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Measurement of electron temperature with special emphasis to geomagnetic ally disturbed situation : Topside Ionosphere –Review (II)*

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Abstract :

The paper presents Plasma density Ne and Electron temperature Te . focusing on the low latitude topside ionosphere behavior during magnetic storms using the HINOTORI satellite measurements. Starting with two cases of storm-time responses to N_e and T_e at low and equatorial stations, a detailed T_e and N_e statistical study on the storm induced character at low latitudes during night time has been presented using a large volume of data. The observed data are compared with model evaluated values. The Physics and dynamics of modification in electron temperature at plasma sphere - altitudes are then given through the observational analysis . The paper also focuses on the use of on board special sensors (like in satellite OHZORA/Akebono) for measurement of temperature anisotropy at the plasma sphere.

Key words*: Plasam density, Electron temperature ,satellite, on board sensors*

** In continuation of the review (I) article published in IJEAR vol. 4, issue II*

1. Introduction

Magnetic storms provide excellent opportunities to study several aspects of space weather including departures in the ionospheric plasma characteristics, namely the electron density and ion temperature and electron temperatures . In fact this has been a subject of extensive research in this field for more than 50 years with data from a varieties of experiments including ground–based ionosondes, satellite radio beacons, incoherent scatter radar, topside sounders and in-situ satellite experiments [Su et al , 1995; Su et al 1996: Watanabe and Oya , 1986 ; Watanabe and Oyama , 1986 ; Oyama , 1991 :Oyama et al 1995; Pavlov et al , 2000] and significant progress in understanding stormed induced modifications in electron temperature and associated parameters are now achieved. High resolution in-situ measurements from satellites [Hirato and Oyama 1970, Oyama and Hirao 1982, Amatucci et al 2001] are particularly suitable for studying both temporal and spatial variations in plasma densities and temperatures on global scale. Incoherent radar experiments have provided valuable information on plasma temperatures and are well suited for studying altitudinal and diurnal variations, but are restricted to a particular location. While there have been a large number of studies during the last several decades to model storm-time variations in bottom side F region electron densities especially in view of their application in ionospheric radio communications, comparatively very little attention has been paid to model storm time variations in topside ionospheric parameters, especially, plasma temperatures. But the thermal structure of the ionosphere and its perturbations during space weather events are of primary concern today as we try to understand the integrated solar-terrestrial environment and hence a need exists for such models. The present paper is one in that direction to study storm-time variations in electron densities and temperatures at 600 km using the database from the Japanese HINOTORI satellite.

Some of the earliest studies on topside plasma density (N_e) and temperature (T_e) including their storm-time variations have resulted from in-situ experiments on-board the satellites Explorer 22 and TIROS 7 [Brace et al., 1967; Reddy et al., 1967]. The TIROS-7 provided the initial results on global behavior of topside ionosphere at 640 km during magnetic storms that were restricted to only electron density variations. These results showed significant day time increases in N_e at mid and high latitudes, either a slight decrease or practically no change in day time N_e at equatorial and low latitudes depending on the severity of the storm and a significant increase in nocturnal N_e around the equator. Richards et al (2000) discussed a remarkable increase in electron temperature (T_e) at 550 km at a high latitude station Millstone Hill during a storm in Jan. 1997 and it was attributed to a stable auroral arc caused by ring current heating [Foster et al., 1997]. The present effort focuses on the behavior of low latitude topside ionosphere during magnetic storms using the HINOTORI satellite measurements of N_e and T_e to study storm-time responses.

2. Analysis and results

In this paper, a detailed T_e and N_e statistical study on the storm induced character at low latitudes during night time has been presented using a large volume of data.

2.1 Ne and Te dutring magnetic storm observed by Satellite and model evaluated values

The presentation started with variations of these parameters observed during a magnetic storm of 1 March 1982 with special reference to equatorial and low latitudes. Two important results of the March,1 1982 storm are : (a) large increases in T_e accompanied by only small variations in N_e during day time over low-to-mid latitudes and (b) large night time enhancements in N_e accompanied by significant increases in T_e, during storm periods over low latitudes. The day time and night time N_e variations from HINOTORI data over low latitudes are found to be in general agreement with those reported from TIROS –7 observations for storm periods [Reddy et al., 1967], at a similar altitude.

