Features of the Diurnal Variation of Electron and Ion Temperatures in the Low Latitude Upper Ionosphere

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Abstract

The electron temperature Te and the ion temperature Ti was found to exhibit a sharp morning enhancement, a day time trough, evening enhancement and stable night-time value. At sunrise the photoelectron production begins in the ionosphere through the ionization of the neutral particles .As the photoelectrons share their high energy with the ambient electrons, the electron temperature (Te) increases. This increase is rapidly in the early morning hours due to the low electron density. As more and more electrons are produced the sharing of energy for each electron decreases. After reaching a maximum decrease and attains a steady state as the day progress. The SROSS C2 satellite has provided some valuable data on the thermal structure of the topside ionosphere over the Indian region. The Japanese Hinotori satellite, which had a near circular orbit at 600 km, provides an ideal database for studies of temporal and spatial variations of electron temperature in the topside ionosphere. The temperatures Te and Ti are found to have similar diurnal variations. The morning and evening peaks arise basically from the photoelectron heating of the morning and evening electron gas. The diurnal pattern of Te and Ti clearly shows the morning overshoot, evening enhancement, daytime valley and night-time stability.

1. Introduction

The ionosphere undergoes a marked diurnal variation as the Earth rotates into and out of sunlight. The electrons are heated by photoelectrons that are created in the photoionization process and by a downward heat from the magnetosphere. At sunrise the photoelectron production begins in the ionosphere through the ionization of the neutral particles .As the photoelectrons share their high energy with the ambient electrons, the electron temperature (Te) increases. This increase is rapidly in the early morning hours due to the low electron density. As more and more electrons are produced the sharing of energy for each electron decreases. After reaching a maximum decrease and attains a steady state as the day progress. A secondary maximum is also observed before sunset. Finally the nighttime stability is attained.

Results of studies based on *in situ* measurements and comparisons with the existing ionospheric models on the spatial and temporal variations of electron density and temperature are available in the literature (Brace and Theis , 1981; Su et al., 1996; Watanabe et al., 1995; Bhuyan et al., 2002,; Niranjan et al., 2003). The electron temperature is characterized by a sharp increase in the morning hours due to low electron density at the onset of photoelectron heating. Oyama et al. (1997) from Hinotori satellite measurements reported high electron temperatures during evening-night time hours in the equatorial region.

The electron and ion temperatures at the upper ionosphere depends on solar activity level and is found to exhibit diurnal, seasonal, altitudinal and latitudinal variations (Bilitza, 1991; Oyama et al., 1996a; Otsuka et al.,1998; Borgahain and Bhuyan, 2012). The electron temperature was found to exhibit a sharp predawn enhancement, a daytime trough, evening enhancement and stable night-time value. The heating occurring before the sunrise is caused by the photoelectrons arriving from the conjugate hemisphere at a time corresponding to the sunrise in the magnetically conjugate ionosphere (Schunk and Nagy, 1978). This morning peak become prominent in the low latitudes due to the vertical E x B drift which increases the morning Te and decreases the day time Te (Su *et al*., 1995; 1996; Balan *et al*., 1997; Otsuka et al., 1998). A secondary maximum is also observed before sunset (Bhuyan *et al*., 2002). Afternoon enhancement of Te in the low latitude region is strongly affected by both the neutral wind and E x B drift. The electron temperature and density at the equatorial ionosphere have been modeled utilizing the IRI model, computer simulation and Hinotori satellite measurements (Watanabe *et al*., 1995; Bhuyan *et al*., 2002).

A number of local and non-local processes can affect the low latitude thermosphere. The electrons and ions are not in thermal equilibrium and under most circumstances the temperature of electrons is higher than ion temperature. Heat gained by the ambient electron gas from solar EUV produced photoelectrons act to raise the electron temperature above the neutral temperature (Schunk and Nagy, 1978; Bilitza, 1991). This paper investigates the features of the diurnal variations of electron and ion temperatures measured by the SROSS C2 satellite during the rising phase of solar activity period (1995-2000). The Hinotori satellite provides an additional database for the study of diurnal variation of electron temperature at low latitudes around solar maximum. The observations of the diurnal pattern of Te evaluated using SROSS-C2 data is compared with the Hinotori satellite measured, diurnal pattern of electron temperature.

