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Low latitude N_e and T_e variations at 600 km during 1 March 1982 storm from HINOTORI satellite

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This paper presents for the first time a study of HINOTORI satellite measurements of electron density and electron temperature in the topside ionosphere exclusively for magnetic storm departures. Special focus was given to the major storm of 1 March, 1982. While large enhancements in T_e characterize the day time storm response, marked increases in N_e dominate the night time deviations. The night time N_e enhancements which are rather remarkable during 0000–0400 LT are also found to be accompanied by significant T_e increases, by as much as 300 K. The statistical picture that emerges from the study of a large number of storms suggests significant nocturnal T_e enhancements which correlate with the magnitudes of storm intensities. Ring current particles through charge exchange processes seem to be a major source of heat input to thermal electrons, though other sources may also be important.

Key words: Electron temperature, ionospheric storm, low latitude, satellite data, storm time.

1. Introduction

Magnetic storms provide excellent opportunities to study several aspects of space weather including departures in the ionospheric plasma characteristics, namely the electron concentrations, the ion temperatures and electron temperatures. In fact this has been a subject of extensive research for more than 50 years now using data from a variety of experiments including ground-based ionosondes, satellite radio beacons, incoherent scatter radar, topside sounders and in-situ satellite experiments. High resolution in-situ measurements from satellites 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 densities (N_e) and temperatures (T_e) including their storm-time variations have resulted from in-situ experiments on-board Explorer 22 and TIROS 7 satellites (Brace *et al.*, 1967; Reddy *et al.*, 1967). TIROS-7 satellite 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 low latitude topside ionosphere behavior during magnetic storms using the HINOTORI satellite measurements of N_e and T_e for the first time to study storm-time responses.

HINOTORI satellite was put into a circular orbit in February 1981 at a height of 600 km with an orbital inclination of 31° and provided excellent data until July 1982 in the latitude range of 30 S to 30 N and this high resolution data is ideally suited to study N_e and T_e variations in equatorial and low latitudes. A number of studies have been conducted using the HINOTORI satellite observations which yielded several important results regarding equatorial and low latitude ionosphere. They include studies on anomalous electron temperature variations (Dabas *et al.*,