Figure 1 shows local time variations in Ne and T_e as seen from HINOTORI during 1- 6 March 1982 (passes 5578, 5589,5590, 5591 and 5605). The reference values (shown in thin line) for N_e are from the models developed by Isoda (1996), and those of T_e are from the models developed by Oyama et al., (2002). Both of the models represent an average quiet time picture and were widely tested for consistency. The plots in thick black lines show the values during a particular pass. The top panel in the figure shows the Dst values for the period (1- 6 March 1982). This is a moderately severe storm which began with a Sudden Commencement (SC) at 11 38 UT on 1 March 1982 and Dst had maximum negative excursion of around 200 nT. The recovery phase started around 0600 UT on 2 March 1982 reaching pre storm levels by 4 March 1982. The relative positions of HINOTORI passes are indicated by pass numbers in the top panel on the time axis. While the pass 5578 is close to SC of the storm, the passes 5589, 5590 and 5591 correspond to Dst minimum period and pass 5605 is during the recovery phase of the storm. Pass 5578 on 1 March 1982 is considered to represent pre storm conditions. Several important features of storm-time responses in N_e and T_e, in relation to their pre storm conditions and model values [Isoda, 1996, Oyama et al., 2002] may be noted as itemized below.

- During pre storm conditions (pass 5578) N_e and T_e values remain close to model values most of the time in the entire latitude range covered by the satellite. In general, a negative correlation between N_e and T_e variations exists during day time, in agreement with the dominant process of coulomb collisional cooling with ions.
- During the storm period there are certain distinct differences in day time N_e and T_e behaviour depending on the latitude as well as on local time (Passes 5589,5590,5591). While N_e shows little

variation with respect to the model values in the region of -24 to –33 Geomagnetic Latitude during 0800 - 1200 LT, T_e exhibits a remarkable increase by more than 1500 K from the model values. The longitude during these passes varied between 0°E -80°E. T_e values as high as 4000K were observed during these periods. However, during 1200 –1600 LT, both N_e and T_e in general tend to follow model values.

- The pre sunrise increase or morning over shoot in T_e is higher during storm days compared to normal days.
- During the pass 5591 when recovery of the storm has begun, the T_e values are lower than the model values for a short duration from 0600-0800hrs

