A STUDY OF THE SEASONAL VARIATION OF IONOSPHERIC ELECTRON DENSITY OVER BAGHDAD

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ABSTRACT: *In this work, a study of the seasonal behavior of electron density has been conducted for the years 2009, 2010, and 2011, during which the seasonal variation in the electron density has been observed. The seasonal behavior has been investigated in two parts. The first part was allocated to describe the behavior of electron density during the four seasons at different heights for each of the test year. The second part, on the other hand, focused on to describe the behavior at a specific height and day of each season for the three years. The dataset of the electron density has been generated using the international reference ionosphere model (IRI model). The result of this study showed that there was a correlation between the electron density and the solar activity and height parameters. Therefore, the electron density increases with an increment of the solar activity and height until it reaches its maximum at F2 layer peak. The peak of electron density for E layer has a relationship with the angle of the sun where it increased at summer time. However, the F layer does not observe this rule and demonstrates that the increase during winter was greater than during summer which leads to what is known as the seasonal anomaly.*

KEY WORDS: Electron Density (Ne), Total Electron Content (TEC), Ionosphere Layer, IRI Model

1. INTRODUCTION

The early history of ionosphere is very much bound up with the development of communications. The first suggestions that there are electrified layers within the upper atmosphere date back to the nineteenth century, although the modern development really began with Marconi's well-known experiment in trans-Atlantic communications (from Cornwall to Newfoundland) in 1901. This led to the suggestions by Kennely and Heaviside (made independently) that, as a result of the curvature of the earth, the waves could not have travelled directly across the Atlantic but must have been reflected from an ionized layer. The name Ionosphere came into use in around 1932, having been coined by Watson-Watt several years earlier. Subsequent research have revealed a great deal of information in relation to ionosphere: its vertical structure, its temporal and spatial variations and the physical process by which it is formed and which influences its behavior [1].

The ionosphere is the ionized component of the atmosphere, comprising of free electrons and positive ions, generally in equal numbers, in a medium that is electrically neutral. Though the charged particles are only a minority amongst the neutral ones, they nevertheless exert a great influence on the electrical properties of the medium, and it is their presence that brings about the possibility of radio communications over large distances by making use of one or more ionospheric reflections [2]

2. IONOSPHERIC PARAMETERS

The ionospheric parameters are used in order to give an indication on the physical state of the ionospheric medium by providing an explanation about the many characteristics of the ionosphere. The following are some of these parameters:

2.1 ELECTRON DENSITY (Ne)

The electron density (Ne) is defined as the number of electrons per unit volume. The ionospheric electron density varies geographically, diurnally, seasonally, and with solar activity [3]. Available information is provided mainly by vertical incidence sounders, rockets and by satellites and they have revealed that below the peak of F2 region the electron density increases with altitude. The traditional ground-based vertical incidence sounding (ionosonde) measurements are sufficient for a precise determination of the bottom-side electron density profile. However, the ground-based ionosonde measurements alone are incapable of delivering information about the topside electron profile [4]. In addition, above the mentioned region, measurements indicate a rather smooth and slow decrease in electron concentrations with increasing altitude as clearly illustrated in Fig.1[5].

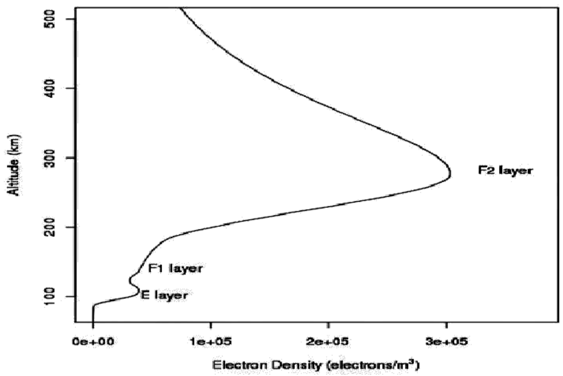


Figure 1: The variation of electron density with altitude [6].

2.2 TOTAL ELECTRON CONTENT (TEC)

The total electron content (TEC) of the earth's ionosphere is defined as the total number of free, thermal electrons in a unit area column of ionosphere from the ground to a height well above the peak of ionization, to at least 1000 km. This TEC is usually described as a vertical column one square meter in area. Typical TEC values range from 1016 to 1019 el/m^2, although the exact value is a function of many variables. `Some of these variables which influence the TEC are geographic location, local time, season, solar EUV flux and magnetic activity [7]. Most measurements and applications of total electron content are concerned with arbitrary slant ray paths between a satellite and a ground station. However, for comparative purposes it is necessary to define the observations in a more standard way [8].

