The Impact of Sunspots Number on Critical Frequencies f_oF_2 for the IONOSPHERIC Layer-F_2 Over Erbil Station During the Down Phase of Solar Cycle 24

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Abstract

The ionosphere layer (F_2) is known as the most important layer for High frequency (Hf) radio communication because it is a permanent layer and excited during the day and night so it is able to reflect the frequencies at night and day due to its high critical frequency, and this layer is affected by daily and monthly solar activity. 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 (2015, 2016, 2017, 2018, 2019, 2020) which represents the down phase of the solar cycle 24 over Erbil station (36° 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 caried 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.

Key Words: Ionospheric Layer F, Critical Frequency (f_oF_2), IRI2016 Model, Solar Cycle 24, Sunspots Number, Down Phase.

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Introduction

The ionosphere is a layer of the Earth's atmosphere that extend from upper center of the Mesosphere to the end of the Exosphere. It was divided into four diurnal regions according to different electronic density. And they are D, E, $F_1$and F_2 (Y & H. Ali, 2019). This layer ionized by solar and cosmic radiation, and they are important for waves propagations. 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 (Ouattara & Zerbo, 2011) (Diabate, Zerbo, & Ouattara, 2019) (Faynot & Villa, 1979).

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.

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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 F2 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 (A.D, 2011) (D. & P., 1998).

The Sun contains a blast that increases at times. Is on the increase Solar activity shows glare that may cool down and dark spots appear It is relatively cold in the photosphere, its temperature is about (4600) K^o is in the form of groups known as Sunspots caused by huge explosions occurring in the Sun and then it cools gradually (Campbell, 1997) (Craig, 1965). Its number is between (0-200) When they are few in number, the solar activity is quiet and Ri Known as minima (Sunspots), when the number is large the solar activity is high, then they are called Sunspots maxima (Y & H. Ali, 2019) (E., M. B., B., & M., 2019).

The global Sunspot count is calculated Through (Ri) (International Sunspot number) represents in the following relationship (2015 ،مجماں) (Akasofu & S, 1972).

$$Ri = K\,(10G + I) \qquad (1)$$

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 (Lakshimi, Reddy, & Dabas, 1998) (Kleczek, 1952).

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.

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 Erbil 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. Erbil station in Iraq (https://embedgooglemaps.com, n.d.)

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 critical frequency of ionospheric F^2 layer (f^oF^2) is one of the most important parameters in the ionospheric research which is observed regularly by several observatories. In recent studies the hourly averaged value of f_oF_2 were taken into consideration (http://wdc.nict.go.jp/IONO/HP2009/ISDJ/indexE. html, n.d.). In this investigation the 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 (https://omniweb.gsfc.nasa.gov/vitmo/iri vitmo.html, n.d.). 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 (D., L. A., B., & T., 2011) (S. K., et al., 2015).

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, 21December) 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 in this study. The critical frequency of an ionospheric layer is the maximum frequency that can be radiated vertically up wards by a radio transmitter and be returned to earth. This condition corresponds to a wave that travels to the top of the layer. Where the electron density is at its maximum value, before its angle of refraction becomes 90^o. The angle of incidence is 0^o (Bandopadhyaya, 1994).

Therefore $\sin 0^o = 0 = \sqrt{1-(81N_{max} / f_o^2)}$ (2)

And then $f_o^2 = 81 N_{max} = 9\sqrt{N_{max}}$ (3)

Where f_o is the critical frequency, N_{max} is maximum electron density.

Critical frequency are the optimal form that gives an indication of the state of the ionosphere and the nature of the propagation of Radio waves at **HF -** scale. Radio waves of frequencies equal to or less than the critical frequency that will definitely be reflected from the layer irrespective of the angle of incidence. The critical frequency depends on solar zenith angle χ and the mean Sunspot number Ri, according to the following formula (Hall & Barclay, 1989) (Rishbeth, 1988).

$f_o = A(1 + aR)(\cos x)^n$, $n = 0.25$ (4)

Where A and a are constants. Where x varies with time of day, season, and latitude and so f_o varies regularly with the Sunspot number (Solar cycle variations).

In this research the linear equation below will be used to find the relationship the critical frequencies (f_oF_2) and the Sunspots number (Ri) (F. A., 2015).

The linear equations for the relationship between f_oF_2 and Ri (Sunspots number)

Were:

Spring $f_oF_2 = 0.0231$ Ri $+ 7.4974$ (5)

Summer $f_oF_2 = 0.0208$ Ri $+ 5.6078$ (6)

Autumn $f_oF_2 = 0.0024$ Ri $+ 8.5702$ (7)

Winter $f_oF_2 = 0.0647$ Ri $+ 5.298$ (8)

And for the relationship between f_oF_2 and Rn (Sunspots number in northern half of the Sun), were:

Spring $f_oF_2 = 0.0506$ Rn $+ 7.5858$ (9)

Summer $f_oF_2 = 0.0084$ Rn $+ 6.8837$ (10)

Autumn $f_oF_2 = 0.0066$ Rn $+ 8.5525$ (11)

Winter $f_oF_2 = 0.031$ Rn $+ 8.2918$ (12)

Whereas for the relationship between f_oF_2 and Rs (Sunspots number in southern half of the Sun), were:

Spring $f_oF_2 = 0.0216$ Rs $+ 8.1186$ (13)

Summer $f_oF_2 = 0.0096$ Rs $+ 6.8625$ (14)

Autumn $f_oF_2 = 0.0017$ Rs $+ 8.6551$ (15)

Winter $f_oF_2 = 0.0304$ Rs $+ 7.826$ (16)

Application and Discussion

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 Erbil station (36.188679 ° N 44.013390 ° E), for the days of spring equinox and autumn equinox and winter summer solstices days for the years (2015-2020) with low Solar activity represented by the down phase, were compared with the total number of

Sunspots that were obtained on it from the site Silso (www.sidc.be/silso/datafiles, n.d.). 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. Figure (2) represents the solar cycle 24 and the deflection rates of critical frequencies f_oF_2 for solstice days and equinoxes for years (2015-2020) for solar cycle 24 as shown in Tables (1).

