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Studying the Relationship between the Maximum Electron Density with the Critical Frequency in the Ionospheric E-layer over Kirkuk City During the Solar Cycle 24

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Abstract

This research aims to study the relationship between the values of maximum electron density (NmE) with the critical frequency (foE) of ionospheric E layer over Kirkuk city (lon: 44° E, lat: 35° N) which was obtained through the use of the International Reference Ionosphere (IRI2016) during the years (2008, 2014, 2018), which represents each (ascending phase, peak, desending phase) for the solar cycle 24, and in dates (22 December, 20 March, 20 June and 22 September) which represent the days of (Winter solstice, Spring equinox, Summer solstice, Autumn equinox) respectively. The results indicated that there is a strong linear correlation between the values of maximum electron density with critical frequency where the values of correlation coefficients ranged between (0.984) – (0.998), and this indicates that with the increase in maximum electron density the critical frequency increase, and vice versa.

1. Introduction:

The atmosphere is defined as a gaseous envelope surrounding the Earth consisting of a mixture of gases that are divided into two main parts, namely the basic or active gases, which enter into the vital reactions near the surface of the earth, and these gases are nitrogen gas (N_2 and its percentage) (78%) and oxygen gas O_2) and its percentage (21%) and carbon dioxide and a group of other gases, but in small proportions, and the other section is inert or rare gases [1].

The atmosphere is divided into several layers, and these layers are divided according to the elevation from the ground level and according to the temperature declination. A protective shield for the earth and a roof that protects it from harmful solar rays and from the large cosmic meteors that burn in the upper atmosphere to reach the surface of the earth in the form of small meteors [2]. The ionosphere refers to that upper part of the atmosphere surrounding the Earth, which extends from a height of 60-1000 km above the surface of the Earth, which extends from the middle of the mesosphere and contains ions and free electrons that have certain electrical properties that can cause radio waves to be bent or even completely reflected. This feature enables long-range wireless communications [3]. The ionosphere is not only controlled by the radiation of the Sun but also due to the coupling with the neutral atmosphere and other local phenomena. All these influences whether solar or local disturb the ionosphere and make it irregular. This results in the spatial and temporal variability of the ionosphere. It is now established that the state of ionosphere changes from hour to hour, day to day, season to season, year to year and even from place to place. A number of studies conducted in the past have revealed some important similarities and differences between the high, mid and low latitude ionosphere [4],[5],[6]. Were it not for the existence of the ionosphere, radio waves would have penetrated into outer space forever. The ionosphere consists of several distinct layers during the day, which are (D, E, E_s, F_1, F_2) according to its maximum electron density [7]. As for the name of the ionosphere, that was done by (R.A Watson-watt) in the year 1926, and the name of the layers came by (Appleton) in the year 1929 [8].

As for the E layer, which is the middle layer of the ionosphere and is located at a height of (90-120) km above the surface of the earth. The most of the ionization in this layer is by means of (Soft X-rays) rays of low frequency and with a wavelength that extends from (1-10) nano meters as well as extreme ultraviolet (EUV) rays, which ionize (O_2) molecules. This layer reflects radio waves with a frequency less than (10) MHz and partially absorbs radio waves with frequency greater than (10) MHz There is an hourly change in the maximum electron density, especially at higher latitudes, the maximum electron density in the (E) layer reaches ($10^5 cm^{-3}$). The solar activity, the distance of the sun from the earth, and the zenith angle (χ) affect the values of the maximum electron density of the layer [9]. Because of this change in the value of the maximum electron density changes the frequency of electromagnetic waves that can be reflected by the (E) layer [10].

Solar activity increases or decreases during a period that takes an average of 11 years, so it repeats periodically. The duration may be short, lasting 9 years, or long, lasting 14 years. The changes in solar activity include the number of sunspots and levels of solar radiation as well as solar glare, as well as other changes that each cycle has a limit [11]. A maximum for sunspots is usually occurs in the middle of the cycle when the number of sunspots increases and a minimum is at the beginning and end of the cycle in which the number of sunspots decreases [12],[13]. The critical frequency and maximum electron density are among the main important parameters in the ionosphere, and it is the most important and most widely used ionospheric property, the critical frequency of a particular layer in the ionosphere is defined as the highest frequency at which the signal or electromagnetic wave that travels vertically upward to the Earth is reflected [14]. The relationship between frequency and maximum electron density there is relationship can be illustrated in the following equation:

$$Ne = 1.24 \times 10^4 fo^2 \quad (1)$$

Where: fo^2 = critical frequency (MHz).

The ionospheric electron density vary with different conditions, like altitude, longitude, latitude, solar cycle and local time. For this variation a very vital role to understanding the lower as well as the upper atmosphere. The increase in maximum electron density can give rise to great disorders in radio-wave propagation conditions (reflection, absorption, and scatter) [15].

Khalid et.al, in 2019 investigated the effect of solar activity on the critical frequency parameters of the layers (foE, foF1, foF2) over the ionosphere region in Iraq, and for altitudes from 100-1000 km. Showed the result that the critical frequency coefficient increases in general during noon time due to solar radiation [16]. Wafaa et.al, in 2020 the effect of sunspots number (Ri) on the Total electronic content (TEC) were studied for the years (2008, 2014, 2018) which represents the rising phase, the peak and the down phase of the solar cycle 24 over Kirkuk station in Iraq at latitude 35° North and longitude 44° East, by finding the TEC values for the E – layer, the layer's impression times are determined for the days of solstice and equinox. Showed the result There is a strong correlation between the Total Electron Content (TEC) of Ionospheric layer E and Sunspot number for solar cycle 24 [17]. Elaf et.al, in 2021 find the relationship (correlation) and interdependence between the critical frequency (foF2) of Ionospheric layer F2 and Sunspot number. In this study the characteristics and behavior of oF2 layer during Solar cycle 24 were studied, the effect of Sunspots number (Ri) on the critical frequency (foF2),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 It was concluded that the correlation is strong and positive, this indicate that critical frequency (foF2) increase with increasing Sunspots number (Ri) for solar cycle 24 [18]. Also, Asma'a et.al ,in 2021 examined the annual behavior of the critical frequency and electron density for the years that represent the maximum and minimum in the sun cycles (22, 23 and 24), respectively. This study showed that During the maximum solar cycles (Ne) parameter values change with altitude as the electron density increases with altitude and its maximum value reaches 400 km during the maximum solar cycles and 300 km during the minimum solar cycles, while the critical frequency indicates differences in values over different years and locations [19].

In this research, the nature of the relationship between the maximum electron density values (NmE) with the critical frequency in the ionospheric E (foE) layer over the city of Kirkuk will be explained by describing the hourly changes and calculating the correlation coefficient between the two variables to show the extent of their relationship to each other.

2. Study area and data used:

In this research, the relationship between the maximum electron density values (NmE) with the critical frequency of the ionospheric E (foE) layer over the city of Kirkuk (longitude 44° E, latitude 35° N) was studied, as shown in Fig.1. The data used in the research included both the maximum electron density values (NmE) as well as the critical frequency of the ionospheric E (foE) layer during the years (2008, 2014, 2018), which represent the (rising phase, peak, down phase) of the solar cycle 24, as shown in Table 1, [20] On the dates (December 22, March 20, June 20, September 22) that represent the days (winter solstice, vernal equinox, summer solstice, autumnal equinox) respectively and shown in Tables 2, 3 4 which were obtained through Using the Global Reference Ionosphere Model (IRI2016) published in the website [21]. The International Reference Ionosphere (IRI) is an international project sponsored by the International Union of Radio Science (URSI) and the Committee on Space Research (COSPAR). For given location, time and date, IRI provides monthly averages of electron temperature,

Table 1. The monthly-observed data for Sunspot number (SN) during different phases of solar cycles (24)[21].

