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A study of the correlation between sunspot number and solar flux during solar cycle 24

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Abstract

In this research, a study of the behavior and correlation between sunspot number (SSN) and solar flux (F10.7) have been suggested. The annual time of the years (2008-2017) of solar cycle 24 has been adopted to make the investigation in order to get the mutual correlation between SSN) and F10.7. The test results of the annual correlation between SSN & F10.7 is simple and can be represented by a linear regression equation. The results of the conducted study showed that there was a good fit between SSN and F10.7 values that have been generated using the suggested correlation equation and the observed data.

Key words
Activity - sunspots, solar flux, solar activity, solar cycle, and correlation.

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دراسة الارتباط بين عدد البقع الشمسية و الفيض الشمسي للدورة الشمسية 24

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الخلاصة

في هذا البحث، تم اقتراح دراسة السلوك والارتباط بين عدد البقع الشمسية (SSN) والفيض الشمسي (F10.7). تم اعتماد الوقت السنوي للسنوات (2008 - 2017) من الدورة الشمسية 24 لإجراء التحقيق من أجل الحصول على العلاقة المتبادلة بين SSN و F10.7. نتائج اختبار الارتباط السنوي بين SSN و F10.7 بسيطة ويمكن تمثيلها بمعادلة انحدار خطية. أظهرت نتائج الدراسة التي أجريت أن هناك تناسقًا جيدًا بين قيم SSN و F10.7 التي تم إنشاؤها باستخدام معادلة الارتباط المقترحة والبيانات المرصودة.

Introduction

The 24th solar cycle has been strongly weak as calculated by the sunspot number (SSN), in addition it's the smallest since the early age of the universe. The low activity of the solar cycles has been associated to the weakness of the strength polar field in cycle 23 [1]. The sun magnetic activity means the complex of hydrodynamic processes and electromagnetic in the atmosphere of the sun. There are many active regions in the sun such as plages and spots in the photosphere, flocculae in the chromosphere and prominences in the corona of the Sun. The analysis of these regions is required to study the physics of magnetic activity and magnetic field of the Sun. the activity phenomena and the solar cycle which are interesting physical processes that are not well understood. The origin and formation of the sunspot with their cycle activity also remains ambiguous [2].

Sunspots are appearing as dark areas on the surface of the Sun. Each sunspot has a dark core, the umbra and a less dark halo, the penumbra. The existence of penumbra is important to discriminate between the sunspots and usually smaller pores. The evolution of the solar cycle can be recorded by the sunspot number (SNN) which is the counting of the sunspot and groups of sunspots on the surface of the Sun. this number can play role on the long-term evolution of the solar cycle and the probable long-term influence of the sun on the vicinity of the earth [3, 4]. The number of sunspots that has been registered over various centuries are employed as the proxy of the solar activity level. Furthermore, monthly data of sunspot numbers are available since 1749. Southworth was coined the wavelengths solar radio emissions in 1945 [5].

The F10.7 has been considered to be one of the common parameters that used for measure the solar activity. This flux (F10.7) considered to an extension of the solar radio radiation intensity determined via the frequency of 2800MHz (a wavelength of 10.7cm) or the wavelength 10.7cm, in average of hour. It measured by the solar flux units, where 1 solar flux units equal $10^{-22}W.m^{-2}.Hz^{-1}$ [6]. F10.7 was considered the indicator of a solar activity, and serves for determining other solar amounts. It's been most utilized in astronomy, geophysics, climate modelling, communications, satellite system, and meteorology etc. [7]. The applications of solar radio flux use as a simple solar activity level indicator, as a replacement for other solar ejections or amounts which are most complex to obtain, and also as a usually available data for antenna standardization [8]. It includes a time-varying medley of up to three main emission technique that may be different distribute through the solar disk and may change independently for time. It includes thermal free ejection from the chromosphere and corona, and from focus of plasma propped in the chromosphere and corona by active region magnetic fields [9]. The amount of F10.7 that is observed as the flux density and vastly indicate as the flux, in actuality, is the, estimate of total solar flux released as every sources on the solar disk, for 1hour era and 10.7 cm wavelength. The solar emissions are sensitive to the conditions in lower corona and the upper chromosphere, the 10cm wavelength region is best one for monitoring the level of solar activity [10].