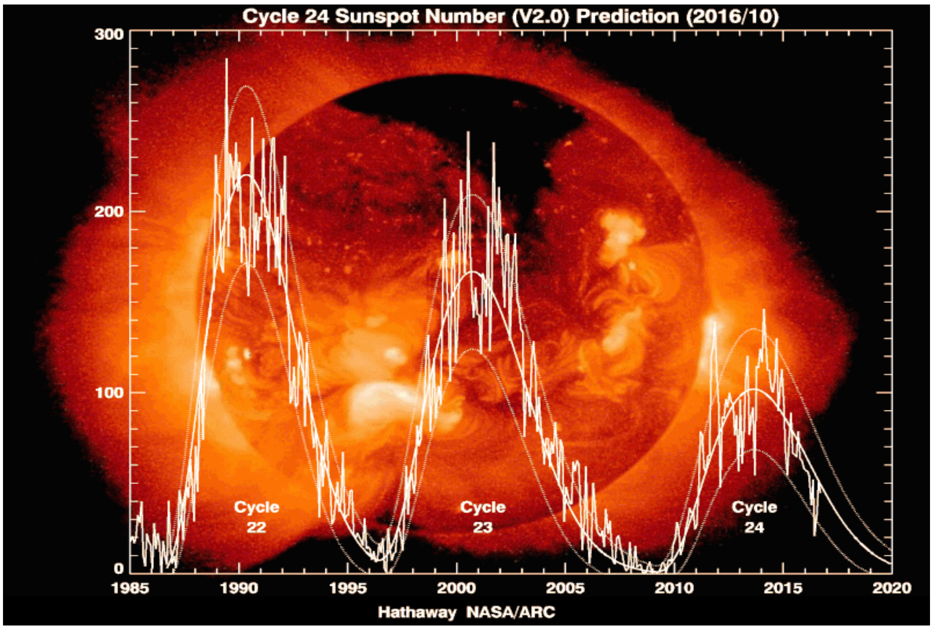


Figure 2. Solar cycle 24 (www.sidc.be/silso/datafiles, n.d.)

Table 1. The critical frequency (f_oF_2) value from IRI2016 at altitude 400 km (F_2 layer) for the years (2015 – 2020) for days of solstice and equinox over Erbil station

Year	f_oF_2 2015				f_oF_2 2016				f_oF_2 2017				f_oF_2 2018				f_oF_2 2019				f_oF_2 2020			
Time LT(hour)	21 Mar	21 Jun	23 Sep	21 Dec	21 Mar	21 Jun	23 Sep	21 Dec	21 Mar	21 Jun	23 Sep	21 Dec	21 Mar	21 Jun	23 Sep	21 Dec	21 Mar	21 Jun	23 Sep	21 Dec	21 Mar	21 Jun	23 Sep	21 Dec
0	3.459	6.509	5.860	3.176	3.723	5.182	4.795	3.092	2.942	5.601	3.370	2.899	2.416	6.069	2.964	2.719	3.899	4.196	2.965	2.719	2.418	4.197	0	0
1	3.690	6.140	5.658	3.534	3.932	4.757	4.842	3.478	3.212	5.193	3.489	3.242	2.733	5.680	3.103	3.053	4.093	3.728	3.103	3.054	2.734	3.729	0	0
2	3.807	5.788	5.508	3.796	4.030	4.389	4.746	3.773	3.360	4.830	3.484	3.499	2.919	5.321	3.123	3.311	4.179	3.346	3.123	3.312	2.919	3.345	0	0
3	3.589	5.488	5.116	3.765	3.811	4.114	4.399	3.465	3.202	4.546	3.209	3.366	2.777	5.029	2.846	3.184	3.950	3.089	2.869	3.185	2.777	3.088	0	0
4	3.249	5.402	4.836	3.291	3.457	4.064	4.125	3.031	2.884	4.485	2.947	2.935	2.485	4.955	2.590	2.759	3.586	3.064	2.610	2.759	2.484	3.063	0	0
5	3.288	5.747	5.267	3.047	3.500	4.415	4.483	2.825	2.914	4.835	3.183	2.711	2.505	5.303	2.788	2.505	3.631	3.421	2.809	2.504	2.504	3.420	0	0
6	3.991	6.432	6.542	3.475	4.243	5.096	5.579	3.287	3.541	5.517	3.982	3.095	3.052	5.987	3.498	2.747	4.400	4.098	3.523	2.746	3.049	4.097	0	0
7	5.057	7.048	8.097	4.474	5.381	5.723	6.897	4.337	4.479	6.141	4.904	3.993	3.849	6.608	4.302	3.364	5.586	4.734	4.331	3.362	3.844	4.733	0	0
8	6.018	7.348	9.319	5.585	6.411	6.023	7.915	5.515	5.313	6.441	5.582	4.993	4.545	6.908	4.881	4.035	6.662	5.035	4.913	4.033	4.540	5.034	0	0
9	6.753	7.513	10.115	6.428	7.190	6.139	8.598	6.404	5.978	6.573	6.076	5.753	5.130	7.057	5.322	4.554	7.465	5.114	5.352	4.552	5.123	5.114	0	0