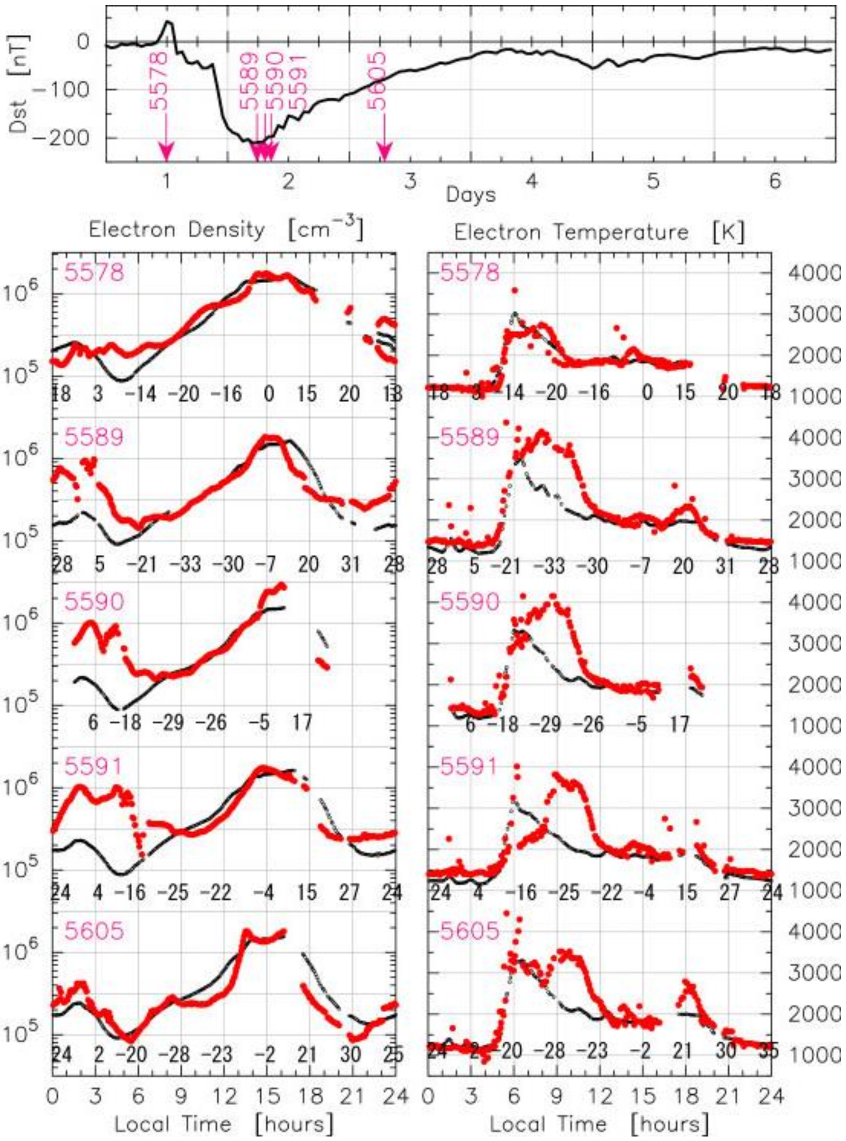


Figure.1 Observed Electron density and Electron temperature values (thick black lines) for HINOTORI passes 5578, 5589, 5590, 5591 and 5605 during March 1982 along with model values (thin black lines). Geomagnetic latitude is also shown separately for each of the passes in the figure. The Dst variation for the same period is shown in the top panel with pass positions marked on time axis.

An increase in night time (2000 LT – 0600 LT) electron density (N_e) values as compared to model values is obvious during disturbed days as evidenced by the passes 5589, 5590 and 5591. The increase in N_e is particularly large reaching an order of magnitude higher than its quiet time reference during 0000-0600 LT. For example during pass 5591, the night time enhancements in N_e values are closer to the day time maximum. Correspondingly there are significant increases in T_e by 200 to 300 K as compared to the model.

It can be seen from Figure 1, that on 1st March 1982 (pass 5578) during 0000 – 0400 hrs , T_e is around 1200 K, close to model value; however, on 2nd March , T_e values are around 1500K (pass 5589). The increase is by 300° K during the minimum of Dst. The fact that this increase in T_e occurred in association with substantial increase in N_e , points to a very significant source of heat input.

