The Effect of Sunspots Number on the Total Electron Content (TEC) of the Ionospheric Layer E Over Kirkuk Station for Solar Cycle 24

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Abstract

In this work, 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. In this study the International Reference Ionosphere program (IRI) program have been applied to find the values of TEC which provided by the space research committee (COSPAR) and International Union of Radio Sciences (URSI), IRI have three upper side electron density options. The accuracy of this study was verified by the application conducted of the university of Hacettepe in Ankara, Turkey by matching the reading of TEC from Global Position System (GPS) with output data of TEC from the IRI for Ankara station which located at (39.7 N;32.76 E). And from this investigation turns out that the output data from the option IRI2001 was more consistent with reading of the GPS, than the rest of the other options. From this study by using the statistical program Minitab version 2018. There is a strong correlation between the Total Electron Content (TEC) of Ionospheric layer E and Sunspot number for solar cycle 24.

Keyword: Ionospheric layer E, Total Electron Content (TEC), IRI2016model, Solar cycle 24, Minitab 2018.

تأثير البقع الشمسية على المحتوى الإلكتروني الكلي (TEC) للطبقة E للايونوسفير فوق محطة كركوك للدورة الشمسية 24

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الملخص

في هذا العمل تم دراسة تأثير عدد البقع الشمسية (Ri) على المحتوى الإلكتروني الكلي(TEC) وذلك للسنين (2008، 2014، 2018) والتي تمثل الطور الصاعد، القمة والطور النازل للدورة الشمسية 24 فوق محطه كركوك في العراق والتي تقع على خط الطول 44° شرقاً وخط عرض 35° شمالاً. ومن خلال ايجاد قيم (TEC) للطبقة الايونوسفيرية E تم تحديد أوقات الظهور للطبقة لايام الانقلاب والاعتدال للسنوات التي اشير اليها بهذه الدراسة. تم في هذا العمل تطبيق برنامج الايونوسفير المرجعي العالمي (IRI) لايجاد قيم المحتوى الإلكتروني الكلي (TEC) والذي يدعمه لجنة أبحاث الفضاء كاسبر (CASPER) والاتحاد الدولي لعلوم الراديو (URSI). ويحتوي هذا البرنامج على ثلاث خيارات لايجاد الكثافة الإلكترونية في الجانب العلوي للطبقة الايونوسفيرية. تم التحقق من دقة هذا العمل من خلال تطبيق أجري في جامعة حاج تبة (Hacettepe) في انقرة/تركيا عن طريق مطابقة القيم النظرية للمحتوى الإلكتروني الكلي (TEC) الناتجة من البرنامج (IRI) مع القيم العملية لقراءات (TEC) المأخوذة من النظام العالمي لتحديد المواقع GPS لمحطة أنقرة والتي تقع على خط طول 32,76° شرقاً وخط عرض 39.7° شمالاً ونتيجة لهذه المطابقة تبين أن الخيار هو استخدام (IRI2001) للحصول على افضل النتائج وهو أكثر اتساقاً و توافقاً من باقي الخيارات للبرنامج IRI. وقد تم ايجاد تأثير عدد البقع الشمسية على (TEC) من خلال البرنامج الاحصائي (Minitab) اصدار2018 وتبين أن هناك ترابط وثيق بين المحتوى الإلكتروني الكلي للطبقة الايونوسفيرية E مع عدد البقع الشمسية للدورة الشمسية 24.

1. Introduction:

According to the electrical classification of Earth atmosphere layers, are divided in to three main layers, the Troposphere, Stratosphere, and the Ionosphere [1]. The Ionosphere is ionized gas (charged and neutral) particles [2, 3]. The ionization is change in the day than in the night and in the summer more than rest of the seasons and in the sunspots maximum than minimum this varies depending on the time of day and season as well as location and solar cycle [4]. The ionosphere is a layer of the Earth's atmosphere that stretches from upper center of the Mesosphere to the end of the Exosphere. It was divided into four diurnal layers according to different electronic density. And they are D, E, F1and F2 [5]. The proportion of production of ions in these layers depends on the zenith angle (x). An angle made by the sun with the column and be the highest value at the time of sunrise, sunset and also the angle value varies depending on the time of days, year and location. Studying the Ionosphere parameter is very important such as Total Electronic Content (TEC) because finding TEC values is great importance in calculating the phase delay of radio waves traveling through the Ionosphere, and in determining Scintillation, which is the time rate of fluctuations in the intensity of radio waves. Which affects to the communication, navigation systems and space observation systems to work more efficiently [4, 6]. TEC is widely used recently which is the sum of the electrons on a vertical path consisting of the cross- sectional area 1 m^2 of the satellite altitude of 20,200 km to the recipient on Earth if its value is then determined from GPS. Its unity 1TECU= 1 X 10^{16} electron/m^2 [7]. There is a lot of research for the Ionosphere study especially the Total electronic content parameter of these studies. In 2015, researcher Fahmy Abdel-Rahman compared the measurements of the Total electronic content of the Aetna station ionograms with the IRI2012 data in the period of increased solar activity from (2009-2010) to the 24 cycle. It was found that the expected values from IRI are higher than the measured values in all hours, days and seasons, but the difference is less in winter compared to other seasons [8]. The researcher Dragan B. presented a study on the changes of the Total electronic content over Serbia, showing them that the (TEC) values increase from 6 am and reach the maximum limit at 12 am in the local time and the lowest values are after