2. Data analysis

The SROSS C2 satellite was launched from Shriharikota, India in May 1994. It is a spin stabilized orbiting satellite placed in an elliptical orbit at 620 x 420 Km altitude, inclined at 46.3^0 with equatorial plane. The retarding potential analyzer (RPA) payload on SROSS C2 satellite consists of two sensors viz., electron and ion sensors and associated electronics (Garg *et al*., 1996).The electron and ion RPAs are used for insitu measurements of ionospheric electron and ion parameters. The two sensors are mechanically identical but have different grid voltages suitable for collection of electrons and ions. The charged particles whose energies are greater than the applied voltage on the retarding grid pass through various grids and finally reach the collector electrode to cause the sensor current. For the data collection from Bangalore ground station, latitudinal coverage extend from 5^0 S to 30^0 N and longitude range can extend from 50^0 E to 100^0E. The longitudinal variations of the satellite from 40^0 E to 100^0 E are used to identify the local time of observation.

The RPA probes make simultaneous measurements of electron and ion parameters along the orbital path of the satellite. The I-V characteristic curves obtained from the ion and electron RPA are used for retrieving these parameters using curve fitting techniques. Hinotori satellite recorded the electron temperature at an altitude of about 600 km at low latitude ionosphere. All the datas were grouped in to one hour in local time. Average of such diurnal patterns are evaluated separately for each year to get annual pattern and averaged over 1995 to 2000 combined for all seasons, latitude, longitude and altitude to obtain the mean diurnal pattern of Te and Ti during SROSS-C2 observation period. The data of electron and ion temperatures pertaining to the rising phase of solar activity is used to study the temporal and spatial variations of plasma temperatures low latitude upper ionosphere.

3. Results and Discussion

The SROSS C2 satellite has provided some valuable data on the thermal structure of the topside ionosphere over the Indian region. The Japanese Hinotori satellite, which had a near circular orbit at 600 km, provides an ideal database for studies of temporal and spatial variations of electron temperature in the topside ionosphere. Figure 1 depicts a typical diurnal pattern of electron temperature using SROSS C2 data. The average F10.7 solar radio flux corresponding to the period of observation is ~ 113 s.f.u. The data used for Figure 1 were restricted within the latitude range 5^0 S and 30^0 N. Each point in this diurnal pattern is an average of nearly 24 values. For a comparison, the diurnal pattern of Te obtained using Japanese Hinotori satellite during 1981-1982 is plotted in figure 2. The data from the Hinotori is limited to a period of high solar activity with solar radio flux F10.7 varied between 150 and 220 s.f.u.

Each point in this diurnal pattern is an average of 365 values spread over one year. These values of Hinotori satellite are acceptable for comparison since the observational data at all hours of a day are available. All the diurnal patterns of Te and Ti are smoothed by adjacently averaging for three points. Figure 3 depicts the diurnal variation of ion temperature using SROSS C2 satellite. For the evaluation of diurnal variation of Ti, data from the entire range of latitude, longitude and altitude covered by SROSS C2 are used. It is noticed that the SROSS C2 observation of electron temperature exhibits the typical electron temperature profile with morning overshoot, daytime valley, evening enhancement and night time constant values. The diurnal behavior of electron and ion temperatures were characterized by rapid increase in the morning peak and comparatively slow decrease in the evening. At night the ionosphere is observed to isothermal. Te and Ti starts to increase from its nighttime value at about 0400 LT and reaches a peak after 2-3 hours irrespective of season and solar phase.