YEARS	SOLAR CYCLE PHASE	SUNSPOT NUMBER (SN)
2008	Rising phase	4.15
2014	peak	113.6
2018	Down phase	7

Table 2. Maximum electron density values (NmE, m^{-3}) and critical frequency of the ionospheric E (MHz foE) layer over the city of Kirkuk during the year (2008) of the 24 solar cycle, and on the dates (December 22, March 20, June 20, September 22), Sunspot number = 4.15[21]

HOUR LOCAL TIME	Critical Frequency (MHz, foE) E (2008)				Maximum electron density NmE, m^{-3} (2008)			
	22 Dec.	20 Mar.	20 Jun.	22 Sep.	22 Dec	20 Mar.	20 Jun.	22 Sep.
06:00	0.441	1.159	2.132	1.369	0.24129E+10	0.16651E+11	0.56342E+11	0.23250E+11
07:00	1.126	2.077	2.572	2.189	0.15722E+11	0.53491E+11	0.82022E+11	0.59433E+11
08:00	1.986	2.564	2.867	2.624	0.48910E+11	0.81522E+11	0.10191E+12	0.85368E+11
09:00	2.447	2.861	3.074	2.893	0.74229E+11	0.10148E+12	0.11714E+12	0.10381E+12
10:00	2.701	3.050	3.213	3.063	0.90471E+11	0.11538E+12	0.12802E+12	0.11634E+12
11:00	2.836	3.160	3.295	3.156	0.99734E+11	0.12384E+12	0.13461E+12	0.12348E+12
12:00	2.878	3.201	3.323	3.180	0.10274E+12	0.12706E+12	0.13689E+12	0.12537E+12
13:00	2.835	3.176	3.298	3.137	0.99650E+11	0.12509E+12	0.13485E+12	0.12206E+12
14:00	2.699	3.084	3.219	3.025	0.90298E+11	0.11790E+12	0.12850E+12	0.11348E+12
15:00	2.442	2.915	3.083	2.831	0.73951E+11	0.10535E+12	0.11785E+12	0.99400E+11
16:00	1.977	2.648	2.880	2.526	0.48483E+11	0.86959E+11	0.10286E+12	0.79146E+11
17:00	1.113	2.222	2.591	2.018	0.15349E+11	0.61237E+11	0.83248E+11	0.50506E+11
18:00	0.437	1.426	2.162	1.069	0.23641E+10	0.25198E+11	0.57944E+11	0.14167E+11

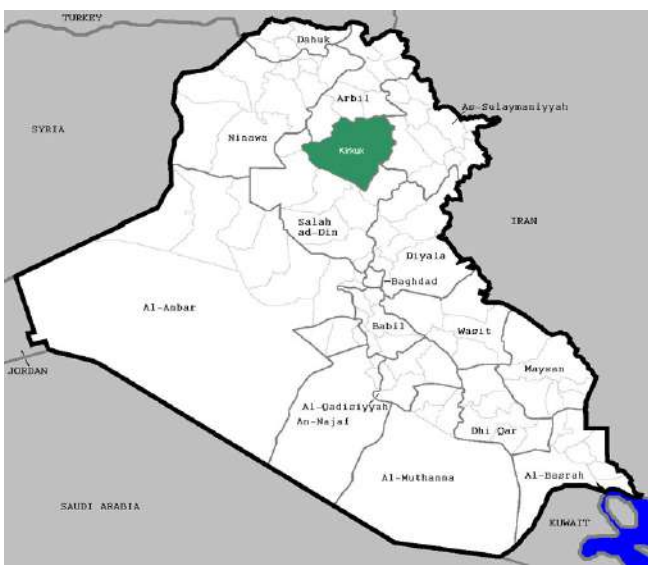


Figure 1. The map of Iraq (the city of Kirkuk) [22].

maximum electron density, ion composition and ion temperature ... etc in the ionospheric altitude range [23]. The maximum electron density and critical frequency data are obtained after entering the date in the mathematical model, as well as entering the longitude and latitude to be studied, as well as entering the daily sunspot values obtained from the global site for monitoring sunspots.

3. Results and discussion:

In this research, the relationship between the values of the maximum electron density NmE with the critical frequency foE in the ionospheric E layer has been studied by clarifying the hourly changes, and calculating the values of the correlation coefficients between the two variables to show the extent of the relationship between each of them, by making use of the data shown in Tables 2, 3 4 which included the values of maximum electron density and critical frequency in the E ionospheric layer, and the results were as follows:

3.1 Hourly changes of maximum electron density values (NmE, m^{-3} and critical frequency (foE,MHz) over the city of Kirkuk during the years (2008, 2014, 2018) of the 24 solar cycle:

3.1.1 During the ascending phase of the solar cycle 24 - (Year 2008):

Fig. 2 a, b, c, d shows the hourly changes of the maximum electron density values and critical frequency over the city of Kirkuk during the year 2008, where the following was

Table 3. The values of the maximum electron density (NmE, m^{-3}) and the critical frequency of the ionospheric E (MHz foE) layer over the city of Kirkuk during the year (2014) of the 24 solar cycle, and on the dates (December 22, March 20, June 20, September 22) Sunspot number = 113.6 [20].

HOUR LOCAL TIME	Critical Frequency (MHz, foE) E (2014)				Maximum electron density NmE, m^{-3} (2014)			
	22 Dec.	20 Mar.	20 Jun.	22 Sep.	22 Dec	20 Mar.	20 Jun.	22 Sep.
06:00	0.502	1.285	2.435	1.568	0.31210E+10	0.20469E+11	0.73540E+11	0.30468E+11
07:00	1.282	2.337	2.937	2.490	0.20365E+11	0.67718E+11	0.10696E+12	0.76903E+11
08:00	2.251	2.896	3.273	2.980	0.62829E+11	0.10400E+12	0.13284E+12	0.11015E+12
09:00	2.769	3.235	3.509	3.285	0.95097E+11	0.12978E+12	0.15266E+12	0.13382E+12
10:00	3.056	3.452	3.668	3.477	0.11579E+12	0.14773E+12	0.16681E+12	0.14993E+12
11:00	3.207	3.577	3.761	3.582	0.12756E+12	0.15865E+12	0.17537E+12	0.15912E+12
12:00	3.254	3.624	3.792	3.610	0.13134E+12	0.16283E+12	0.17832E+12	0.16159E+12
13:00	3.204	3.596	3.764	3.563	0.12733E+12	0.16033E+12	0.17564E+12	0.15738E+12
14:00	3.049	3.491	3.674	3.436	0.11530E+12	0.15110E+12	0.16735E+12	0.14641E+12
15:00	2.758	3.299	3.518	3.218	0.94310E+11	0.13497E+12	0.15346E+12	0.12841E+12
16:00	2.229	2.996	3.286	2.875	0.61624E+11	0.11130E+12	0.13392E+12	0.10252E+12
17:00	1.248	2.510	2.956	2.307	0.19315E+11	0.78145E+11	0.10835E+12	0.65983E+11
18:00	0.491	1.600	2.465	1.241	0.29834E+10	0.31730E+11	0.75358E+11	0.19089E+11

Table 4. Maximum electron density values (NmE, m^{-3}) and critical frequency of the ionospheric E (MHz foE) layer over the city of Kirkuk during the year (2008) of the 24 solar cycle, and on the dates (December 22, March 20, June 20 , September 22) , Sunspot number = 4.15[20].

HOUR LOCAL TIME	Critical Frequency (MHz, foE) E (2018)				Maximum electron density NmE, m^{-3} (2018)			
	22 Dec.	20 Mar.	20 Jun.	22 Sep.	22 Dec	20 Mar.	20 Jun.	22 Sep.
06:00	0.445	1.138	2.139	1.388	0.24587E+10	0.16060E+11	0.56711E+11	0.23875E+11
07:00	1.137	2.070	2.579	2.205	0.16044E+11	0.53132E+11	0.82481E+11	0.60263E+11
08:00	1.998	2.565	2.874	2.638	0.49496E+11	0.81596E+11	0.10244E+12	0.86315E+11
09:00	2.458	2.866	3.081	2.908	0.74916E+11	0.10183E+12	0.11772E+12	0.10486E+12
10:00	2.712	3.057	3.221	3.078	0.91216E+11	0.11591E+12	0.12864E+12	0.11749E+12
11:00	2.847	3.168	3.303	3.171	0.10049E+12	0.12448E+12	0.13524E+12	0.12469E+12
12:00	2.889	3.210	3.330	3.196	0.10347E+12	0.12776E+12	0.13751E+12	0.12663E+12
13:00	2.844	3.185	3.305	3.154	0.10031E+12	0.12579E+12	0.13545E+12	0.12333E+12
14:00	2.706	3.092	3.226	3.042	0.90831E+11	0.11856E+12	0.12906E+12	0.11473E+12
15:00	2.448	2.922	3.089	2.849	0.74297E+11	0.10590E+12	0.11835E+12	0.10063E+12
16:00	1.979	2.654	2.886	2.545	0.48546E+11	0.87327E+11	0.10327E+12	0.80339E+11
17:00	1.108	2.224	2.596	2.042	0.15216E+11	0.61313E+11	0.83554E+11	0.51706E+11
18:00	0.435	1.417	2.165	1.098	0.23503E+10	0.24896E+11	0.58113E+11	0.14958E+11

observed:- The highest value of the critical frequency of the ascending phase of the solar cycle 24 was recorded at (12:00) and during the days (winter solstice, vernal equinox, summer solstice, autumnal equinox). This is due to the high value of the maximum electron density, and the lowest value for the critical frequency of the phase the ascending of the solar cycle 24 was recorded at (18:00) during the two days (autumn equinox, winter solstice), and at (06:00) during my two days (spring equinox, summer solstice) due to the decrease in the maximum electron density value, during the two days (autumn equinox, winter solstice), and reached during the two days (vernal equinox, summer solstice) and respectively, as shown in Fig. 2 and Table 2, and this result is consistent with the result of the study (Asma'a et.al, 2021).