IONOSPHERIC ANOMALIES

3.1 EQUATORIAL ANOMALY

The Equatorial Anomaly is an important phenomenon occurring at low latitudes that results in the highest plasma densities in the ionosphere [9]. The ionosphere may be divided into three regions according to their geomagnetic latitude, namely the high latitude, mid latitude and equatorial regions which vary along the course of the day. During the day, with increasing latitude, the solar radiation strikes the atmosphere more obliquely, and hence the intensity of radiation and the daily production of free electrons decrease with increasing latitude [10]. In the F region this latitude variation persists throughout the light due to the action of upper atmospheric wind currents from day-side to night-side hemispheres. In addition, deviations from the generally low to high latitude decreases are also apparent. Moreover, daytime F region frequencies do not peak at the geomagnetic equator, but 15° to 20° north and south of it. This is called the equatorial anomaly. Additionally, during the night, frequencies reach a minimum of approximately 60° latitude north and south of the geomagnetic equator, and this is named the mid-latitude trough [11].

3.2 SEASONAL ANOMALY

Seasonal anomaly is the result of the Earth revolving around the sun. The relative position of the sun moves from one hemisphere to another with the change in season. Seasonal variations of the D, E and F1 layers correspond to the highest angle of the sun; and thus the ionization density of these layers is greatest during the summer. The F2 layer, however, does not follow this pattern; its ionization is the greatest in winter and the least in summer, the reverse of what might be expected [12].

Essentially, the ionosphere's seasonal variation is related to a solar zenith angle change, while its solar cycle variation is linked to a change in the solar Extreme Ultraviolet (EUV) and x-ray radiation. An important feature is that the maximum electron density of F2 layer (NmF2) is larger in winter than in summer, in spite of the fact that the solar zenith angle is smaller in summer. This trend is called the seasonal anomaly, and occurs as a result of the seasonal changes in the neutral atmosphere. Specifically, the summer-to-winter neutral circulation results in an increase in the O/N2 ratio in the winter hemisphere and a decrease in the summer hemisphere. Furthermore, the daytime wavelengths are much shorter than the night-time ones. It is noteworthy that the daytime electron density of the F2 layer is very high and can reflect the higher frequencies, while the night-time electron density of F2 layer deteriorates [13].

4. International Reference Ionosphere (IRI)

In the present report, the IRI international model was selected in order to gather the data of the electron density (Ne) over the city of Baghdad (33.35N,44.42W) for three years. The International Reference Ionosphere (IRI) is the defacto standard for a climatological specification of ionospheric parameters which is based on a wide range of ground and space data and has been steadily improved ionospheric data and with better mathematical descriptions of the observed global and temporal variation patterns. Also, the validation of IRI model has been compared with a large amount of data including data from the most recent ionospheric satellites (KOMPSAT, ROCSAT and TIMED) and data from global network of ionosondes. Several IRI teams are working on specific aspects of the IRI modeling effort including an improved representation of the topside ionosphere [14].

The International Reference Ionosphere (IRI) project was initiated by the Committee on Space Research (COSPAR) and by the International Union of Radio Science (URSI) in the late sixties with the goal of establishing an international standard for the specification of ionospheric parameters based on all worldwide available data from ground-based to satellite observations [15].

For a given location, time and date, IRI provides monthly averages of the electron density, electron temperature, ion temperature and ion composition in the altitude range from 50 km to 2000 km. Additionally parameters provided by IRI include the Total Electron Content (TEC), the occurrence probability for Spread-F and the F1-region, and the equatorial vertical ion drift [16]. Fig. 2 displays a section of the interface of the IRI model.

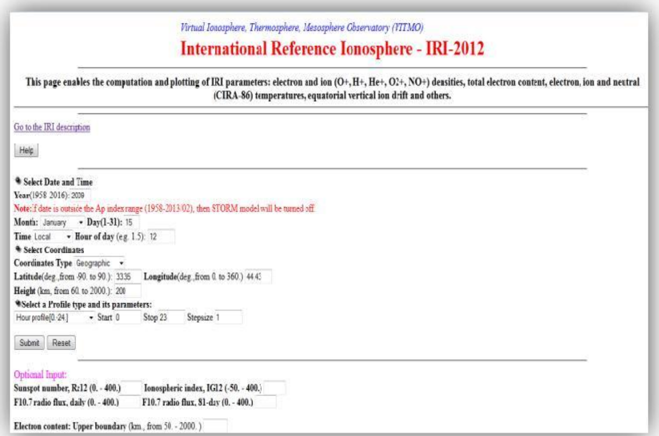


Figure 2: A display on the interface of the IRI model [17].

