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Study the Influence of Solar Activity on the Ionospheric Electron, Ion and Neutral Particle Temperatures over Iraqi Region Using Ionospheric Models

Mahmood K. Mardan, Khalid A. Hadi
Department of Astronomy & Space, College of Science, University of Baghdad, Baghdad, Iraq.

Abstract

The influence of solar activity on the predicted ionospheric temperature parameters (electron T_e, Ion T_i and neutral particle T_n) have been investigated over ionospheric Iraqi region by data generated using International Reference Ionosphere (IRI) and Madrigal models, the models result have been compared during the minimum and the maximum of solar cycle 24 for the years 2009 and 2016 respectively and for an altitudes ranged from 200-1000 km. The region under consideration spans over (latitude 29.1-37.2^{o}N; longitude 38.9-47.7^{o}E) within Iraq territory, the purpose of this paper is to determine the affection of the solar activity represented by the (sunspot number and solar flux) on the annual behaviors of the ionospheric temperature parameters (T_e, T_i and T_n).The results of the conducted study showed that the solar activity of the adopted years exhibited a weak affection on the ionospheric temperature parameters, where (T_n) was the highly affected parameter and (T_e) was the poorly affected one. Also, the ionospheric temperature parameters were increased with altitudes increment except for (T_n) which was increased with altitudes till 400 km, than it reaches its maximum value and keep constant.

Keywords: Solar Activity, Electron Temperature T_e, Ion Temperature T_i, Neutral Temperature T_n.

دراسة تأثير النشاط الشمسي على درجة حرارة الألكترون والأيون والجسيمات المتعادلة فوق منطقة العراق بأستحدام الموديلات الأيونسفيرية

محمود كريم مردان ، خالد عبد الكريم هادي
قسم الفلك والفضاء، كلية العلوم، جامعة بغداد، العراق.

الخلاصة

تم التحقق من تأثير النشاط الشمسي على معاملات الغلاف الأيوني الحرارية المتوقعة (حرارة الألكترونT_eو حرارة الأيون T_i والحرارة المتعادلةT_n) للغلاف الأيوني فوق منطقة العراق للقيم المحسوبة

*Email:hoodaa1991@gmail.com

بأستخدام موديل الـ (IRI) وموديل Madrigal، قورنت نتائج الموديلات للقيمة الصغرى والعظمى للدورة الشمسية 24 (السنين 2009 و 2016) ولمدى أرتفاعات حوالي (200كم– 1000كم).تقع منطقة الدراسة ضمن أحداثيات (خطوط عرض 29.1–37.2 شمالا; وخطوط طول 38.9–47.7 شرقا) ضمن منطقة العراق. الغرض من هذا البحث هو قياس مدى تأثير النشاط الشمسي المتمثل (بالبقع الشمسية والتدفق الشمسي) على التغيرات السنوية لمعاملات الغلاف الأيوني الحرارية. أظهرت النتائج بأن النشاط الشمسي للأعوام المعتمدة أظهر تأثير ضعيف على المعاملات الحرارية، حيث كانت الحرارة المتعادلة المعامل الأعلى تأثرا وحرارة الألكترون المعامل الأقل تأثرا،كذلك فأن معاملات الغلاف الأيوني تزداد مع زياة الأرتفاع ماعدا الحرارة المتعادلة (T_n) التي ازدادت مع الأرتفاع الى حدود 400 كم حيث وصلت الى أعلى قيمة لها وبقت ثابتة.

1. Introduction

The Ionosphere of any planet is defined as that portion of the atmosphere where free electrons and ions of thermal energy exist under the control of the gravity and magnetic field of the planet. Therefore the Earth's ionosphere is taken to be that part of the upper atmosphere where electrons and ions of thermal energy are exists in amounts appropriate to influence the radio waves propagation [1]. The Earth ionosphere was discovered when it was noticed that radio waves can transfer through massive areas, and one thence had to assume the presences of an electrical conductive layer in the upper atmosphere which could reflect the waves. The electrically conductive zone extends from about 50km to 1000km above the Earth surface, and the densities of electrons N_e fluctuate between 10^4 particles per cubic centimeter at 50 km to a max value of 10^6 particles per cubic centimeter at 250-300km. The ionized layer of the atmosphere is produced when active electromagnetic and particle rays from the space and Sun ionize air molecules, producing plasma in the upper atmosphere. This plasma is poorly ionized; the proportion between electron concentration and concentration of neutral air not ever be greater than 10^7 particles per cubic centimeter, even at the height when N_e reaches its max values.The ordinary ionospheric layers we will mention in this paper are created by extreme ultraviolet (EUV) and X-ray radiation of the sun, and have a distinctive alteration with the daytime and latitude. The electron concentration for a regular ionosphere at day and night time is splitted into three various major layers (D-layer 50-90km, E-layer 90-150km and F-layer 150-500km). In these layers the electron density change with the exposure to various forms of radiation, various forms of recombination and different transmission operations, and none of the layers attitude precisely as the ideal Chapman layer with regard to differences in height, latitude, and daytime. Also, none of the layers vanish completely sunset, because of transport mechanisms, and scattered radiation, which can relocate plasma from a sunny region to a blackish region of the atmosphere **[**2].