The electron temperature varies between 750 K to 850 K during night time (2000 – 0400 LT), rises sharply during sunrise (0400-0600 LT) to reach a level of ~ 3500 K and with in a couple of hours and then falls between 0700 1000 LT to a day time average value of ~ 2000 K.

A secondary maximum is observed between 1600-1800 LT. The ion temperature varies between 650 K to 700 K during night time and reaches 1600 K during morning enhancement and a daytime constant of 1200 K and a secondary maximum of 1300 K. Observation with Hinotori satellite with in ± 31^0 at ~ 600 km during periods of moderate (F10.7 ~ 150) and high (F10.7~ 230) solar activity, the electron temperature varies between 1200 K to 1300 K during night time and rises sharply during sun rise about 2800 K then reaches a day time average of 1900 K and reaches the secondary maximum of 2100 K.

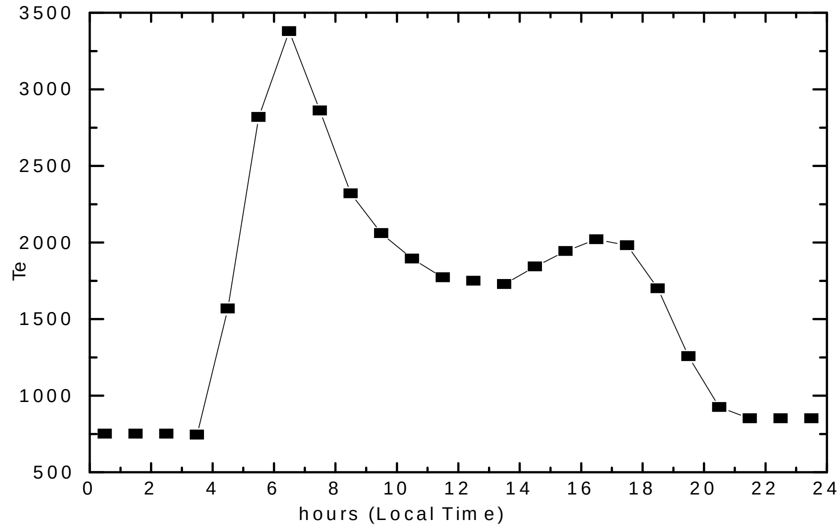

Figure .1 Diurnal variation of electron temperature using SROSS C2 satellite

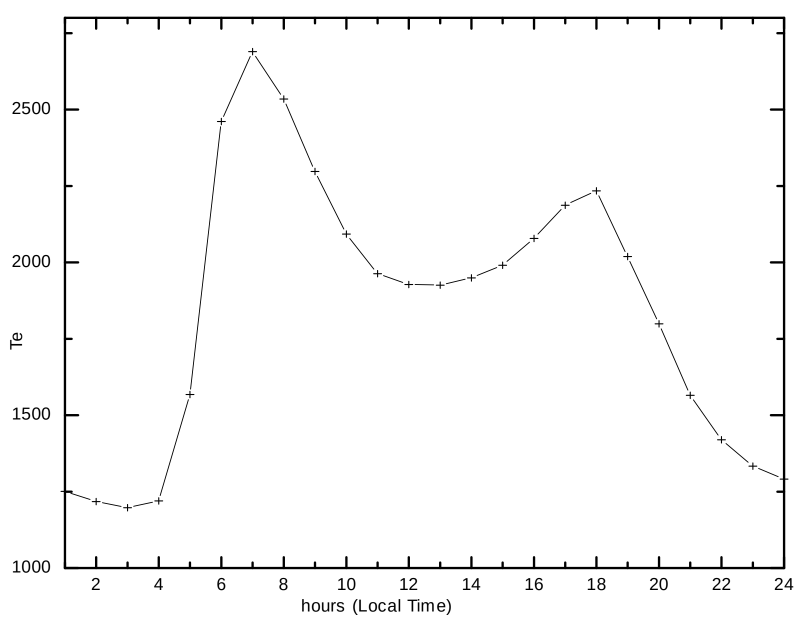

Figure .2 Diurnal variation of electron temperature using Hinotori satellite

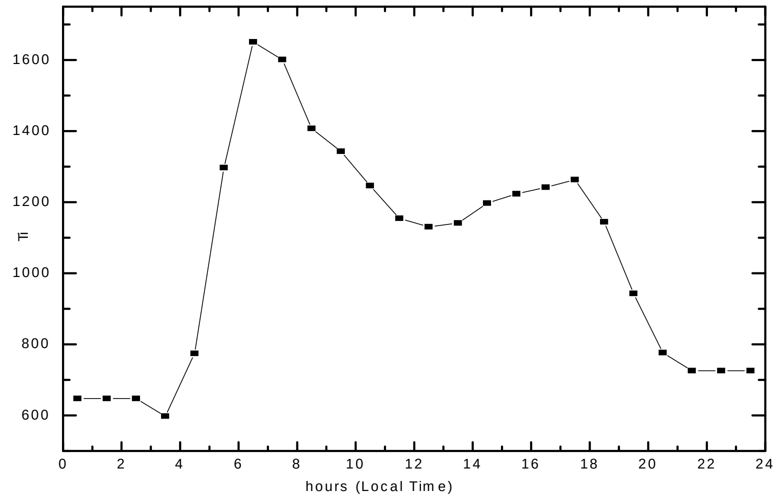

Figure. 3 Diurnal variation of ion temperature using SROSS C2 satellite

Following the morning peak there is a rapid decrease in the electron and ion temperatures, which reaches a minimum at around 1200 LT and then increases. Around 1500 LT the Te again starts to enhance and attains a second elevated temperature (evening overshoot) around 1600 LT and 1800 LT. The evening overshoot appears to be smaller than the morning one. The electron temperature decreases quickly between Sun set and 2000 LT and slowly between 2000 LT and 0300 LT. It is observed in all cases that after an initial, fairly rapid decrease the temperature decreases much more slowly through out the night, reaching a minimum just before dawn. The Te values near noon are much lower than the dawn and evening. The transition between the day and night time structure occur in a regular fashion. The rate of decrease of night-time values is much slower than the rapid increase near