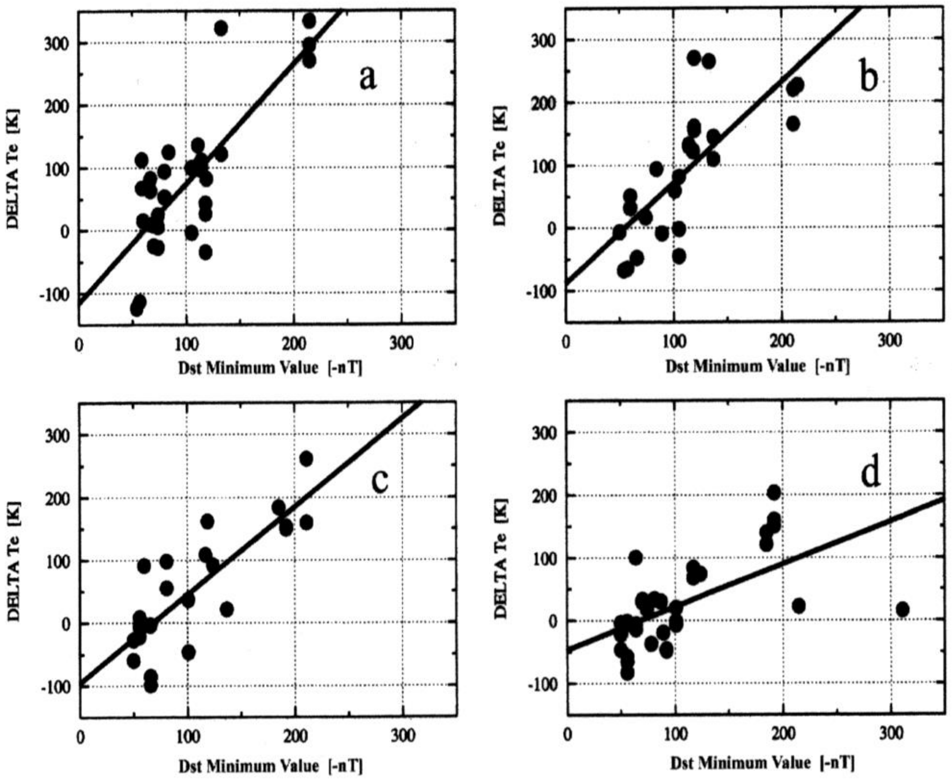
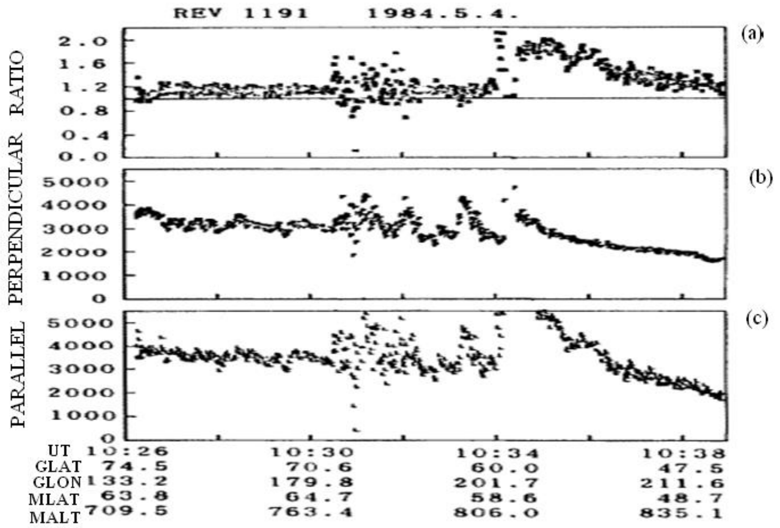


Figure .2 Deviations in T_e at 600 km from the model values (ΔT_e) in the magnetic storms event , during 0300-0400 LT plotted against Dst minimum values for different time slots. a) ΔT_e values during 0-4 hrs prior to Dst minimum, b) ΔT_e values 0-4 hrs after the Dst minimum, c) ΔT_e values for 4-8 hrs after the Dst minimum and d) 8-12 hrs after the Dst minimum. Dst values are in units of (-nT).

Figure 2 shows deviations in T_e at 600 km from the model values (Delta T_e) during 0300-0400 LT for 21 magnetic storms considered for this analysis. T_e deviations (Delta T_e) are plotted against Dst minimum in 4 different time slots. The first slot is for 0 to 4 hours prior to Dst minimum and shows T_e deviations during that time interval, the second is for 0 to 4 hours after the Dst minimum, the third is for 4-8 hrs after the minimum and the last corresponds to T_e deviations during the period 8-12 hrs after the Dst minimum. Increasing tendency in T_e deviations with Dst is obvious from all the four plots. The elevation of T_e suggests ingestion of the energy across the magnetic line of force. However, the increase in neutral temperatures during magnetic storms by itself could be a significant contributor to enhanced nocturnal T_e. There are also reports of control on of Te by diurnal, seasonal. and longitudian (geomagnetic) factors [Oyama et al 1996 a, Oyama etal 1996 b].

2.2 Anisotropy in electron temperature

The above results show that the measurement of anisotropy in temperature is important for understanding storm induced effect on it . Electron Temperature Sensors (ETP) are therefore placed on the edges of 4 solar cell panels attached to the 4 walls of OHZORA satellite which was launched in 1985 , for analysis of isotropy or otherwise of electron temperature . Figure 3 shows the anisotropy of electron temperature in the midlatitude trough [Watanabe et al.,1989]. Te observed by a circular disk planar electrode whose normal is parallel to the geomagnetic field is calculated and observed to be higher than Te which is measured by an electrode of the same dimension and of same diameter but whose normal is perpendicular to geomagnetic field. The presence of anisotropy in electron temperature during magnetic disturbed situation is thus well reflected .