2. Data Selection

In this paper the dataset of the measured parameters have been generated using **I**nternational **R**eferences **I**onospheric (IRI) [3] and Madrigal models [4]. A model is a numerical statistical description of the ionosphere in terms of location (geographic latitudes and longitudes), time, seasons, and other factors such as the solar activity (10.7 cm solar flux, sunspot number) [5].

First Model: International Reference Ionosphere (IRI) model project was established jointly by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI) in the late sixties with the goal to develop an international standard for the specification of plasma parameters in the Earth's ionosphere [6]. IRI is the standard for the ionosphere for the International Standardization Organization (ISO) [7]. IRI represents the monthly average behavior of the ionosphere at a given place and time, for a given level of solar activity [8]. Neutral, Ion, and Electron temperatures are the subject of this paper so IRI provides two options for the electron temperature T_e. In both cases the model built-up is the same, using a spherical harmonics representation of the global temperature variations at fixed heights and Epstein functions to describe the altitudinal variation [6]. While, Ion temperature profile is similar to electron temperature profile IRI uses the COSPAR International Reference Atmosphere (CIRA) as its neutral temperature mode [9].

Second Model: Madrigal is a database of ground-based measurements and models of the Earth's upper atmosphere and ionosphere. It is neatlylinked to the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) platform, which is devoted to the description and conception of the atmosphere above about 60 km above F2 layer, with assurance on the different operations that define the basic installation and components of the atmosphere, and on the technicalities that couple various atmospheric zones. Madrigal was primarily sophisticated to serve the needs of the incoherent scatter

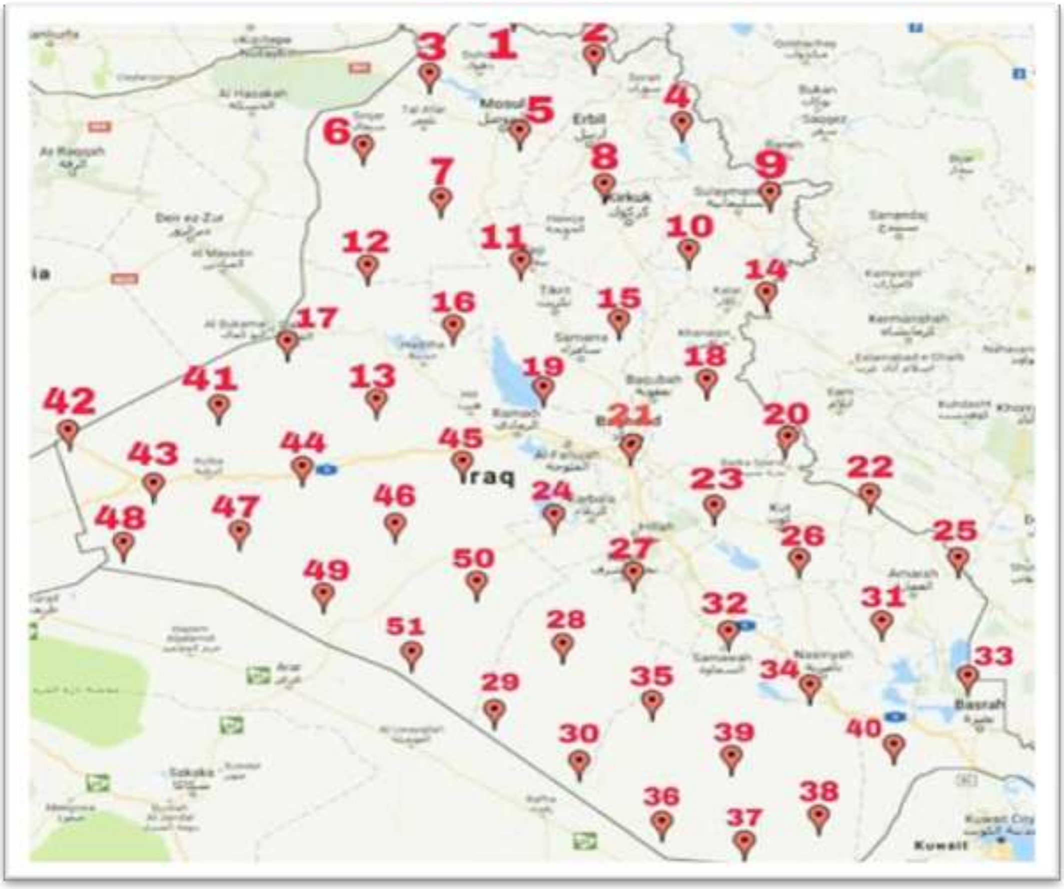


Figure 1-The studied locations of transmitter and receiver stations over Iraqi region.