10	7.400	7.813	10.665	6.883	7.851	6.364	9.117	6.870	6.608	6.821	6.540	6.162	5.737	7.330	5.771	4.855	8.132	5.282	5.799	4.854	5.727	5.281	0	0
11	7.927	8.213	10.985	7.031	8.380	6.718	9.445	7.012	7.138	7.188	6.883	6.294	6.268	7.712	6.119	4.969	8.657	5.601	6.144	4.967	6.256	5.599	0	0
12	8.151	8.478	11.026	7.056	8.599	6.979	9.495	7.018	7.361	7.448	6.950	6.316	6.494	7.973	6.192	5.020	8.873	5.856	6.213	5.018	6.479	5.853	0	0
13	8.070	8.496	10.934	7.071	8.511	7.005	9.390	6.996	7.276	7.470	6.820	6.328	6.411	7.990	6.060	5.095	8.782	5.885	6.075	5.093	6.395	5.881	0	0
14	7.903	8.330	10.897	6.955	8.337	6.852	9.323	6.857	7.108	7.312	6.706	6.223	6.247	7.826	5.935	5.054	8.606	5.740	5.946	5.051	6.231	5.735	0	0
15	7.774	8.100	10.880	6.466	8.202	6.648	9.302	6.415	6.982	7.099	6.678	5.791	6.128	7.603	5.910	4.642	8.471	5.555	5.917	4.640	6.114	5.549	0	0
16	7.570	7.926	10.728	5.576	7.995	6.509	9.191	5.635	6.782	6.949	6.636	5.006	5.933	7.440	5.891	3.847	8.265	5.445	5.896	3.844	5.922	5.437	0	0
17	7.127	7.870	10.362	4.557	7.550	6.507	8.886	4.721	6.338	6.931	6.432	4.105	5.491	7.404	5.719	2.972	7.824	5.482	5.723	2.969	5.484	5.478	0	0
18	6.405	7.837	9.730	3.729	6.824	6.586	8.314	3.928	5.613	6.976	5.961	3.369	4.768	7.412	5.281	2.343	7.099	5.648	5.285	2.341	4.764	5.645	0	0
19	5.490	7.670	8.773	3.224	5.898	6.584	7.445	3.438	4.713	6.925	5.240	2.917	3.891	7.305	4.606	2.068	6.168	5.774	4.610	2.066	3.889	5.773	0	0
20	4.571	7.383	7.611	3.006	4.953	6.418	6.427	3.162	3.840	6.723	4.462	2.720	3.071	7.063	3.900	2.085	5.206	5.703	3.905	2.084	3.071	5.703	0	0
21	3.858	7.146	6.588	2.961	4.204	6.167	5.562	2.994	3.191	6.477	3.862	2.679	2.494	6.824	3.378	2.259	4.434	5.443	3.382	2.258	2.496	5.445	0	0
22	3.458	7.006	5.962	2.965	3.771	5.904	5.039	2.897	2.852	6.254	3.511	2.687	2.222	6.644	3.077	2.426	3.980	5.089	3.080	2.426	2.224	5.092	0	0
23	3.347	6.823	5.703	2.996	3.634	5.587	4.819	2.891	2.786	5.979	3.356	2.724	2.212	6.415	2.939	2.536	3.826	4.672	2.941	2.537	2.215	4.674	0	0

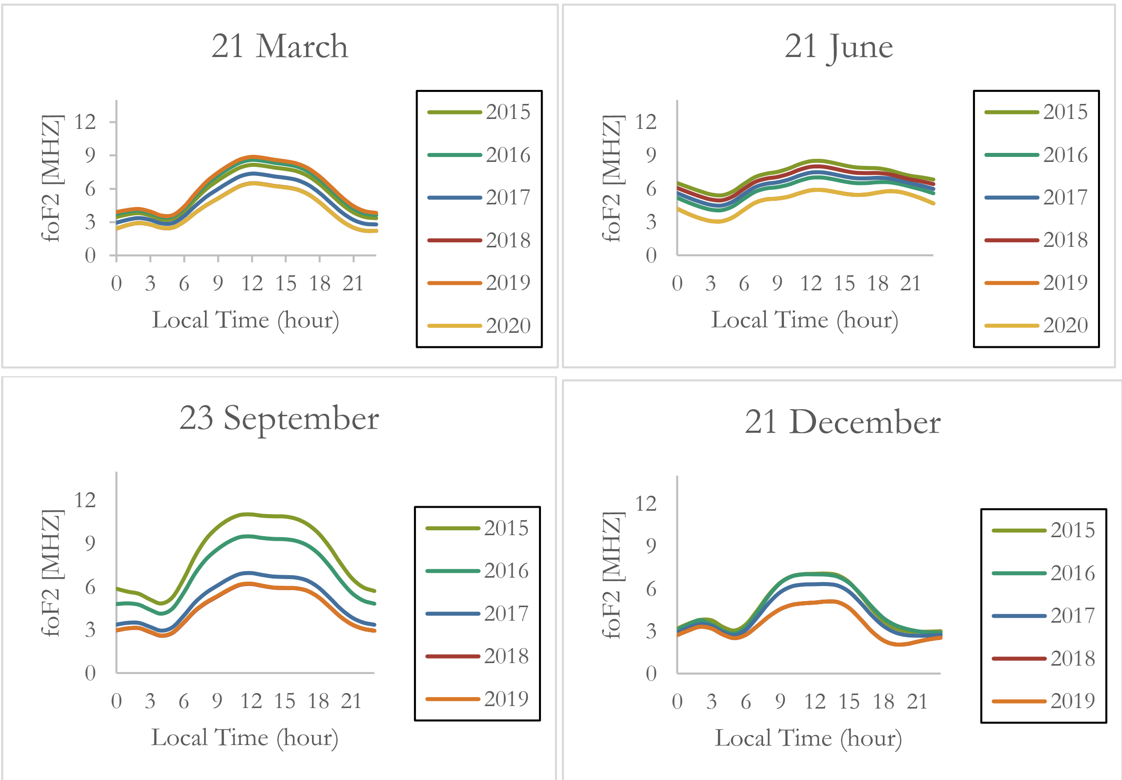


Figure 3. Daily changes on equinox and solstice days of f_oF_2 values obtained by International Reference Ionosphere models IRI2016 over Erbil station for Down phase (2015-2020) (solar activity periods).

Figure 3 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 Erbil station. In the year of the down phase (2015 - 2020) the f_oF_2 in March and September were the highest value at 07.00 Am to12.00 Pm. In June and December the f_oF_2 were the highest value at 07.00 Am to 13.00 Pm. For the last four months **(September, October, November and December)** of the year 2020 was not taken in to account because NASA and the National Oceanic and Atmospheric Administration (NOAA), with the participation of a committee of experts, announced in a remote media conference on Tuesday,15 September 2020, that the new solar cycle 25 is now underway, and according to the committee, the minimum period between the Solar Cycle 24 and Solar Cycle 25, the period during which the Sun is less active has occurred, in December 2019 when the number of Sunspots decreased (https://m.akhbarelyom.com, n.d.).