sunrise. Generally during night, Te and Ti remain roughly constant. The diurnal variation of electron temperature using Hinotiri satellite is found to be in good agreement with the SROSS C2 pattern of diurnal variation. Similar diurnal behaviors of Te and Ti observed were reported at other locations (Schunk and Nagy, 1978; Watanabe and oyama,1996; Otsuka, 1998; Niranjan et al., 2003)..

Figures 1, 2 and 3 depict the mean diurnal variation of Te and Ti . In general Te and Ti exhibits a typical diurnal variation with a sharp enhancement around 0600LT, daytime valley, evening enhancement and night time constant value. By means of elastic electron ion collision electron energy is transferred to the ions increasing the ion temperature (Banks, 1967). So in general the electron and ion temperatures have similar diurnal variation. The electron temperature increases by more than 2500 K from it's night time value in the post sunrise hour. Oyama et al. (1996) reported that the electron temperature in the morning rises from about 1200K to about 4000K with in $\pm 30^0$ magnetic latitude. Experimental evidence of the morning enhancement has been reported (Su et al., 1995; Oyama et al., 1996). and it becomes very strong around equatorial topside ionosphere at 0600 LT (Balan et al., 1996). Photoelectron production begins at sunrise through the ionization of neutral particles. As the photoelectrons share their high energy with the ambient electrons, the electron temperature increases, where the increase is rapid in the early morning hours due to low electron density. Oyama et al. (1996) found a correlation between an increase in morning temperature and a decrease in electron density. At higher altitudes, where electrons are increasingly cooled by collisions with ions, the temperature and density begins to exhibit an inverse relationship. This relationship was found to be the same over a wide range of latitudes, longitudes and seasons, which allows for an estimation of electron temperature wherever plasma density measurements from other sources are available (Bhuyan et al., 2002).