3.1.2 During the peak of the Solar Cycle 24 - (Year 2014):

Fig. 3 a, b, c, d shows the hourly changes of the maximum electron density values and critical frequency over the city of Kirkuk during the year 2014, where the following was observed: - The highest value of the critical frequency during the peak of the solar cycle 24 was recorded at (12:00) and during the days (winter solstice, vernal equinox, summer solstice, autumn equinox) is due to the high value of the maximum electron density, respectively, and the lowest value of the critical frequency during The peak of the solar cycle 24 was recorded at (18:00) during the two days (autumn equinox, winter solstice), and at (06:00) during the two days (vernal equinox, summer solstice). This is due to the decrease in the maximum electron density value, during the two days (autumn equinox, winter solstice), and during the two days (vernal equinox, summer solstice) and respectively, as shown in Table 3 and Fig. 3 and this result is consistent with the result of the study (Asma'a et.al, 2021).

3.1.3 During the descending phase of the 24 solar cycle - (Year 2018):

Fig. 4 a, b, c, d shows the hourly changes of the maximum electron density values and critical frequency over the city

Table 5. The values of correlation coefficients and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2008) - the rising phase of the solar cycle 24

DATE	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
22-Dec.2008	0.984	NmE=(-2.47E+10)+(4.19E+10foE)
20 Mar.2008	0.992	NmE=(-5.61E+10)+(5.57E+10foE)
20 Jun.2008	0.998	NmE=(-9.12E+10)+(6.81E+10foE)
22 Sep.2008	0.991	NmE=(-5.29E+10)+(5.45E+10foE)

Table 6. The values of the correlation coefficients and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2014) - the peak of the solar cycle 24

DATE	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
22-Dec.2014	0.984	NmE=(-3.16E+10)+(4.74E+10foE)
20 Mar.2014	0.992	NmE=(-7.09E+10)+(6.28E+10foE)
20 Jun.2014	0.998	NmE=(-1.19E+10)+(7.77E+10foE)
22 Sep.2014	0.991	NmE=(-6.91E+10)+(6.22E+10foE)

Table 7. The values of the correlation coefficients and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2018) - the descending phase of the solar cycle 24.

DATE	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
22-Dec.2018	0.984	NmE=(-2.49E+10)+(4.20E+10foE)
20 Mar.2018	0.992	NmE=(-5.57E+10)+(5.57E+10foE)
20 Jun.2018	0.998	NmE=(-9.16E+10)+(6.83E+10foE)
22 Sep.2018	0.991	NmE=(-5.41E+10)+(5.50E+10foE)

of Kirkuk during the year 2018, where the following was observed:- The highest value of the critical frequency of the descending phase of the solar cycle 24 was recorded at (12:00) and during the days (winter solstice, vernal equinox, summer solstice, autumnal equinox). This is due to the high value of the maximum electron density, and the lowest value for the critical frequency of the phase The descending of the solar cycle 24 was recorded at (18:00) during the two days (autumn equinox, winter solstice) at (06:00) during the two days (spring equinox, summer solstice) due to the decrease in the value of the maximum electron density, during the two days (autumn equinox, winter solstice), during the two days (vernal equinox, summer solstice) and respectively, as shown in in Table 4 and Fig. 4 and this result is consistent with the result of the study (Asma'a et.al,2021).

Table 8. The values of the correlation coefficients and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2008) - the peak of the solar cycle 24.

DATE	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
Dec.2008	-0.172	NmE=(1.26E+11)-(1.41E+08SN)
Mar.2008	0.694	NmE=(1.25E+11)+(82320465SN)
Jun.2008	0.160	NmE=(1.37E+11)+(2666247SN)
Sep.2008	-0.288	NmE=(1.27E+11)-(2.17E+08SN)

Table 9. The values of the correlation coefficients and simple linear regression equations between the values of critical frequency with Sunspots Number over the city of Kirkuk during the year (2008) - the ascending phase of the solar cycle 24.

DATE	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
Dec.2008	-0.170	foE=(3.187)-(0.001767SN)
Mar.2008	0.692	foE=(3.169)-(0.001039SN)
Jun.2008	0.160	foE=(3.323)-(0.000040SN)
Sep.2008	-0.290	foE=(3.203)-(0.002753SN)

Table 10. The values of the correlation coefficients and simple linear regression equations between the values of maximum electron density with Sunspots Number over the city of Kirkuk during the year (2014) - the peak of the solar cycle 24.

DATE	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
Dec.2014	-0.453	NmE=(1.33E+11)-(8488531SN)
Mar.2014	-0.407	NmE=(1.73E+11)-(95258717SN)
Jun.2014	-0.379	NmE=(1.78E+11)-(2235486SN)
Sep.2014	-0.271	NmE=(1.67E+11)-(24705109SN)

3.2 Correlation between the maximum electron density values (NmE, m-3) and critical frequency (foE, MHz) over the city of Kirkuk during the years (2008, 2014, 2018) of the 24 solar cycle:

For the purpose of clarifying the nature of the relationship between the maximum electron density values with the critical frequency over the city of Kirkuk during the years (2008, 2014,

Table 11. The values of the correlation coefficients and simple linear regression equations between the values of critical frequency with Sunspots Number over the city of Kirkuk during the year (2014) - the peak of the solar cycle 24.

DATER	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
Dec.2014	-0.449	foE=(3.272)-(0.000104SN)
Mar.2014	-0.407	foE=(3.739)-(0.001067SN)
Jun.2014	-0.373	foE=(3.793)-(0.000024SN)
Sep.2014	-0.271	foE=(3.671)-(0.000275SN)

Table 12. The values of the correlation coefficients and simple linear regression equations between the values of maximum electron density with Sunspots Number over the city of Kirkuk during the year (2018) - the descending phase of the solar cycle 24.

DATE	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
Dec.2018	0.269	NmE=(1.04E+11)+(24283619SN)
Mar.2018	0.043	NmE=(1.27E+11)+(19927143SN)
Jun.2018	0.312	NmE=(1.37E+11)+(1695770SN)
Sep.2018	0.110	NmE=(1.28E+11)+(39116055SN)

Table 13. The values of the correlation coefficients and simple linear regression equations between the values of critical frequency with Sunspots Number over the city of Kirkuk during the year (2018) - the descending phase of the solar cycle 24.

DATE	CORRELATION COEFFICIENT	LINEAR REGRESSION EQUATIONS
Dec.2018	0.254	foE=(2.895)-(0.000320SN)
Mar.2018	0.040	foE=(3.195)-(0.000233SN)
Jun.2018	0.206	foE=(3.328)-(0.000013SN)
Sep.2018	0.130	foE=(3.213)-(0.000504SN)

2018) of the 24 solar cycle, and on the dates (December 22, March 20, June 20, September 22), which represent the days (winter solstice, the vernal equinox, the summer solstice, the autumnal equinox) respectively, the values of the correlation coefficients and the nature of the correlation were calculated and clarified, and the linear regression equations were found by using the Correlation Coefficient available in (Minitab17) and the obtained results were as follows:-

3.2.1 For the ascending phase of the 24 solar cycles:(Year 2008)

Table 5 and Fig. 5 a, b, c, d show the values of the correlation coefficient and nature and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2008), where It is noted that there is a strong direct correlation between the two variables.

3.2.2 For the peak of the solar cycle 24: (Year 2014)

Table 6 and Fig. 6 a, b, c, d show the values of the correlation coefficient and nature and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2014), where it is noted that there are There is a strong direct correlation between the two variables.

3.2.3 for the descending phase of the 24-year solar cycle :(Year 2018)

Table 7 and Fig. 7 a, b, c, d show the values of the correlation coefficient and nature and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2018), where It is noted that there is a strong direct correlation between the two variables.

3.3 Correlation between the maximum electron density values (NmE, m^{-3}) and critical frequency (foE, MHz) with Sunspots Number (SN) over the city of Kirkuk during the years (2008, 2014, 2018) of the 24 solar cycle:

For the purpose of clarifying the nature of the relationship between the maximum electron density values and the critical frequency with Sunspots Number over the city of Kirkuk during the years (2008, 2014, 2018) of the 24 solar cycle, and on the month (December, March, June, September), the values of the correlation coefficients and the nature of the correlation were calculated and clarified, and the linear regression equations were found by using the Correlation Coefficient available in (Minitab17) and the obtained results were as follows: -

3.3.1 For the ascending phase of the 24 solar cycle:(Year 2008)

Fig. 8 a (i, ii, iii, iv), Table 8 and Fig. 8 b (i, ii, iii, iv), Table 9 show the values of the correlation coefficient and nature and simple linear regression equations between the values of maximum electron density and critical frequency with sunspots number respectively over the city of Kirkuk during the year (2008).

3.3.2 For the peak of the 24 solar cycle:(Year 2014)

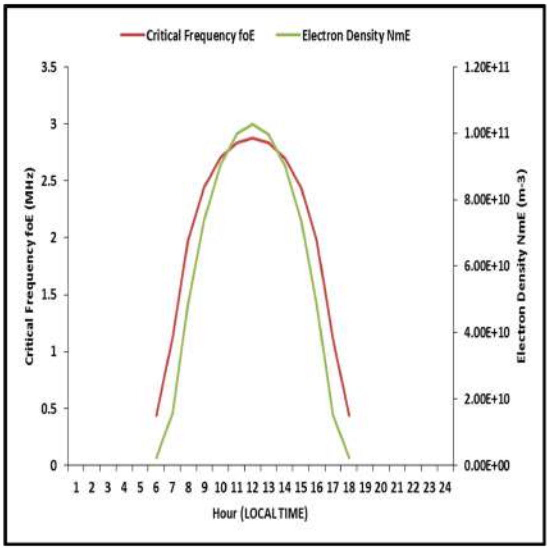
Fig. 9 a (i, ii, iii, iv), Table 10 and Fig. 9 b (i, ii, iii, iv) Table 11 show the values of the correlation coefficient and nature and simple linear regression equations between the values of maximum electron density and critical frequency with sunspots number respectively over the city of Kirkuk during the year (2014).