There have been many studies focused on the prediction of the space weather, for instances: multiplicative autoregression sample for monthly prediction values of F10.7 [11], as well as the prediction of the solar activity via algorithms network neural [12]. (Vitinsky et al. 1986) have studied solar cycles 18 to 20 and suggest that correlation between SSN and F10.7 does not display linear relation over the activity of solar cycle [13]. The history of the evolution of solar flux has been reconstructed and developed a method to predict F10.7 by (Zhao & Han, 2008) [14]. In 2015 (Bruevich & Yakunina) found that the minimum values of correlation coefficients between F10.7 and SSN, happen twice through the 11-year cycle [15]. Finally in 2018 (Tiwari & Kumar) were determine the correlation coefficient between SSN and F10.7 to be 0.97[16]. The current work is concentrated on the study the correlation between sunspot number SSN and solar flux F10.7 to know the behavior among them because of the importance of the two parameters to study solar activity.

Data selection

In this research, the data on sunspot numbers (SSN) were obtained from Marshall Space Flight Center, USA (https://solarscience.msfc.nasa.

gov/SunspotCycle.shtml). Meanwhile, the data for the solar flux (F10.7) were downloaded from WDC-SILSO, Royal Observatory of Belgium, Brussels (http://www.sws.bom.gov.au/Solar/1/6) during the period from January 2008 to December 2017 through solar cycle 24.

Test and result

The aim of this study is to make an analytical study to investigate the behavior and variation of SSN and F10.7 in order to get the mutual correlation between SSN and F10.7 during the period (2008– 2017) of solar cycle 24.

In this work data have been taken monthly for mean total SSN and F10.7 observed data for the year (2008–2017) of the solar cycle 24.

The monthly-observed SSN during (2008 – 2017) which have been chosen to be the studied time period. Table 1 shows the values of the observed SSN for every month of the chosen time period.

Table 1: Monthly -observed SSN during (2008-2017) determine in our study.

Years	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2008	4.1	2.9	15.5	3.6	4.6	5.2	0.6	0.3	1.2	4.2	6.6	1
2009	1.3	1.2	0.6	1.2	2.9	6.3	5.5	0.0	7.1	7.7	6.9	16.3
2010	19.5	28.5	24	10.4	13.9	18.8	25.2	29.6	36.4	33.6	34.4	24.5
2011	27.3	48.3	78.6	76.1	58.2	56.1	64.5	65.8	120.1	125.7	139.1	109.3
2012	94.4	47.8	86.6	85.9	96.5	92	100.1	94.8	93.7	76.5	87.6	56.8
2013	96.1	60.9	78.3	107.3	120.2	76.7	86.2	91.8	54.5	114.4	113.9	124.2
2014	117	146.1	128.7	112.5	112.5	102.9	100.2	106.9	130	90	103.6	112.9
2015	93	66.7	54.5	75.3	88.8	66.5	65.8	64.4	78.6	63.6	62.2	58
2016	57	56.4	54.1	37.9	51.5	20.5	32.4	50.2	44.6	33.4	21.4	18.5
2017	26.1	26.4	17.7	32.3	18.9	19.2	17.8	32.6	43.7	13.2	5.7	8.2

The monthly-observed F10.7 during (2008 – 2017) which have been chosen to be the studied time period. Table 2 shows the values of the observed F10.7 for every month of the chosen time period.

Table 2: Monthly -observed F10.7 during (2008-2017) determine in our study.

Years	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2008	70.4	69.9	69.6	69.6	69.7	69.4	69.0	68.9	68.6	68.2	68.1	68.1
2009	68.2	68.3	68.5	68.7	68.8	69.1	69.8	70.9	72.0	72.8	73.3	73.9
2010	74.7	76.0	77.5	79.0	80.6	81.6	82.0	82.9	85.1	88.8	92.4	95.1
2011	97.7	100.3	104.6	111.1	118.7	126.2	132.5	135.1	135.4	136.2	138.2	141.3
2012	144.3	147.1	147.2	143.9	139.7	135.4	133.4	133.9	134.1	134.6	136.5	136.9
2013	135.6	134.9	133.3	133.2	135.8	139.7	143.4	147.9	153.7	156	155.9	156.7
2014	158.4	159.6	163.5	165.7	164.2	163.3	161.8	157.4	150.8	146.2	143.5	141.0
2015	138.1	134.9	131.1	127.9	125.2	121.3	117.7	116	115.5	114	111.2	108.1
2016	105.1	103.5	101.7	99.5	97.0	94.3	91.9	90.0	87.8	86.6	85.4	84.4
2017	83.9	82.9	82.4	81.7	80.7	80.0	79.2	78.2	77.5	76.7	75.8	75.2

The seasonal variation of the SSN and F10.7 has been investigated for the four seasons in Iraq of the studied period. Each year is divided into four seasons namely Winter (December–January–February), Spring (September –October – November), Summer (June –July–August), and Autumn (September – October – November) which is shown in Fig.1. Table 3 shows the values of the Seasonal observed SSN of the studied period.

