Diurnal Variation of Electron and Ion Temperatures with Altitude

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Abstract

The observations on the ionospheric electron and ion temperatures measured by the RPA payload aboard the SROSS C2 satellite have been used to study the variation of electron and ion temperatures with altitude. The SCROSS C2 Satellite Retarding Potential Analyzer measurements during 1995 – 2000 are used to make a direct comparison of electron and ion temperatures at the low latitude upper ionosphere with altitude. The orbit of SROSS C2 satellite covers an altitude range 420 – 620 km. It also covered a latitude range 5.0^0 S to 30.0^0 N. The temperatures Te and Ti are found to have similar diurnal, latitude and altitude variations. The features like morning overshoot, day time valley and evening enhancement show larger values at higher altitudes.

Introduction

The electron and ion temperatures (Te,Ti) at the upper ionosphere depends on the solar activity level and is found to exhibit diurnal, seasonal, altitudinal variations (Oyama et al.,1980). The upper atmospheric temperature is a key to understanding variations in the ionosphere and thermosphere (Shun-Rong and John., 2013). The observational data of electron and ion temperatures includes ground-based radar measurements (Otsuka *et al* ., 1998), rocket measurements (Oyama et al., 1980) and satellite based experiments (Oyama et al ., 1996a).At sunrise, photoelectron production begins in the ionosphere through the ionization of neutral particles. The electron and ion temperature variations in the Earth's ionosphere have been studied extensively through ground-based and *in situ* observations (Brace and Theis 1978; su et al., 1995; Sharma et al 2003;) The electron temperature was found to exhibit a sharp morning enhancement, a day-time trough, an evening enhancement and stable night time value. The heating occurring before the sunrise is caused by the photoelectrons heating the morning low density electrons (Schunk and Nagy,2000). This morning peak becomes prominent at the low latitude ionosphere due to the vertical E × B plasma drift which decreases the electron density followed by an increase in electron temperature (Te) (Balan et al., 1997; Su et al .,1996). Within an hour or two the buildup of electron density causes enhanced electron cooling and restore Te to a lower equilibrium value. A secondary maximum is also observed before sunset (Otsuka et al.,1998; 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). SROSS-C2 pay Load provides an excellent opportunity to probe directly and simultaneously, the electron and ion temperatures and densities during the period 1995-2000. The purpose of the present paper is to study the electron and ion temperature variations with altitude over low latitude ionosphere.

Electron/ion Temperature Measurements by SROSS-C2

The SROSS-C2 satellite was launched from Shriharikota, India on May 1994. It is a spin stabilized orbiting satellite placed in an elliptical orbit inclined at 46.3^0 with equatorial plane. The orbit of the satellite was brought to 620 x 420km altitude. The retarding potential analyzer (RPA) payload on SROSS C2 satellite consists of an electron RPA, ion RPA and potential probe sensors and the associated electronics (Garg et al., 1996). The satellite makes about 16 orbits a day out of which, on an average two high elevation passes, during day time as well as nighttime are visible from a single telemetry station. But due to operational reasons data collection on a regular basis is restricted to one daytime and one nighttime orbit per day during overhead passes of the satellite over the ground station located at Bangalore (12.5^0 N, 77.3^0 E). The satellite visibility varies from 7 to 12 minutes depending on the satellite elevation angle. For the data collection from Bangalore ground station, latitudinal coverage extends from 5^0 S to 30^0 N and longitude range can extend from 50^0 E to 100^{0}E. 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 probe makes simultaneous measurements of electron and ion parameters. All the data are 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 and longitude to obtain the mean diurnal pattern of Te and Ti during SROSS-C2 observation period.

Characteristics of Diurnal Variation Electron and Ion Temperatures

The SROSS C2 satellite has provided some valuable data on the thermal structure of the topside ionosphere over the Indian region. Figure 1 depicts a typical diurnal pattern of electron temperature using SROSS C2 data. The data used for Figure 1 were restricted within the latitude range 5^0 S and 30^0 N and combined for all seasons and years from 1995 to 2000. All the diurnal patterns of Te and Ti are smoothed by adjacently averaging for three points. Figure 2 depicts the diurnal variation of ion temperature using SROSS C2 satellite. 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 was 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 within 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 from 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.

