BEHAVIOUR OF IONOSPHERIC TEMPERATURES DURING LOW SOLAR ACTIVITY (LSA) AND HIGH SOLAR ACTIVITY (HSA)

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Abstract- SROSS-C2 satellite data and two modelled data obtained from IRI – 2016 and NRLMSISE-00 models are used to analyze the diurnal behavior of ionospheric plasma temperatures (electron – T_e and ion - T_i) and neutral temperature (T_n) during LSA (year – 1995) and HSA (year – 2000). The measured SROSS-C2 satellite data and the modelled data of IRI2016 and NRLMSIS00 was obtained over the Indian region of ~ 5-30ºN geographic latitude and ~ 65-95ºE geographic longitude at an altitude of ~500 km. Plasma temperatures (Te and Ti) show similar diurnal features while the neutral temperature (Tn) shows completely different features. During morning time, T_e and Ti exhibit morning overshoot during LSA and HSA. Evening enhancement is observed only during LSA. Te and Ti as estimated by IRI2016 underestimates the measured SROSS-C2 satellite values. The Tn as estimated by both the models have similar magnitude values.

1. INTRODUCTION

Ionosphere is very important layer present in the earth's atmosphere which is responsible for satellite communication and navigation. Various physical phenomena like changing solar flux, electro-dynamic drift, EEJ etc., makes the ionosphere respond in a very complicated manner. These complexity further variates various ionospheric parameters - like electron density, electron temperature, ion density, ion temperature, etc. Studies on ionospheric plasma temperature is still less because of few satellite-based measurements. The world we dwell in is completely dependent on communication and navigation systems. The ionosphere is the vital layer in terms of communication systems. Thus, understanding, forecasting and monitoring changes in ionosphere weather phenomena has become extremely important. This can be only done via analyzing the ionospheric parameters like ionospheric temperatures, electron density, NmF2, hmF2, Ne, Ni etc., Moreover, understanding the ionosphere's complexity and forecasting the changes has become an important aspect of present-day research to suggest improvements of prevailing ionospheric models.

Many researches were based on the ion composition and electron densities. Some of the extensive reports were provided by Balan et al. (1997), Watanabe et al. (1995), Titheridge (1998), Schunk et al. (2003), Bhuyan et al. (2002), Aggarwal et al. (2007), Sharma et al. (2010) and many more, on ionospheric temperature. Ionospheric temperatures in F-region are determined by heating, cooling and energy flow (Schunk and Nagy, 1978). Neutral atoms are ionized by the solar radiations and photoelectrons lose their energy by sharing it with ambient electrons causing a rise in electron temperature. The increase in electron temperature is higher during early morning as the electron density is low (Sharma et.al, 2003). During the day time, the production of electrons increases and hence, shared energy of each electron decreases. In early morning, the electron and ion temperatures are at their peak thereafter decreases and achieve a constant value by the afternoon. However, the peak in ion temperature is delayed as compared to electron temperature (Aggarwal et al., 2007; Sharma et al., 2010). Magnetic field lines over the lower latitudes acquires more horizontal component, which gives a new aspect and different dynamics compared to mid and higher latitudes. Some of the unique features like equatorial electrojet, vertical E×B drift, etc. are key features of the equatorial or low latitudes. Over the Indian sub-continent, electron and ion temperatures in the upper ionosphere have been studied by researchers based on the SROSS-C2 satellite data (Bhuyan et al., 2002, 2004, 2006; Aggarwal et al., 2007, 2009). In T_e, there are two interesting features called "Morning Overshoot" and "Evening Overshoot" and was found by Oyama et al. (1996). In T_e, the morning overshoot was observed during winter in high solar activity and evening over-shoot was found at higher latitudes in all seasons with more enhancements in winter. These phenomena also showed longitudinal differences. In the early morning, the T_e shows a steep rise known as "morning overshoot", and then a decrease after that is called an "evening overshoot".