In this study, the empirical values of f_oF_2 for the Ionospheric layer F_2 were obtained from IRI2016 program option Ne Quick (https://omniweb.gsfc.nasa.gov/vitmo/iri vitmo.html, n.d.). As well as the values of Sunspot number for solar cycle 24 were applied in this program (www.sidc.be/silso/datafiles, n.d.). Figure (4) represents the monthly Sunspot numbers (Ri) for years (2015, 2016, 2017, 2018, 2019, 2020).

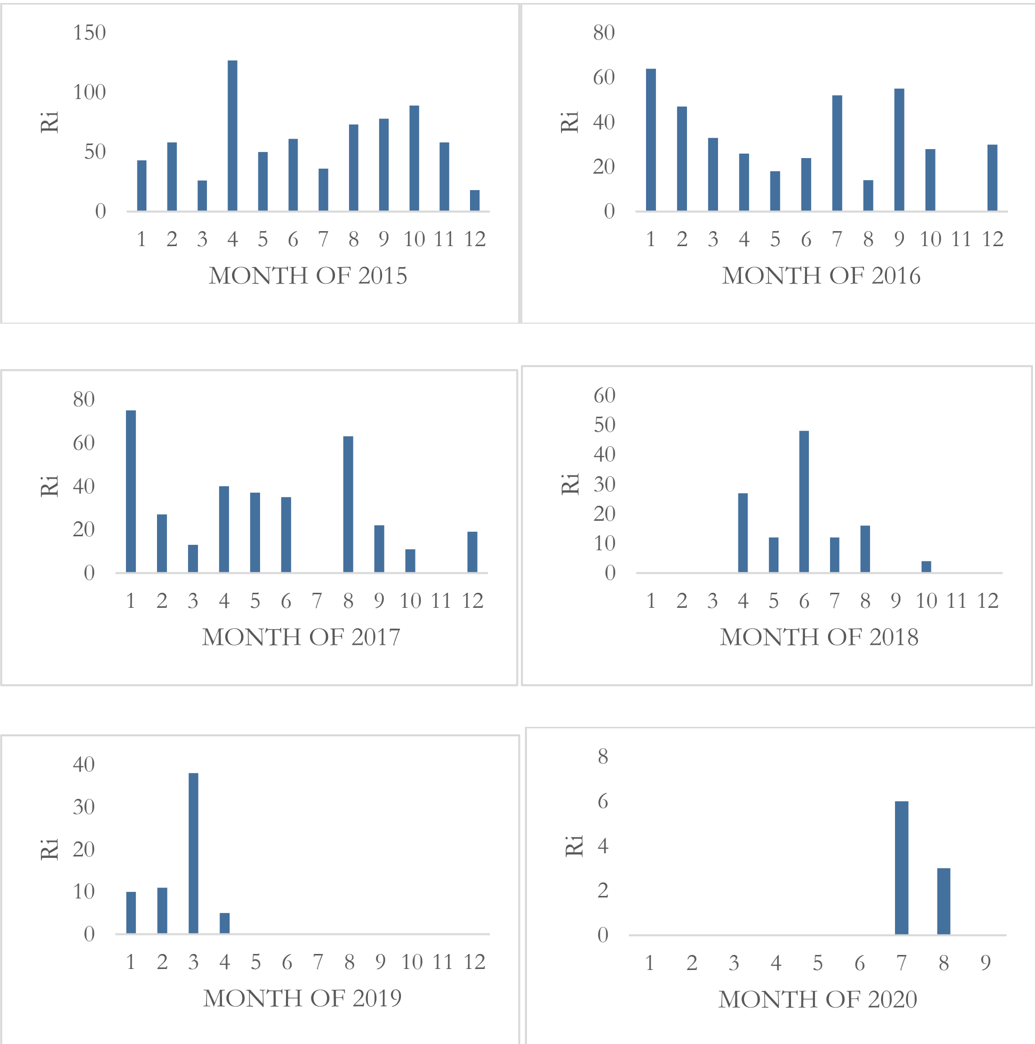


Figure 4. The monthly mean Sunspot numbers in 2015, 2016, 2017, 2018, 2019, 2020.

Statistical Investigation

Through data processing using the statistical program Minitab version 2018, the effect 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 (2015- 2020) which is represents (down phase) of the Solar cycle 24 over Erbil station as shown in Figures (5), (6), (7), (8), (9), (10).