midnight and in the seasonal changes it was found that the highest values occur in the spring and autumn months and found that the change in values depends on the location and the change in the solar activity, as it increases with increasing [9]. Ezquer, R. G. showed in 2017 that the Ne-Quick model provides good forecasts for the (TEC) values in mid-latitudes in North America, especially for the region (35°-50°). It has been shown that nothing exceptional happened during the period of low solar activity 2008 [10]. Ramazan Atici in 2018 through a study in which he compared (GPS-TEC) values with (IRI2016-TEC) and (IRIPlas-TEC) over Istanbul for the years (2009-2012). The predictive power of the IRI model depends on the ability to access the experimental database in place predictions for low IRI concluded that the option (IRI2001) offers better predictions than other IRI options [11]. The ionospheric layer E was chosen due to it is importance in reversing the medium wavelength of radio waves, as well as to the clarity of the effect of sunspots on it. The aim of this study is to determine the nature of the relationship between the numbers of sunspots with the Total electron content of Ionospheric layer E, over Kirkuk station during the solar cycle 24 using the empirical model IRI, by comparing it with GPS reading over Ankara station, Turkey. The geographical location of the study stations are shown in Fig. 1.

Fig. 1: Kirkuk station in Iraq and Ankara station in Turkey**[12].**

2. Methodology:

2.1 Obtaining TEC values from IRI:

International reference ionosphere (IRI2016) program was applied in this study and this programs sponsored by the Space Research Committee (COSPAR) and the International Union of Radio Science (URSI). They are organizations that formed a working group in the late 1960 to produce an experimental standard model for the Ionosphere based on all available

data sources [13]. This model provides the values of (TEC) and (electron density) Ne at altitudes ranging from 50 to 2000 km at any date or time and anywhere in addition to provided other ionosphere parameters [14, 15]. This model was based on various ground and space measurements and provides the values of (vertical Total electronic content) VTEC through numerical integration of the vertical electron density from the lower boundaries to the upper boundaries. The upper boundary by the height of layer E was determined to obtain the values of VTEC in units TECU. This model provides three options for electron density distribution of the upper side A- (IRI2001) model that was based primarily on Alouette 1 topside sounder data with some Monitoring Data Analysis section USA (AEROS AE-C and DE-2) in situ data. B- (IRI01-Correction) of the 2001 mode with the help of Aloutte 2, ISIS 1and 2 topside sounder data. C- (Ne-Quick) the model developed International Centre for Theoretical Physics (ICTP) using intercosmos 19 topside sounder data in addition to the ISIS 1 and 2 data [13]. These three options were applied to estimate the value of VTEC in order to compare it with the reading of TEC of the GPS over Ankara station to fit the results of Kirkuk station. The value of the vertical electron content is determined by the integration of the vertical electron density according to the equation.

$$\text{TEC} = \int_0^\infty N(h)dh \tag{1}$$

$N(h)$: Vertical electron density: dh Track length [16, 17]. The equation of Ionization production.

$$q/q° = \exp[1 - z - \sec(x)^{-2}] \tag{2}$$

X: Zenith angle

Z: Reduced height

q°: The highest Value of ion production is at noon

$$qm = q°cos(x) \tag{3}$$

qm: The Maximum range of ion production is limited at $x = zero$

$qm = q°$ [18, 19]

$$Ne = No(e)Cos^{1/2}(x) \tag{4}$$

Ne: Electron Density, $No(e)$: maximum value of electron density.