During 1995-1996 the diurnal, seasonal variation of electron and ion temperatures along with electron density were given by Bhuyan et al. (2002). They have also observed that during sunrise, the electron and ion temperatures shows an increment, although the electron temperatures were found to be higher than the ion temperatures in all seasons and latitudes in a study. Nayar et al. (2004) shows the comparison of electron and ion temperatures at the low latitude topside ionosphere. They observed that during morning and evening enhancement similar diurnal features were exhibited by electron and ion temperatures. During sunrise, at 500 km altitude electron and ion temperatures were studied by Aggarwal et al. (2009). And Sharma et al. (2005) observed during the period 1995–1999 variation of electron and ion temperatures ratio over the Indian region as measured by SROSS-C2 satellite. Using Indian satellite SROSS-C2, Prabhakaran Nayar et. Al (2004) found morning and evening enhancements in both T_e and T_i which develops with season, altitude, latitude and solar activity respectively. Recent studies reported by Bardhan et.al (2015) based on temperature ratios of plasma (T_e & T_i) and neutrals (T_n) during different seasons with varying solar activities (year 1995-2000) found an equilibrium between T_e, T_i, T_n and plasma cooling faster than neutrals in nightime.

The aim of present study is to examine the variation in the ionospheric temperatures during LSA and HSA as obtained by Indian SROSS-C2 satellite and compare with IRI 2016 & NRLMSISE-00 models. The study is not confined to specific hours of a day and has been carried for both morning and quiet hours. One can find lots of work on ion density, however statistical/analytical work on plasma and neutral temperature is still very less. Thus, we believe that detailed treatment of the Te, Ti and Tn would give a better understanding of the variation of ionospheric temperature ratios with the varying solar activity and help in improving the existing ionospheric models. Here, the section 2 gives the description of data and models used in the present study followed by Results and discussions in section 3. Finally, Conclusions are presented in section 4.

2 DATA USED

2.1 SROSS-C2 satellite Data

The ionospheric plasma temperatures (electron temperature, T_e and ion temperature T_i) are obtained above the Indian region of ~ 5-30ºN geographic latitude and ~ 65-95ºE geographic longitude) at an altitude of ~500 km. By using Retarded Potential Analyzer (RPA) of SROSS-C2, the ionospheric parameters were obtained which was launched by Indian Space Research Organization (ISRO). The data was obtained monthly and the hourly averaged data of ionospheric temperatures were plotted during LSA and HSA. The ionospheric parameters were studied for LSA year 1995 and for HSA year 2000.

2.2 Other data used

In the present study, observation of SROSS-C2 satellite have been compared with IRI-2016 and NRLMSISE models. IRI-2016 modelled data of the ionospheric plasma temperatures (electron and ion temperature, T_e and T_i respectively) and neutral temperature (T_n) were obtained from (https://ccmc.gsfc.nasa.gov/modelweb/models/iri2016_vitmo.php). The neutral temperature was also obtained using NRLMSISE-00 model (https://ccmc.gsfc.nasa.gov/modelweb/models/nrlmsise00.php). The IRI 2016/ NRLMSISE -00 data has been obtained at about 77.5ºE longitude, averaging over 5-30ºN latitude and at altitude of ~500 km. The SROSS-C2 satellite does not measure the neutral temperature thus we have used the modelled values from IRI and NRLMSISE-00 models to get a comprehensive study of plasma and neutral temperatures. For LSA (year-1995) and HAS (year-2000), the variability of ionospheric parameters (Te, Ti and Tn) measured yearly through averaging the monthly data (from January to December) for local time (0-24 hrs) for year 1995 and 2000 has been done respectively to plot the figures.

3 RESULT AND DISCUSSION

3.1 Behavior of ionospheric temperatures during LSA

The diurnal behavior ionospheric temperatures - T_e, T_i and T_n during LSA is represented in fig. 3.1.

