Studying the Relation between the Electron Temperature, Maximum Peak Heightand Maximum Electron Densityfor F2 Region as a Function of Solar Activity

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Abstract- This research aims to study the effect of the solar activity on the correlation between the electron temperature T_e with both maximum peak height hmF2 and the maximum electron density N_{emax} for F2 region. The data used has been obtained using the International Reference Ionosphere IRI-2012 model which gives overall description of ionospheric parameters. The results show that the effect of high solar activity on the cross correlation coefficient (CCC) of ($T_e$with hmF2) has an intangible change at equator and no correlation will control it, while for other latitudes, the high solar activity try to shift the CCC from negative to no correlation especially at high latitudes. The second correlation (T_e with N_{emax}), CCC at equator change from positive correlation to no correlation. For mid latitude, the process is opposite. Finally, for high latitude, the process is a typical for an equator.

Index Terms- Ionosphere, Electron Temperature, F2 region, Electron density, Solar Activity

I. INTRODUCTION

Solar soft x-ray and extreme ultra violet (EUV) photons ionize a fraction of the neutral atmosphere. Resulting photoelectrons and secondaries produced by electron impact ionization with energies in excess of their surroundings, referred to as the supra thermal electron population, ionize neutral species further or heat up the ambient plasma. Thermal electrons that are heated by the supra thermal electron population cool down through interactions with colder ions and neutrals.

Heat exchange between ions and other particles occurs through collisions. This fundamental heating process drives plasma temperature in ionosphere. Also, precipitating particles or solar wind interactions at the upper atmosphere can introduce additional heating source to the local plasma. The thermal structure of plasma can affect ion-chemistry and dynamics. Several chemical reactions rates have direct or inverse plasma temperature dependence [1]. The electron temperature can be studied using the theoretical models and observation. The theoretical model produces time-dependent, three dimensional distributions for the ion-temperature and the ion (NO+, N2+, O2+, N+, O+, He+) and electron densities. The observations include the data aided by both satellite and ground based stations [2].

The main energy source responsible for space and time variations of meteorological parameters is the visible/infrared solar radiation intercepted by the earth. Also, the upper atmosphere (ionosphere) arises from ionization of different constituent gaseous molecules by the atmospheric absorption of solar radiations of the wavelength less than 1026 Ao. It should be expected that the change in solar energy or in its distribution would produce changes in climate and also in the ionosphere. It has a periodicity of approximately 11 years, whose most obvious aspect is the sunspot number [3].

L.H. Brace et al developed an empirical model of the interrelationship of electron temperature and density in the daytime thermosphere at solar minimum [4]. T.L. Gulyaeva et al, have been used data from 23 ionospheric stations for September 1999 to produce the electron temperature, Te, at the F2 layer peak height, hmF2, on the base of empirical relation between Te and the electron density, Ne, at a given height for a given index of solar radio flux [5]. A. V. Pavlov develop a new theoretical model of the Earth's low and mid latitude ionosphere and plasmasphere. The new model uses a new method in ionospheric and plasmaspheric simulations which is a combination of the Eulerian and Lagrangian approaches in model simulations. The electron and ion continuity and energy equations are solved in a Lagrangian frame of reference which moves with an individual parcel of plasma with the local plasma drift perpendicular to the magnetic and electric fields [6].