3.3.3 For the peak of the 24 solar cycle:(Year 2014)

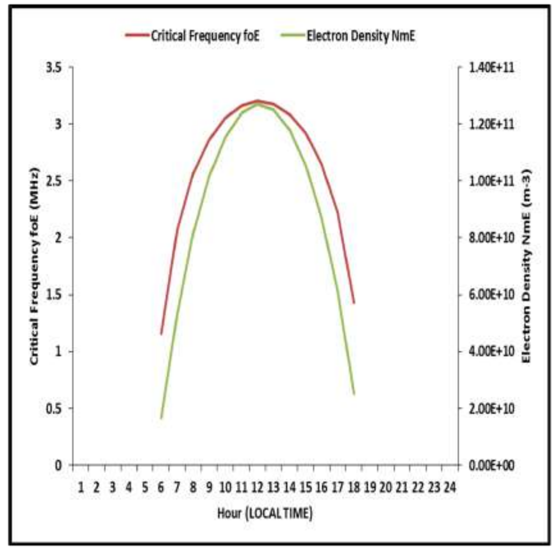
Fig. 9 a (i, ii, iii, iv), Table 10 and Fig. 9 b (i, ii, iii, iv) Table 11 show the values of the correlation coefficient and nature and simple linear regression equations between the values of maximum electron density and critical frequency with sunspots number respectively over the city of Kirkuk during the year (2014).

3.3.4 For the descending phase of the 24 solar cycle:(Year 2018)

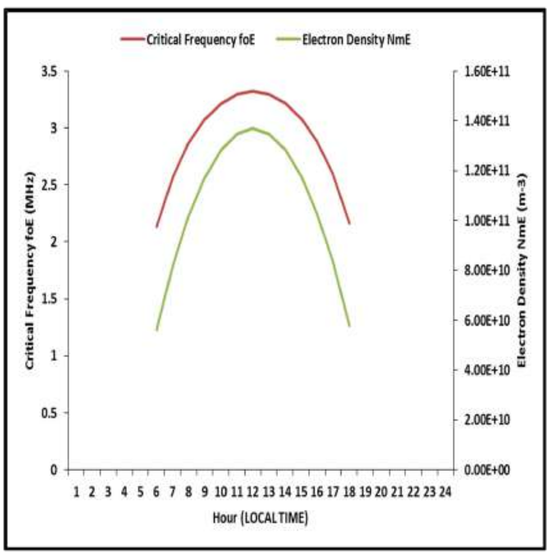
Fig. 10 a (i, ii, iii, iv), Table 12 and Fig. 10 b (i, ii, iii, iv), Table 13 show the values of the correlation coefficient and nature and simple linear regression equations between the values of maximum electron density and critical frequency with sunspots number respectively over the city of Kirkuk during the year (2018).



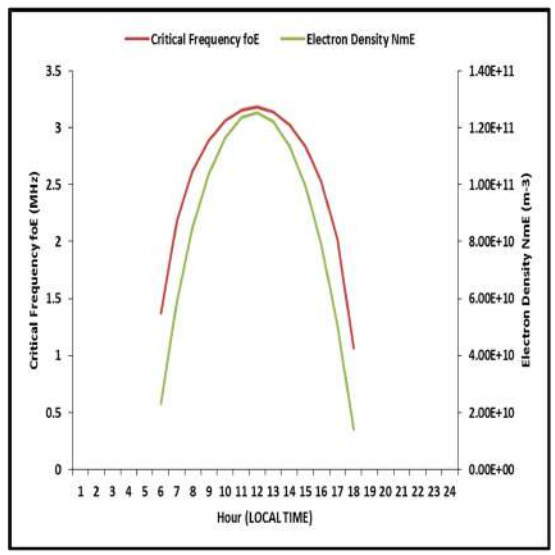
a- Winter Solstice (22 December, 2008)



b- Vernal Equinox (20March, 2008)

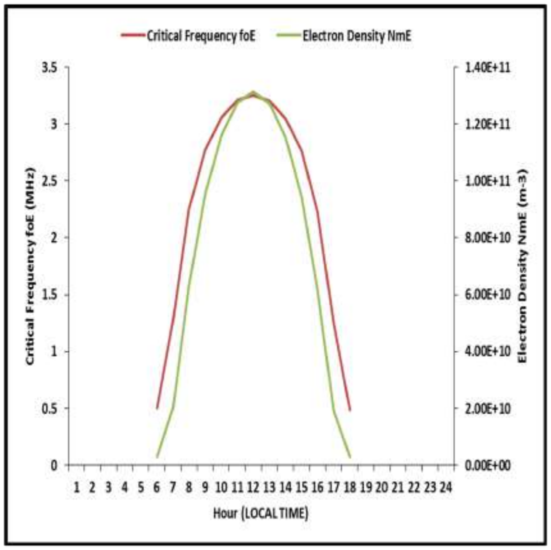


c - Summer Solstice (20June, 2008)

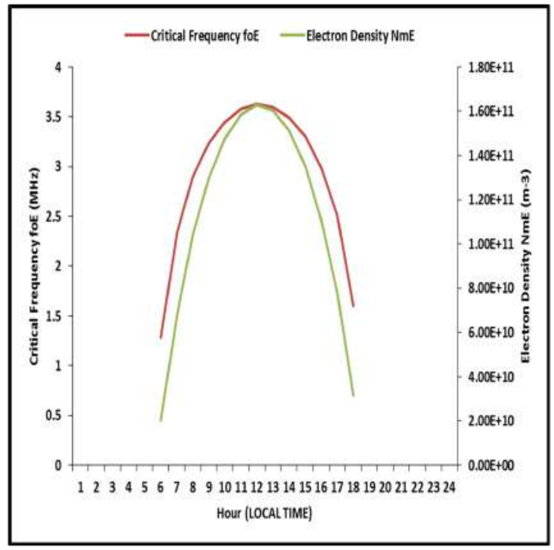


d- Autumnal Equinox (22September, 2008)

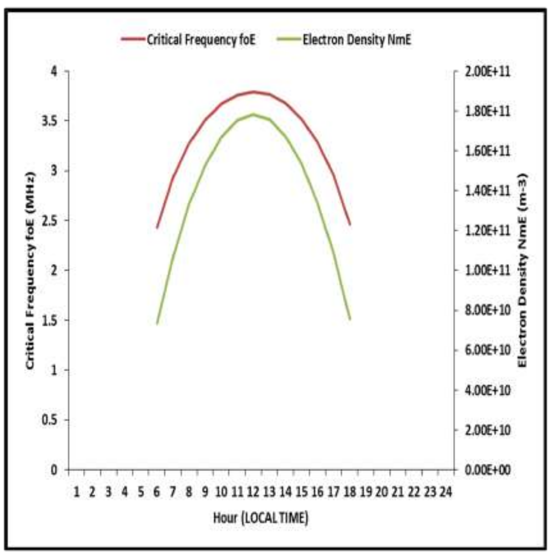
Figure 2. Hourly changes of maximum electron density values (NmE, m^{-3}) and critical frequency (foE, MHz) over the city of Kirkuk during the year 2008, which represents the rising phase of the 24 solar cycle with Sunspot number = 4.15 during (a) - the day of the winter solstice (b) - The day of the vernal equinox (c) - the day of the summer solstice (d) - the day of the autumnal equinox.