radar society. There are Madrigal locations holding incoherent scatter radar data information at Millstone Hill, USA, SRI International, USA, Arecibo, Puerto Rico, EISCAT, Sweden, Jacamarca, Peru, and Cornell University, USA. As well, much of these locations also save data from visualdevices on Madrigal, and the Millstone location storage total electron content data derived from the world-wide network of Global Positioning System (GPS) receivers. Madrigal is destined to save data from any ground-based device that scanning atmospheric science [10].

3. Data Analysis and Discussion.

In the present work, the electron, ion and neutral temperatures (T_e, T_i & T_n) have been determined. The study has been made for the Iraqi zone that located within the mid-latitude region. Baghdad city (44.42 °E, 33.32 °N) which represents the capital of Iraq has been considered as a transmitter station and many communication locations (fifty one location) that are speared over studied zone within the range of up to (500 km) have been considered as receiver stations, as shown in Figure-1.

The years 2009 and 2016 have been selected to be the studied time period, which represent the minimum and peak of solar cycle 24. (Table-1) shows the monthly values of the adjusted solar flux (F10.7) and the monthly Smoothed Sunspot Number (SSN) for the selected years [11].

Table 1- Monthly Sunspot Number (SSN) and Solar Flux (F10.7 cm) of the years (2009 and 2016). [11]

Month Name	2009		2016	
	SSN	F10.7 (cm)	SSN	F10.7 (cm)
January	1.8	68.7	32.6	99.9
February	1.9	68.8	31.5	98.1
March	2	69	30.2	96.6
April	2.2	69.3	28.7	95.3
May	2.3	69.7	26.9	93.2
June	2.7	70.2	24.9	90.4
July	3.6	71	23.2	87.7
August	4.8	72.1	21.3	85
September	6.2	73.3	20.1	84.1
October	7.1	74.1	19.2	82.5
November	7.6	74.5	17.3	80.8
December	8.3	74.9	17.7	79.4

The geodesic parameters [Distance and Bearing (transmitter to receiver and receiver to transmitter)] for the tested connection links between transmitter and receiver station have been determined. Table-2 shows a list of geographical location coordinates (longitude and latitude), spherical geodesic parameters (bearing transmitter to receiver and bearing receiver to transmitter) and distance for connection links over Iraq Region.

Table 2-Geographical location coordinates and spherical geodesic parameters for the connection links over Iraqi region.