Scope of the study

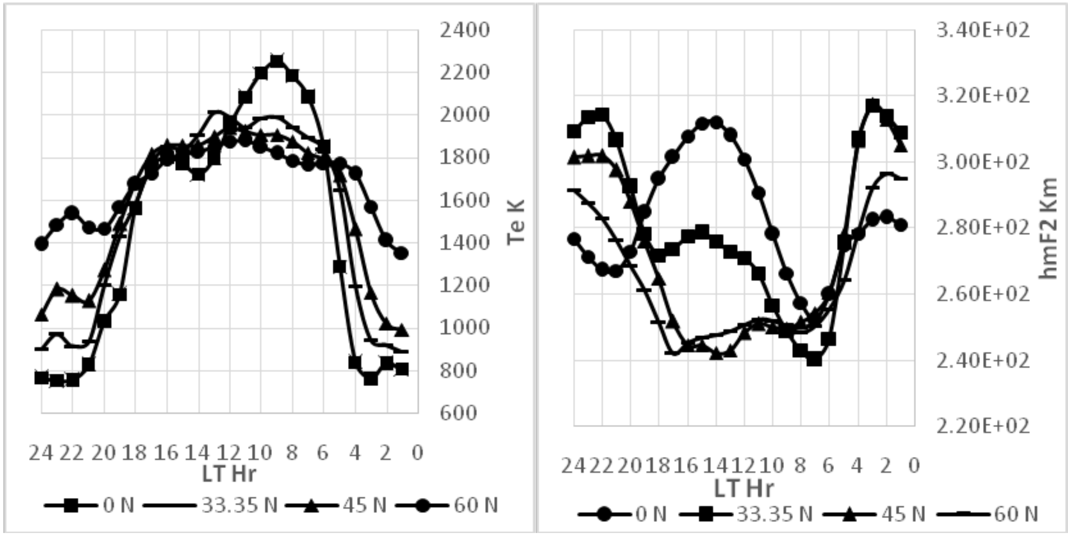
The aim of this study is to investigate the effect of the solar activity on the correlation between the electron temperature with both the maximum electron density N_{emax} max and the maximum peak height hmF2 using the data presented by the International references Ionosphere (IRI)-2012 model http://iri.gsfc.nasa.gov.

II. DATA SELECTION AND ANALYSIS

The ionospheric electron temperature, maximum electron density and maximum peak height were obtained using the International Reference Ionosphere (IRI)-2012 model. The International Reference Ionosphere (IRI), a joint project of URSI and COSPAR, is the de facto international standard for the climatological specification of ionospheric parameters and as such it is currently undergoing registration as Technical Specification (TS) of the International Standardization Organization (ISO). IRI by charter and design is an empirical model based on a wide range of ground and space data. It describes monthly averages of ionospheric densities and temperatures in the altitude range 50–1500 km in the non-auroral ionosphere. Since its inception in 1969 the IRI model has been steadily improved with newer data and with better mathematical descriptions of global and temporal variation patterns. A large number of independent studies have validated the IRI model in comparisons with direct and indirect ionospheric measurements not used in the model development [7].

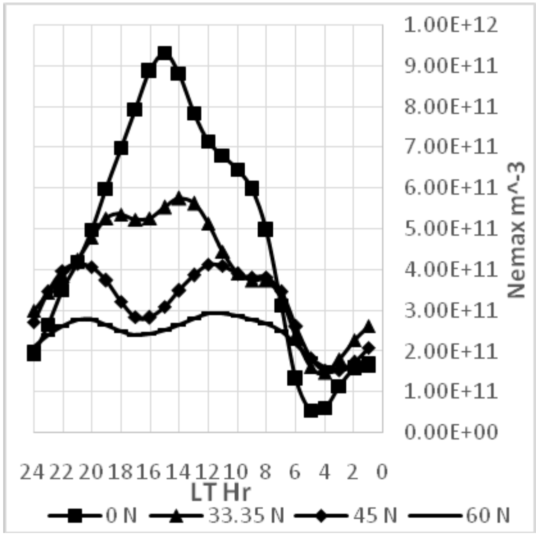
III. RESULTS

To study the effect of the solar activity on the correlation between the electron temperature with both the maximum peak height (hmF2) and maximum electron density (NemaxF2), data estimated by IRI-2012 model have been adopted for two levels of solar activity YSSN=9 and 119. Figures (1 -3) show the local time variations of Te, hmF2 and NemaxF2 for YSSN=9, 119, and for four different latitudes.