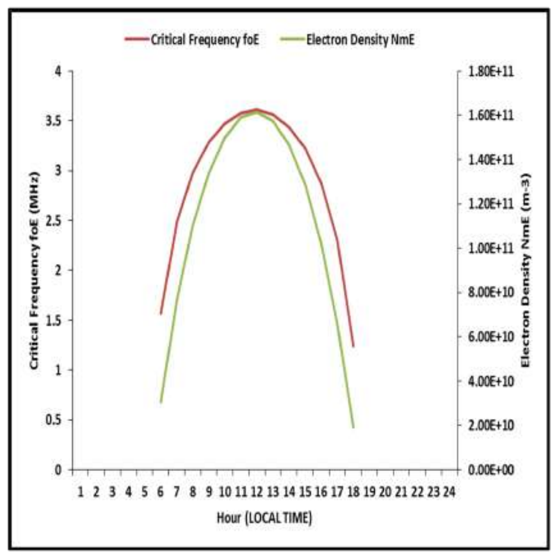
a- Winter Solstice (22 December 2014)



b- Vernal Equinox (20March, 2014)

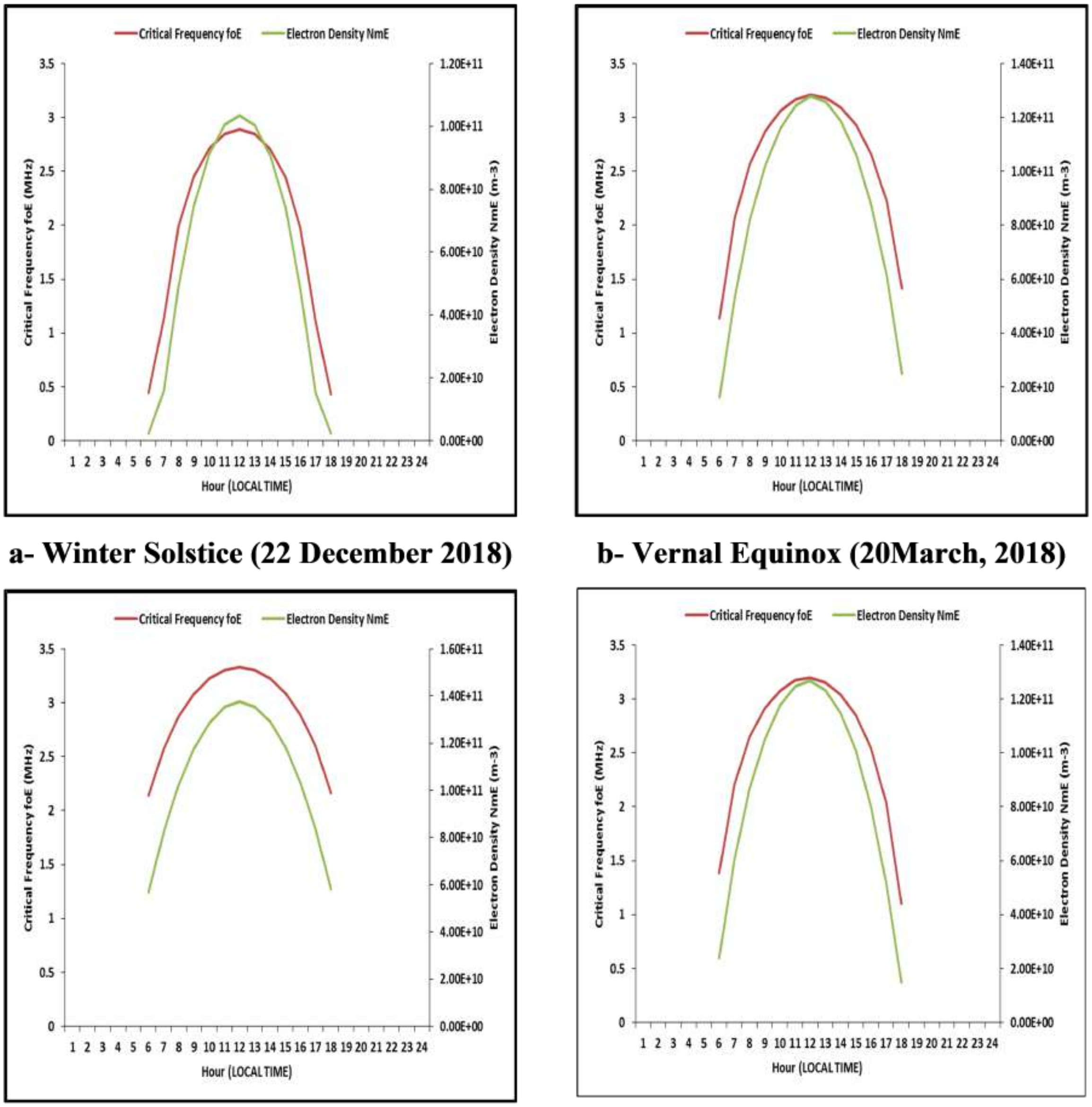


c - Summer Solstice (20June, 2014)



d- Autumnal Equinox (22September, 2014)

Figure 3. Hourly changes of maximum electron density values (NmE, m^{-3} and critical frequency (foE, MHz) over the city of Kirkuk during the year 2014, which represents the peak of the solar cycle 24 with Sunspot number = 113.6 during (a) - the day of the winter solstice (b) - day The vernal equinox (c) - the day of the summer solstice (d) - the day of the autumnal equinox.



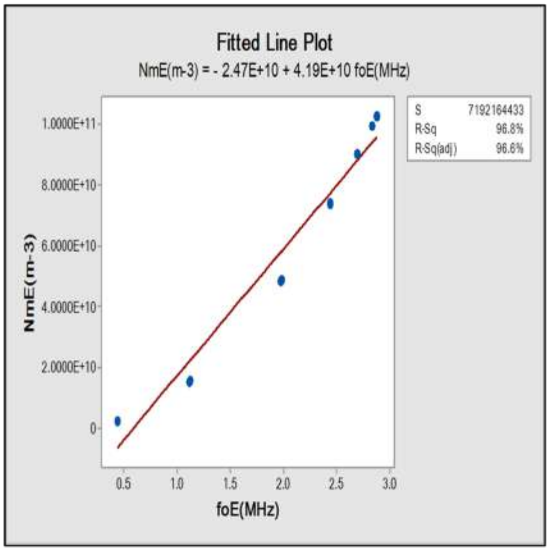
a- Winter Solstice (22 December 2018)

b- Vernal Equinox (20March, 2018)

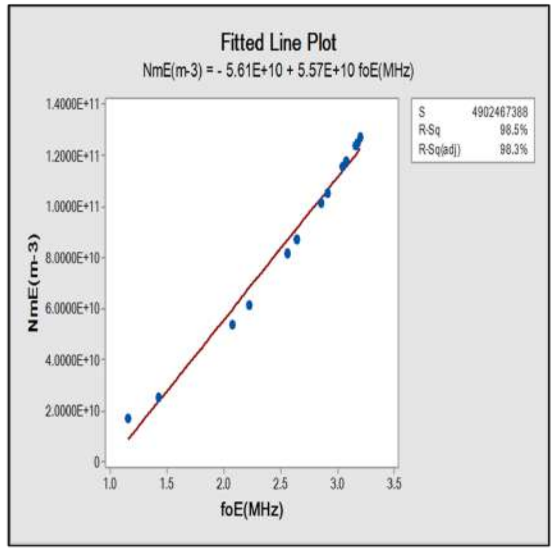
c - Summer Solstice (20June, 2018)

d- Autumnal Equinox (22September, 2018)

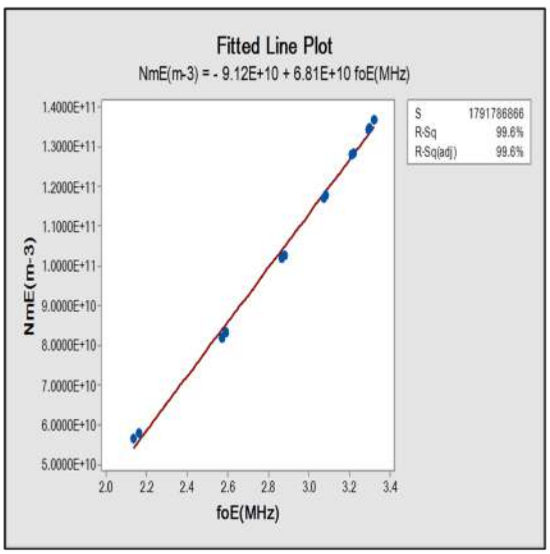
Figure 4. Hourly changes of maximum electron density values (NmE, m^{-3} and critical frequency (foE, MHz) over the city of Kirkuk during the year 2018, which represents the descending phase of the 24 solar cycle with Sunspot number = 7 during (a) - the day of the winter solstice (b) - The day of the vernal equinox (c) - the day of the summer solstice (d) - the day of the autumnal equinox.



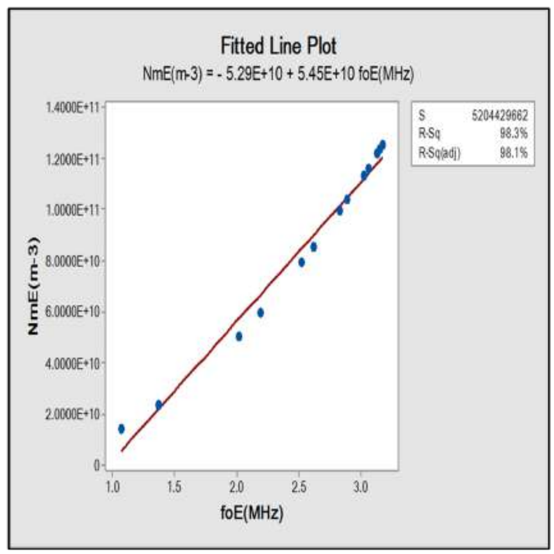
a- Winter Solstice (22 December, 2008)



b- Vernal Equinox (20March, 2008)



c - Summer Solstice (20June, 2008)



d- Autumnal Equinox (22September, 2008)

Figure 5. The values of the correlation coefficients and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2008) - the rising phase of the solar cycle 24 during (a) - the day of the winter solstice (b) - the day of the vernal equinox (c) Summer Solstice (d) - Autumnal Equinox.