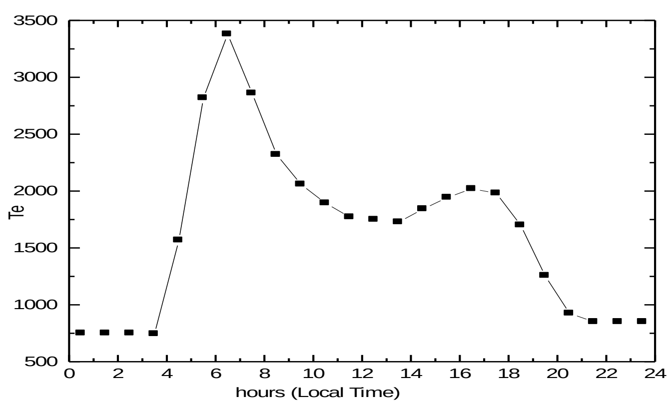

Figure 1 Diurnal Variation of Electron Temperature

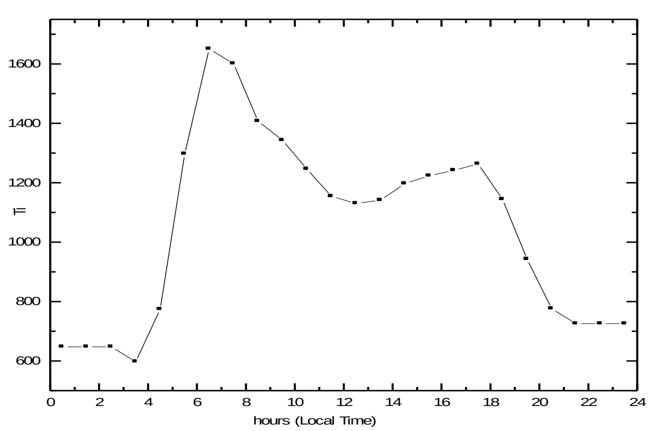

Figure 2: Diurnal Variation of Ion Temperature

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 throughout 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; Brace and Theis,1981; Watanabe and oyama,1996; Otsuka, 1998; Niranjan et al., 2003).

Dependence of Diurnal Variation of Electron and Ion Temperature on Altitude

The orbit of SROSS-C2 satellite covers an altitude range 420 to 620 km. To study the variation of the electron and ion temperature and its diurnal variation with altitude, the entire set of data is divided in to three groups (i) altitude less than 500 km (ii) altitude in the range 500 to 575 km (iii) altitude range greater than 575km. The diurnal profile of Te and Ti corresponding to each altitude is depicted in figures 3 and 4. The number inside bracket for each category corresponds to the average number of observations used for calculating each point of the curve. The features morning overshoot, day-time valley and evening enhancement in the diurnal profiles of Te and Ti show larger values at higher altitudes. The sharp rise in Te in the morning is nearly the same at all altitude ranges. The morning enhancement for the ion temperature is steeper at higher altitudes. Similarly the evening enhancement in Te and Ti are less prominent in the altitude range below 500 km. Ti values in the altitude range below 500 km do not exhibit neither a clear morning overshoot nor an evening enhancement. The rate of decrease of both Te and Ti to nighttime values increases with altitude. The night-time values of Te and Ti during 2200 LT to 0400 LT do not exhibit any visible altitude dependence, but it is similar for the observed altitudes. The day to night temperature difference increases with altitude for both Te and Ti. With altitude the temperatures increase during both day-time and night-time. The morning increase, caused by the photoelectron heating of the morning low-density electron gas is rapid at all altitudes for Te whereas in Ti, it increases with altitude. The evening peak occurs earlier, at lower altitudes for both Te and Ti.