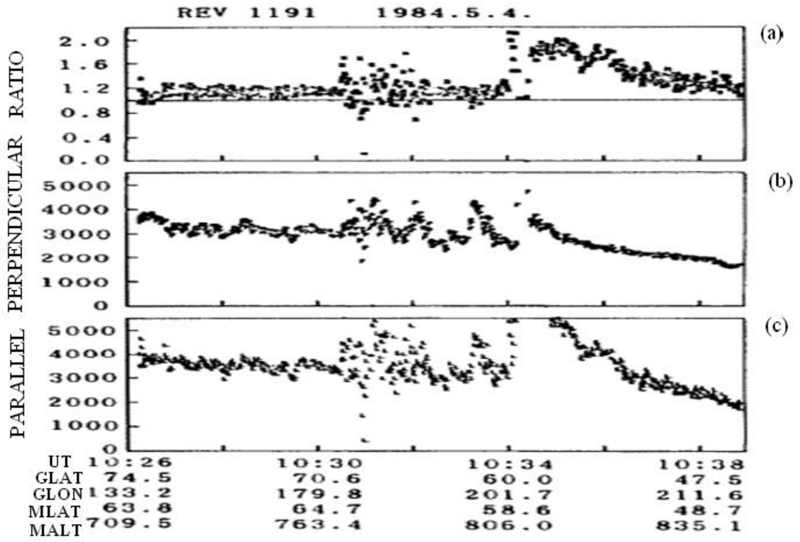


Figure 3: Shows the anisotropy of electron temperature in the midlatitude trough [Watanabe et al.1989]. X -axis shows UT, Geographic latitude/longitude (GLAT/GLON) and Magnetic latitude/longitude (MLAT/MALT)

3. Plasma sphere

3.1 Measurement of electron temperature in plasma sphere

The measurement of temperature above the height of 3000 km by a DC Langmuir probe becomes difficult, because secondary electrons from the electrode affect the measurement. Further, the high gain of amplifiers which makes the measurement possible is not easily available, especially in the mid latitude trough, where Ne is low.

Brace and Theise (1981) constructed empirical model of Te and Ne up to the height of 3000 km by using the data obtained by AE-C, ISIS-1, and ISIS-2 satellite. Te above the height of 3000 km, has been measured only by S-3-3 [Rich et al.,1979].

Japanese satellite " Akebono" was launched in polar orbit in 1989 and since then the data are being acquired. An instrument to measure Te onboard the satellite successfully measured Te up to the height of 8000 km systematically in mid and low latitude. The electrode is a circular disk of 100 mm in diameter and 1.6 mm in thickness.

One of the two key points of successful measurement is that the electrode was put vertical to the solar cell paddle which always points the sun. This means that the surface area of 1.6 cm^2 (1.6 mm x 10 cm) is radiated to the sun out of 78.5 cm^2 . Figure 4 shows the location of the probes attached at the end of solar cell panels.

Figure 4: Locations of 4 electrodes which are attached at the ends of solar cell panels.

The second of the two key points of successful measurement is that we applied the Druyvesteyn method to get the second derivative of voltage (v) –current(i) relation. To get this derivative of the v-i curve, sinusoidal wave was superposed to the probe sweep voltage and second harmonic component was picked up from the probe current distorted by the non-linearity of the sheath. Thus all dc components generated by the radiation of EUV on the electrode were removed.

Figures 5 a ,b and c show the height distribution of Te at three different latitude zone. The purpose of the figure is to show the variation and scattering of the data. Although one can note that the deviation from the average values is more than 1000 K above the height of 5000 km