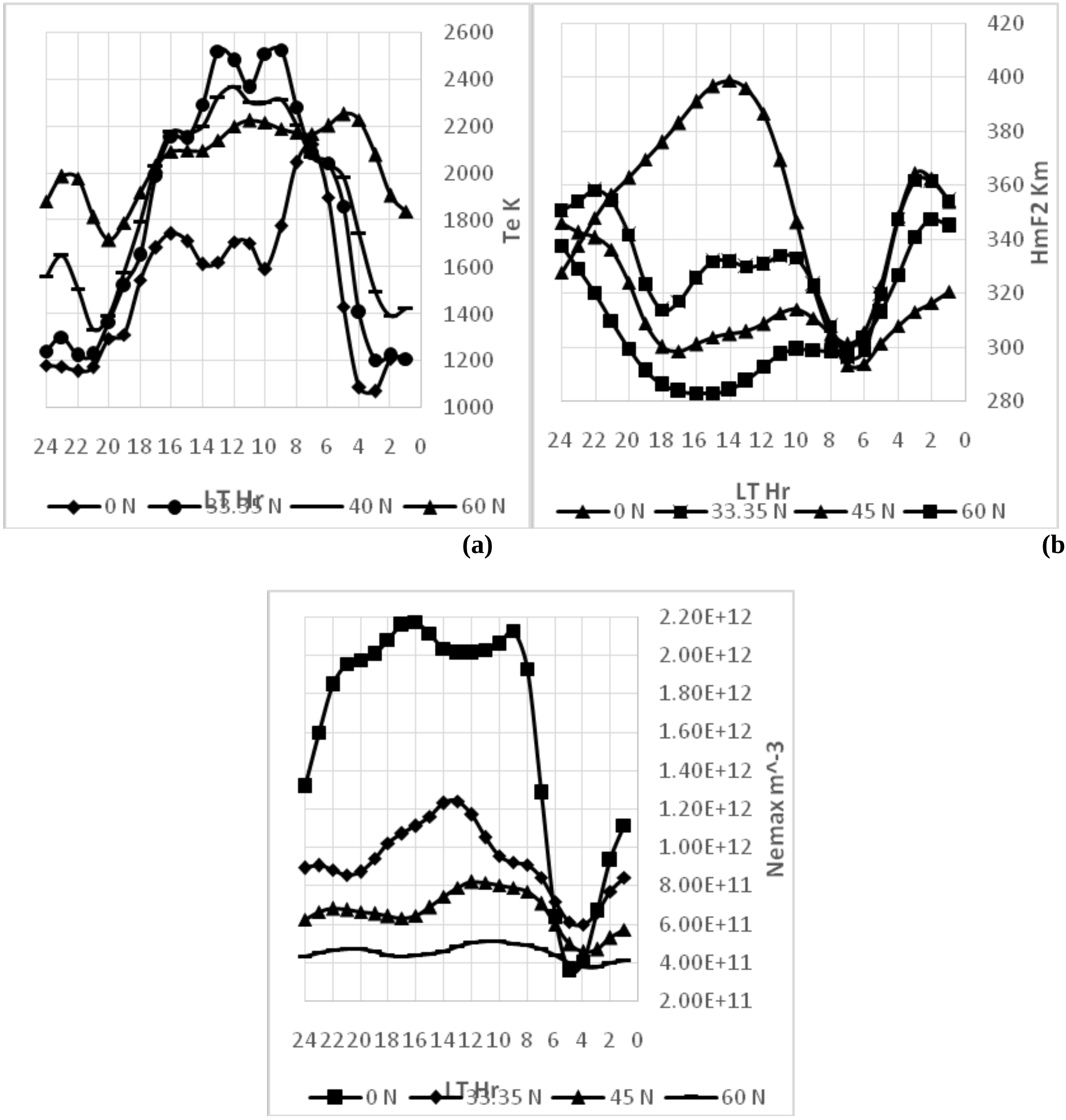
(a) **(b)**

Figure (1): The local time variations for (a) electron temperature T_e, (b) maximum peak height hmF2 for YSSN=9



(c)

Figure (2): The local time variations for (c) maximum electron density $N_e$max for YSSN=9