$$cosx = sin\emptyset sin\delta + cos\emptyset cos\delta cos\theta \qquad (5)$$

θ: Geographic longitude:$\emptyset$ Geographic latitude: δ: solar Declination

This theory concluded that the greatest density is in summer [20] and subjected to layers D, E, F1 and not to F2 [16]. The tiring way of studying in this research can be seen through the flowchart in Fig. 2.
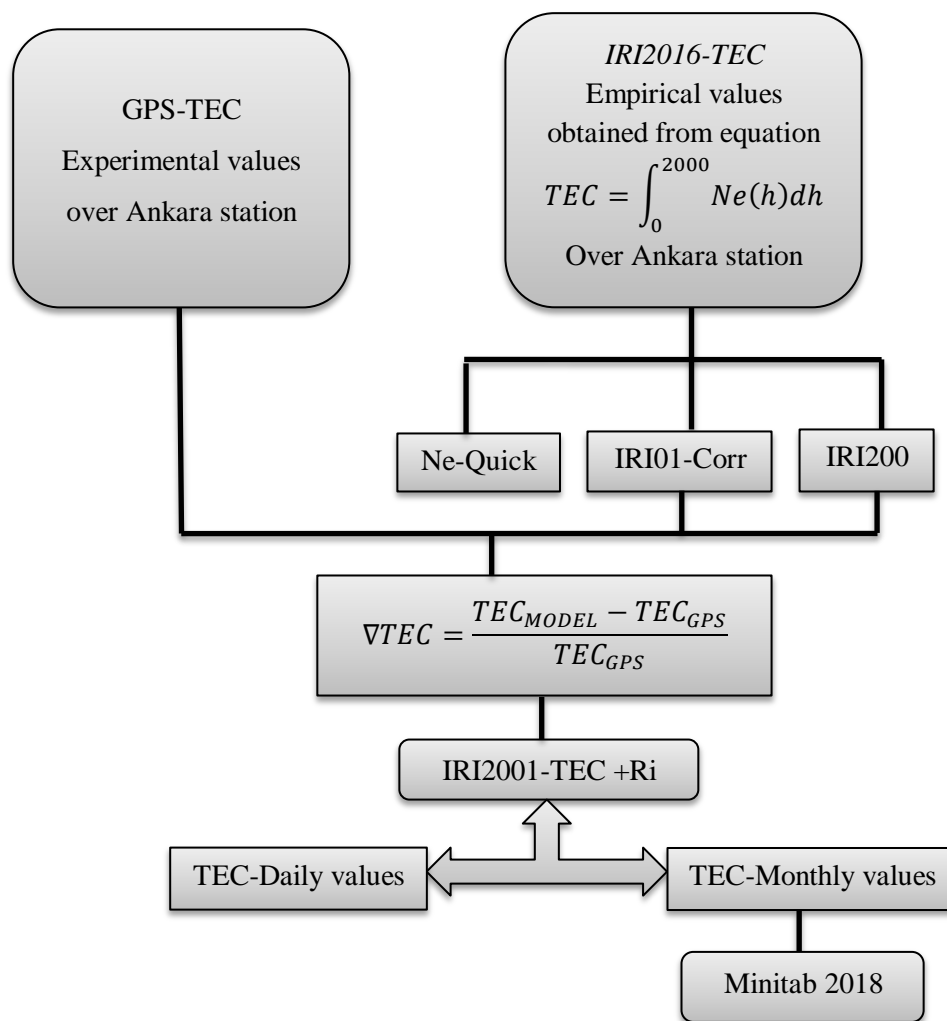

Fig. 2: The flowchart of the work.

3. Results and Discussion:

In the present study were compared the values of TEC obtained from (GPS –TEC) from Ion lab group of Ankara station (39.7 N; 32.76 E) and between the values of TEC obtained from empirical model IRI have been values for the days of spring equinox and autumn

equinox and winter summer solstice for years (2008, 2014, 2018). The values of TEC that obtained from GPS are at an altitude of 20,200 km. That includes the Total electro content of the Ionosphere and plasma. The TEC values obtained from the top three options are (Ne-Quick), (IRI01-Corr) and (IRI2001) which the maximum height was 2000 km and the comparison after neglecting TEC plasma. Because the error rate is consistent with the three option because the maximum height of all options is similar. Target finds out which option is closer to the GPS values. The deviation rate has been found for the days of equinox and solstice as shown in Table 1 and by comparing the TEC values shown in Fig. 3. The curves (a-e) represent the days of spring and autumn equinox and the curves(f-l) represent the days of winter and summer solstice for years (2008, 2014, 2018) for solar cycle 24.The relative deviation rats calculated by this equation [2],[14].

$$\nabla TEC\% = \frac{TEC_{MODEL} - TEC_{GPS}}{TEC_{GPS}} \times 100 \tag{6}$$

From the statistical equation, it was found that the IRI2001 option is the closest to the reading of the GPS over Ankara station. So this model was used to estimate the results of VTEC for E layer over Kirkuk station. Fig. 3 shows that the lowest deviation is for the IRI2001 option which is closest option for GPS. So then use this option to study Total electron content (TEC) for Ionosphere layer E.

Table 1: The results of some statistical calculations indicate the average relative deviation ΔTEC% between GPS-TEC values and IRI 2016 models values of equinox and solstice day in 2008, 2014, 2018 over Ankara station.