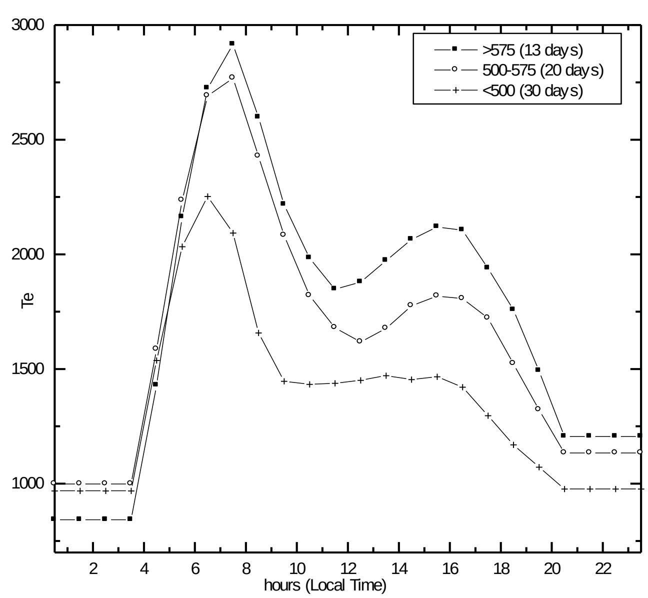

Figure 3: Diurnal Variation of Te for Three Altitude Ranges

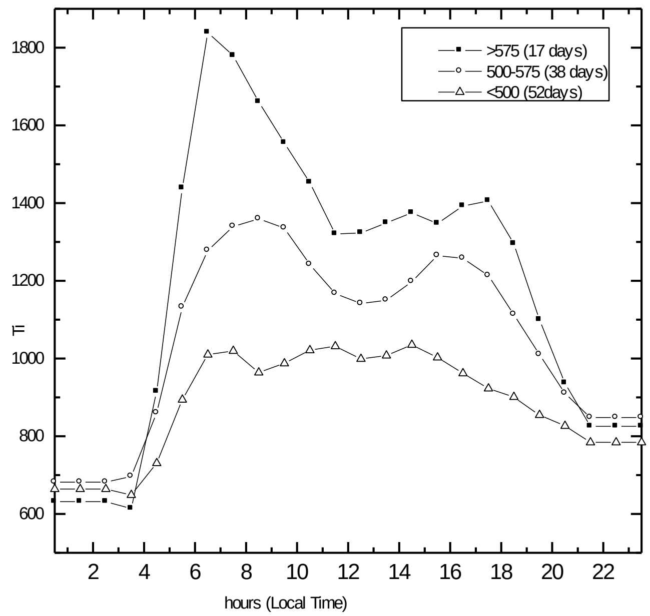

Figure 4: Diurnal Variation of Ti for Three Altitude Ranges

Discussion

Figures 1 and 2 depict the mean diurnal variation of Te and Ti. In general Te and Ti exhibit a typical diurnal variation with a sharp enhancement around 0600LT, daytime valley, evening enhancement and night time constant value. 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 also 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).

The day time valley is the result of the balance between electron heating and cooling processes. 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 (Bilitza, 1983a; 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).

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; Ewa and Hanna., 2013). Around the equatorial anomaly, Te increases at high latitude in the evening (Watanabe et al., 1995). 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. SUPIM model calculations support this argument. The increase in Te around 1800 LT might correspond to an adiabatic compression (Triskova et al., 1997). 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 is caused by the increased plasmaspheric heating at that time. The maximum heat flow rate occurs just before sunset (Schunk and Nagy, 1978; Roble, 1975).

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 (Roble, 1975) and reach a thermal equilibrium state at night.

The night-time heating of Te is caused by heat conducted down from the plasma-sphere (Spencer et al., 1962). 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 (Geisler and Bowhill, 1965).

Figure 3 and 4 depict the variation of the diurnal profile of electron and ion temperature with altitude. The morning enhancements in Te and Ti are found to increase with altitude in agreement with the observations of Otsuka et al. (1998). The enhancement in the electron and ion temperature at higher altitudes could be understood in terms of the reduction in the ambient electron and ion density and the dominance of heat conduction term over the heat balance equation (Bilitza, 1991). The morning and evening enhancements are nearly absent in Ti at altitudes below 500 km. This absence is due to the transfer of energy between ions and neutrals at lower altitudes. Above 400 km, thermal conduction dominates and Te increases with altitude in response to a downward heat flow from the magnetosphere (Schunk and Nagy, 2000). The morning enhancements in Te and Ti have larger values around the dip equator. This may be associated with the $E \times B$ drift and the decrease in electron density as explained by Oyama et al. (1996a). Larger values of Te and Ti at higher latitudes are associated with the presence of neutral wind. The evening enhancement in Te is prominent with increasing altitude and latitude. Afternoon enhancement in Te becomes prominent with increasing altitude and latitude, at the low latitude region it is strongly affected by both the neutral wind and the $E \times B$ drift in agreement with the result of Watanabe et al. (1995).

Conclusions

The occurrence and strength of morning and evening peaks are found to depend on altitude. The 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 altitudinal variations show that the morning overshoot and evening enhancement increases with altitude. 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 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. Magnitude of Te and Ti increases with altitude and maximum increase with altitude occur around the morning and evening enhancements.

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