Table 4 shows the values of the seasonal observed F10.7 of the studied period.

Table 3: Seasonal -observed data of SSN during (2008-2017) determine in our study.

Seasonal	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Winter	2.7	6.3	24.2	61.6	66.3	93.7	125.3	72.6	44.0	20.2
Spring	7.9	1.6	16.1	71.0	89.7	101.9	117.9	72.9	47.8	23.0
Summer	2.0	3.9	24.5	62.1	95.6	84.9	103.3	65.6	34.4	23.2
Autumn	4.0	7.2	34.8	128.3	85.9	94.3	107.9	68.1	33.1	20.9

Table 4: Seasonal -observed data of F10.7 during (2008-2017) determine in our study.

Seasonal	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Winter	69.5	70.1	81.9	113.1	142.8	142.4	153.0	127.0	97.7	80.7
Spring	69.6	68.7	79.0	111.5	143.6	134.1	164.5	128.1	99.4	81.6
Summer	69.1	69.9	82.2	131.3	134.2	143.7	160.8	118.3	92.1	79.1
Autumn	68.3	72.7	88.8	136.6	135.1	155.2	146.8	113.6	86.6	76.7

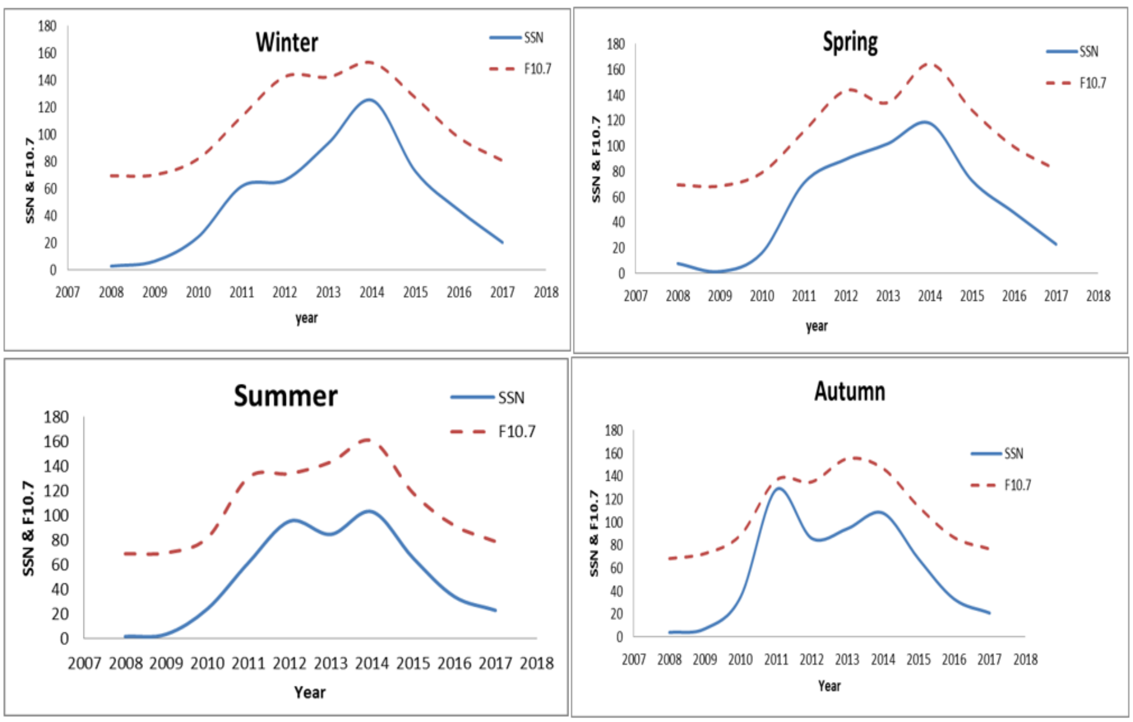

Fig. 1: The Seasonal variation of the (SSN & F10.7) for four seasons in Iraq of the study.