no.	Station Name	Location		Bearing (Deg.) Transmitter to Receiver			Bearing (Deg.) Receiver to Transmitter			Distance (Km)
		Lat. (°N)	Long. (°E)	Method (1)	Method (2)	Average (Deg.)	Method (1)	Method (2)	Average (Deg.)	
1	Amedi	37.248	43.275	344.18	347.29	345.74	164.18	166.65	165.42	444.88
2	Aqrah	36.845	44.055	54.693	355.74	355.22	174.69	175.56	175.12	389.75
3	Tel Afar District,	36.677	42.462	330.05	335.27	332.66	150.05	154.17	152.11	409.08
4	Rania	36.209	44.901	10.32	8.36	9.34	190.32	188.66	189.49	321.45
5	Al-Hamdaniya	36.138	43.330	339.37	343.10	341.24	159.37	162.50	160.94	324.51
6	Baiji	36.005	41.814	315.98	322.25	319.11	135.98	140.78	138.38	197.99
7	Hatra	35.505	42.561	319.84	325.66	322.75	139.84	144.63	142.24	291.97
8	Kirkuk	35.631	44.143	354.07	355.17	354.62	174.07	175.04	174.55	254.56
9	Halabja	35.541	45.748	31.97	26.86	29.42	211.97	207.63	209.80	274.02
10	Chamchamal	35.003	44.957	19.24	15.95	17.59	199.24	196.27	197.76	191.31
11	Baiji	34.904	43.330	325.96	331.07	328.52	145.96	150.48	148.22	197.99
12	Anah 1	34.868	41.847	300.94	306.60	303.77	120.94	125.18	123.06	287.86
13	Anah 2	33.578	41.924	275.30	277.03	276.16	95.30	95.67	95.49	229.23
14	Khanaqin	34.588	45.698	46.79	41.08	43.93	226.79	221.81	224.30	183.63
15	Samarra	34.334	44.275	53.25	47.68	50.47	233.25	228.42	230.84	109.84
16	Haditha	34.289	42.671	298.79	303.95	301.37	118.79	123.00	120.89	189.28
17	Al-Qa'im	34.143	41.067	283.46	286.98	285.22	103.46	105.13	104.30	318.74
18	Baladrooz	33.752	45.121	61.52	56.73	59.13	241.52	237.14	239.33	81.93
19	Tharthar City	33.688	43.539	291.90	295.97	293.93	111.90	115.50	113.70	86.55
20	Badra	33.193	45.901	95.89	96.62	96.26	275.89	277.45	276.67	142.48
21	Babylon	33.128	44.396	175.88	176.55	176.21	355.88	356.55	356.22	24.73
22	Ali Al-Gharbi	32.649	46.725	106.64	108.98	107.81	286.64	290.25	288.45	232.16
23	Al-Samawa	31.288	45.341	134.41	139.18	136.80	314.41	319.64	317.02	246.42
24	Ain Al-Tamur	32.454	43.649	219.21	214.61	216.91	39.21	34.21	36.71	120.76
25	Amara	32.008	47.582	112.74	115.60	114.17	292.74	297.33	295.03	334.76
26	Al-Hayy	32.009	46.033	129.05	133.50	131.27	309.05	314.39	311.72	214.86
27	Al-Manathera	31.878	44.418	178.52	178.74	178.63	358.52	358.76	358.64	163.72
28	Najaf 1	31.166	43.726	196.67	194.39	195.53	16.67	14.04	15.35	250.51
29	Najaf 2	30.506	43.056	204.96	201.91	203.43	24.96	21.21	23.08	340.02
30	Najaf 3	29.984	43.880	188.45	187.34	187.89	8.45	7.08	7.76	377.26
31	Al-Maimouna	31.383	46.835	128.71	132.83	130.77	308.71	314.14	311.42	317.79
32	Al-Samawa	31.288	45.341	155.02	158.24	156.63	335.02	338.76	336.89	246.42
33	Shatt Al-Arab	30.827	47.670	127.49	131.27	129.38	307.49	313.01	310.25	418.01
34	Al-Salman 1	30.742	46.132	146.11	149.87	147.99	326.11	330.80	328.46	333.70
35	Al-Salman 2	30.591	44.594	175.57	176.18	175.87	355.57	356.29	355.93	307.45
36	Al-Salman 3	29.363	44.681	175.69	176.23	175.96	355.69	356.39	356.04	444.25
37	Al-Salman 4	29.167	45.484	165.22	167.00	166.11	345.22	347.57	346.40	476.81
38	Al-Salman 5	29.421	46.209	155.05	157.85	156.45	335.05	338.80	336.92	470.09
39	Al Muthanna	30.031	45.363	163.51	165.59	164.55	343.51	346.11	344.81	380.59
40	Al-Zubair	30.136	46.945	141.42	145.15	143.29	321.42	326.50	323.96	431.88
41	Rutba 1	33.532	40.397	272.62	274.23	273.42	92.62	92.04	92.33	370.10
42	Rutba 2	33.294	38.936	269.41	270.79	270.10	89.41	87.80	88.60	505.81
43	Rutba 3	32.778	39.749	262.96	262.88	262.92	82.96	80.36	81.66	436.18
44	Rutba 4	32.935	41.199	262.57	262.02	262.29	82.57	80.28	81.42	299.73
45	Rutba 5	32.981	42.759	257.18	255.23	256.20	77.18	74.34	75.76	156.36
46	Rutba 6	32.371	42.099	246.77	243.56	245.16	66.77	62.32	64.54	239.24
47	Rutba 7	32.308	40.584	254.65	252.94	253.80	74.65	70.89	72.77	373.10
48	Rutba 8	32.194	39.452	256.80	255.76	256.28	76.80	73.09	74.94	478.29
49	Rutba 9	31.681	41.397	240.77	237.24	239.01	60.77	55.64	58.21	335.64
50	Rutba 10	31.794	42.891	223.74	219.29	221.51	43.74	38.49	41.11	222.26
51	Rutba 11	31.091	42.253	223.27	219.11	221.19	43.27	37.98	40.62	321.12

The study of the temperature parameters (T_e, T_i, and T_n in kelvin) have been performed for (fifty one) locations over Iraq region. The behavior of the annual variations of the ionospheric parameters for the years (2009 and 2016) at minimum and maximum solar activity of the solar cycle 24 has been determined. The calculations have been conducted using the two models (IRI-2016 and Madrigal calculator). The adapted models have been tested for the selected locations; the predicted values of the ionospheric parameters have been calculated for five different altitudes (200,400,600,800 and 1000 km).