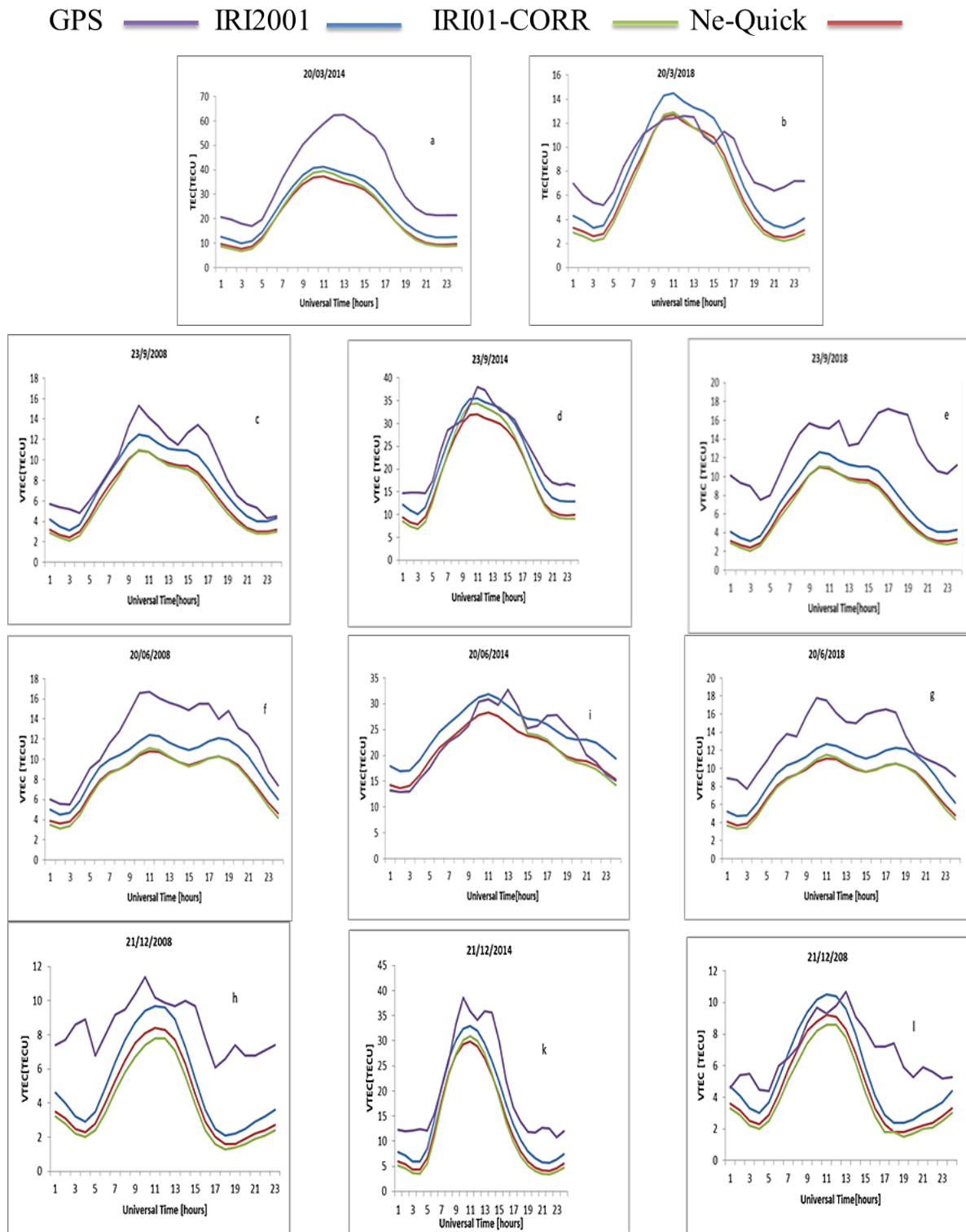| IRI2016		20 March	23 September	20 June	21 December
2008	Ne-Quick	No data	-32	-34	-53
	IRI01-Corr		-29	-33	-49
	IRI2001		-15	-21	-36
2014	Ne-Quick	-43	-20	-7	-38
	IRI01-Corr	-44	-25	-7	-36
	IRI2001	-34	-8	8.5	-25
2018	Ne-Quick	-28	-53	-38	-40
	IRI01-Corr	-25	-49	-37	-34
	IRI2001	-12	-48	-25	-20

Fig. 3: Daily changes on equinox and solstice days of TEC values obtained by GPS-TEC and by empirical models IRI2016 over Ankara station for Rising phase (2008), peak (2014), Down phase (2018) (solar activity periods).