The largest mean total sunspot number and solar flux were in 2014 with mean total sunspot number and solar flux of 113.6, 156.3 respectively. This indicates that the solar cycle maximum for the 24 cycle was occurred in 2014. Table 5 shows the values of the annual behavior of the SSN and F10.7 of the studied period.

The smallest mean total sunspot number and solar flux were in 2008 and 2009 and increased in 2010, 2011, 2012, 2013 and 2014, then decreased in 2015, 2016 and 2017 which is shown in Fig.2.

Table 5: Annual-observed data of (SSN) & (F 10.7) during (2008-2017) determine in our study.

year	SSN (Obs.)	F 10.7(Obs.)
2008	4.2	69.1
2009	4.8	70.4
2010	24.9	83.0
2011	80.8	123.1
2012	84.4	138.9
2013	93.7	143.8
2014	113.6	156.3
2015	69.8	121.8
2016	39.8	93.9
2017	21.8	79.5

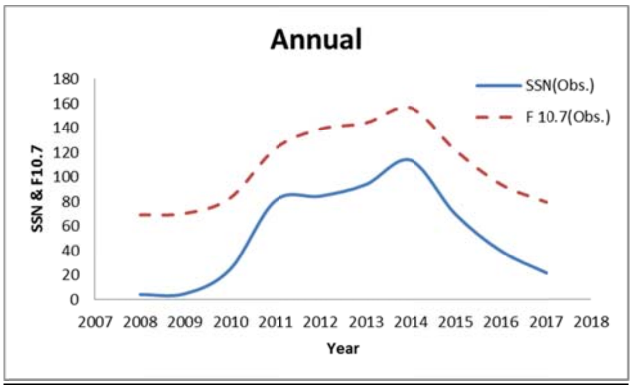

Fig.2: The annual observed data of SNN and F10.7 during (2008-2017) determine in our study.

Investigating the annual and seasonal correlation between the studied parameter (SSN) and (F10.7). Figs. 3 and 4 show data of the annual and seasonal correlation between the F10.7 and SSN for the years (2008-2017) of solar cycle 24.

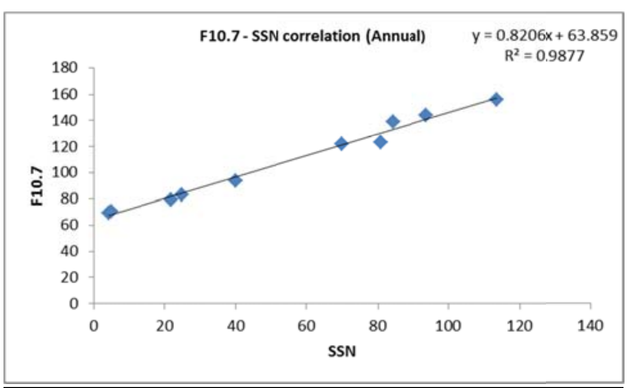

Fig.3: Correlation relationship between F10.7 and SSN (Annual).

