The maximum value of f_oF_2 for the years (2012, 2014) for F_2 - layer in March was greater than September, and December was greater than June. And the maximum value of f_oF_2 for years (2013) of F_2 - layer was in September was greater than March and December was greater than June.

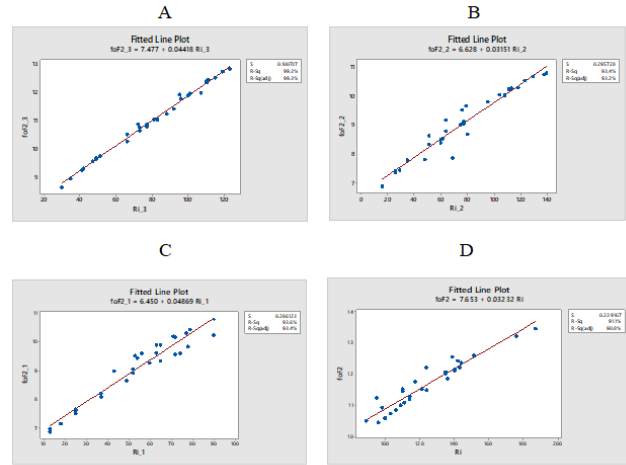


Figure 7. Relationship between Critical frequency f_oF_2 (MHz) And Sunspots number (Ri) at maximum height of the layer F_2 h= 400 km for the year 2013, represents A-March, B-June, C-September and D-December.

6. Critical frequency (f_oF_2) in Winter are more clear than other seasons.
7. The values of f_oF_2 begin to increase from 7 Am Local Time and reach the maximum value at 12 Pm Local time.
8. The relationship between the critical frequencies (f_oF_2) and Sunspots number (Ri) is linear positive relation and strong for all months of years (2012, 2013, 2014) this means strong correlation between the critical frequency (f_oF_2) of ionospheric layer- F_2 and Sunspots number (Ri) in most months, especially in the years of high Solar activity (ascending phase) for Solar cycle 24.

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Declarations:

Conflict of interest The authors declare that they have no conflict of interest

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تأثير عدد البقع الشمسية على الترددات الحرجة (f_oF_2) لطبقة F_2 الأيونوسفيرية فوق مدينة كركوك خلال مرحلة الطور الصاعد للدورة الشمسية 24

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الخلاصة

تعد دراسة خصائص الطبقة F_2 والتردد الحرج (f_oF_2) ضرورية لفهم المميزات الديناميكية وبالتالي التنبؤ بشكل أكثر دقة بسلوك الطبقة F ، ويهدف هذا البحث إلى إيجاد العلاقة والترابط بين التردد الحرج (f_oF_2) لطبقة 24 الأيونوسفيرية وعدد البقع الشمسية (Ri) . في هذه الدراسة تمت دراسة خصائص وسلوك طبقة f_oF_2 خلال الدورة الشمسية 24 ، وتم دراسة تأثير عدد البقع الشمسية (Ri) على التردد الحرج (f_oF_2) ، للأعوام (2012 ، 2013 ، 2014) والتي تمثل مرحلة الطور الصاعد وسنة 2014 تمثل (القمة) من الدورة الشمسية 24 فوق مدينة كركوك التي تقع عرض 35 شمالاً وخط طول 44 درجة شرقاً من خلال إيجاد قيم التردد الحرج (f_oF_2) ، تم تحديد أوقات الظهور للطبقة لأيام الانقلاب وكذلك الاعتدال ، حيث تم الفحص والتحقق من النشاط الشمسي لأيام الانقلابين الصيفي والشتوي وأيام الاعتدالين الربيعي والخريفي لمدة 24 ساعة من خلال تطبيق نموذج الدولي المرجعي للأينوسفير (IRI 2016) . تم التحقق من بيانات الإخراج لـ f_oF_2 باستخدام الخيار $IRI-Ne-Quick$ عن طريق تحديد الوقت والتاريخ ومعلومات البقع الشمسية (Ri) . تم إجراء التحليل الإحصائي من خلال تطبيق برنامج $Minitab$ (الإصدار 2018) من أجل إيجاد العلاقة بين التردد الحرج (f_oF_2) لطبقة 24 الأيونوسفيرية وعدد البقع الشمسية (Ri) . أُسْتُنتُ أن الارتباط بين التردد الحرج (f_oF_2) وعدد البقع الشمسية (Ri) قوي وإيجابي (طردي) ، وهذا يشير إلى أن التردد الحرج (f_oF_2) يزداد مع زيادة عدد البقع الشمسية (Ri) للدورة الشمسية 24 .

الكلمات الدالة: طبقة الأيونوسفير F ؛ التردد الحرج (f_oF_2) ؛ نموذج $IRI2016$ ؛ الدورة الشمسية 24 ؛ عدد البقع الشمسية