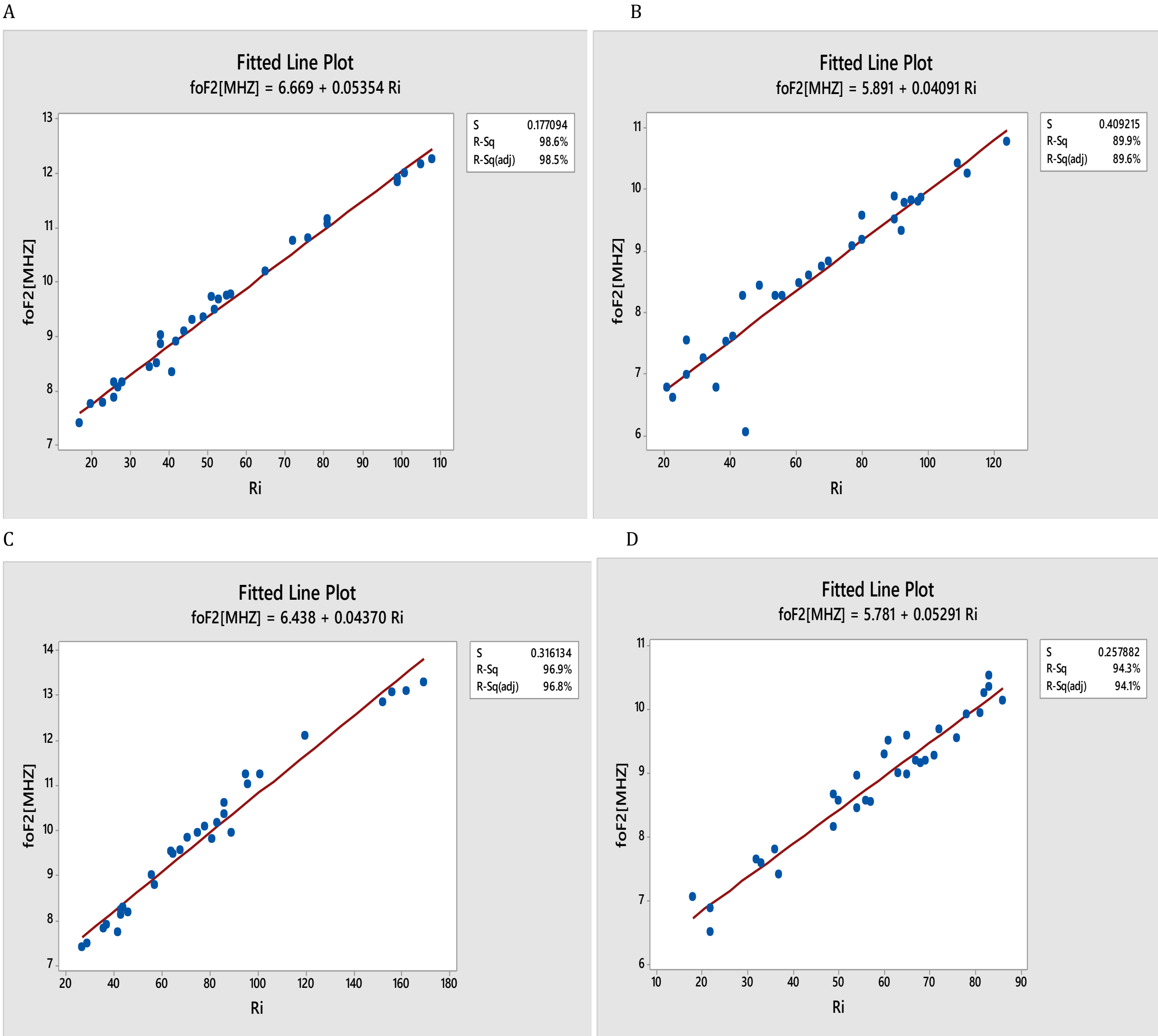


Figure 5. Relationship between Critical frequency f_oF_2 (MHZ) and Sunspots number (Ri) at maximum height of the layer F_2 h=400km for the year 2015, represents A-March, B-June, C-September and D-December

Figure (5) represents the relationship between f_oF_2 values and Ri at a Height, h=400 km (F_2 layer) for year 2015 over Erbil station 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 R^2=0.993 in March, and R^2=0.948 in June, and R^2=0.984 in September, and R^2=0.971 in December. And linear regression equations respectively as follows,

A- in March f_oF_2[MHZ]=6.669 + 0.05354Ri
B- in June f_oF_2[MHZ]=5.891 + 0.04091Ri
C- in September f_oF_2[MHZ]=6.438 + 0.04370Ri
D- in December f_oF_2[MHZ]=5.781 + 0.05291Ri

The relationship between f_oF_2 and Ri for 2015 is similar to (2016, 2017, 2018, 2020) at 400km elevation due to the decrease in Solar activity for these years.

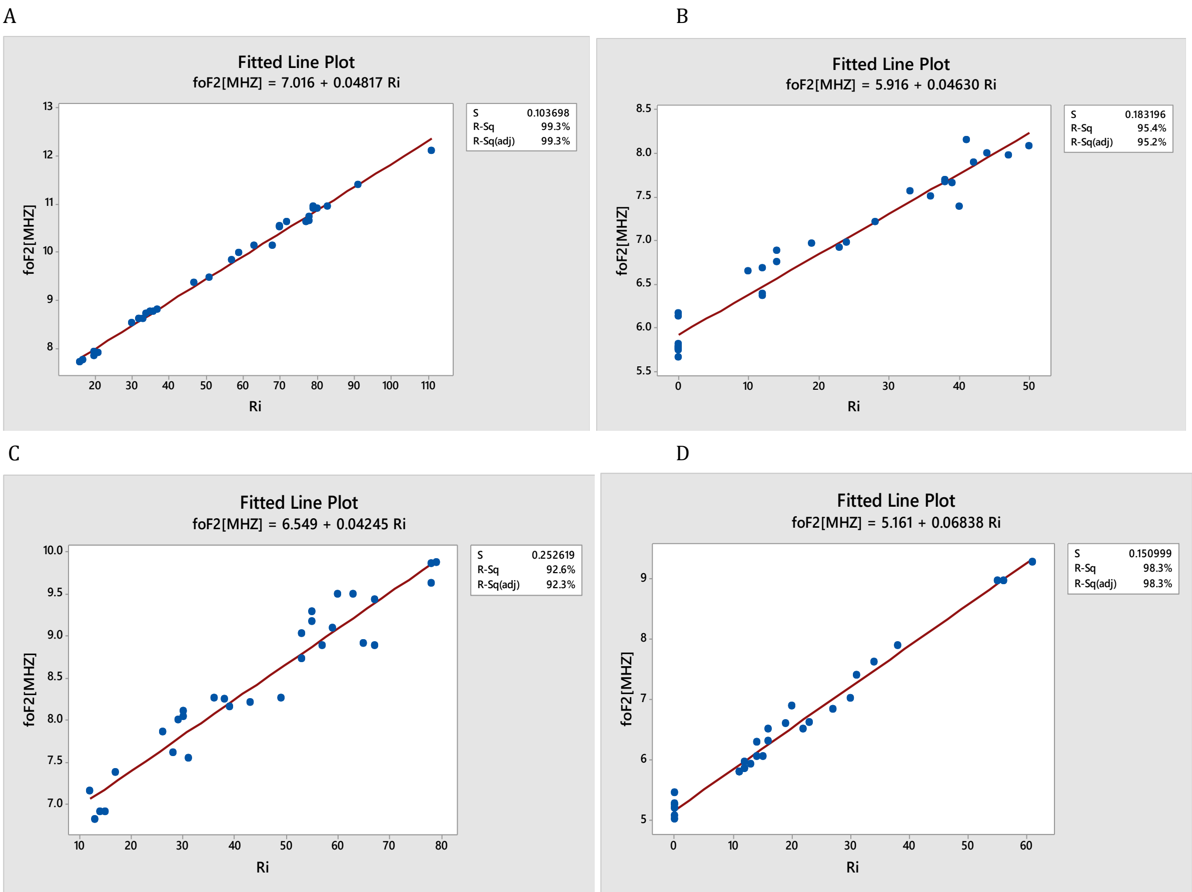


Figure 6. Relationship between Critical frequency f_oF_2 (MHZ) and Sunspots number (Ri) at maximum height of the layer F_2 h=400km for the year 2016, represents A- March, B- June, C- September and D-December