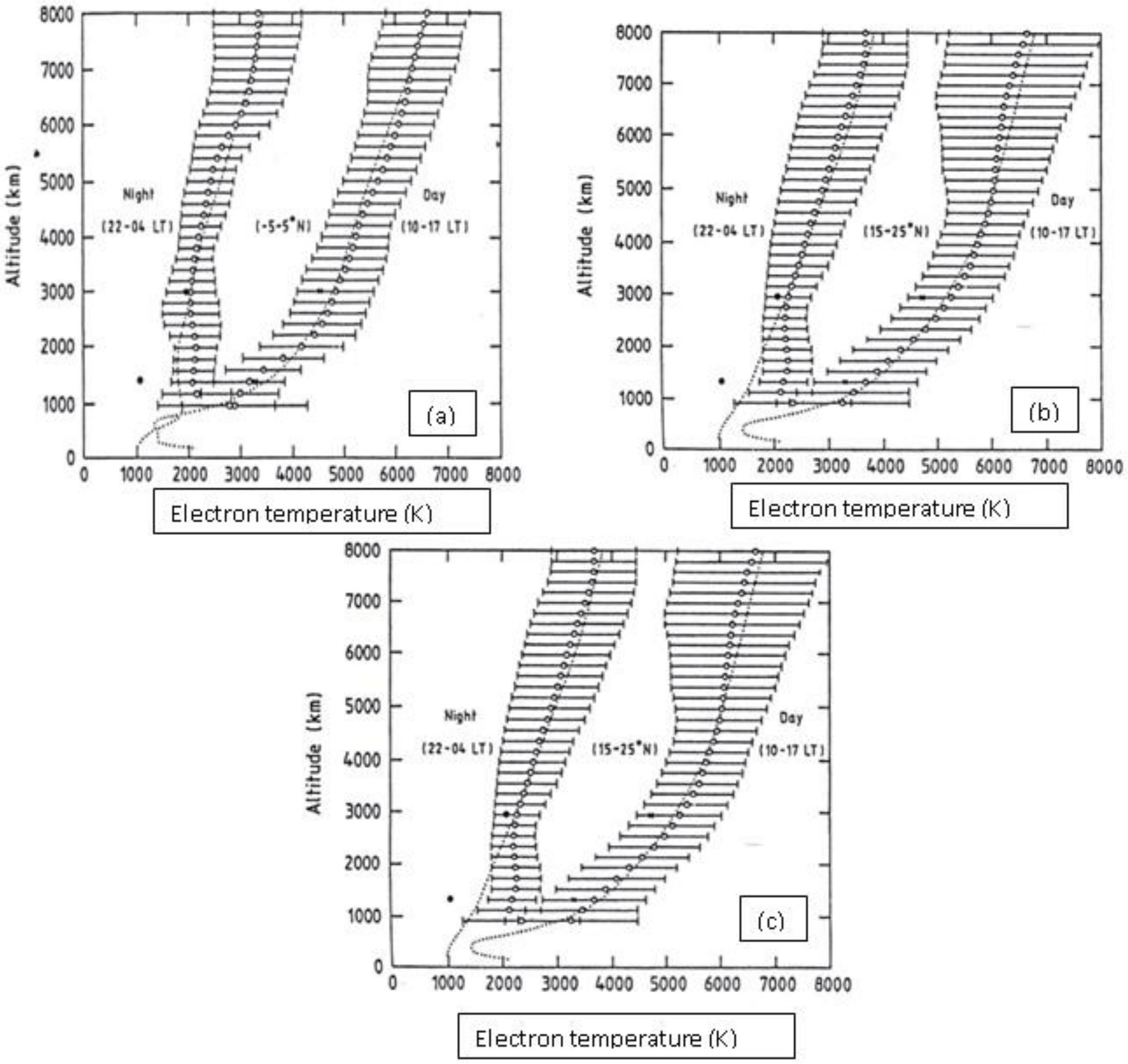


Figure .5 a,b, c and d : Te up to the height of 8000 km at three different latitude zones;(a) - 5- +5, (b) 15-25 and (c) 35-45

3.2 Comparison between model and observation

The observed data are than compared with Sheffield University Code which calculates the height profiles [Balan et al.,1996a,1996b; Abe et al., 1997] of electron temperature and the outputs are shown in Figure 6.