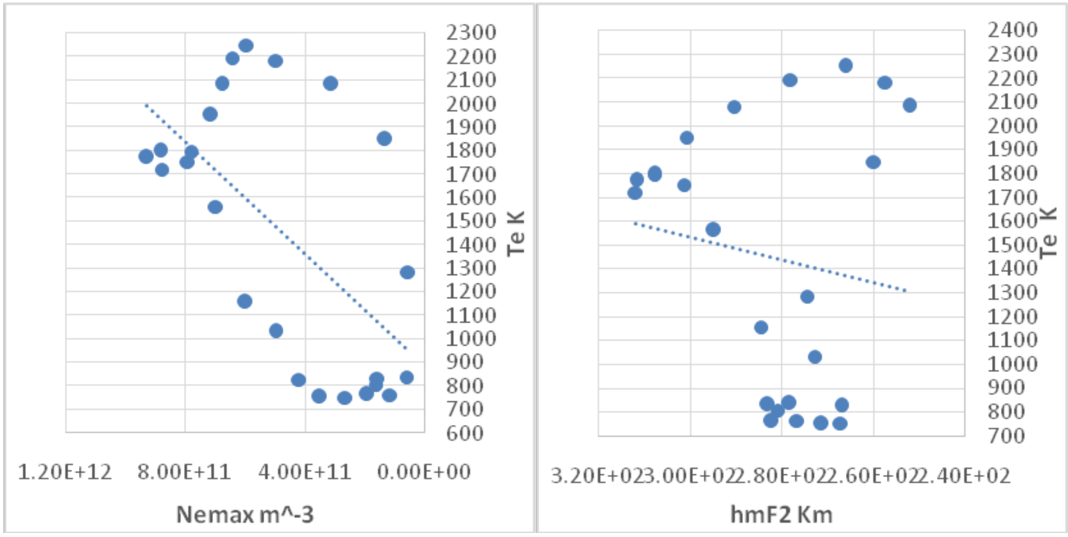


(a) **(b)**

(c)

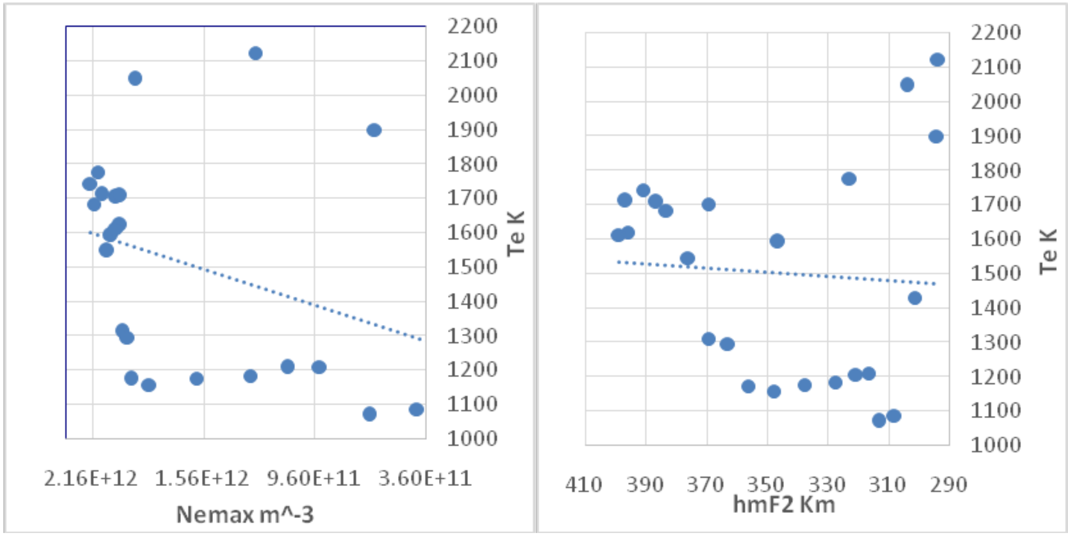
Figure (3): The local time variations for (a) Electron temperature T_e (b) maximum peak height hmF2 (c) $N_e$max for YSSN=119.

From figures (1-3) some important notices can be observed. Generally, it is seen that the T_e and N_{emax} and hmF2 have greater values for YSSN=119 than for YSSN=9. Also, the day values of both electron temperature T_e and electron density Nemax are greater than for night hours. While hmF2 has greater values at night and decreasing through day hours except for equator and low latitudes where there is a strong dependency of *hm*F2 on dynamic forces such as electric fields and neutral winds [8]. Results analysis according to latitude have a significant index because the N_{emax} has greater value at equator and low latitude than for other latitudes and for two solar activity levels. The differences between the day and night values of both the electron temperature and electron density are due to heating and ionization respectively by solar emissions which increases at times of high solar activity, and higher ionization for equator and low latitude. The latitudinal distribution of hmF2 shows a maxima at the geomagnetic equator, gradually decreasing on both sides of the equator. Our investigation shows that the peak over the geomagnetic equator is prominent during daytime, but becomes weaker during nighttime [8]. Figures (4-10) show the correlation between the electron temperature with both the maximum electron density N_{emax} and maximum peak height hmF2 for YSSN=119 and YSSN=9 respectively and for four latitudes.