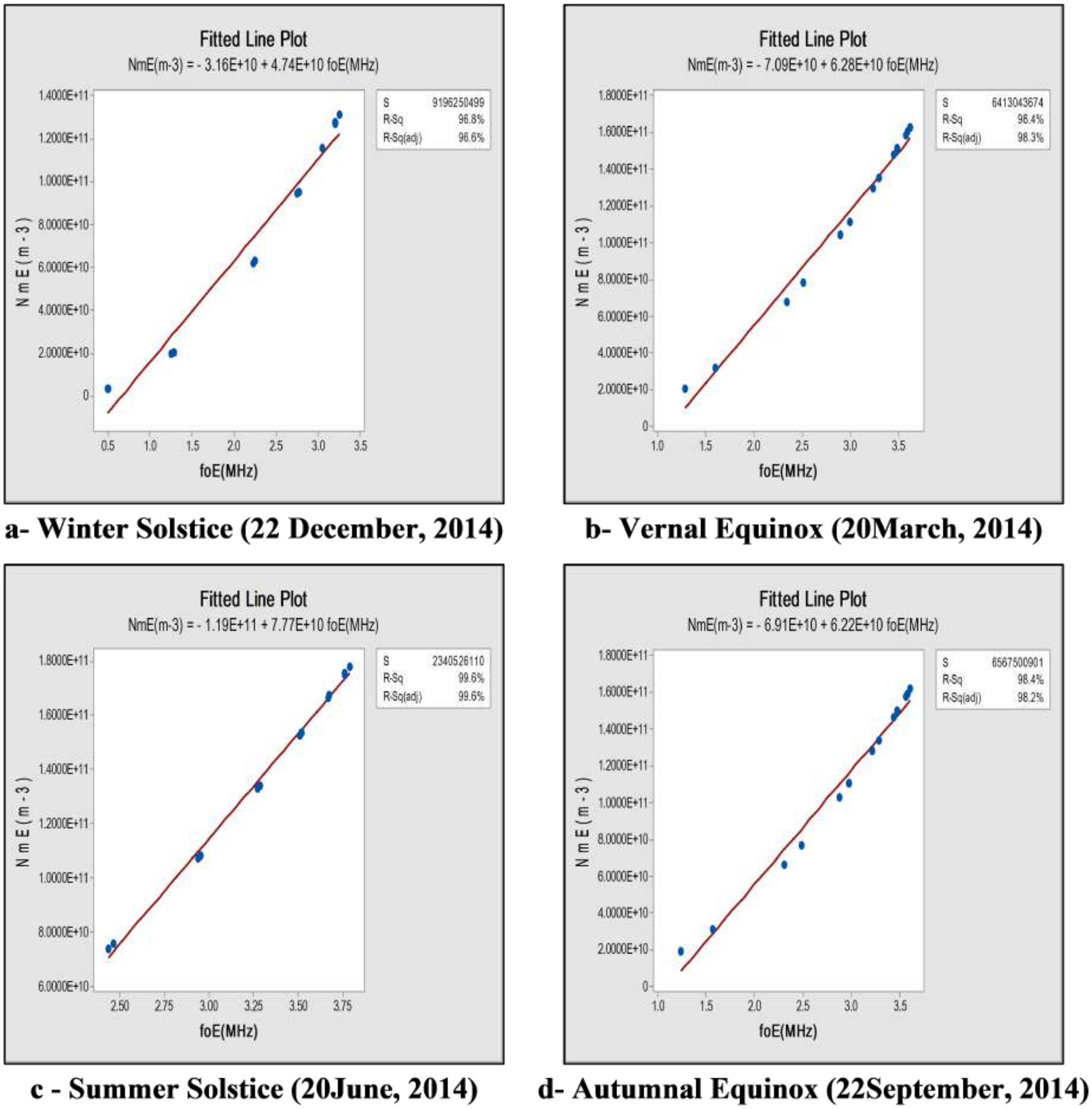
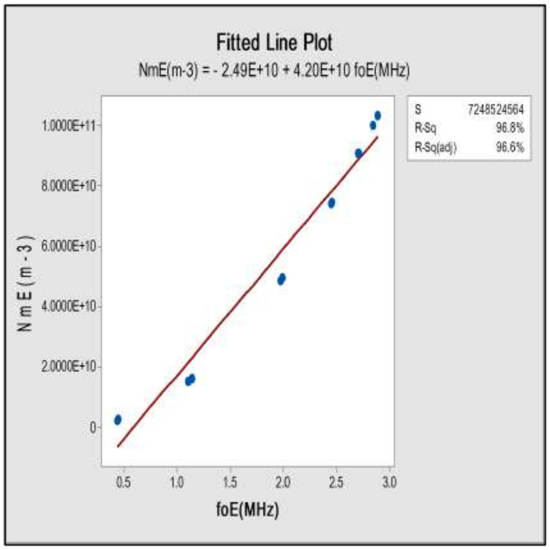
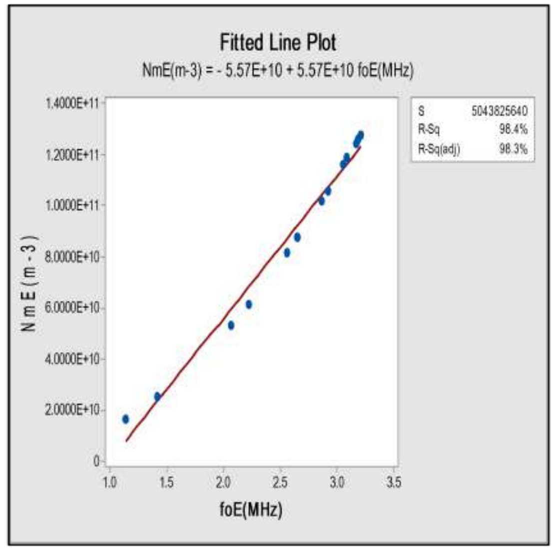


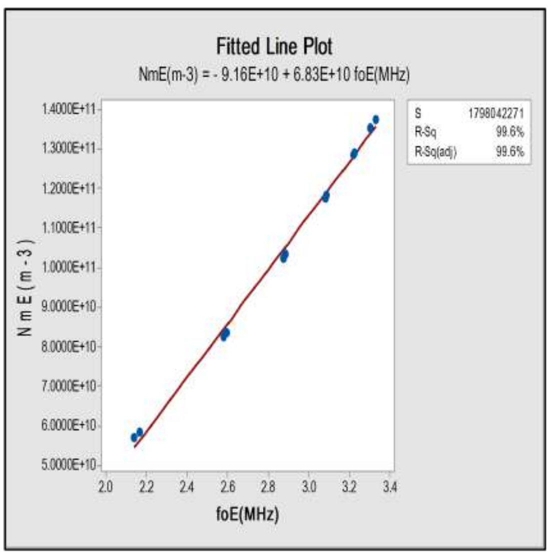
Figure 6. The values of the correlation coefficients and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2014) - the peak of the solar cycle 24 during (a) - the day of the winter solstice (b) - the day of the spring equinox (c) - Summer Solstice Day (d) - Autumn Equinox Day.



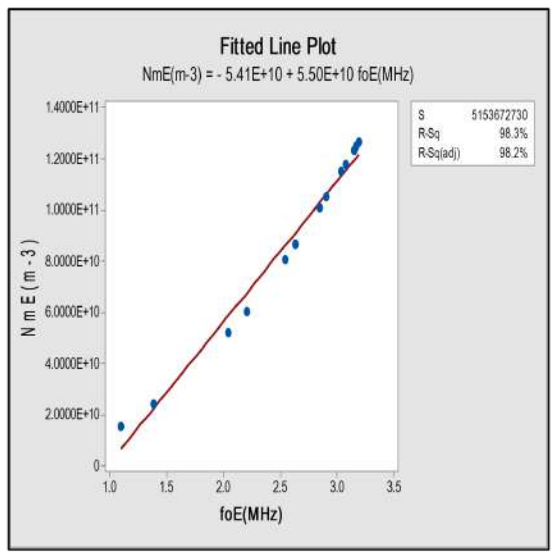
a- Winter Solstice (22 December, 2018)



b- Vernal Equinox (20March, 2018)

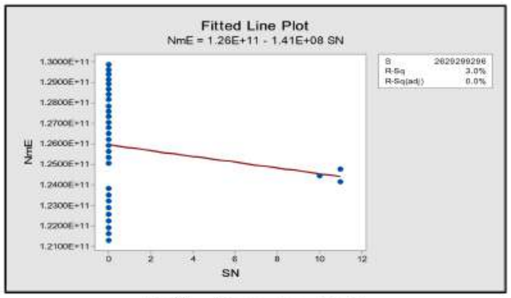


c - Summer Solstice (20June, 2018)

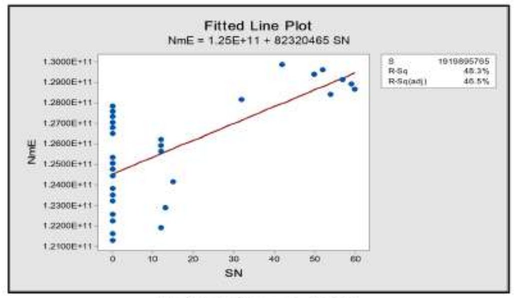


d- Autumnal Equinox (22September, 2018)

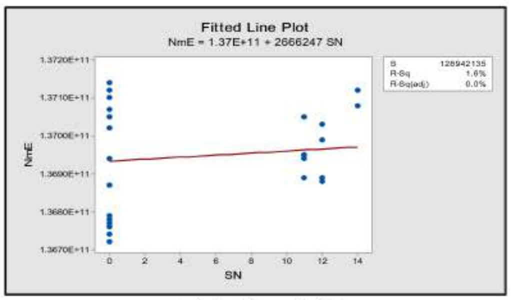
Figure 7. The values of the correlation coefficients and simple linear regression equations between the values of maximum electron density and critical frequency over the city of Kirkuk during the year (2018) - the descending phase of the solar cycle 24 during (a) - the day of the winter solstice (b) - the day of the vernal equinox (c) Summer Solstice (d) - Autumnal Equinox.