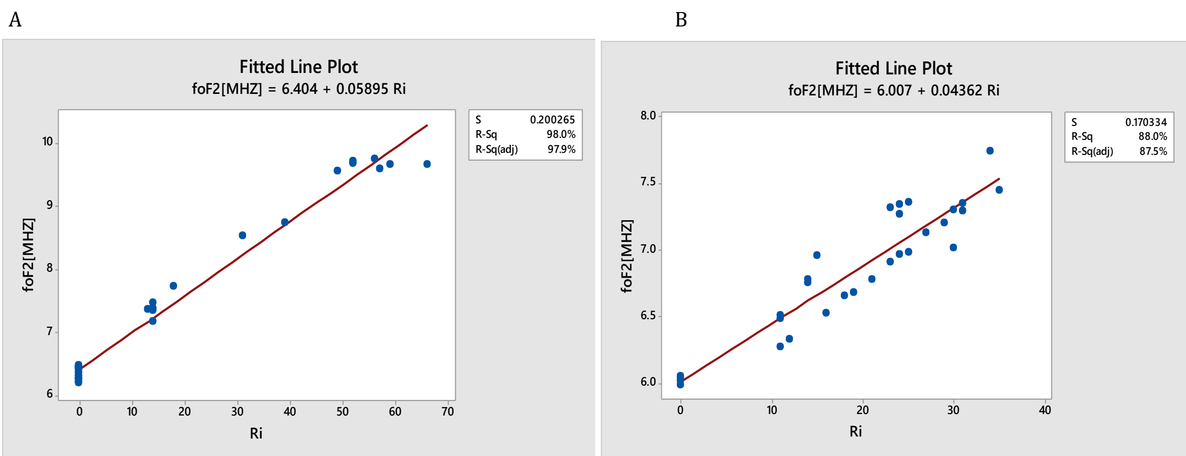
Figure (6) represents the relationship between f_oF_2 values and Ri at a Height, h=400 km (F_2 layer) for year 2016 over Erbil station at 12 Pm o'clock in A-March, B-June, C-September, D-December. According to the statistical output data is a good agreement between critical frequencies (f_oF_2) and Sunspot number (Ri), for all months where R^2=0.997 in March, and R^2=0.977 in June, and R^2=0.962 in September, and R^2=0.992 in December. And linear regression equations respectively as follows,

A- in March f_oF_2[MHZ]=7.016 + 0.04817Ri

B- in June f_oF_2[MHZ]=5.916 + 0.04630Ri

C- in September f_oF_2[MHZ]=6.549 + 0.04245Ri

D- in December f_oF_2[MHZ]=5.161 + 0.06838Ri



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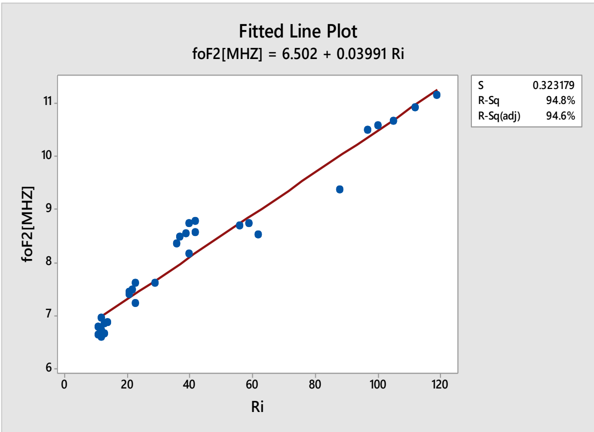

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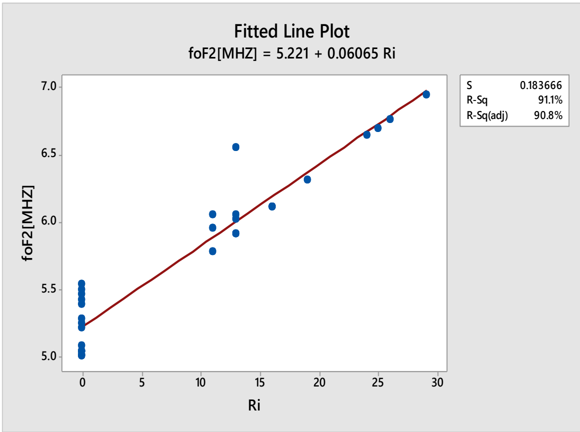


Figure 7. Relationship between Critical frequency f_oF_2 (MHZ) And Sunspots number (Ri) at maximum height of the layer F_2 h=400km for the year 2017, represents A- March, B- June, C- September and D- December

Figure (7) represents the relationship between f_oF_2 values and Ri at a Height, h=400 km (F_2 layer) for year 2017 over Erbil station 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 R^2=0.895 in March, and R^2=0.938 in June, and R^2=0.974 in September, and R^2=0.955 in December. And linear regression equations respectively as follows,

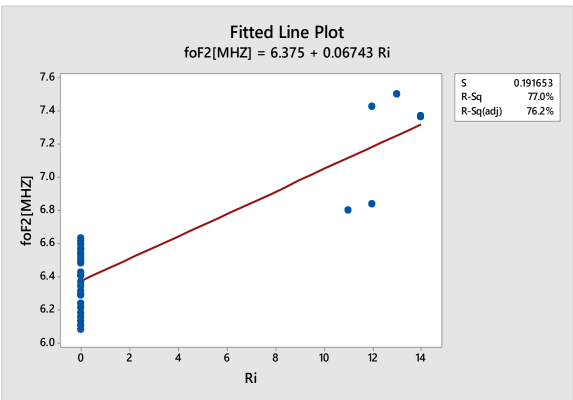
A- in March f_oF_2[MHZ]=6.404 + 0.05895Ri