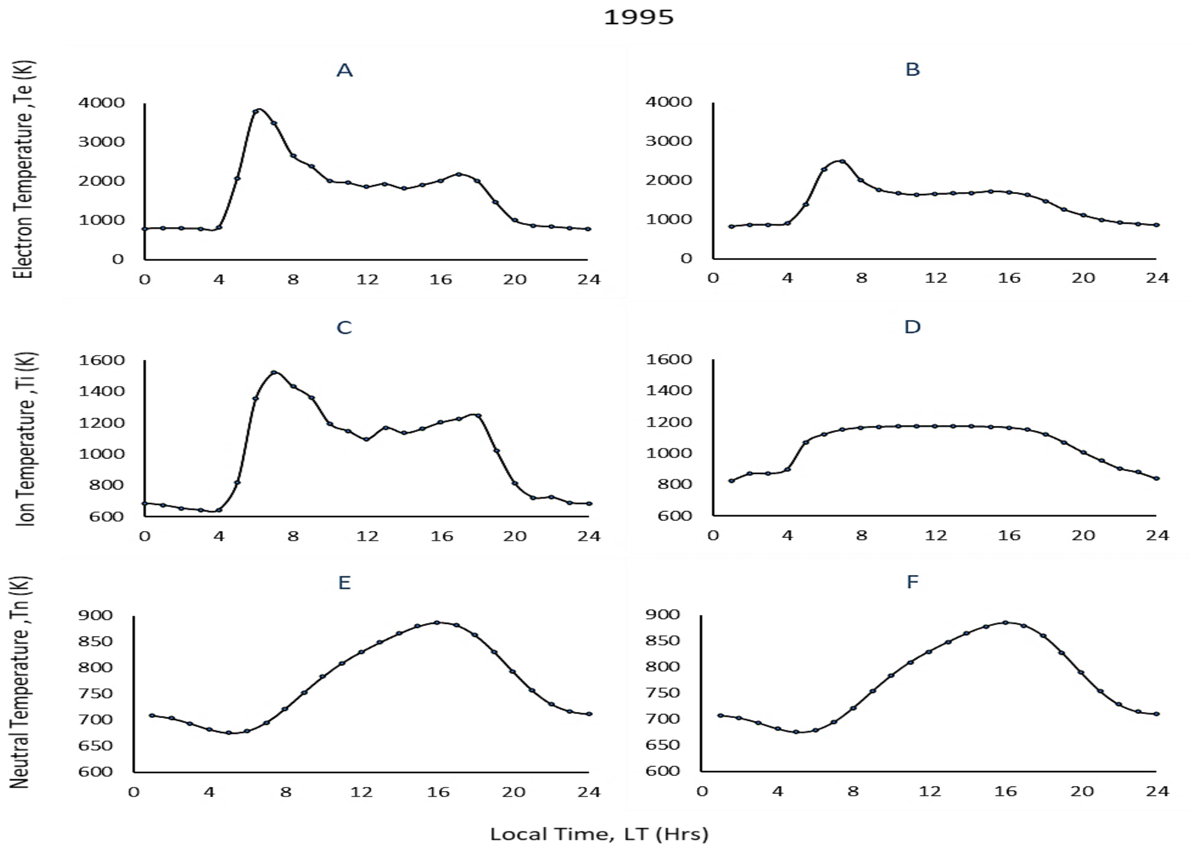

Fig. 3.1 Diurnal variation of ionospheric temperatures - Electron Temperature (A - SROSS-C2; B - IRI 2016), Ion Temperature (C - SROSS-C2; D – IRI 2016) and Neutral Temperature (E - NRL MSIS; F – IRI 2016) during Low Solar Activity