In this study, the empirical values of TEC for the Ionospheric layer E were obtained from IRI2016 program option IRI2001 [13]. For daily values as shown in Table 2 and Fig. 5. As well as the values of sunspot number for solar cycle 24 were applied in this program [21]. See the monthly mean sunspot numbers for years (2008, 2014, and 2018) in Fig. 4. The a accuracy of this results was verified by the application conducted of the university of Hacettepe in Ankara, Turkey by Matching the reading of TEC from IRI for Ankara station which located (39.7 N;32.76 E) [22, 23].
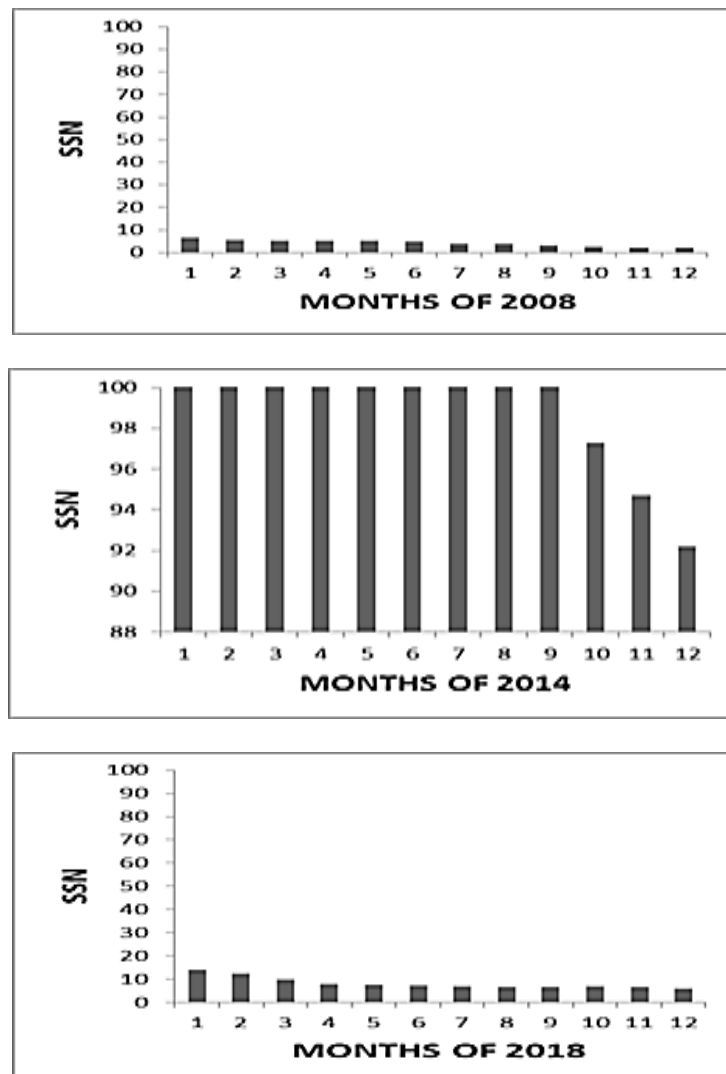

Fig. 4: The monthly mean sunspot numbers in 2008, 2014, 2018.

Table 2: TEC value from IRI2016 at altitude 130 km (E layer) for the years 2008, 2014, 2018 for days of solstice and equinox over kirkuk station.