Table 3- display sample of the calculations that have been made using IRI model for the annual values at different altitudes for the year 2009

Time	Height 200km			Height 400km			Height600km		
(hour)	Tn (k)	Ti (k)	Te (k)	Tn (k)	Ti (k)	Te (k)	Tn (k)	Ti (k)	Te (k)
0	640.7	640.7	859.5	651.1	879.1	902.1	651.1	1053.6	1079.1
1	635.9	635.9	1067.6	648.0	968.3	1021.3	648.0	1234.6	1371.0
2	632.4	632.4	1315.8	647.6	1011.0	1466.4	647.6	1390.2	1970.2
3	634.6	634.6	1489.9	653.4	1045.3	2104.5	653.4	1517.9	2632.6
4	644.8	644.8	1557.4	666.2	1067.7	2326.6	666.3	1596.7	2804.7
5	662.4	662.4	1578.0	685.3	1080.1	2188.2	685.3	1634.7	2686.1
6	683.0	683.0	1584.0	706.5	1087.0	2115.3	706.5	1650.4	2608.4
7	704.2	704.2	1584.6	728.6	1091.4	2108.8	728.6	1656.4	2528.2
8	723.0	723.0	1585.7	748.5	1094.5	2075.1	748.6	1658.5	2507.7
9	737.9	737.9	1587.0	765.7	1096.6	2073.5	765.8	1659.1	2550.1
10	750.4	750.4	1588.5	782.4	1098.1	2083.1	782.5	1658.7	2568.4
11	759.1	759.1	1591.8	798.2	1098.8	2024.7	798.4	1656.9	2595.2
12	761.0	761.0	1592.5	810.9	1097.8	2012.1	811.2	1651.8	2656.9
13	755.3	755.3	1589.0	818.2	1093.4	1960.9	818.9	1638.5	2645.0
14	742.8	742.8	1574.5	815.2	1083.0	1781.7	816.5	1605.7	2481.3
15	728.3	728.3	1511.3	800.0	1062.4	1507.9	801.3	1535.6	2161.9
16	714.5	714.5	1354.1	774.5	1028.9	1315.4	775.2	1417.1	1775.4
17	699.2	699.2	1134.3	742.2	987.1	1166.1	742.4	1252.1	1463.1
18	680.3	680.3	914.0	708.4	937.3	1033.1	708.4	1098.6	1242.5
19	663.1	663.1	774.2	681.7	914.6	962.0	681.7	1020.9	1115.9
20	650.7	650.7	710.7	664.3	888.7	928.7	664.3	953.9	1041.6
21	644.5	644.5	679.5	655.6	858.7	887.3	655.6	902.8	965.1
22	642.1	642.1	693.9	651.9	844.1	876.9	651.9	898.5	922.9
23	640.1	640.1	745.0	649.6	851.5	885.4	649.6	948.5	960.8

Time	Height800km			Height 1000km		
(hour)	Tn (k)	Ti (k)	Te (k)	Tn (k)	Ti (k)	Te (k)
0	651.1	1229.8	1466.3	651.1	1330.1	1493.2
1	648.0	1489.1	1906.5	648.0	1728.6	1942.8
2	647.6	1769.6	2493.7	647.6	2148.9	2594.7
3	653.4	2001.7	2904.7	653.4	2485.4	3071.2
4	666.3	2145.0	2949.6	666.3	2693.3	3133.8
5	685.3	2213.9	2899.0	685.3	2793.2	3126.9
6	706.5	2242.4	2906.7	706.5	2834.6	3175.3
7	728.6	2253.4	2948.3	728.6	2850.4	3193.9
8	748.6	2257.3	2968.3	748.6	2853.3	3187.6
9	765.8	2258.4	2895.1	765.8	2840.1	3123.1
10	782.5	2257.9	2786.6	782.5	2821.8	3037.3
11	798.4	2254.7	2779.8	798.4	2827.6	3035.5
12	811.2	2245.2	2887.5	811.2	2835.1	3125.0
13	818.9	2220.9	2917.5	818.9	2802.1	3152.2
14	816.5	2161.3	2767.9	816.5	2716.1	3013.8
15	801.4	2033.9	2501.4	801.4	2506.9	2719.3
16	775.3	1811.5	2111.8	775.3	2081.6	2297.6
17	742.4	1469.4	1640.4	742.4	1655.7	1822.5
18	708.4	1213.3	1327.2	708.4	1316.5	1465.0
19	681.7	1100.7	1258.0	681.7	1153.2	1327.1
20	664.3	987.9	1226.6	664.3	1022.0	1266.4
21	655.6	916.1	1128.2	655.6	929.4	1166.9
22	651.9	926.3	1088.3	651.9	954.1	1130.8
23	649.6	1031.0	1203.8	649.6	1081.1	1243.7

The analytical study for the annual variations of the ionospheric temperature parameters (T_e, T_i and T_n) that have been performed using the two adopted models for the selected sample "Al Tharthar city"(33.69°N, 43.54°E) over the tested area for the chosen altitudes (200,400, 600, 800 &1000) Km for the years 2009 and 2016 have been shown in Figure-2.