The electron/ion temperature (T_e/T_i) as measured by SROSS-C2 satellite is compared with IRI 2016 modelled values. In fig. 3.1A, the peak temperature was observed at ~6 LT in the morning (i.e., ~ 3794 K) then it starts decreasing till 17 LT (i.e., ~ 2181 K) which is the second peak in the graph then again it starts decreasing till night. While in fig. 3.1 B (IRI 2016 modelled values) there is a single peak observed in the graph at 7 LT (i.e., ~ 2490 K) afterwards it shows consistency in temperature from 10 LT to 16 LT (i.e., between ~ 1650 K to 1700 K) then shows the downfall in the graph. In the comparison of SROSS-C2 and IRI 2016 values of temperatures initially at low temperatures (i.e., between 750 K to 900 K) for 0 to 4 LTs. The first peaks were observed for satellite value and modelled value at between ~ 6 to 7 LT with temperatures (~ 3794 K & ~ 2490 K) respectively. For ion temperature (Ti) we compared SROSS-C2 and IRI 2016 data. From Fig. 3.1 c it is observed that initially from 0 LT to 4 LT the temperatures were lies between ~600 K to ~700 K and the peak temperature (i.e., ~ 1523 K) was observed at 7 LT there is sudden increment in temperature from ~ 4 to ~ 7 LT. Then decrement in temperature was observed till 12 LT and second major peak temperature taken out at ~18 LT (i.e., ~ 1245 K). After second major peak temperature graph decreases rapidly. While from fig 1d it is noticed that the temperature was quite consistent without showing any peak temperature. It shows an increment after 4 LT with temperature ~ 900 K and then decrement starts at 18 LT with temperature ~ 1121 K. In the comparison of SROSS-C2 and IRI 2016 graphs, there were peaks in both the graphs at 4 LT with temperatures ~600 K and ~ 900 K respectively but SROSS-C2 shows many fluctuations instead of showing consistency as in IRI 2016 's graph.

Neutral temperatures (Tn) were compared using two models i.e., IRI 2016 (Fig 3.1E) and NRLMSIS-00 (Fig 1F). As the fig. 3.1E and 3.1F shows there is no difference in both of the modelled values. We studied observation between 1 to 24 LT for both the models. Graphs show the wavy nature with one highest peak at 16 LT with ~ 887 K temperature and one lowest peak at 5 LT with ~ 675 K temperature.

3.2 Behavior of ionospheric temperatures during HSA

The diurnal behavior ionospheric temperatures - Te, Ti and Tn during HAS is represented in figure 2. For electron temperature (Te) we compared SROSS-C2 satellite and IRI 2016 modelled value. Both graphs in fig. 2A and 2B show similar nature with one peak at 6 LT and 7 LT with ~ 3010 K and 1846 K temperatures respectively. The graphs in fig. 2A and 2B become consistent after 8 LT and 9 LT with temperatures ~ 1888 K and ~ 1218 K respectively. Initially, the temperature for each case is low and after 4 LT for SROSS-C2 (fig. 2A) and 5 LT for IRI 2016 (fig. 2B) temperature starts increasing till their respective peak conditions. And after 2 hrs of time period both shows constant graphs.

The ion temperature (Ti) data as obtained from SROSS-C2 satellite has been compared with IRI 2016 model. From fig. 2C, it is shown that the graph is fluctuating in nature. Firstly, it shows a decrease in graph between 0 LT to 3 LT with 960 K and 890 K temperature respectively and then starts increases and shows many ups and downs. From fig. 2D, there was not too much variation in graph and the graph is from 1 LT to 24 LT initially it starts increases till 16 LT with ~ 1318 K temperature then it shows a drop at 17 LT and after that it starts decreases.

For neutral temperature (Tn) we compared two models i.e., IRI 2016 and NRLMSIS-00. As figures 2E and 2F. show there is no such difference in both of the modelled values. We studied observation between 1 to 24 LT for both the models. From fig. 2E, shows the wavy nature with one highest peak at 16 LT with ~ 1318 K temperature and one lowest peak at 5 LT with ~ 956 K temperature. And from fig. 2F there are two peaks at 16 LT and 18 LT with temperatures ~ 1310 K and ~ 1268 K respectively. And a low peak 5 LT with ~ 947 K temperature.