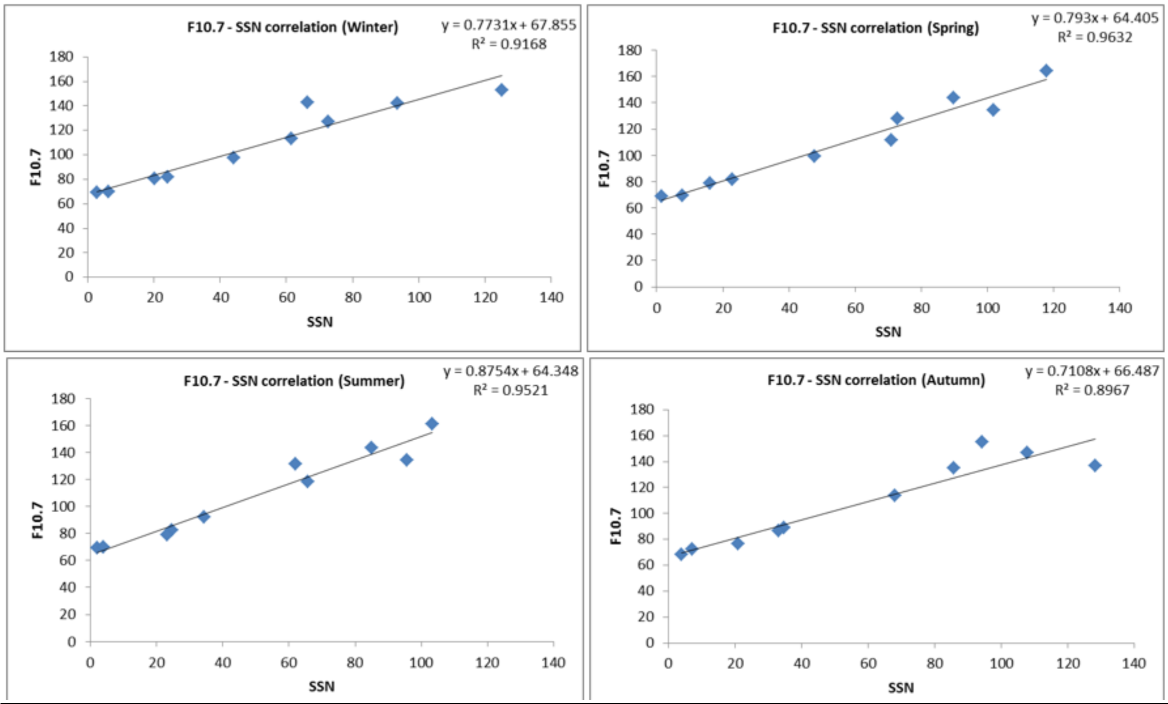

Fig.4: Correlation relationship between F10.7 and SSN (Seasonal).

In this work, we performed a statistical analysis of the calculated data sets for correlation study between F10.7 and SSN. Depending on the previous steps, the annual and seasonal values will be predict on the suggested equation (True line equation) (polynomial equation of N^{th} order). Therefore, we proposed the equation of the correlation between SSN and F10.7 by the following equation:

$$Y = \sum_{n=0}^{\infty} a_{nX^n} \tag{1}$$

$$Y = a_0 + a_1 X^1 + a_2 X^2 + a_3 X^3 + a_n x X^n \tag{2}$$

$$F10.7 = \sum_{n=0}^{\infty} a_n \ (SSN)^n \tag{3}$$

The mutual correlation between F10.7 and SSN have been determined for the annual time of the years (2008-2017). According to the result of the statistical analytical study, the mutual correlation equation has been found to be a polynomial equation of the First Order. Table 6 shows samples of the correlation coefficients (a_0 & a_1), correlation parameter (R^2) and the root mean square error (RMSE) for different relations of the annual and seasonal of the years (2008 – 2017) of solar cycle 24.

Table 6: Samples of the correlation coefficients and correlation parameter of the year (2008- 2017).

		a_o	a_1	R^2	RMSE(SSN)	RMSE(F10.7)
Annual		63.859	0.8206	0.9877	3.4	2.8
Seasonal	**Winter**	67.8550	0.7731	0.9168	7.5	5.8
	Spring	64.4050	0.7930	0.9632	6.4	5.1
	Summer	64.3480	0.8754	0.9521	6.6	5.8
	Autumn	66.4870	0.7108	0.8967	9.6	6.8

A comparison of the behavior of the observed and predicted values (SSN & F10.7) that have been computed using the suggested correlation equation (F10.7=0.8206 SSN+63.859) in Eq. (3) (Current work) with the observed data have been presented in Table 7.

Table 7: Theoretical and Predicted value of the SSNs & F10.7 for the annual Time during (2008 – 2017).

Annual				
	SSN		**F10.7**	
Year	**Obs.**	**Pred.**	**Obs.**	**Pred.**
2008	4.2	6.4	69.1	67.3
2009	4.8	7.9	70.4	67.8
2010	24.9	23.3	83.0	84.3
2011	80.8	72.2	123.1	130.1
2012	84.4	91.5	138.9	133.1
2013	93.7	97.5	143.8	140.8
2014	113.6	112.6	156.3	157.1
2015	69.8	70.5	121.8	121.1
2016	39.8	36.6	93.9	96.5
2017	21.8	19.1	79.5	81.8

The behavior of the observed and predicted values of the SSN & F10.7 parameters that have been computed using the suggested equation for the annual and seasonal value of the years (2008 – 2017) of solar cycle 24 as showing in Fig.5.