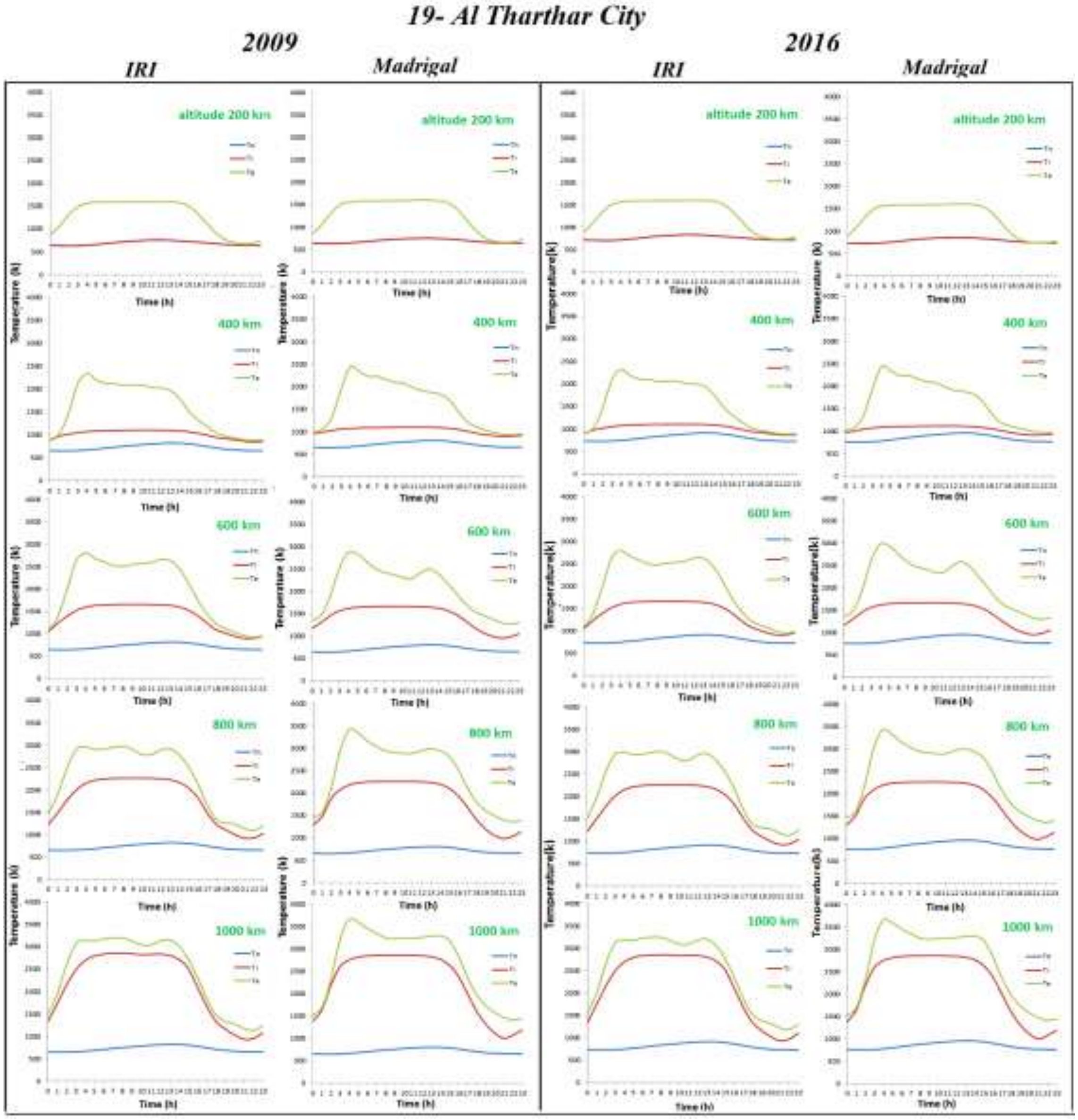
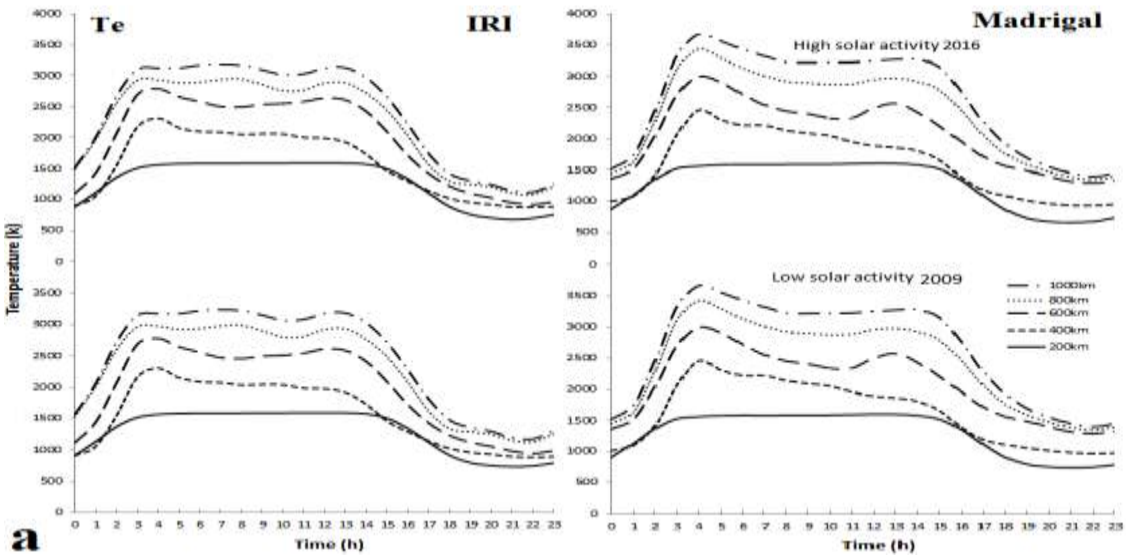