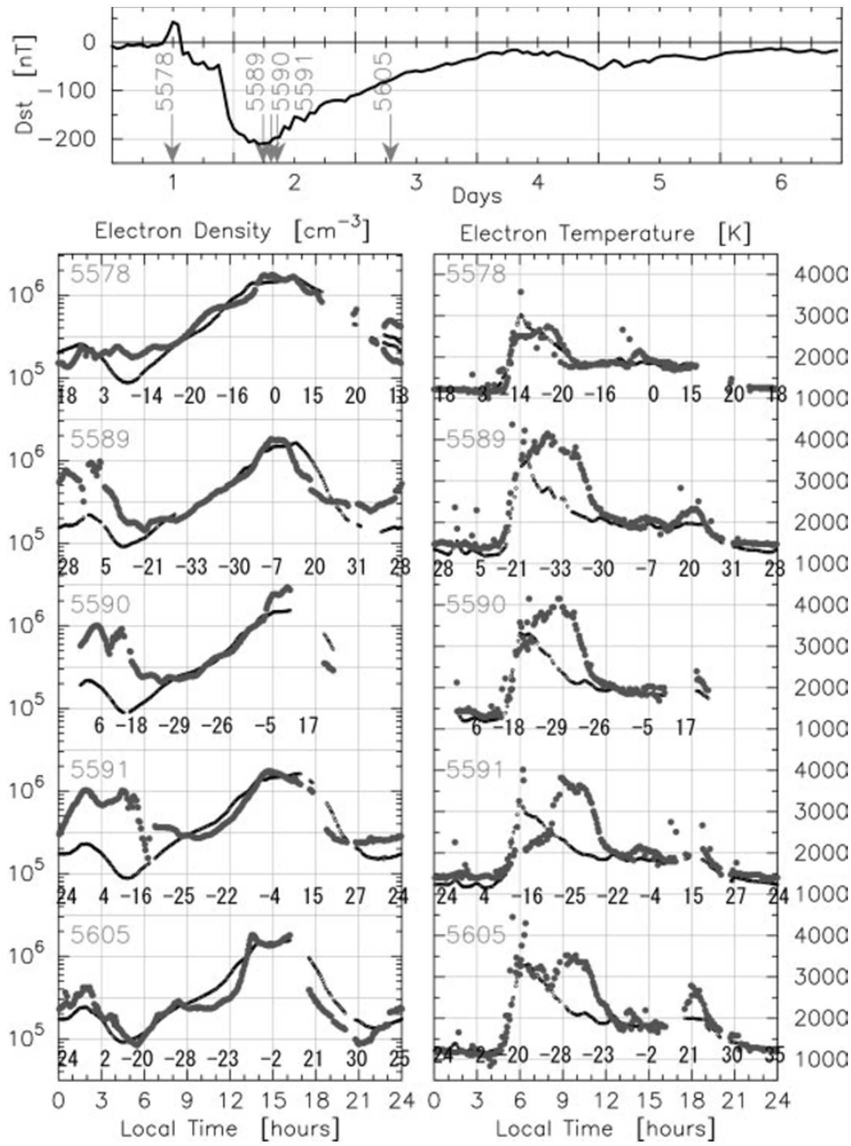

Fig. 1. Shows observed Electron density and Electron temperature values (thick black lines) for HINOTORI passes 5578, 5589, 5590, 5591 and 5605 during 1–6 March 1982 along with model values (thin black lines). Geomagnetic latitude is also shown separately for each of the passes in the figure. The Dst variation for the same period is shown in the top panel with pass positions marked on time axis.

2000; Oyama *et al*., 1984), morning overshoot of T_e in the equatorial topside ionosphere (Oyama *et al*., 1996), effects of neutral wind on the electron temperature in the low latitudes (Watanabe and Oyama, 1996) and high electron temperatures associated with the pre reversal enhancement in the equatorial ionosphere (Oyama *et al*., 1997).

In this paper T_e and N_e variations observed during a magnetic storm that occurred on 1 March 1982 are studied with special reference to equatorial and low latitudes. In addition, a detailed statistical study has been made using a large volume of data on storm-time T_e variations at low latitudes during night time. Two important results of the March, 1 1982 storm concern: (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.

2. Magnetic Storm of 1st March 1982

The magnetic storm that occurred on 1 March 1982 is examined in detail to study the storm-time variations in N_e and T_e in the topside ionosphere at 600 km using data obtained from HINOTORI satellite. Figure 1 shows local time variations in Electron density (N_e) and Electron temperature (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 these 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 Geomag. Lat 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 0–80 E. T_e values as high as 4000 K 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 as 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 0600–0800 hrs.

- An increase in night time (2000–0600 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 enhanced 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.

2.1 Storm-time departures in T_e during day time

While a remarkable increase between midnight and 0600 hrs LT characterizes the storm-time N_e departures, the departures in T_e are dominated by a large increase during day time. It is again instructive to note that quiet time T_e distribution shown for pass 5578 follows closely the quiet time model. The T_e enhancements occur between 0700 and 1200 LT for passes 5589 and 5590 while they occur between 0800 and 1200 LT for passes 5591 and 5605, but in all the cases the maximum T_e increase seems to be near the highest latitude of the HINOTORI orbit. The passes in between have also been found to show similar trend. This pre-noon electron temperature enhancement by as much as the 1500 K is remarkable; but the usual inverse relation with N_e cannot be invoked as the N_e departures are either nil (5589 and 5590) or only marginal (5591 and 5605). In view of the outstanding features of the day time T_e enhancements we will discuss possible mechanisms vis-à-vis the presently known physical processes, in the following section.

1. The ionosphere at 600 km is heated during the day by photoelectrons escaping from lower F region along field lines. Near and below the F region peak, with high neutral densities, the elastic and in elastic collisions with neutrals, mainly with atomic oxygen, can contain the photoelectrons for longer durations so that local heating predominates. However, in the topside ionosphere at 600 km, the ambient electrons are heated primarily by photoelectrons from the lower ionosphere of both the hemispheres. In addition, a modest amount of energy may be available through ring current particles and the strength of this source increases as we move off from the magnetic equator and especially during storms. The heat loss is mainly due to electron thermal conduction downward from 600 km level into the lower ionosphere. The heat loss per unit volume U due to thermal conduction is given (Hanson and Cohen, 1968) as

$$U = -\frac{\partial}{\partial l}\left(K\frac{\partial T_e}{\partial l}\right) \tag{1}$$

where K is the electron thermal conductivity given by

$$K = 7.7 \times 10^5 T_e^{5/2} \mathrm{eV/sec.cm.deg} \tag{2}$$

for a completely ionized gas, and l is the length parameter along field lines. Thus the heat loss depends on T_e and T_e gradient and also on the constant in K parameter.