After inserting all the required information and selecting the desired parameters as outputs, the output results would be illustrated as per Fig.3 below.

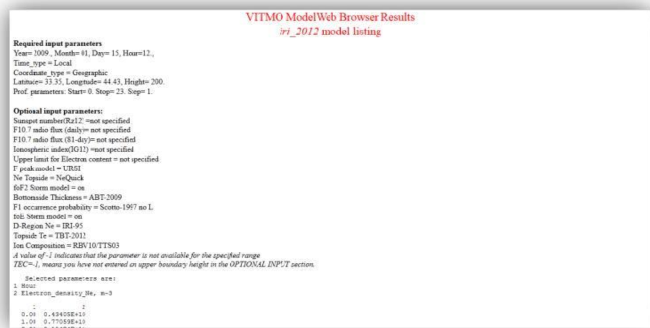


Figure 3: Output of the IRI model [17].

5. TEST& RESULT

In the present work, the behavior of electron density (Ne) during the four seasons over Baghdad city whose geographical coordinates are (33.350N, 44.430E), was studied. The years 2009, 2010 and 2011 which represented the beginning of the solar cycle 24 were selected, during which the seasonal behavior of the electron density was noticed. The dataset of the electron density was obtained from the IRI international model and an analytical study for the IRI outputs was prepared using the Microsoft Excel program.

In general, it was clear that the electron density is greater in the year 2011, as compared to the years 2009 and 2010, due to the increment in solar activity in 2011 as shown in Fig. 4.

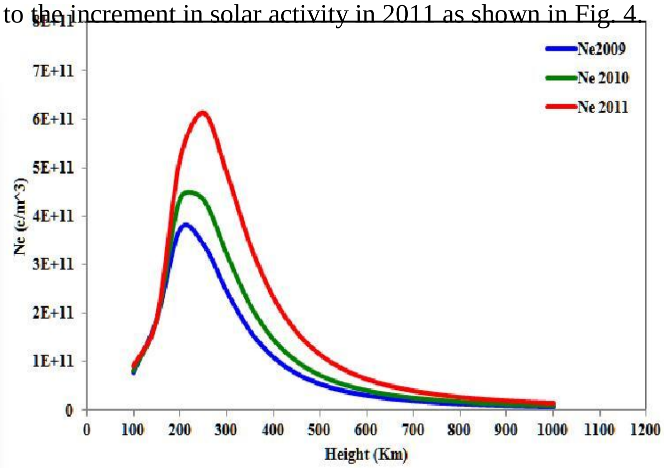


Figure 4: The electron density as function of height the three studied years.

The study of the seasonal behavior of the electron density has been conducted in two parts:

- The first part represents a study of the seasonal variation of the electron density over Baghdad city for each year at different heights (100 km - 1000 km) and for a specific time of the day (noon time) on the 15th of the months: January (as winter), April (as spring), July (as summer), and October (as autumn).

The sunspot numbers for the selected months are as shown in the table below [18]:

Year	Jan	Apr	Jul	Oct
2009	1.8	2.2	3.6	7
2010	9.2	13.9	16.7	23.2
2011	31.0	41.8	57.3	59.9

The following graphs (Fig. 5) display the seasonal variation in electron density at different heights for each year:

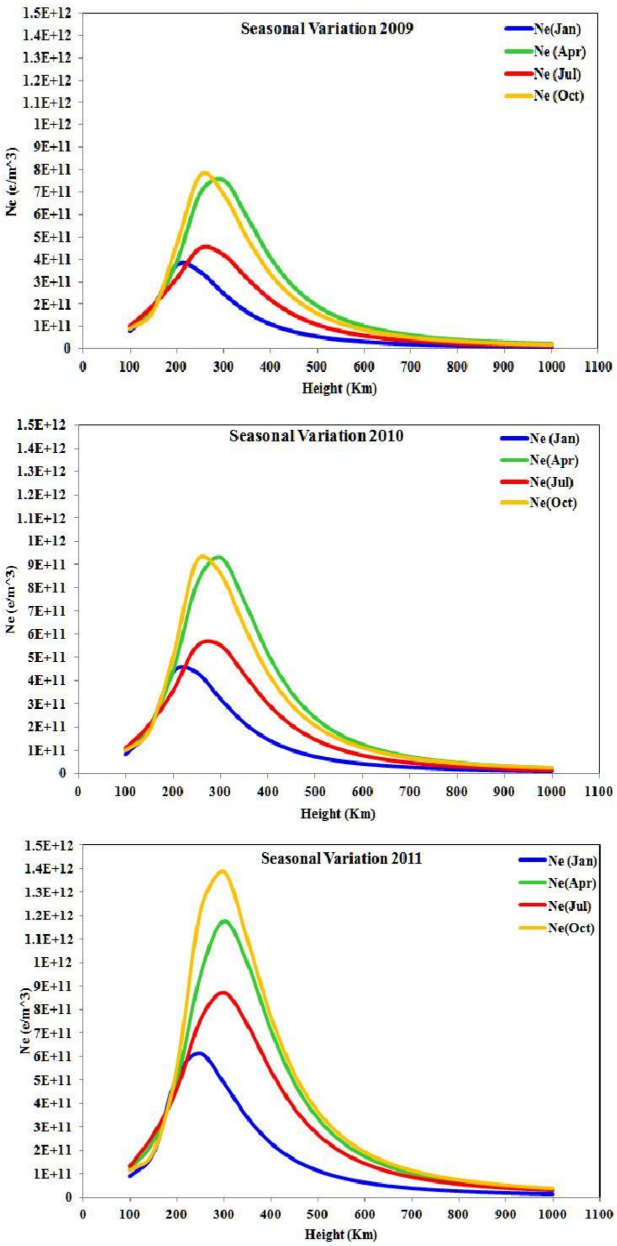


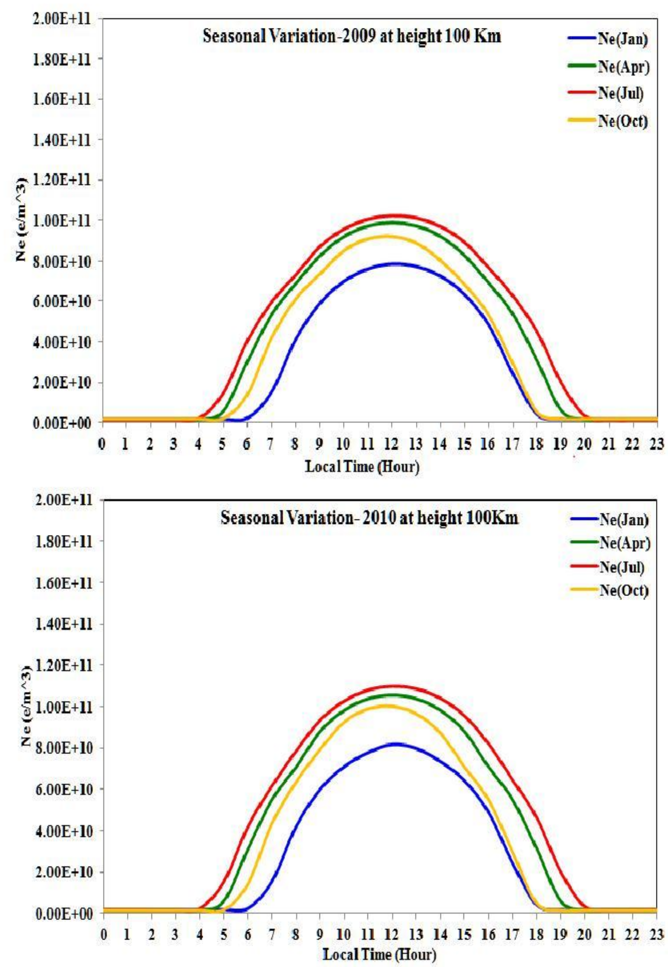
Figure 5: shows the seasonal variations of the electron density with height for the three selected years

In Fig. 5, it is apparent that the electron density increases with height until it reaches its maximum in the altitude range of 200 km - 300 km where the peak electron density of the F2 layer takes place. Subsequently, the electron density begins to fall with height as the ionosphere starts to merge with the outer space.

During the three studied years, the electron density peak of the F2 region is higher in both equinoxes (spring and autumn), as compared to the solstices (winter and summer). This is due to the seasonal changes in the neutral atmosphere (as mentioned previously), as well as the high sunspot number of the months April and October.