| Time LT(hours)	2008				2014				2018			
	20 Mar	20 Jun	22 Sep	22 Dec	20 Mar	20 Jun	22 Sep	22 Dec	20 Mar	20 Jun	22 Sep	22 Dec
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0.2	0	0	0	0.2	0	0	0	0.2	0	0
6	0.1	0.5	0.2	0	0.2	0.7	0.3	0	0.1	0.5	0.2	0
7	0.5	0.9	0.6	0.2	0.7	1.2	0.7	0.3	0.5	1	0.6	0.2
8	0.8	1.1	1	0.4	1.3	1.5	1.3	0.9	0.8	1.3	0.9	0.4
9	1.1	1.2	1.3	0.7	1.7	1.6	1.7	1.7	1.1	1.5	1.2	0.7
10	1.3	1.4	1.5	0.9	1.8	1.9	1.8	2.2	1.3	1.6	1.4	0.9
11	1.4	1.5	1.5	0.9	1.8	2	1.9	2.4	1.4	1.7	1.4	0.9
12	1.4	1.5	1.5	1	2	2	1.9	2.2	1.4	1.8	1.4	1
13	1.4	1.5	1.5	1	1.7	2	1.8	2.1	1.4	1.7	1.4	1.1
14	1.2	1.3	1.4	1.2	1.6	1.8	1.6	2.1	1.2	1.5	1.3	1.2
15	1.1	1.2	1.1	1	1.5	1.5	1.4	1.4	1.1	1.3	1.1	1
16	0.8	0.9	0.8	0.6	1.2	1.3	1.1	0.8	0.8	1	0.8	0.6
17	0.6	0.8	0.5	0.2	0.9	1.1	0.7	0.3	0.6	0.9	0.5	0.2
18	0.2	0.5	0.2	0	0.6	0.8	0.3	0.3	0.2	0.6	0.2	0
19	0	0.2	0	0	0.2	0.3	0.1	0.2	0	0.2	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
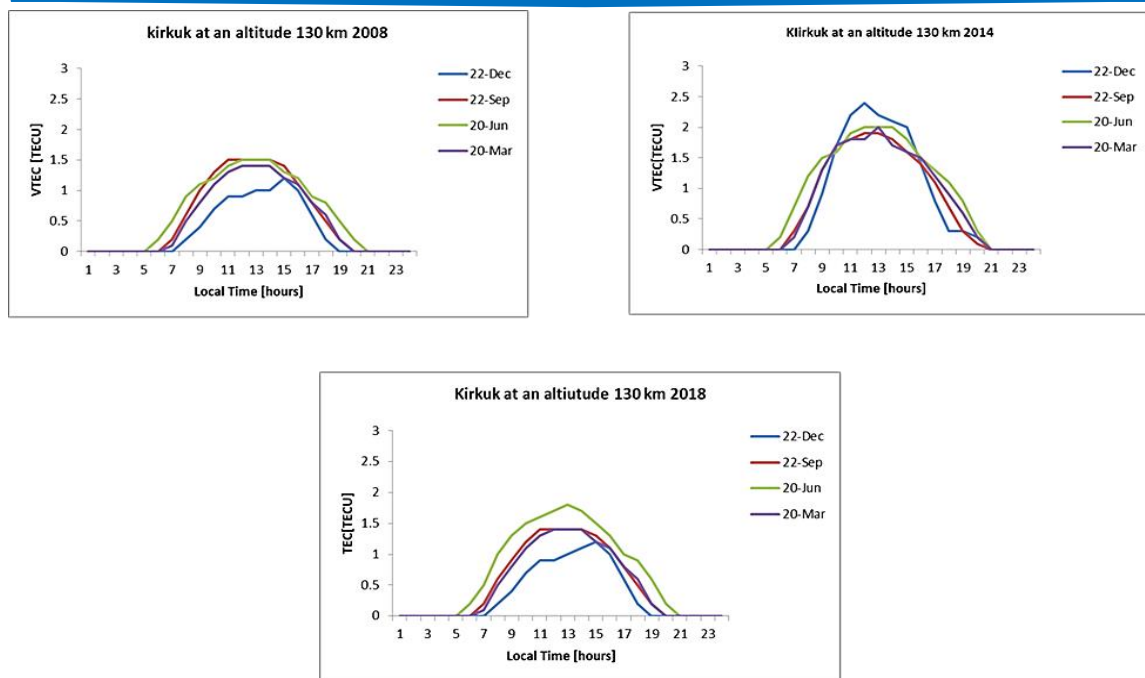
Fig. 5: comparison of daily TEC value at altitudes 130 km (E layer) for he years 2008, 2014 and 2018 for the days of the solstice and equinox over Kirkuk station.

For the height of 130 km (maximum height of layer E). In 2008 the TEC in March September and June be the highest value at 11.00 to 13.00 pm. In December at 14pm, the highest value will be in summer, autumn, spring and Winter. For the year 2014 at an altitude of 130 km, the emergence of values began in March from 6.00am to 19.00pm. That is the hours of appearance are one hour higher than March 2008 and maximum value in 12.00 am. In June the apparition starts at 5.00 to 19.00 pm and the highest value is at 11.00 to 13.00 pm. In September the apparition starts at 6.00 to 19.00 pm, it increases by one hour and the highest value is at 11.00 to 12.00 am, in December 2014 the apparition starts at 7.00am to 19.00pm and highest value in 11.00 is local time. In 2014, the values are higher in winter, summer, spring and autumn. In 2018 the time of the impression of TEC values is similar to that of 2008 because solar activity has increased at the beginning of the rising phase (2008) and of the down phase (2018).

4. Statistical Analysis :

Through data processing using the statistical program Minitab version 2018, the effect of solar activity (sunspots) on the Total electron content at maximum height of layer E was