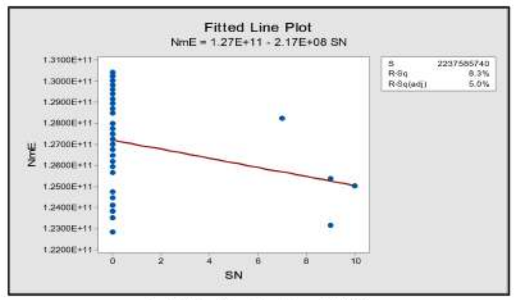
8a (i) - (December, 2008)



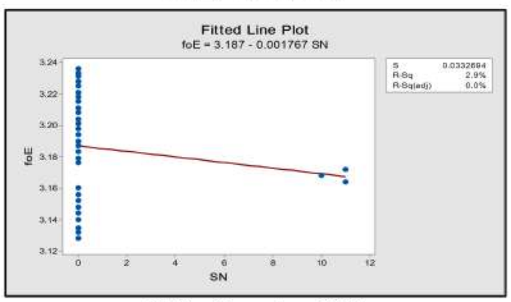
8a (ii) i- (March, 2008)



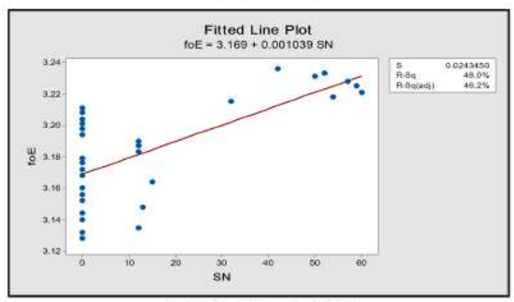
8a (iii) - (June, 2008)



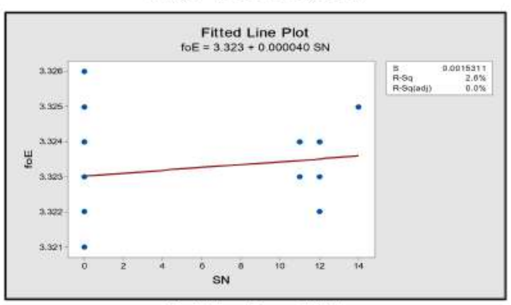
8a (iv) - (September, 2008)



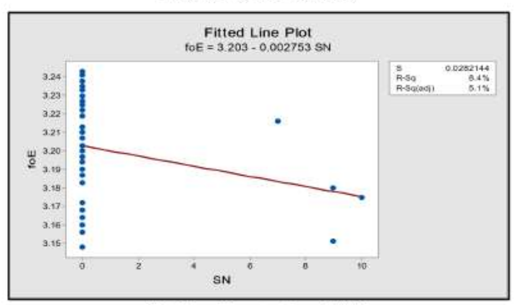
8b (i) - (December, 2008)



8b (ii) i- (March, 2008)

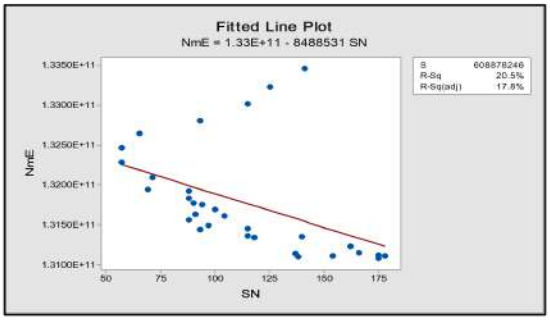


8b (iii) - (June, 2008)

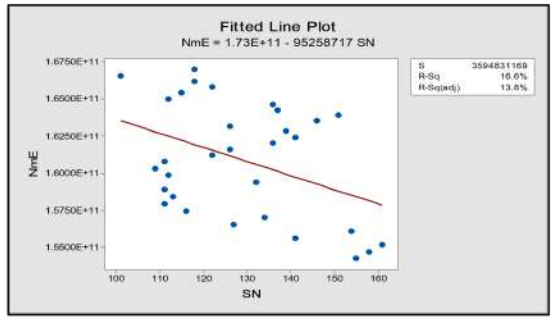


8b (iv) - (September, 2008)

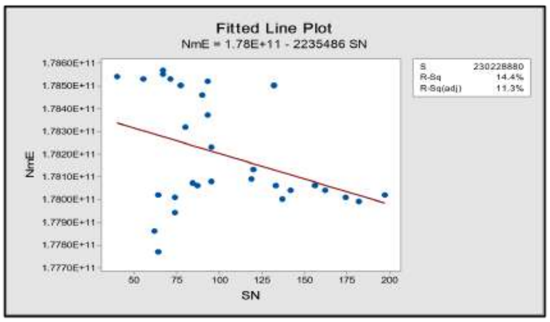
Figure 8. The values of the correlation coefficients and simple linear regression equations between the (a) values of maximum electron density with Sunspots Number (b) values of critical frequency with Sunspots Number over the city of Kirkuk during the year (2008) - the descending phase of the solar cycle 24.



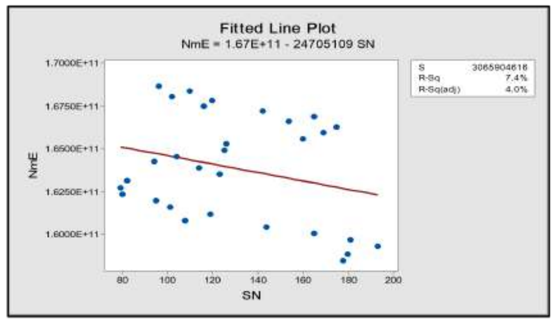
9a (i) - (December, 2014)



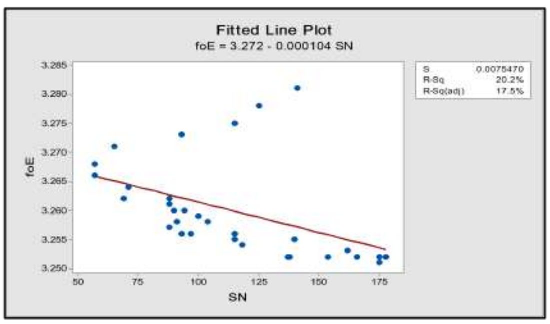
9a (ii) i- (March, 2014)



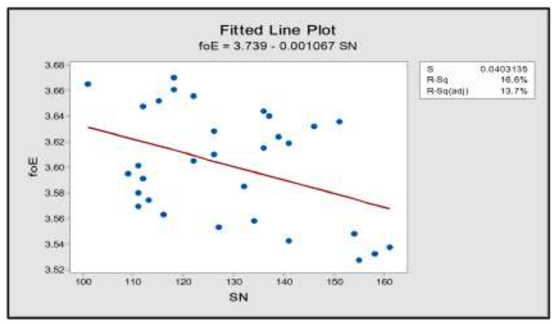
9a (iii) - (June, 2014)



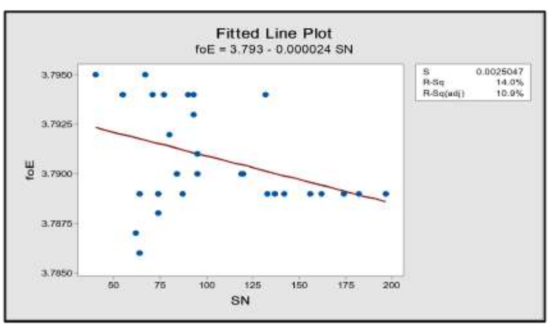
9a (iv) - (September, 2014



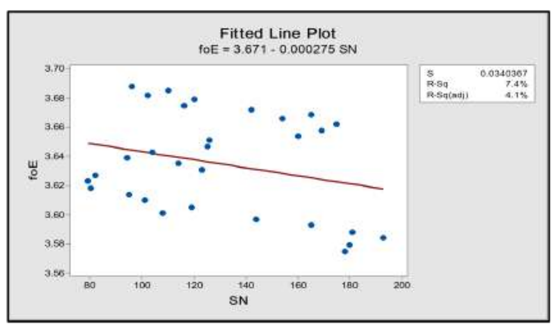
9b (i) - (December, 2014)