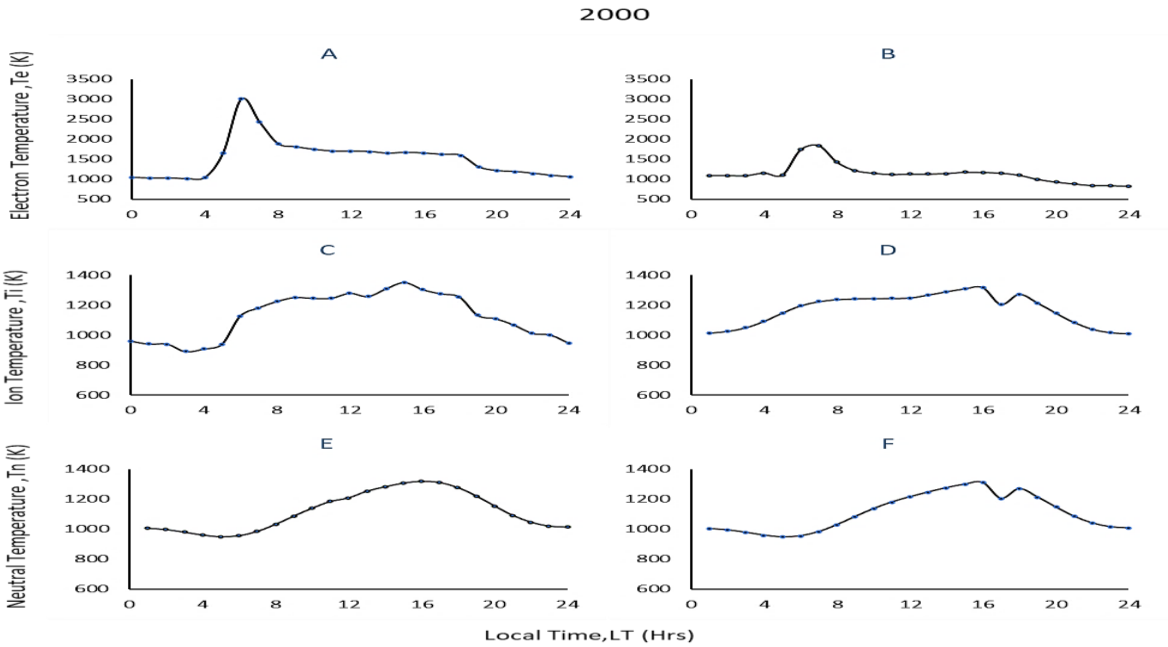

Fig. 3.2 Diurnal variation of ionospheric temperatures - Electron Temperature (A - SROSS-C2; B - IRI 2016), Ion Temperature (C - SROSS-C2; D – IRI 2016) and Neutral Temperature (E - NRLMSISE; F – IRI 2016) during High Solar Activity

3.3 Comparison between behavior of ionospheric temperatures during LSA & HSA

By comparing fig. 3.1A & 3.2A we observed that the magnitudes of temperature during LSA is less than during HSA (i.e., ~ 818 K and ~ 1037 K) respectively. And both figures have nearly show same nature with major peak temperatures at ~ 6 LT but there is a bit difference in temperatures shown in fig. 3.1A and 3.2A (i.e., ~ 3794 K and ~ 3010 K) respectively. Afterwards these both figures show decreasing nature but from ~ 8 LT we saw some fluctuations in fig. 1A and consistency in fig. 3.2A respectively.

By comparing fig. 3.1B & 3.2B we observed very much similarities like both shows peak temperature at ~ 7 LT with ~ 2490 K and 1846 K values respectively and the curve of graphs also similar. Initially the magnitude of temperature is high in (HSA) fig. 3.2A than fig. 3.1A (LSA).