Anomalous enhancements in electron temperatures in the topside ionosphere at ~ 600 km occur at almost all longitudes in both the hemispheres (Dabs et al., 2000). From theoretical simulation of observed Te enhancements, Oyama et al. (1996) have shown that intense morning enhancement of Te observed over the equator is due to reduction in electron density caused by the downward drift of plasma, which usually occurs in the morning hours.

This sharp enhancement in Te at the dawn begins when the depleted F- region plasma is disproportionately heated by the onset of photoelectrons arriving from conjugate hemisphere and by those produced locally. The photoelectron heating-rate does not vary appreciably during the early morning hours, but the electron density continues to increase. As more and more electrons are produced with the progress of the morning the energy share for each electron decreases. Thus the Te after reaching a maximum decrease attains a steady value by the end of the morning. The temperature increase at dawn is clearly controlled by the Sun. The morning peak in Te is enhanced due to the downward E x B drift in the equatorial F-region which increases, Te in the morning hours due to the pushing of the top side plasma downward which in turn decreases plasma density *Ne* (Su et al., 1995; Watanabe et al., 1995; Oyama *et al*., 1996; Balan *et al*., 1997), with in an hour or two the build-up of electron density causes enhanced electron cooling and restore Te to a lower equilibrium value (Brace and Theis, 1981).

The cooling of electron gas behavior between 0800 LT and 0900 LT is a manifestation of the inverse relationship between the Te and Ne. As Ne increases during day time, the coupling of the neutrals increases and hence Te decreases (Schunk and Nagy, 1978, Dabas et al., 2000). Te decreases through out the day owing to the electron density (Roble, 1975). The day time valley is the result of the balance between electron heating and cooling processes. Though near noon electron heating by solar EUV is maximum, it is more than offset by electron cooling, resulting from the higher noontime electron density. At 0040 LT the heat flow from the magnetosphere increases abruptly, reaching a plateau of about 8 x 10^9 eV $cm^{-2}s^{-1}$ at sunrise (Schunk and Nagy, 1978). The day-time temperature in the upper ionosphere depends very strongly on the electron heating and loss rates which in turn results in a strong electron density dependence (Mahajan, 1977; ,Su et al.,1996). During day-time Te is maintained by a flow of heat from the magnetosphere above 300 km (Schunk and Nagy, 1978).

The electron temperature may also be controlled by the neutral wind under the geomagnetic field in the low latitude ionosphere (Watanabe et al., 1995). At the low latitude upper ionosphere around 1800 LT, Te is strongly influenced by the conduction of heat along the field lines and its variation could depend on local solar radiation and conditions at the magnetically conjugate point which causes a downward drift and reduce Ne and hence Te increase . The Te crests are formed by the combined effects of the evening pre-reversal upward E x B drift, post reversal downward E x B drift and nighttime cooling. The downward drift which brings the hot plasma from high altitudes and latitudes in the form of reverse fountain causes the electron temperature to increase in the region of plasma fountain.