2. In addition to the enhanced radial transport during the main phase of a storm, the ring current particles can be removed by various collisional processes (Fok *et al.*, 1995; Chen *et al.*, 1997). They are lost through (a) charge exchange with neutrals, (b) Coulomb collisions with thermal plasma and (c) certain wave particle interactions which are not yet understood properly. The mechanisms (b) and (c) involve local processes and therefore they are more important over middle latitudes. During the passes considered here (5589, 5590, 5591 and 5605) the geomagnetic latitude of the satellite varied from -18 to -33 degrees latitude wherein T_e enhancement was observed between 0700 to 1200 LT. The L values varied between 1.5 to 1.75 during this period at HINOTORI altitude. Thus the L value in this case may be just enough for the inner most ring current ions to be able to dump some limited energy. Recent work by Fok *et al.* (1991) and Fok *et al.* (1993) described the role of Coulomb drag on ring current decay and showed how it depends on the electron densities and particle energies. For O^+ ions in particular, the Coulomb decay is more effective if the electron densities are higher at the altitude in question. However, the low L values would make this process a secondary one if present. The mechanism (a) can be a more efficient source of heating at latitudes covered by the HINOTORI satellite. The latitude variation of the resulting neutral particle flux maximizes at mid-latitude but

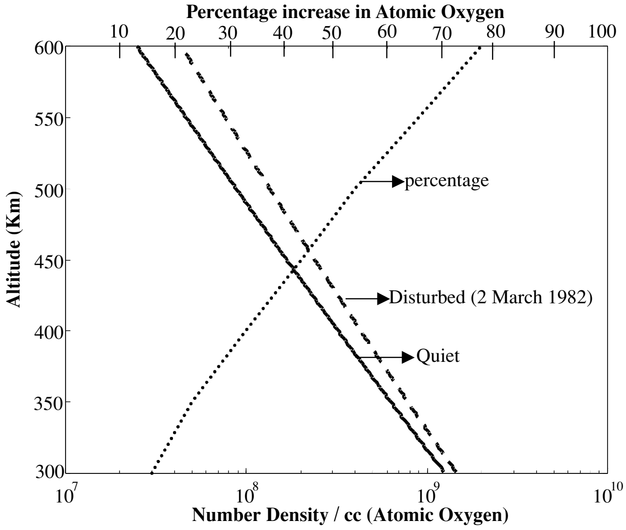

Fig. 2. Altitudinal profiles of atomic oxygen number densities for quiet period (averaged for 5 quiet days in March 1982) and disturbed day (2 March 1982) from MSIS −90 at 30 S latitude. Corresponding percentage increases in atomic oxygen number densities above the quiet values are also shown (top scale). This increase may be important in decreasing the electron thermal conduction, especially at 300 km or below.

with significant amount of energy input into the low latitude down to dip equator, according to the calculations by Tinsley (1979) (see also, Tinsley *et al.*, 1988). The energy input is also height dependent as explained by Tinsley *et al.* (1988). This Energetic Neutral Atom (ENA) flux is a source of ionization, excitation and heating and if the ring current ions have a pancake pitch angle distribution, then the bulk of precipitation will occur at low or equatorial latitudes (Kozyra and Nagy, 1991).

3. During day time, especially during a storm, the neutral densities are enhanced at all ionospheric altitudes including at 600 km. This may not be very large at equatorial latitudes, but still will have to be reckoned with. The storm time neutral density enhancement becomes a dominant factor at geomagnetic latitudes >20 degrees. This has two consequences. On one hand, the heat loss (to the ionosphere below) due to thermal conduction gets reduced, as K is sensitive to the ratio of plasma to neutral densities while the now increased neutral densities provide conducive conditions for the ring current ions to decay through charge exchange collisions with neutrals. There is credible evidence from satellite measurements to show that the densities of all neutrals increase even at very low latitudes in the F-region though there is some uncertainty as to whether the neutral density perturbations also include significant composition changes (Prolss, 1997). In any case, this is not relevant here as the photoelectron flux is not sensitive to the relative densities of the neutral constituents (Richards and Torr, 1985). It may also be noticed (especially for passes 5591 and 5605) that the early morning overshoot in T_e (Oyama *et al.*, 1996) is more pronounced than for quiet days.