investigated in the four months December, June, March and September for the years 2008, 2014, 2018 which is represents (rising phase, the Peak and down phase) of the solar cycle 24 over Kirkuk station as shown in Fig. 6, 7.
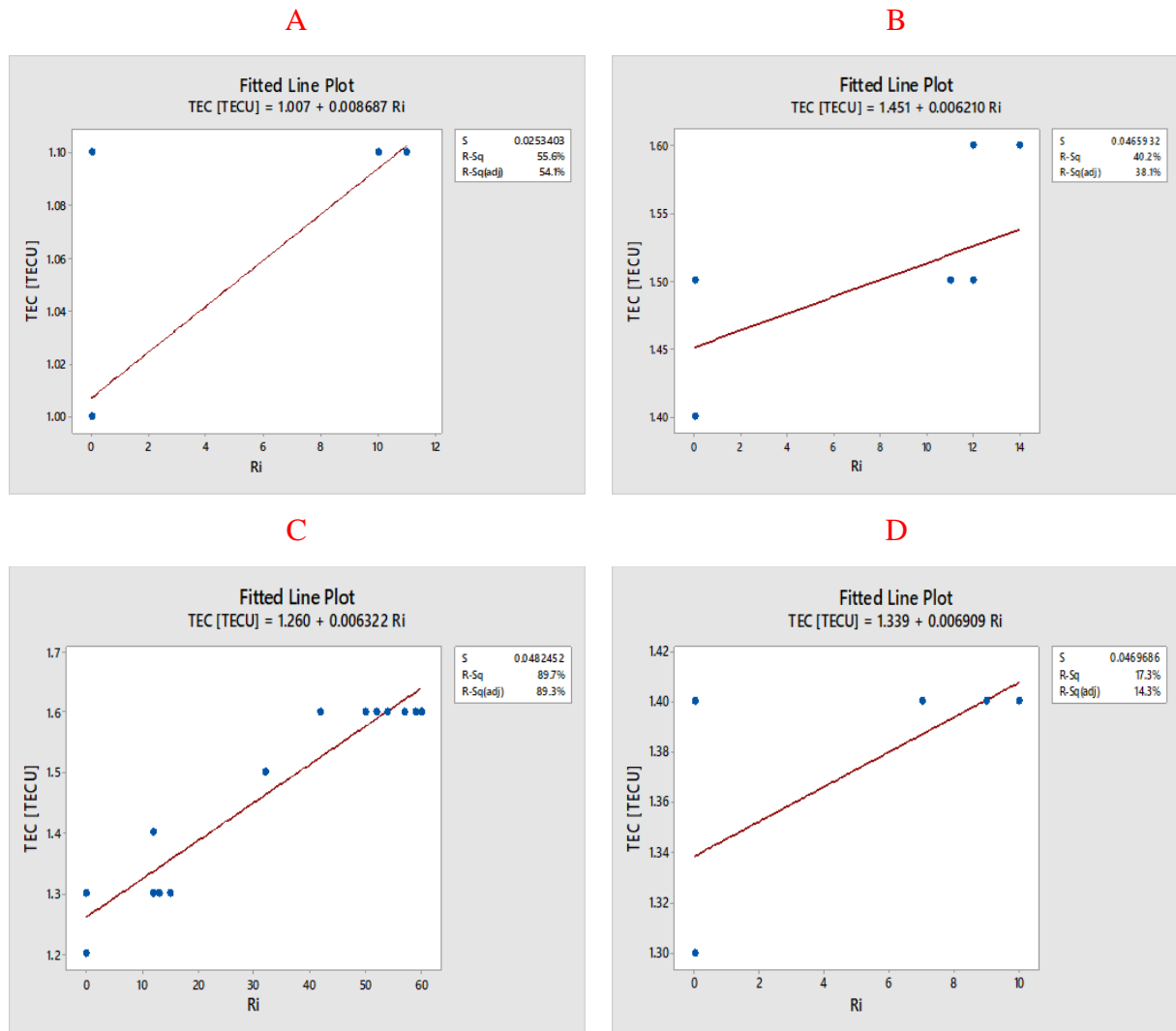