Afternoon enhancement of Te in the low latitude region is strongly affected by both the neutral wind and E x B drift and comes from the balance of heating and cooling which becomes prominent with increasing altitude and latitude (Balan et al., 1996). Around the equatorial anomaly, Te increases at high latitude in the evening (Watanabe et al., 1995). The thermospheric zonal wind is generally strongest in the evening hours, it is conductive to the large amplitudes of the evening zonal electric fields as well as of the vertical electric field, contributing to the mechanism of enhanced electron temperature. The Te crests are formed combined effects of the evening pre-reversal upward E x B drift, post reversal downwards E x B drift and night time cooling. The downward drift which brings the hot plasma from high altitudes and latitudes in the form of reverse fountain causes the electron temperature to increase in the region of plasma fountain (Oyama et al., 1997). SUPIM model calculations support this argument. The effect of neutral wind produced afternoon peak in Te, becomes prominent with increasing altitude and latitude (Watanabe and Oyama, 1996). The afternoon peak in Te also caused by the increased plasmaspheric heating at that time. The maximum heat flow rate occurs just before sunset (Schunk and Nagy, 1978). Under the thermal conduction and non-local heating effects of photoelectrons, it is generally found (Geisler and Bowhill, 1965) that the electron temperature in the regions above 300 km lies significantly above that of the neutral atmosphere, thus providing a heat source for the ion gases. The occurrence of the evening peak in Te and Ti is related to the electron density and its variation during afternoon-evening period. During this period electron density generally decreases with time. The decrease becomes rapid if the neutral wind is poleward. The wind forces the ionosphere to descend to low altitudes of heavy chemical loss which causes the rapid decrease that leads to low electron density before sunset. The temperature of the electron gas, whose density is low and decreases rapidly with time, should increase before sunset because the photoelectron heating is in the same way as the morning increase in Te (Geisler and Bowhill, 1965).

During the night-time the electron temperature is maintained by energy sources such as soft and energetic electron fluxes and heat conducted down from the protonosphere (Schunk and Nagy, 1978; Brace and Theis, 1981). Te and Ti rapidly begin to fall around 1900 LT due to decrease in photoelectron heating and reach a thermal equilibrium state at night. The increased heat flow from the magnetosphere and decrease in electron density act to maintain Te and the decrease Te around sunset is more gradual than the increase at sunrise. The night-time heating of Te is caused by heat conducted down from the plasma-sphere. At this time, the electron distribution is controlled mainly by the loss rate and the post sunset upward plasma drift. Transfer of thermal energy from the protonosphere to the ionosphere has a considerable effect on the thermal structure of the night-time ionosphere and the rate of downward heat conduction slows dramatically at night because of the cooling of the F region and the highly non linear dependence of conduction on electron temperature.

4. Conclusion

The SROSS C2 RPA and HINOTORI observations of the ionospheric temperatures Te and Ti exhibit similar diurnal variations. The morning and evening peaks arise basically from the photoelectron heating of the morning and evening electron gas. The diurnal pattern of Te and Ti clearly shows the morning overshoot, evening enhancement, daytime valley and night-time stability. The morning peak arises from the photoelectron heating of the morning low-density electron gas. The evening peak arises from the photoelectron heating of the evening, low density electron gas, caused by poleward neutral wind. During morning and evening hours Te and Ti undergoes rapid changes, while during the daytime and night time hours the changes are small. The electron and ion temperature are found to be not in thermal equilibrium (Te > Ti). It is possible to understand the F2 region by taking on account of its temperature variations. The photoelectrons produced by the ionization processes are hotter than the neutral atoms from which they are formed. This excess energy is gradually shared with the positive ions, though transfer to the neutrals is less efficient.

Consequently the plasma is hotter than the neutral air, and with in the plasma the electrons are hotter than the ions establishes the lack of thermal equilibrium between the upper ionospheric electron and ion temperatures. The electron temperature can be two or three times the ion temperature by day, though by night their temperatures are more nearly equal. The diurnal pattern obtained in this study for all cases from the RPA experiment, the results show agreement with different studies done earlier. From the discussions, it can be concluded that the morning enhancement in Te and Ti is due to photoelectron heating. The daytime valley is the result of the balance between electron heating and cooling processes. The afternoon enhancement comes from the balance of heating and cooling and is influenced by meridional neutral wind. Around the equatorial anomaly region the electron temperature in the topside F region increases in the evening due to the competing effects of plasma cooling and plasma transport. Downward E x B drift near sunset can carry the high altitude dayside hot plasma into the topside F region, leading to the observed enhancement of electron and ion temperatures. The results obtained from SROSS C2 Satellite data are consistent to that of the Japanese satellite HINOTORI.

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