9b (ii) i- (March, 2014)

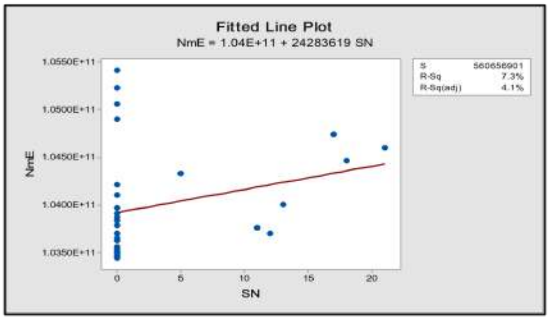


9b (iii) - (June, 2014)

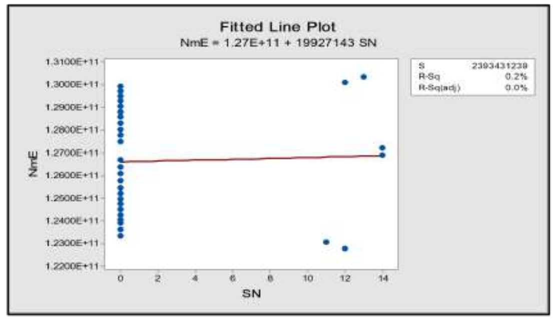


9b (iv) - (September, 2014)

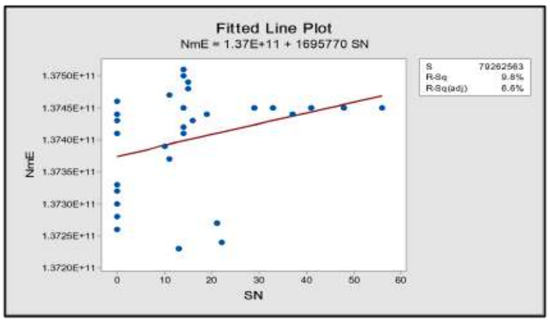
Figure 9. The values of the correlation coefficients and simple linear regression equations between the (a) values of maximum electron density with Sunspots Number (b) values of critical frequency with Sunspots Number over the city of Kirkuk during the year (2014) - the descending phase of the solar cycle 24.



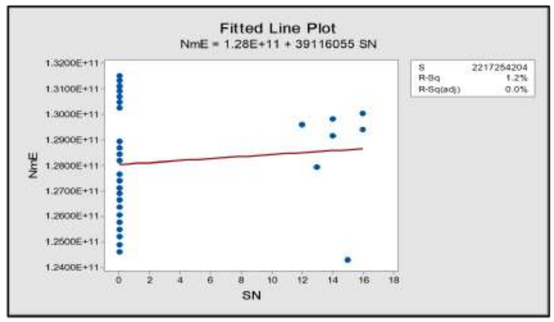
10a (i) - (December, 2018)



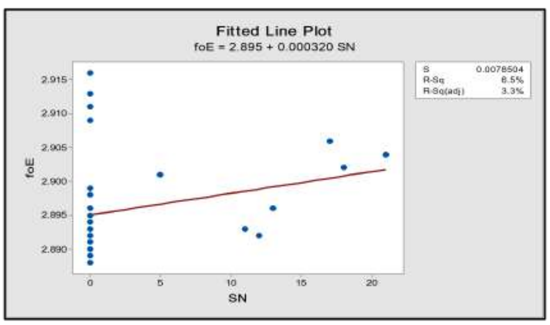
10a (ii) i- (March, 2018)



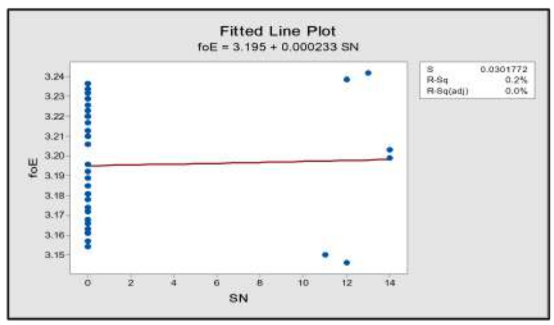
10a (iii) - (June, 2018)



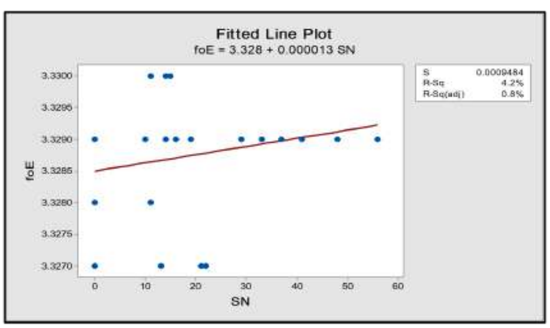
10a (iv) - (September, 2018)



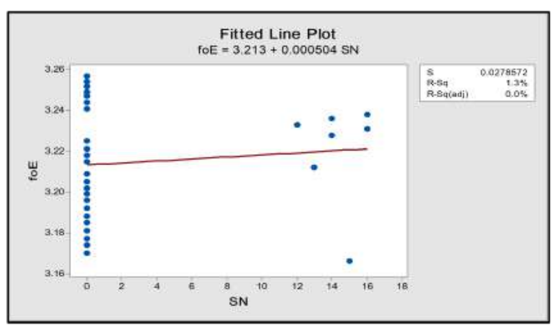
10b (i) - (December, 2018)



10b (ii) i- (March, 2018)



10b (iii) - (June, 2018)



10b (iv) - (September, 2018)

Figure 10. The values of the correlation coefficients and simple linear regression equations between the (a) values of maximum electron density with Sunspots Number (b) values of critical frequency with Sunspots Number over the city of Kirkuk during the year (2018) - the descending phase of the solar cycle 24.

4. Conclusions:

Through the results contained in the research, the conclusions mentioned below were reached:

1- The highest value of the critical frequency foE during the years (2008, 2014, 2018), which represents (the ascending phase, the peak, the descending phase) of the solar cycle 24, was recorded at (12:00) and during (the day of the summer solstice) and this is due to High maximum electron density value NmE.

2- The lowest value of the critical frequency foE during the years (2008, 2014, 2018), which represents (the ascending phase, the peak, the descending phase) of the solar cycle 24, which was recorded at (18:00) and during (the day of the winter solstice) and this is due to Low value of the maximum electron density NmE.

3- The values of critical frequency foE and maximum electron density NmE during the years (2008, 2014, 2018), which represent (the ascending phase, the peak, the declining phase) of the solar cycle 24 on (the day of the vernal equinox) were higher than they are on the (autumn equinox).

4- There is a strong direct correlation between both variables (maximum electron density NmE and critical frequency foE), where the values of the correlation coefficients ranged between (0.984) - (0.998), and this indicates that the increase in the maximum electron density increases the critical frequency, and vice versa.

Funding: None.

Data Availability Statement: All of the data supporting the findings of the presented study are available from corresponding author on request.

Declarations:

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

Ethical approval: The manuscript has not been published or submitted to another journal, nor is it under review.

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دراسة العلاقة بين كثافة الالكترون العظمى مع التردد الحرج في طبقة *E* الايونوسفيرية فوق مدينة كركوك خلال الدورة الشمسية 24

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الخلاصة

يهدف هذا البحث إلى دراسة العلاقة بين قيم كثافة الالكترون العظمى (*NmE*) مع التردد الحرج (*foE*) في طبقة *E* الايونوسفيرية فوق مدينة كركوك (خط طول 44 شرقا ، دائرة عرض 35 شمالا) والتي تم الحصول عليها من خلال استخدام موديل الايونوسفير المرجعي العالمي (*IRI*2016) خلال السنوات (2018,2014,2008) والتي تمثل كل من (الطور الصاعد، القمة، الطور النازل) للدورة الشمسية 24 ، وفي التواريخ (22 كانون الاول، 20 اذار، 20 حزيران، 22 ايلول) التي تمثل ايام (الانقلاب الشتوي، الاعتدال الربيعي، الانقلاب الصيفي، الاعتدال الخريفي) على التوالي. لقد اوضحت النتائج الى وجود ارتباط طردي قوي بين قيم كثافة الالكترون العظمى مع التردد الحرج، حيث تراوحت قيم معاملات الارتباط بين (0.984) (0.998) ،وهذا يشير الى انه بزيادة قيم كثافة الالكترون تزداد قيم التردد الحرج، والعكس بالعكس .

الكلمات الدالة: كثافة الالكترون العظمى؛ التردد الحرج؛ كركوك؛ الدورة الشمسية 24 ؛ موديل *IRI*2016 .

التمويل: لايوجد.

بيان توفر البيانات: جميع البيانات الداعمة لنتائج الدراسة المقدمة يمكن طلبها من المؤلف المسؤول.

اقرارات:

تضارب المصالح: يقر المؤلفون أنه ليس لديهم تضارب في المصالح.

الموافقة الأخلاقية: لم يتم نشر المخطوطة أو تقديمها لمجلة أخرى، كما أنها ليست قيد المراجعة.