- The second part was made to study the electron density behavior during the course of the 15th day each selected month (January, April, July and October) for the three years at specific heights over Baghdad city. The adopted heights were 100, 175
  and 250 km.

At the height of 100 km: Fig. 6 includes the graphs of the seasonal variation at altitude 100 km for 2009, 2010 and 2011.



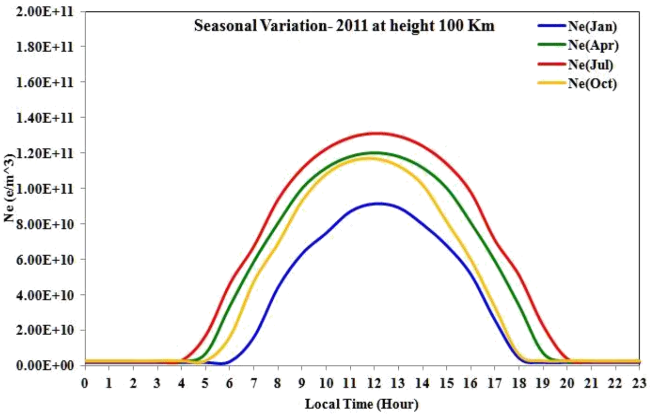
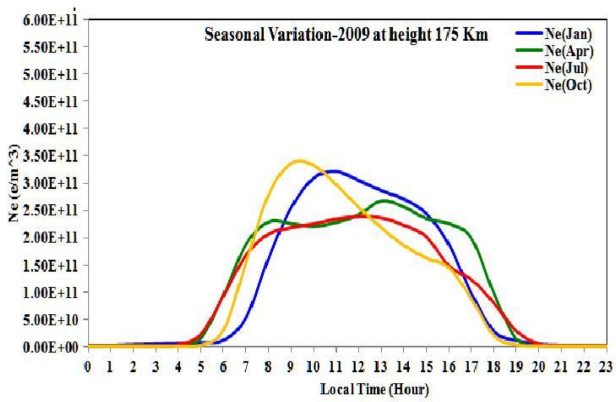
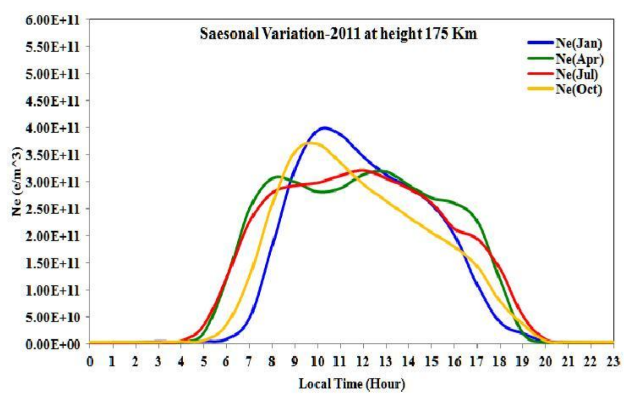


Figure 6: An illustration of the seasonal variations of electron density at the height of 100 km.

At the height of 100 km, which can be considered as the height of the E region, it is clear that the electron density reaches its maximum peak at noon. This may be due to the increment of the ionization process at this time of the day, while it drops on both sides of the noon time reaching its minimum values at the beginning and end of the day (rising time and setting time). Additionally, the electron density is also higher in summer time and lower in winter time.

At the height of 175 km: Fig. 7 presents the graphs of the seasonal variation at altitude 175 km for 2009, 2010, and 2011.