From fig. 3.1C and 3.2C, there is a lot of difference between these 2 graphs but on an average the magnitude of temperature during LSA is low than HSA. From figures 1D & 2D we have observed consistent graphs in both but the magnitude of lowest temperature in case of LSA is ~ 826 K at 1 LT as shown in fig. 3.1D while in case of HSA is ~ 1010 K at 24 LT as shown in fig. 3.2D. For fig. 3.1E and 3.2E we can say that the curves are identical, both show lowest temperature at 5 LT with ~ 675 K and ~ 949 K respectively. And highest temperature values at 16 LT with values of ~ 887 K and ~ 1318 K respectively. As we observe that the magnitude of temperature in LSA is lower than the HSA. Similarly, from fig.3.1 F and 3.2 F, the magnitude of temperature during LSA is lower than HSA.

During morning time, Te shows the maximum variations and highest temperature as we move at nightime the Te starts decreasing. While Ti shows maximum peak after ~ 4 LT in both LSA and HSA. With Tn, the temperature starts rising after ~ 6 LT and gives its maximum magnitude of temperature after noon then again starts decreasing as the nightime comes closer.

From the above results and discussions, we can summarize that photoionization produces photoelectrons, which act main source of energy for thermal electrons. This energy is source of heating of electrons. The same energy via inelastic collisions gets transmitted to ions and neutrals, thus heating ions and neutrals. Although Te, Ti and Tn can be affected by several factors like alignment of geomagnetic field lines, plasma drifts etc (whose effects are out of the scope of present paper). The key factor in determining ionospheric temperatures remains energy transmitted via collisions through photoelectrons. At low latitudes, Te is greatly affected by local heating and cooling processes. The Te increases rapidly during sunrise owing to low electron density and cools down during daytime when photoionization increases the number density via collisions. During nighttime, in absentia of source of ionization, plasma and neutrals cool down to attain an ~ equilibrium temperature. But plasma is more energetic than neutrals, thus losses heat through collisions and cools down more rapidly than neutrals.

We have studied the ionospheric parameters like ionospheric temperature, electron density, neutral temperature, etc., during LSA and HSA. The present work can be extended over complete solar cycle to understand the ionospheric temperatures variations with every phase of changing solar flux. Other models like IRI Plas 2017 can also be analyzed simultaneously to improve the existing empirical models.

CONCLUSIONS

The behavior of ionospheric plasma temperatures (electron, Te and ion, Ti) and neutral temperature have been examined during LSA and HSA obtained by SROSS-C2 satellite measurement and IRI-2016 and NRLMSISE-00 modelled measurements during LSA (year – 1995) and HSA (year – 2000), over 5-30º N geographic latitude and 65-95ºE geographic longitude at ~ 500 Km altitude. From present observations we conclude the following:

- During LSA, Te and Ti both were high in morning time i.e., ~ 6 LT and ~ 7 LT respectively and then starts decreasing. But in Tn it shows peak during evening time i.e., ~ 16 LT.
- During HSA, Te shows peak temperature at morning time i.e., ~ 6 LT and then decreases. Whereas Ti and Tn both showed peak temperatures at evening time i.e., ~ 15 LT and ~ 16 LT respectively.
- On comparing LSA and HSA, we studied that the magnitude of temperature in LSA is less than in HSA and the behavior of Tn is similar in both LSA and HSA.

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REFERENCES

[1] Aggarwal, M., Joshi, H. P., Iyer, K. N., Solar activity dependence of electron and ion temperatures using SROSS-C2 RPA data and comparison with IRI model, J. Atmos. Sol. Terr. Phys., 69, 860-874, 2007.

[2] Aggarwal, M., Joshi, H. P., Iyer, K. N., Jivani, M. N., Studies of electron and ion temperatures at 500 km altitude during sunrise using Indian SROSS C2 satellite, Adv. Space Res., 43, 273-281, 2009.

[3] Balan, N., Oyama, K. I., Bailey, G. J., Fukao, S., Watanabe, S., Abdu, M.A., A plasma temperature anomaly in the equatorial topside ionosphere, J. Geophys. Res., 102, 7485–7492, 1997.