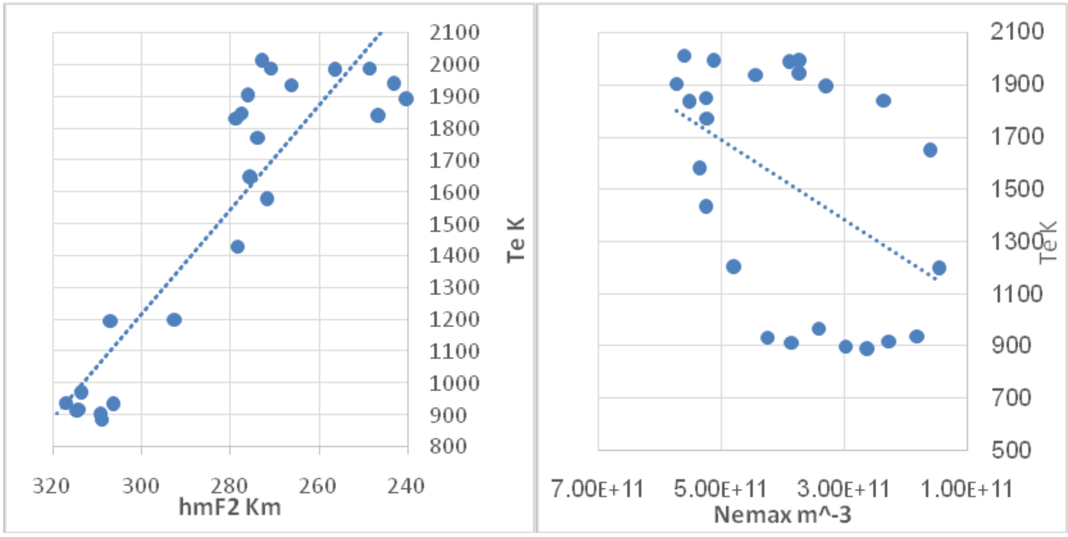
(a) **(b)**

Figure (4) the correlation between T_e with both (a) Nemax and (b) hmF2 for YSSN=9 for latitude=0 N



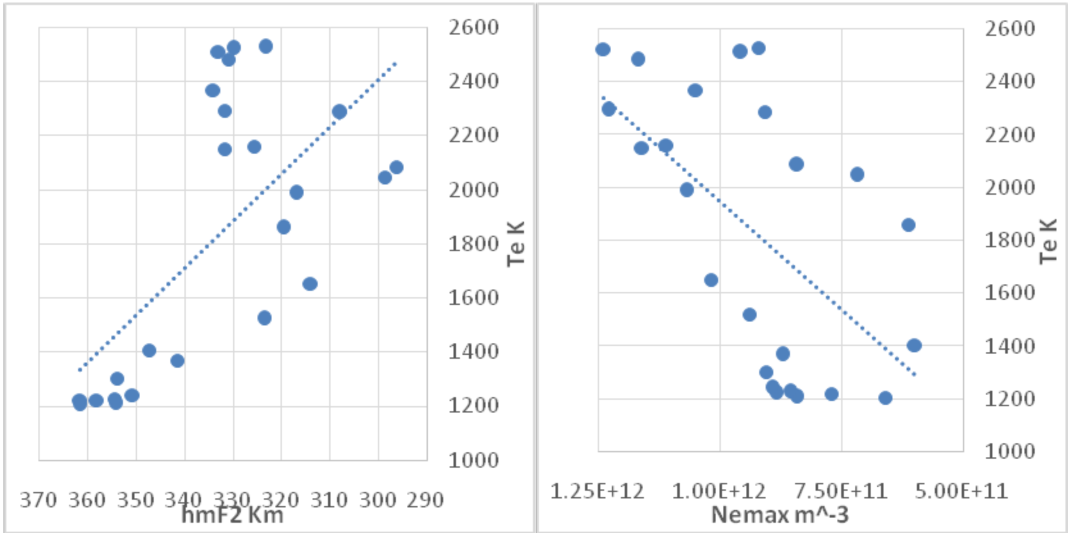
(a) **(b)**

Figure (5) the correlation between T_e with both (a) N_e and (b) hmF2 for YSSN=119 for latitude= 0 N