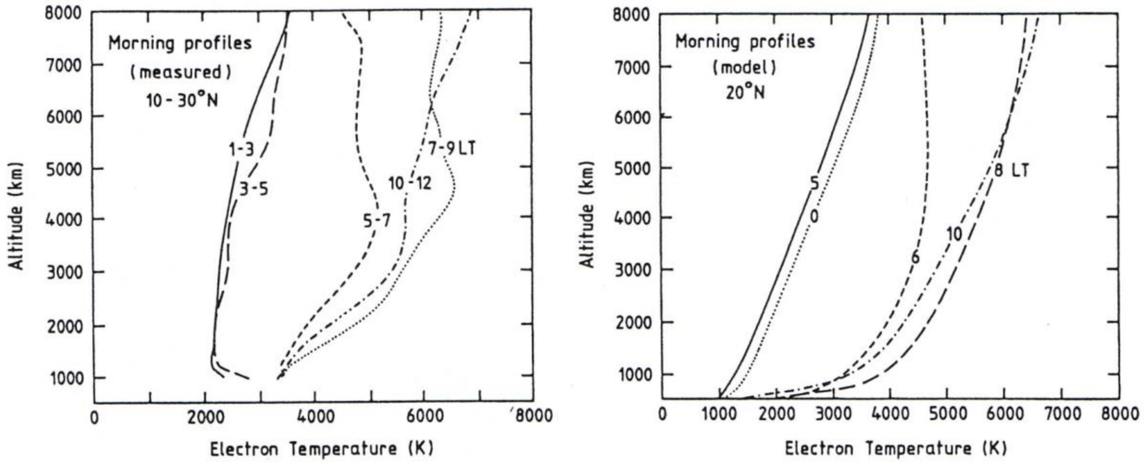


Figure 6 Comparison between model evaluated Electron temperature data with observed data

Although the values between two results are different, the model reproduces the basic feature of the plasma sphere. However, Te variation with respect to local time shows three peaks in the morning , noon, and in the afternoon (Figure 7). The 1st and 3rd peaks can be reproduced by computer model, but the second one cannot be reproduced as shown in Figure 7 .

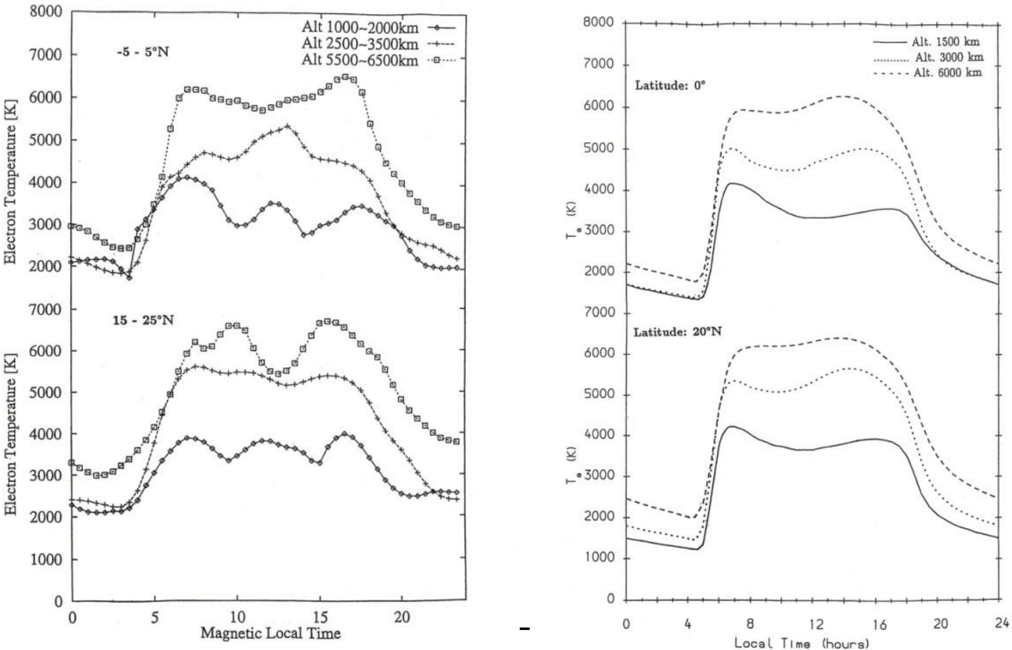


Fig.7 Comparison between observation and model for diurnal variation

3.3 Additional heat conductivity

In 1999, simultaneous measurement of Akebono and Millstone radar has been conducted along the same magnetic line of force. Millstone radar measures Te up to the height of 600 km, while Akebono measures Te at the height of 8000 km. Pavlov et al., (2000) calculated the height profile of Te along the field line. They found that applying additional heat conductivity shows a better agreement with Te observation.