Fig. 6: Relationship between vertical Total electron content (VTEC) and sunspots number (Ri) at maximum height of the layer E, h=130km for the year 2008 A, B represents December and June C, D represents March and September.
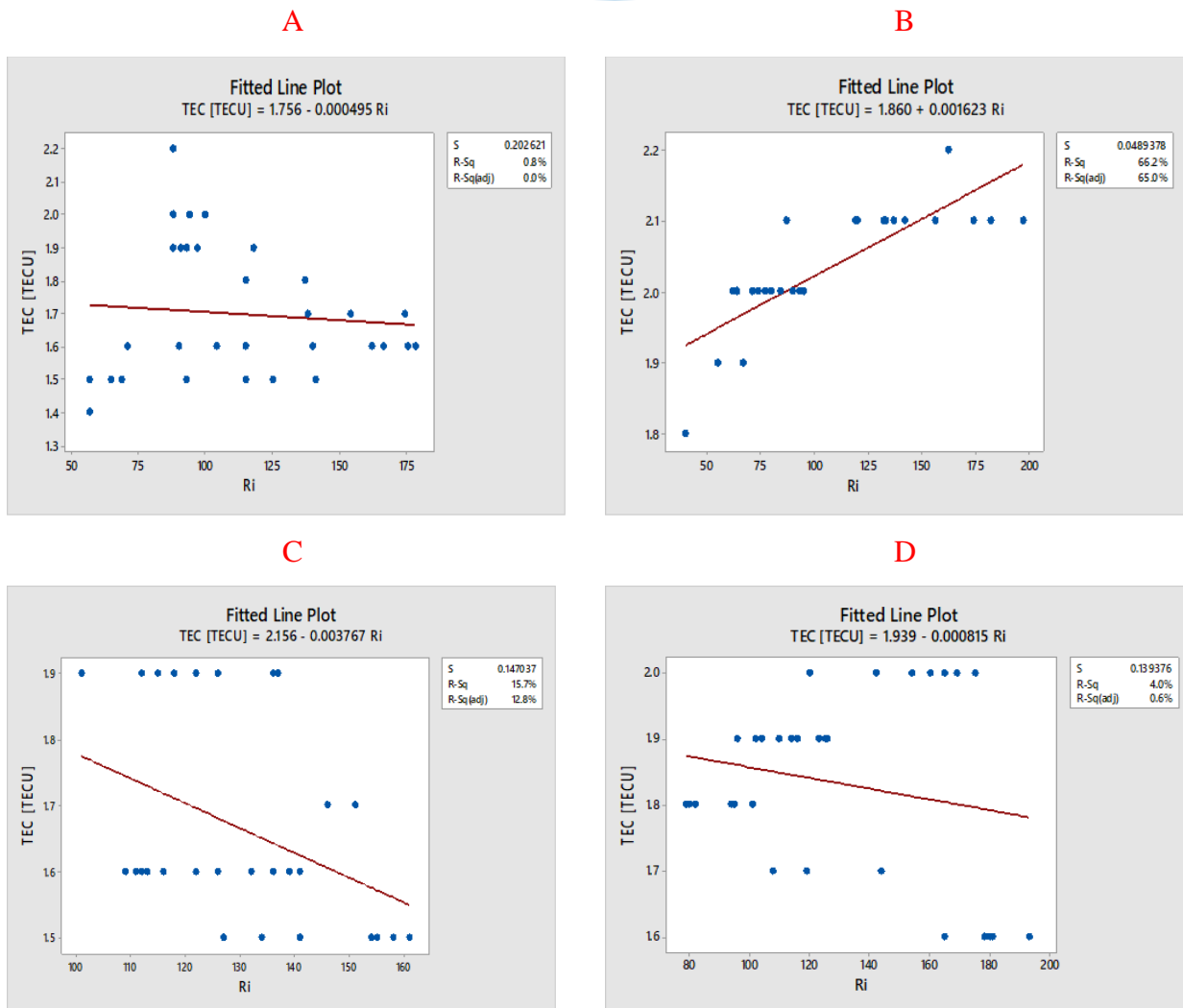
A   B

C   D

Fig. 7: Relationship between vertical total electron content (VTEC) And Sunspots number (Ri) at maximum height of the layer E h=130km for the year 2014. A, B represents December and June C, D represents March and September.

Fig. 7 shows the relationship between VTEC values and Ri at a Height, h=130 km (E layer). Where R^2=0 for December for year 2014.The relationship is good for month June where R^2=0.65 the relationship is weak for the month of March R^2=0.128 For September the relationship is very weak where R^2=0.006 and linear regression equations respectively. A-TEC (TECU) =1.756-0.000495Ri; B-TEC (TECU) =1.860+0.001623Ri; C-TEC (TECU) =I.156-0.003767Ri; D-TEC (TECU) =1.9139-0.000815Ri. The relationship between TEC and Ri for 2018 is similar to 2008 at 130km elevation due to the decrease in solar activity in both years.

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

1-Choose IRI2001-TEC.	It came in agreement with the findings of the researcher Ramazan Atıci [15]
2-The values of TEC begin to increase from 6 am LT and reach the maximum value at 12 am LT.	This is consistent with the researcher Dragan Blagojevic, [9]
3-The relationship between sunspots and the Total electronic content is a positive and a straight line.	This is consistent with the researchers Laith, Y. Yaseen, Fahmy Abdel-Rahman [5][8]
4-In Summer TEC values increase as well as impressions hours in comparison to other seasons.	This is consistent with the researcher Chapman, G. E [20]

5. Conclusions:

1. The closest option to GPS-TEC values from the three options for the empirical model (IRI2016) is an option IRI2001.

2. TEC values at height E layer for 2014 the number of impression Time increases by one hour for March and September then 2008, 2018. The number of hours of impressions remains constant for June. The number of hours for month of December increases two hours and it becomes 12 hours.

3. The maximum value of TEC for the year 2008, 2018 for E layer is in June than September, March and December.

4. The maximum value for TEC 2014 for the E layer is in December, than June, March and September. This means anomalies due to increased solar activity.

5. The values of TEC increase with the increase of solar activity so that 2008 values are lower than 2014 values for all months.

6. The relationship between TEC and Ri for 2008 and 2014 at an altitude of 130 km is moderate in December 2008 and strong for March 2008. And weak for June and be moderate in June and weak for the rest month for 2014 this means strong correlation between the total electron content (TEC) of ionospheric layer E and sunspot number in most months, especially in the years of low solar activity for solar cycle 24.

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