[4] Bhuyan, P. K., Garg, S. C., Subrahmanyam, P., Electron & Ion temperature and electron density at ± 10 0 Magnetic Latitudes from SROSS C2 measurements over India and comparison with the IRI, Adv. Space Res., 29, 865-870, 2002.

[5] Bhuyan, P. K., Chamua, M., Subrahmanyam, P., Garg, S. C., Diurnal, seasonal and latitudinal variations of ion temperature measured by the SROSS C2 satellite in the Indian zone equatorial and low latitude ionosphere and comparison with the IRI, J. Atmos. Sol. Terr. Phys., 66, 301–312, 2004.

[6] Bhuyan, P. K., Chamua, M., Subrahmanyam, P., Garg, S. C., Effect of solar activity on diurnal and seasonal variations of electron temperature measured by the SROSS C2 over Indian latitudes, Adv. Space Res., 37, 885–891, 2006.

[7] Nayar, S. R. P., Alexnder, L.T., Radhika, V.N., Thomas, J., Subrahmanyam, P., Chopra, P., Bahl, M., Maini, H. K., Singh, V., Singh, D., Garg, S. C., Study of the evolution of Te and Ti at the low-latitude upper ionosphere using SROSS C2 RPA observations, J. Atmos. Sol. Terr. Phys., 66, 1075–1083, 2004.

[8] Oyama, K. I., Watanabe, S., Su, Y., Takanashi, T., Hirao, K., 1996. Season, local time, and longitude variations of electron temperature at the height of -600 km in the low latitude region. Adv. Space Res. 18, 269–278.

[9] Schunk, R. W., Nagy, A. F., Electron temperatures in the F region of the ionosphere: theory and observations, Rev. Geophys. Space Phys., 16, 355-399, 1978.

[10] Schunk, R. W., Scherliess, L., Sojka, J. J., Recent approaches to modelling ionospheric weather. Adv. Space Res., 31, 819-828, 2003.

[11] Sharma, D. K., Rai, J., Israil, M., Shalni, P., Subrahmanyam, P., Chopra, P., Garg, S. C., Sunrise effect on ionospheric temperature as measured by SROSS-C2 satellite, Journal Indian Geophys Union, 7, 117-123, 2003.

[12] Sharma, D. K., Chand, R., Israil, M., Rai, J., Variation of electron and ion temperatures ratio over the Indian region during the period 1995–1999 as measured by SROSS-C2 satellite, J. Atmos. Sol. Terr. Phys., 67, 1443–1447, 2005.

[13] Sharma, P. K., Pathak, P. P., Sharma, D. K., Rai, J., Variation of ionospheric electron and ion temperatures during periods of minimum to maximum solar activity by the SROSS-C2 satellite over Indian low and equatorial latitudes, Adv. Space Res., 45, 294–302, 2010.

[14] Titheridge, J. E., Temperature in the upper ionosphere and plasmasphere, J. Geophys. Res. 103, 2261-2277, 1998.

[15] Watanabe, S., Oyama, K. I., Abdu, M. A., Computer simulation of electron and ion densities and temperatures in the equatorial F-region and comparison with Hinotori results, J. Geophys. Res. 100, 14581–14590, 1995.

[16] Bardhan, A., Sharma, D. K., Khurana, M. S., Aggarwal, M., Kumar, S., 2015. Electron–ion–neutral temperatures and their ratio comparisons over low latitude ionosphere. Adv. Space Res. 56, 2117-2129.

[17] Prabhakaran Nayar, S.R., Alexnder, L.T., Radhika, V.N., Thomas, J., Subrahmanyam, P., Chopra, P., Bahl, M., Maini, H.K., Singh, V., Singh, D., Garg, S.C. 2004. Study of the evolution of Te and Ti at the low latitude upper ionosphere using SROSS C2 RPA observations. J. Atmos. Solar Terr. Phys. 66, 1075–1083.