To quantify the neutral density changes during disturbed periods we have taken the atomic oxygen number density which essentially is the total number density (which essentially is the total number density at 600 km) from MSIS-90 Model (Hedin, 1991) for 5 quiet days in March 1982 and compared it for 2 March 1982 data also from MSIS-90 and the results are shown in Fig. 2. The model values are obtained for latitude of 30 S. It can be noticed from the figure that percentage increase in atomic oxygen density (shown at the top of the figure) can be as high as 75% at the altitude of 600 km. The change in neutrals is only 17% around 300 km. It is known that MSIS model underestimates the storm-time temperature increase and hence the density increase (Richards, 2002). Thus, the number density increase we have shown is only the lower limit of the increase and the actual increase in the neutrals may be higher. Also, during day time, the electron densities being high, the ring current ion decay through Coulomb collisions may get enhanced although this factor seems to play only a secondary role at the low latitudes of the HINOTORI orbit.

As the T_e enhancements were remarkable in the pre-noon period with little change in N_e values, either a significant heat input or a bottleneck in cooling mechanism or both should be operational. A change in the photoelectron flux in response to equator-ward winds and lifting of the ionosphere/thermosphere can also contribute to this effect. This is in addition to ring current ion precipitation through charge exchange and a plausible decrease in electron thermal conductivity below 300 km that can affect even the 600 km temperatures. The constant of 7.7×10^5 in Eq. (2) above is for a fully ionized gas and will be affected some what as the degree of ionization decreases (Banks, 1966). So it is tempting to attribute the day time increase in T_e to the possible decrease in thermal conductivity brought about by a change in the constant in the thermal conductivity equation in response to increased neutral densities at 600 km during magnetic storms. But calculations show that the decrease in electron thermal conductivity will be restricted to below 300 km only. It is to be noted that a decrease in conductivity even below 300 km will have a very significant effect on the temperatures at 600 km and above as shown by Banks (1966). While the concept of this bottleneck in electron cooling is plausible, changes in neutral atmosphere during the present storm especially at and below 300 km do not justify this to be a major cause of the observed T_e enhancement; at best, it can be one of the contributing factors.

However, once T_e reaches a high value, say by 1000 LT or so, as was the case in the present storm, the very large T_e is conducive for excellent downward electron thermal conduction which is proportional to $T_e^{5/2}$; so after 1000 LT, T_e rapidly comes down to normal values. We may note that the largest T_e enhancement was observed when the HINOTORI orbit was at its highest latitude. Thus the T_e decrease after 1000 hrs is also the result of the satellite getting out of the latitude range where the aforementioned mechanisms of energy balance were dominant. It may be noted further that even a slight change in N_e can cause a large change in T_e because at high altitudes where cooling to ions is dominant the controlling parameter is Q/N_e^2, while in the bottom side F region it is Q/N_e. (Dalgarno and Mc Elroy, 1965). This can be noticed from the storm time passes 5591 and 5605 around 1000 LT and this is further strengthened by the observation at around 1800 hrs. where there is a significant increase in T_e associated with decrease in N_e.

2.2 Night time variations in N_e and T_e

It was observed that night time plasma densities (0000–0600 LT) during storm-periods are enhanced almost by an order of magnitude as compared to model values. The corresponding T_e values are also higher than model values significantly by a few hundred degrees. Nocturnal enhancements in N_e can be explained in terms of equator-ward winds at mid/high latitudes. At mid latitudes, even at 25–30 deg.lat, the upward drift is about 40 m/sec at night during quiet nights and that decreases the effective loss coefficient by a factor of 3 (Titheridge, 1995). There is also increasing evidence in recent years to show the importance of storm-time equator ward winds in contributing to the observed ionization changes at equatorial and low latitudes (Fesen *et al.*, 1989; Fejer *et al.*, 2000; Fuller-Rowell *et al.*, 2002). Fesen *et al.* (1989) have shown that thermospheric winds can blow across the magnetic equator transporting plasma along nearly horizontal field lines . During solstice months the cross equatorial winds can sweep the electrons away from the equator, but in equinoxes the auroral zones which drive winds during storms towards equator are both equally hot and the equator ward wind systems in both hemispheres converge at equator and can cause a N_e bulge there.