B- in June f_oF_2[MHZ]=6.007 + 0.04362Ri

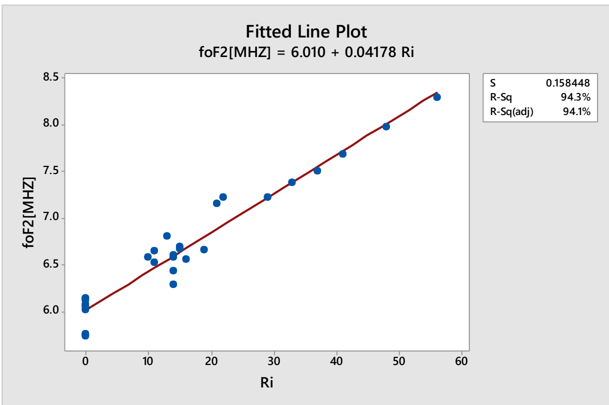
C- in September f_oF_2[MHZ]=6.506 + 0.03991Ri

D- in December f_oF_2[MHZ]=5.221 + 0.06065Ri

A



B



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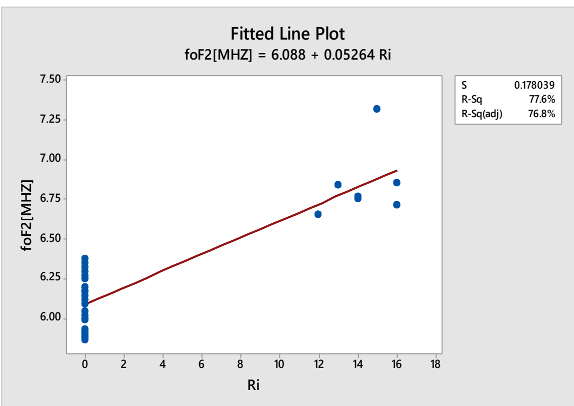

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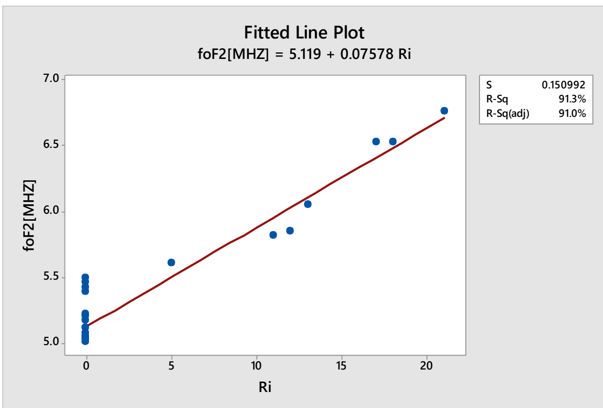


Figure 8. Relationship between Critical frequency f^oF^2 (MHZ) And Sunspots number (Ri) at maximum height of the layer F^2 h=400km for the year 2018, represents A- March, B- June, C- September and D- December

Figure (8) represents the relationship between f_oF_2 values and Ri at a Height, h=400 km (F_2 layer) for year 2018 over Erbil station 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 R^2=0.877 in March, and R^2=0.971 in June, and R^2=0.881 in September, and R^2=0.956 in December. And linear regression equations respectively as follows,

A- in March f_oF_2[MHZ]=6.375 + 0.06743Ri
B- in June f_oF_2[MHZ]=6.010 + 0.04178Ri
C- in September f_oF_2[MHZ]=6.088 + 0.05264Ri
D- in December f_oF_2[MHZ]=5.119 + 0.07578Ri

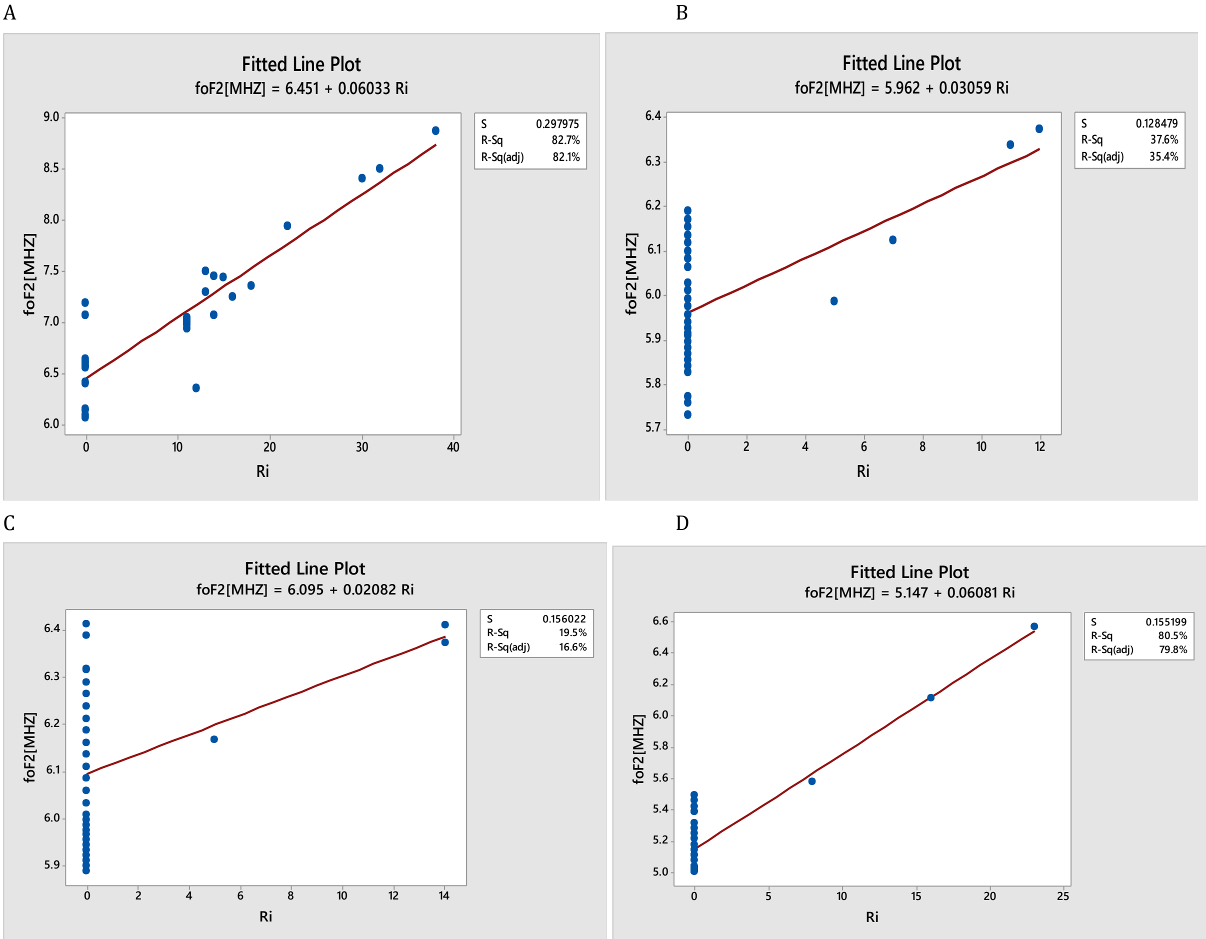
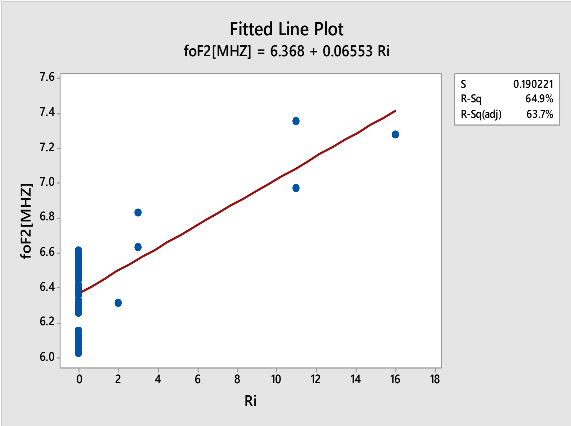