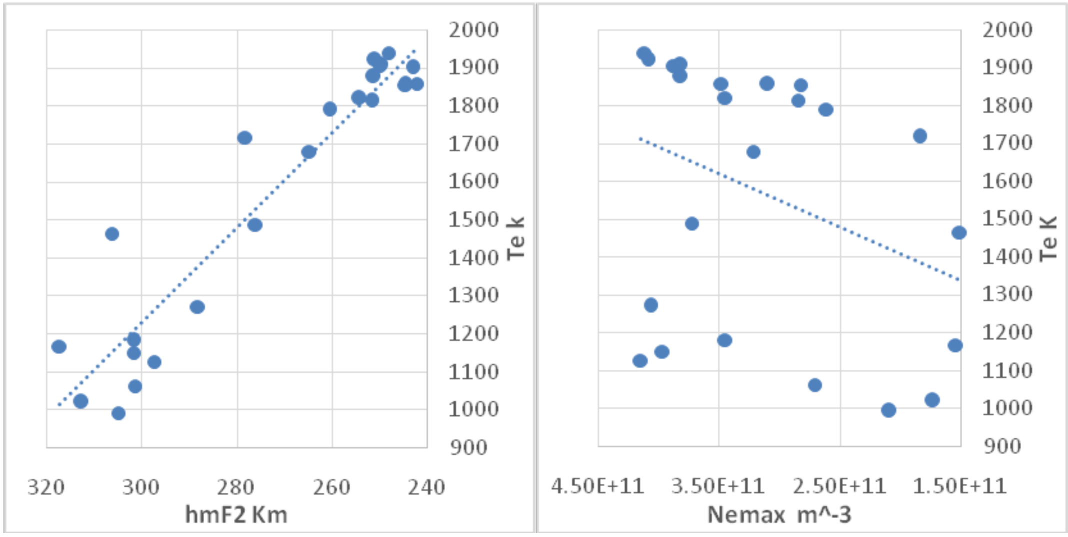
(a) **(b)**

Figure (6) the correlation between T_e with both (a) N_e and (b) hmF2 for YSSN=9 for latitude=33.35 N



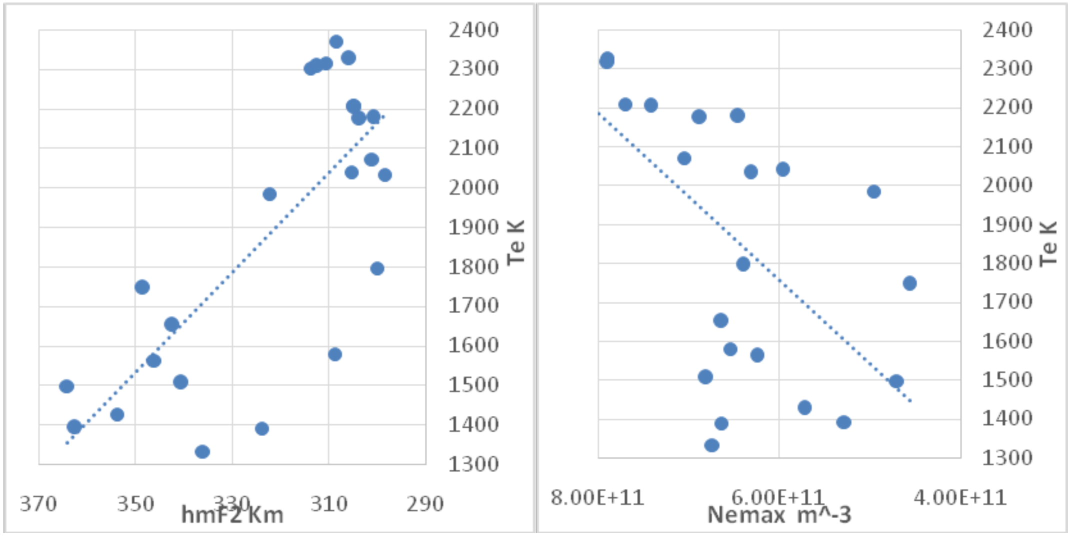
(a) **(b)**

Figure (7) the correlation between T_e with both (a) Nemax and (b) hmF2 for YSSN=119 for latitude= 33.35 N