3.3 Heat capacity of plasma sphere

Akebono data can be used to calculate heat capacity of magnetic flux tube in low and latitudes. Figure 8 shows the local time variation of electron temperature from 1000 km to 8000 km for two geomagnetic latitude zones. The data were accumulated for 3 years from April 1989 to March 1992.

Te starts reducing around 18:00 hrs at the height of 3000 km. Gradual reduction of Te continues toward higher altitude. However at the height of 7000 km, Te still remains within the regime of high value from daytime high value from daytime. Even late in the evening, the heat from the higher altitude keeps flowing into lower altitude. On the contrary to the evening feature, Te in the dawn side shows a rapid increase with time. Gradual reduction of Te in the dusk and rapid increase of Te in the dawn shows a similar feature of capacity charging, showing the filling and refilling process in the magnetic flux tube.

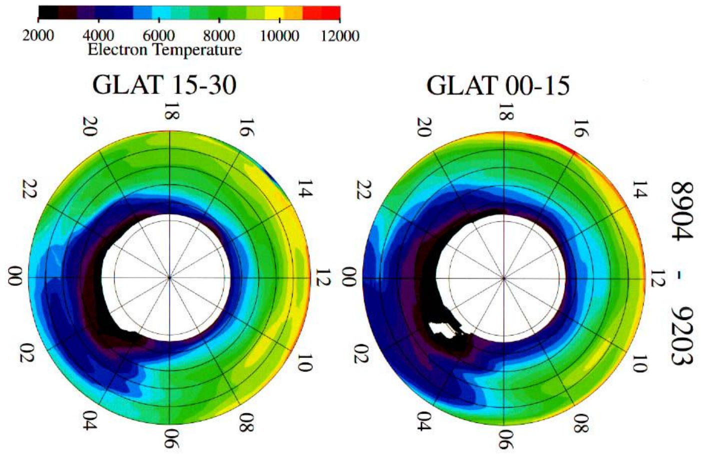


Figure 8: Local time variation of electron temperature from 1000 km to 8000 km for two geomagnetic latitude zones.

Finally one need Plasma- sphere model accommodating modified heat input parameter . That will be the future presentation .

4.Conclusion

The paper describes the current situation of Te measurement by Langmuir probe on board the satellite. It is observed that during the storm period there are increase in electron temperature though with certain distinct differences in day time N_e and T_e behavior depending on the latitude as well as on local time (Passes 5589,5590,5591). The paper also highlights the existences of similarity and differences of observed N_e with model evaluated figures depending on geomagnetic latitudes . While N_e shows little variation with respect to the model values in the region of -24 to –33 Geomagnetic .latitude during 0800 - 1200 LT, T_e exhibits a remarkable increase by more than 1500 K from the model values. T_e occurred in association with substantial increase in N_e , has pointed to a very significant source of heat input The elevation of T_e also suggests ingestion of the energy across the magnetic line of force. However, the increase in neutral temperatures during magnetic storms by itself could also be a significant contributor to enhanced nocturnal T_e.

Future projection :

Ionosphere research is now encountering new era in the field of litosphere-atmosphere-ionosphere coupling. Some large earthquakes seem to influence on the ionosphere.

In order to find the anomalous behavior, we first establish normal days behavior of N_e and T_e as we described before. . Once this is obtained, we can compare the data with the avialble models Spenner and.Plugge 1979 ; Pavlov et al 2000, Kutiev et al , 2004 and others] .. Te values already measured during three large earthquakes show large reduction of Te in the afternoon. Together with ionosonde and satellite data, this observation seems to be caused by westward electric field. But the next question is how and where the electric filed is generated. To answer this question, systematic observation of Te and Ne is required and to get the morphology is essential. This can be done by using 6-7 microsatellites, although we need another larger satellite to find the background of the physics. The instrumentation includes measurement of plasma drift, neutral wind, along with mass spectrometer, photometer and others. Topside sounder might be one of the powerful tool to find the mechanism of–litosphere-atmosphere-ionosphere coupling processes.

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