At equatorial and low latitudes a more likely cause of the plasma density variation is the electro-dynamical drift (EXB drifts) of plasma by dynamo electric fields. The equatorial latitudes are unique due to the horizontal NS geomagnetic field which in combination with the global east-west electric fields produce vertical plasma drifts. During day time when the electric field is eastward, the vertical drift is upward and the reverse is true for night time. The westward electric field during quiet nights causes downward drift bringing electrons to lower heights where they are lost at a faster rate. However, under storm conditions, disturbance dynamo electric field becomes active over equatorial/low latitudes within a few hours (4–8 hours) from the onset of a magnetic disturbance (Blanc and Richmond, 1980). Its polarity is generally opposite to that of the quiet time dynamo electric field. The eastward electric field that is present during the night is more intense during the post midnight/pre sunrise hours (Abdu *et al.*, 1997; Fejer and Scherliess, 1995). The large increase in the N_e having a double humped latitudinal structure during 0000–0600 LT (Fig. 1) suggests that the equatorial ionization anomaly (EIA) plasma is lifted up by an eastward electric field. In the present results the first increase in the pre sunrise EIA density that was observed on the morning of 2 March occurred several hours (at least 6 hours) after the onset of the storm (Dst decrease) which is consistent with the requirement (in terms of the time delay) for the disturbance dynamo electric field over low latitudes. Further evidence for the presence of an eastward electric field can be seen in the ionosonde data of Fortaleza located at 3.6 S, 321.2 E geographic and dip latitude of −6 degrees and Cacheira Paulista at 22.3 S, 315 E geographic and dip latitude of - 28 degrees plotted in Fig. 3. Figure 3 shows diurnal plots of foF2 (critical frequency of F2 layer) and h′F2 (bottom side height of F2 layer) for the storm period for these two stations. It can be seen from the figure that there is a sharp increase in h′F2 at both the locations starting around midnight when the main phase of the storm was in progress and continuing up to 0500 LT (night of 1–2 March 82) indicating the presence of an eastward electric field. It is seen that h′F2 at Cacheira Paulista, a location which is significantly away from the geomagnetic equator, reaches values of >400 km as compared to h′F2 (340 km) values over Fortaleza. This can be due to the storm-time equatorward wind contributing to the increase of layer height at Cacheira Paulista (Abdu, 1997) which could perhaps cause ionization convergence over equator as mentioned above. It may be also mentioned here that the sharp increase in h′F2 seen around 1800 LT is due to the usual pre reversal enhancement in eastward electric field typical of equatorial latitudes. Several important features of the disturbance dynamo electric fields have been identified from analysis of incoherent scatter radar data, Ionosonde data, equatorial and high latitude magnetograms and IMF data (Fejer, 1986; Fejer and Scherliess, 1995; Abdu *et al.*, 2003), and the large increase of upward drift/ eastward electric field during pre sunrise hours is a well identified man-

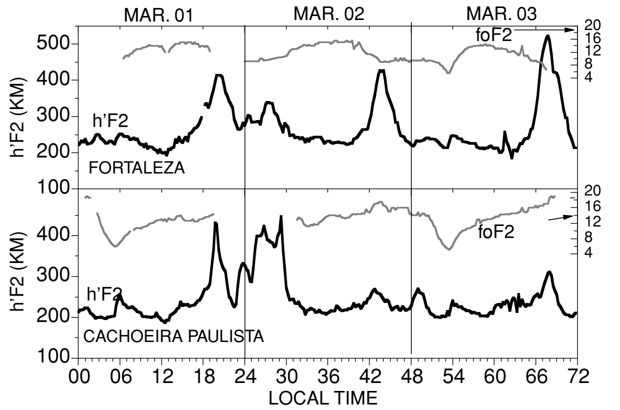

Fig. 3. Shows foF2 (MHz) and h′F2 (km) variations during 1–3 March 1982 for two stations Fortaleza (3.6 S, 321.2 E) and Cacheira Paulista (22.3 S, 315 E). The main features are h′F2 changes in the post midnight period caused by both electric fields and neutral winds (see text).