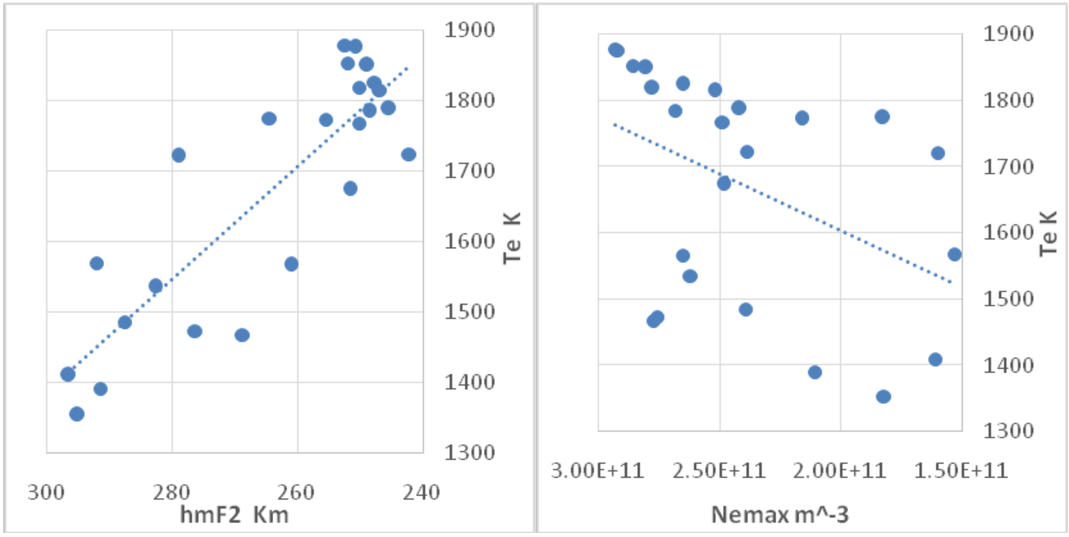
(a) **(b)**

Figure (8) the correlation between T_e with both (a) Nemax and (b) hmF2 for YSSN=9 for latitude=45 N



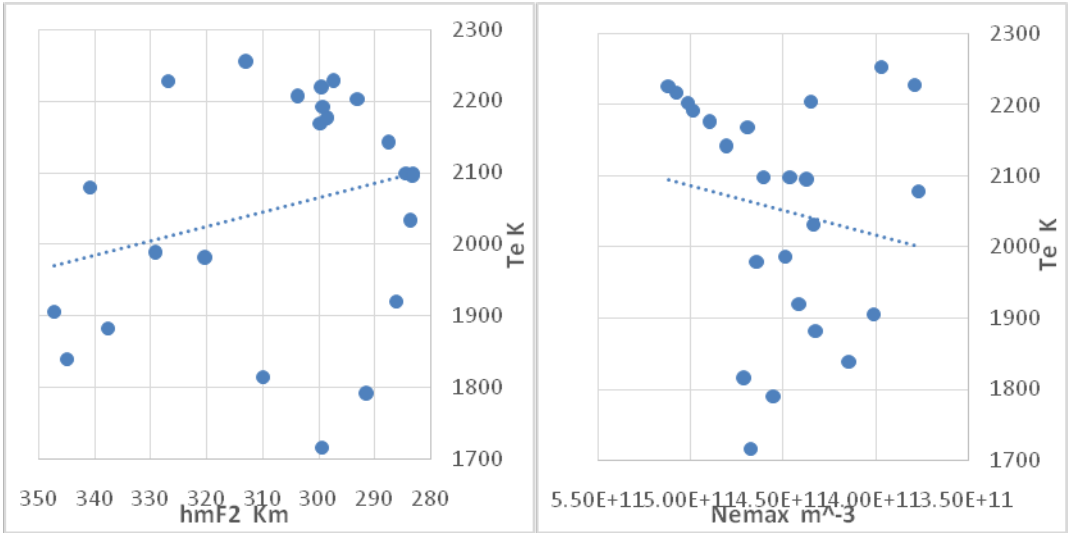
(a) **(b)**

Figure (9) the correlation between T_e with both (a) Nemax and (b) hmF2 for YSSN=119 for latitude= 45 N