Figure 2-sample of the annual variation of Ionospheric temperature Parameters (T_e, T_i and T_n) for two years (2009-2016) for the adopted models (IRI and Madrigal)"Al Tharthar city".



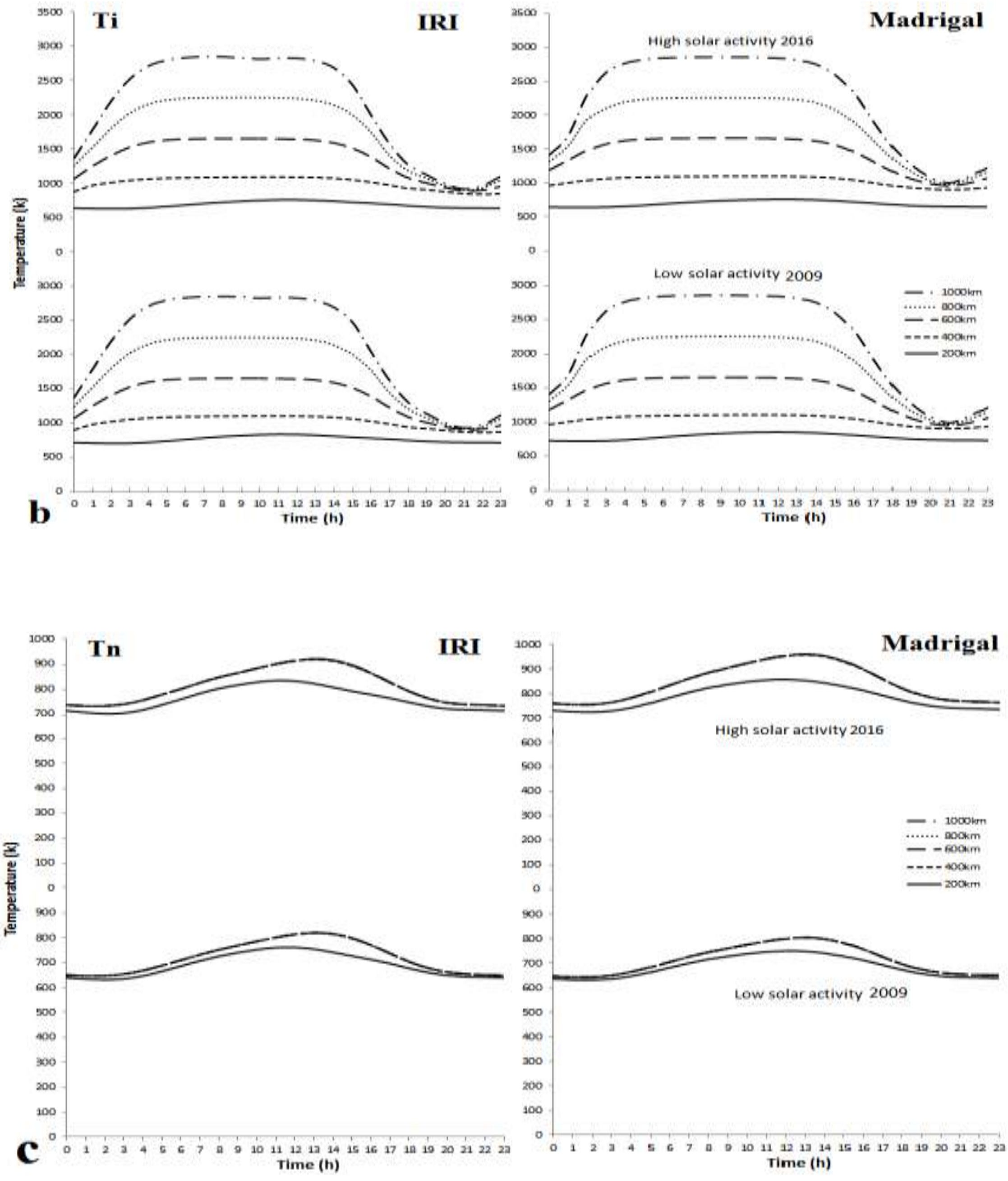


Figure 3 (a, b, c) -The annual comparisons for the tested location "Al Tharthar city" of the ionospheric temperature parameters with altitudes (200, 400, 600, 800, & 1000) km of the years (2009 & 2016).

From data analysis, the results show that the electron temperature (T_e) exhibit similar behavior for all altitudes like morning peak, daytime trough, evening enhancement and night time minimum, except the height 200 km where the electron temperatures T_e increased from (~1am) to (~3am) and preserve almost constant behavior till (~15pm) decrease to minimum at night time. However, neutral temperatures (T_n) presents completely different pattern, so it increased at daytime (~7am) to (~2pm) then start decreasing at (~7pm) then becomes almost constant before start decreasing during night time this behavior was presented the same for all altitudes. while the ion temperatures (T_i) take the neutral temperatures T_n behavior only in the case of low altitudes (200 and 400 km), and for higher altitudes its conduct changed where its values increase with sunrise to certain value and keep almost unalterable during the day at that value afterwards it decreases with sunset and reach its minimum at night time.

In general, it had been found that the behavior of the electron, ion and neutral temperatures (T_e, T_i and T_n) showed that the T_i is similar to T_n at low altitudes (200 km), and by increasing the height the T_i values will raise above the T_n values and reach approximately to T_e values especially at high altitudes (~1000 km) and sort of took its shape which mean at high altitudes ($T_i \leq T_e$), Figure-2.

Also, the Figure- (3) a, b, c shows a comparison between the two adopted models (IRI and Madrigal). At low altitudes (200 km) both models gave approximately the same output values, but at high altitudes (400-1000 km) the two models gave similar values for the T_i and T_n temperatures while for the T_e the IRI model gave more detailed hourly behavior than Madrigal model. In addition to that, the conducted analytical study showed slight variations of the annual ionospheric temperature parameters due to the affection of the solar activity (sunspots number (SSN) and solar flux (F10.7cm). The results have shown that the ionospheric temperatures parameters have been increased with increment of the values of solar activity, so the increment average rate were about (~11%), (~2%) and (~0.5%) for IRI model and (~18%), (~2%) and (~0.1%) for Madrigal model of T_n, T_i and T_e respectively (these ratios calculated by taking the average between the maximum and minimum percentage value of year 2016 and 2009 for the calculated parameter).