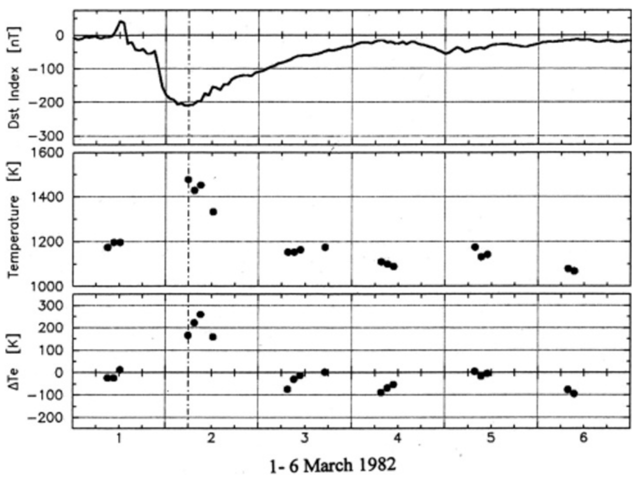

Fig. 4. Electron temperatures (T_e) from HINOTORI satellite during the period 1–6 March 1982 (middle panel) along with Dst variation (top panel). The bottom panel shows deviations in T_e from the model values (ΔT_e).

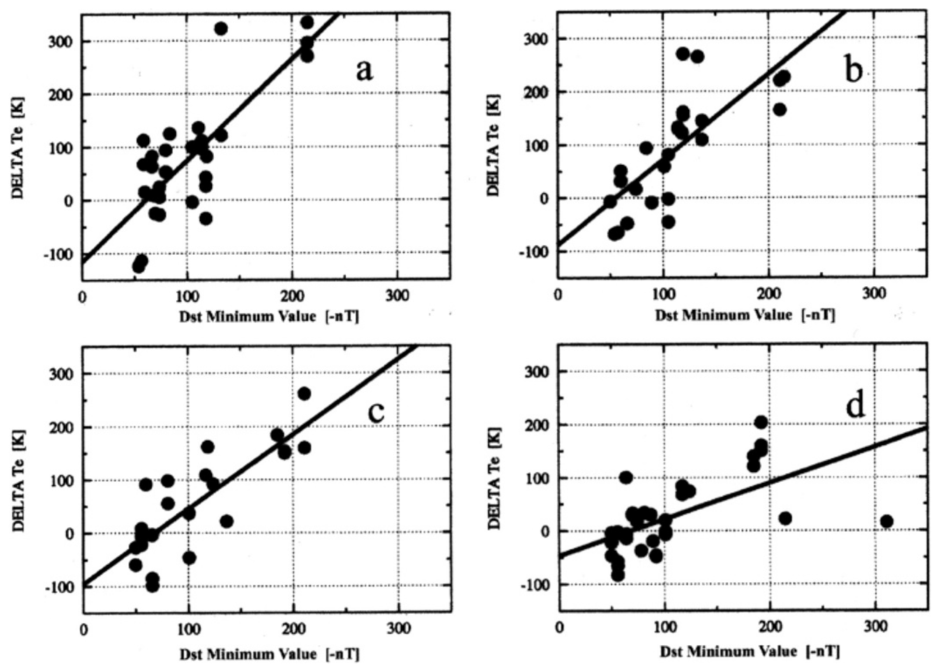

Fig. 5. Shows deviations in T_e at 600 km from the model values (ΔT_e) during magnetic storms during 0300–0400 LT plotted against Dst minimum values for different time slots. a) ΔT_e values during 0–4 hrs prior to Dst minimum, b) ΔT_e values 0–4 hrs after the Dst minimum, c) ΔT_e values for 4–8 hrs after the Dst minimum and d) 8–12 hrs after the Dst minimum. Dst values are in units of ($-$nT).

ifestation of a disturbance dynamo eastward electric field. Thus, it can be concluded that the night time (early hours) enhancement in N_e at 600 km over low latitudes was caused by a disturbance dynamo eastward electric field that lifted the equatorial ionosphere upwards.