(a) (b)

Figure (10) the correlation between T_e with both (a) Nemax and (b) hmF2 for YSSN=9 for latitude=60 N



(a) (b)

Figure (11) the correlation between T_e with both (a) Nemax and (b) hmF2 for YSSN=119 for latitude= 60 N

To reveal the degree of correlation between T_e with both hmF2 and N_{emax} for different latitudes and two solar activity levels it is of interest to use more important statistical parameter called cross correlation coefficient (CCC) given by [8]

$$CCC = \frac{\sum_{i=1}^{24}(\mathrm{hmF2}_i - \overline{\mathrm{hmF2}})(T_e - \overline{T_e})}{\sqrt{\sum_{i=1}^{24}(\mathrm{hmF2}_i - \overline{\mathrm{hmF2}})^2 \sum_{i=1}^{24}(T_e - \overline{T_e})^2}}$$

The bound in CCC equation gives -1$\geq CCC \geq +1$ which indicating maximum correlation and 0 indicating no-correlation. A high negativeindicates a high correlation but inverse of the series. Equation above can be suited for another correlation. Applying this equation for four latitudes each two levels of solar activity resulted in table (1).

Table (1) the values of the Cross Correlation Coefficient (CCC) for different latitudes and solar activity

Latitude (N)	**0**		**33.35**		**45**		**60**	
YSSN	**9**	**119**	**9**	**119**	**9**	**119**	**9**	**119**

Te Vs. hmF2	**0.148**	**0.068**	**-0.903**	**-0.653**	**-0.945**	**-0.754**	**-0.857**	**-0.26**
Te Vs. N_{emax}	**0.608**	**0.340**	**0.467**	**0.582**	**0.353**	**0.633**	**0.437**	**0.163**

From table (1) and for latitude (0 N), the correlation between N_{emax} and hmF2 has roughly no correlation for both two solar activity levels, where CCC=0.1483 and 0.0688 for YSSN=9 and 119 respectively, while for mid latitudes (33.35 N and 45 N), the values of CCC for 33.35 N and 45 N are -0.9034 and -0.9452 for YSSN= 9 and 119 respectively, increasing to -06534 and -0.7543 for YSSN=9and 119 respectively which all represent highly negative correlation. Finally for high latitude (60 N) the value of CCC changes from -0.8575 (high negative correlation) to -0.2067 (no correlation). The second correlation shows more accurate than the first correlation. The CCC for equator equal 0.6086 and 0.3402 for YSSN=9 and 119 respectively which shows the effect of increasing the solar activity for equatorial ionosphere. In the mid latitudes, 33.35 and 45 N, the increasing of solar activity rises up the degree of correlation where CCC for 33.35 N equal 0.467 and 0.5819 for YSSN =9 and 119 respectively, while for 45 N, the CCC ranges from 0.3529 to 0.6336 respectively. Finally, for high latitude 60 N, the CCC decreases from 0.4375 to 0.1636 for YSSN equals 9 and 119 respectively.

IV. CONCLUSION

From figures (1-3), some important conclusions will be show for this study. The local time variations of T_e, N_{emax} and hmF2 have a greater values for high solar activity than for low solar activity due to increasing the intensity of the solar emissions which leads to high ionization and heating which rises up. At equator, N_{emax} has the maximum value than other latitudes. The local time variation of the hmF2 has an important departest, it has an opposite behavior for equator than other latitudes which values rise up at day time and goes down at night hours. Also, from figures (4-11), firstly, two types of correlations between T_e with hmF2 have been observed, no correlation at equator and negative correlation at other latitudes. The solar activity has no strongly effect on this correlation (Te vs. hmF2) at mid latitudes while has a marked effect at high latitudes. For second correlation (T_e vs. N_{emax}), the effect of the solar activity is to decreasing the correlation at equator and high latitude and vice versa for mid latitudes.

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