The electron and ion temperatures have a direct relationship (positive relationship) with altitude i.e.the temperature parameters increased with increasing altitudes. Whereas the neutral temperatures have different behavior value, so its values increased with altitudes until about ~400 km which takes almost constant values. Also, the behaviors of the annual variations affected simply by solar activity variations and locations for both models (IRI and Madrigal).

Conclusions

From data analysis and results it can be concluded the following:

- At low altitudes 200 km T_e take the T_i behavior where it values take an organized behavior (no peaks) and this may related to sunrise and sunset. However; the T_i at ~200 Km take the T_n behavior (increase from about 7am to 2pm and then decrease till 7pm then becomes almost constant and minimum during night time). This is because the high electron density that prevent the heat loss at that layer.
- At high altitudes (400-1000) Km T_e exhibit behavior like morning peak, daytime trough, evening peak and night time stability. The morning and evening peaks arise from the photoelectron heating of the morning and evening low density gas and the daytime valley is the result of the balance between electron heating and cooling processes.
- The behavior of (T_e, T_i and T_n) at low altitudes 200 Km T_i is virtually identical with T_n ($T_i \approx T_n$), whereas at high altitudes it is closely coupled to T_e ($T_i \leq T_e$). This is maybe because T_i gaining energy through collisions with electrons and losing through collisions with neutrals.
- Ionospheric temperature parameters affected with a slight variations by solar activities variation (SSN & F10.7 cm). Temperature parameters increased when sunspots and solar flux are increased, where T_n is the highest affected and T_e is the lowest affected.
- The electron and ion temperatures increase with altitude increment, since the neutral temperature T_n maximum values typically occur at about 400 km, then the temperature becomes constant and that's may be due to the low collisions numbers between plasma particles at high altitudes where the particles density is low.

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