We need now to examine the mechanisms, which can contribute to night time T_e increases during storm periods. The night time energetics are different as no heat input is available through photoelectrons escaping from the bottom side F region. As discussed in an earlier section, ring current particles through Coulomb collisions with thermal plasma can be an important heat source during storms (Fok *et al.*, 1991, 1993, 1995). Liemohn *et al.* (2000) discussed in detail the energy input to the thermal electrons due to Coulomb collisional degradation of hot ions in the inner magnetosphere during the large storm of June 4–7, 1991 (Dst $= -230$ nT). They compared the calculated heating rates from the ring current simulations with thermal plasma calculations from the field line interhemisphere ionospheric plasma (FLIP) model (Richards *et al.*, 1998) for the Millstone Hill field line ($L = 3$). It was found that heating from the ring current is more than adequate to account for the night time topside heat input necessary to obtain the observed electron temperatures during the storm. It was also noted that these high heating rates are only possible during solar maximum conditions when a large O+ population in the tens of keV range is present in the ring current. However, this mechanism could be operative mainly over mid latitudes as commented before. The highest HINOTORI latitude may well be under the influence of this effect. Over lower latitudes the process of energetic neutral particles originating from charge exchange of energetic ring current ions (mainly O^+) with atmospheric constituents, mentioned before might be the main source of heating. For example, temperature increase by $\sim$200 K from 630 nm airglow emission as measured by Fabrey-Perot interferometer over Peru has been reported by Tinsley *et al.* (1988) who have estimated that a heating rate of 100 K/hour can be accounted for by a loss rate of energetic particles from a ring current varying at 20 nT/hour. Their estimation showed that an increase of 100 K could be produced by a Dst decrease of $\sim$100 nT. In the event of 1–6 March 1982 (Fig. 1) the Dst decrease of 200 nT occurred at a rate that exceeded 20 nT/hour. Thus the night time T_e increase observed in this event is consistent with the effect expected from ring current particle precipitation represented by the Dst activity.

It should be mentioned here that, a very probable reason for the night time T_e enhancement could be simply the increase in the neutral temperature. The neutrals being the eventual sink for electron thermal energy, any increase in the temperature of the sink will increase the electron temperature.

3. Night Time Increase in T_e

It can be seen from Fig. 1 that on 1 March 1982 (pass 5578) during 0000–0400 hrs T_e is around 1200 K, close to model value; however, on 2 March T_e values are around 1500 K (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 4 shows T_e values observed during 0300–0400 LT from different passes for the period 1–6 March 82. The T_e values (mid panel) are so plotted that they correspond to the HINOTORI position with respect to Dst variation (top panel). In the bottom panel the differences (ΔT_e) between the model T_e values and observed T_e are plotted. It is obvious from the figure that the thermal electrons are heated during the main phase.

In addition to the single event of 1 March 1982 discussed in detail above, the high-resolution data of HINOTORI satellite pertaining to 21 magnetic storms was used to study statistical trends of night time T_e .

Figure 5 shows deviations in T_e at 600 km from the model values (ΔT_e) during 0300–0400 LT for 21 magnetic storms considered for this analysis. In this figure T_e deviations (ΔT_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.

4. Conclusion

The behavior of topside ionosphere at 600 km during 1 March 1982 magnetic storm is discussed in detail using electron density and electron temperature data from HINOTORI satellite. While the departures in electron temperatures (T_e) are dominated by a very significant increase during day time, the night time departures are characterized by large N_e enhancements. The large day time enhancements in T_e are explained in terms of ring current energy input through ENA and to some extent due to decreased electron thermal conduction below 300 km as a result of increased neutral densities during storms. The night time T_e values also show significant increases, by 200–300 K, during the main phase of a storm. A possible energy source for this is suggested to be inner belt ring current particles through their charge exchange with atmospheric neutral constituents resulting in energetic neutral atom (ENA) precipitation and consequent heating of the low latitude thermosphere, especially dominant under night conditions. The night time T_e enhancement could also be aided simply by the increase in the temperature of neutrals, which is the ultimate sink for electron thermal energy. Based on the data for a large number of storms a model for night time T_e deviations has been developed.

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