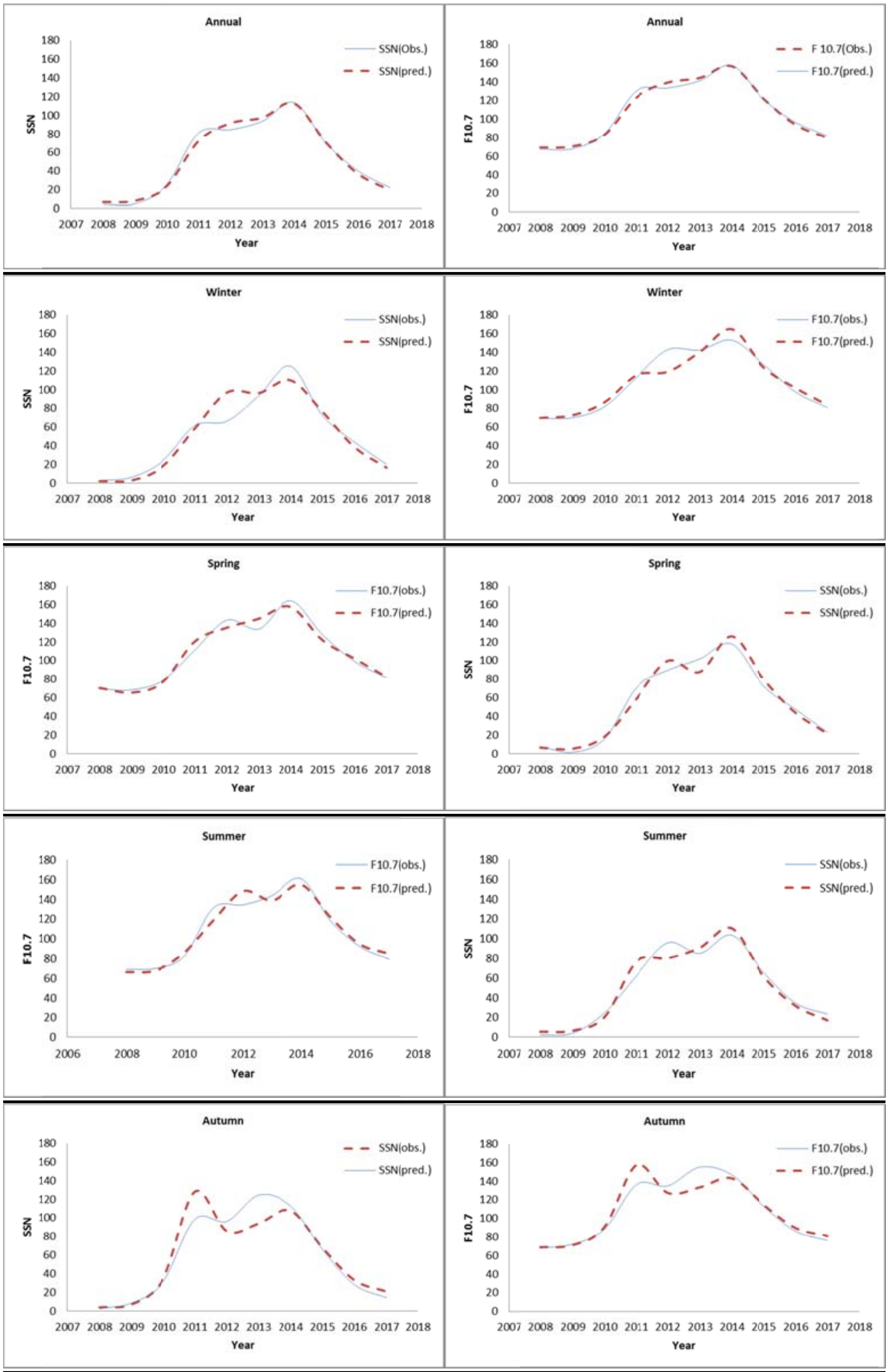

Fig. 5: The observed and predicted value of the SSN and F10.7 of the annual and seasonal during (2008-2017) determine in our study.

Discussion and conclusions

The F10.7 is directly proportional to solar activity which depends on the number of sunspots. There is a high affiliation relation between the solar flux and the number of sunspots. From the correlation relationship we note it is a linear relationship which means there is a close relationship. The results calculated from the suggested equation gave good results when compared to the observed values in which we were able to calculate one of the coefficients in terms of the other parameter. The present results indicated a high affiliation relation between SSN and F10.7 as expected since both generate from active regions of the sun.

From the above discussion, we can summarize the following conclusions:

1. The mutual correlation between F10.7 and SSN is simple and can be denoted by a simple mathematical equation “linear regression equation”.
2. The values determined from the suggested mutual correlation equation gave a good fit with the other values produced from the mutual correlation equation.
3. The correlated relationship between F10.7 and SSN is a polynomial which represented by a first order polynomial equation.
4. A good results generated from the suggested mutual correlation equation was closer to the observed data.

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