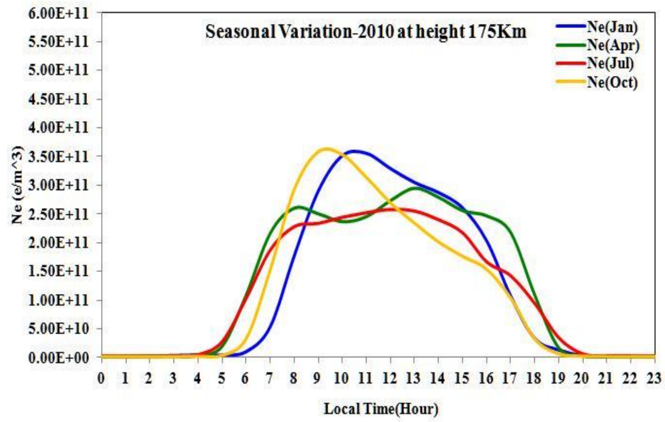
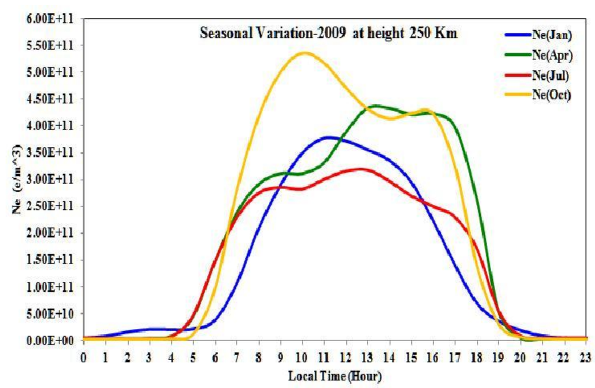
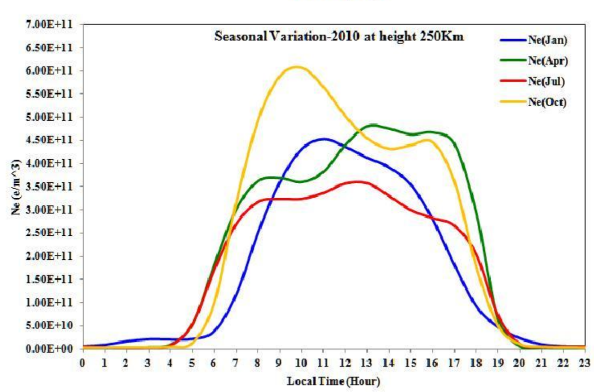


Figure 7: An illustration of the seasonal variation of electron density at the height of 175 km.

At 175 km, which lies within the altitude range of the F1 layer, the situation is different. The electron density reaches a maximum value during noon and decreases between the time of sunrise and sunset. The winter anomaly is clear in this altitude where the winter electron density values are higher than those for the summer season. In spring the electron density seems to fluctuate in the ranges between sunrise and sunset while in autumn the behavior of electron density displays some similarity with the winter behavior.

At the height of 250 km: Fig. 8 illustrates the graphs of the seasonal variation at altitude 250 km for 2009, 2010 and 2011.





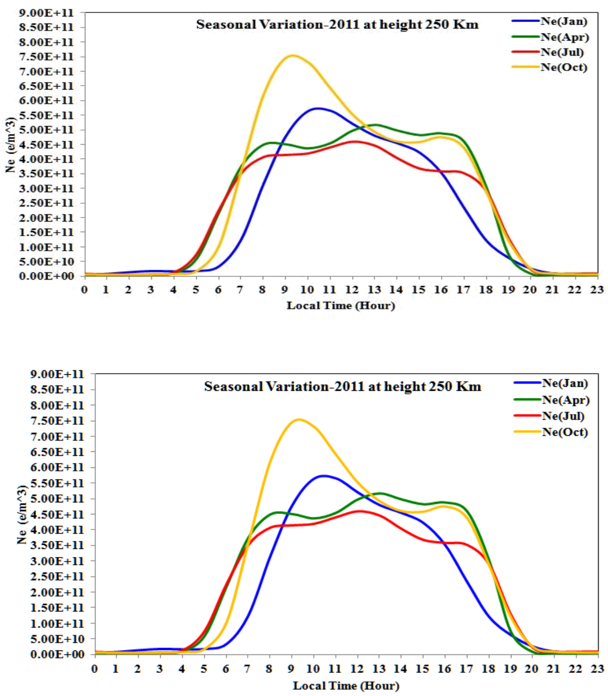


Figure 8: An illustration of the seasonal variation of electron density at the height of 250 km.

At the height of 250 km, which includes the F2 layer, the electron density behavior is more complex. During the years 2009 and 2010, the electron density in winter is higher than that in summer; while in autumn and spring the electron density has an opposite fluctuation during the day time. However, in the year 2011, the electron density is the highest during autumn and the winter anomaly is also visibly noticeable.

6. DISCUSSION AND CONCLUSION

In consequence, it can be concluded that the behavior of the electron density changes with the season and this may be due to the impact of both the activity of the sun and its position. In addition, it is also apparent that there is a form of direct correlation between the electron density and the solar activity, with the increase in electron density by increasing the sunspot number. Moreover, the position of the sun plays an important role in increasing the level of ionization during the summer season in the D and E layers and an anomaly that occurs in the F layer in particular the F2 layer.

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