Figure 9. Relationship between Critical frequency f_oF_2 (MHZ) And Sunspots number (Ri) at maximum height of the layer F_2 h=400km for the year 2019, represents A- March, B- June, C- September and D- December

Figure (9) represents the relationship between f_oF_2 values and Ri at a Height, h=400 km (F_2 layer) for year 2019 over Erbil station 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 months where R^2=0.909 in March, and R^2=0.613 in June, and R^2=0.897 in December. For September the relationship was weak where R^2=0.441, Note (that the Solar Cycle 24 was end in September). And linear regression equations respectively as follows,

A- in March f_oF_2[MHZ]=6.451 + 0.06033Ri
B- in in June f_oF_2[MHZ]=5.962 + 0.03059Ri
C- in September f_oF_2[MHZ]=6.095 + 0.02082Ri
D- in December f_oF_2[MHZ]=5.147 + 0.06081Ri

A



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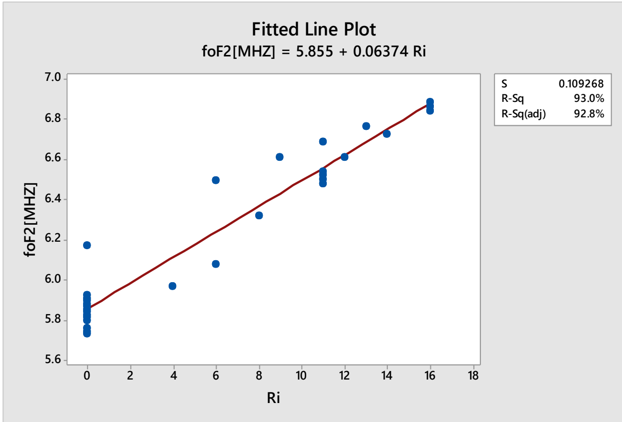

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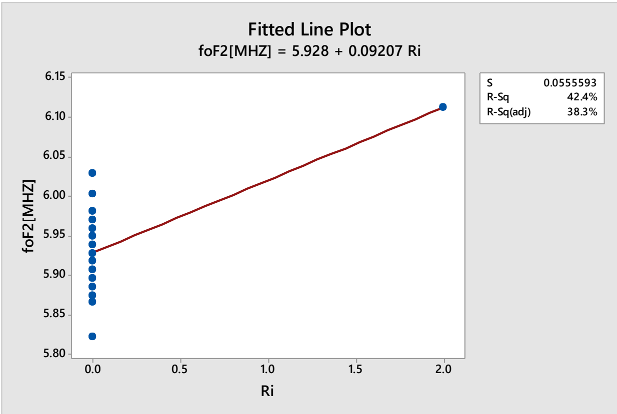

Figure 10. Relationship between Critical frequency f^oF^2 (MHZ) and Sunspots number (Ri) at maximum height of the layer F^2 h=400km for the year 2020, represents A- March, B- June, C- September and D- December

Figure (10) represents the relationship between f_oF_2 values and Ri at a Height, h=400 km (F_2 layer) for year 2020 over Erbil station at 12 Pm o'clock in A-March, B-June, C-September. According to the statistical output data is a good agreement between critical frequencies (f_oF_2) and Sunspot number (Ri), for all months where R^2=0.806 in March, and R^2=0.964 in June, and R^2=0.651 in September. For December data were not taken because in 15 September of year 2020 NASA, announced that the new solar cycle 25 is now underway and the Solar cycle 24 was end, in December 2019 when the number of Sunspots decreased (https://m.akhbarelyom.com, n.d.). And linear regression equations respectively as follows,

A- in March f_oF_2[MHZ]=6.368 + 0.06553Ri
B- in June f_oF_2[MHZ]=5.855 + 0.06374Ri
C- in September f_oF_2[MHZ]=5.928 + 0.09207Ri

Conclusions

1. This study is very useful for those who are working in upper atmosphere and as well as solar terrestrial physics and it shows upper atmospheric environmental condition during space weather.
2. Differences over Erbil station 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 (2017, 2018, 2020) for F_2 - layer in June was

greater than September, March and December. And the maximum value of f_oF_2 for years (2015, 2016, 2019) of F_2 - layer was in September was greater than June, March and December.

6. Critical frequency (f_oF_2) in Summer 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 (2015, 2016, 2017, 2018, 2020).In year 2019 the relationship was good in March and December, and was moderate in June, and was weak in September 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 low Solar activity (down phase) for Solar cycle 24.

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