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Computer simulation of electron and ion densities and temperatures in the equatorial *F* region and comparison with Hinotori results

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Abstract. A time-dependent three-dimensional computer simulation of equatorial *F* region ionosphere has been carried out to understand the electron temperature structure observed by Hinotori satellite in the low and middle ionosphere. This model provides three-dimensional distributions of ion densities, electron temperature, and ion temperatures. The simulations showed the electron temperature enhancements around the equator in the morning, in the midlatitude in the afternoon, and around the equatorial anomaly region from afternoon to midnight. The enhancements in the morning are due to photoelectron heating. The afternoon enhancements in the midlatitude come from the balance of heating and cooling. When no meridional neutral wind is included in the simulation, the electron temperature did not show remarkable enhancements in the midlatitude in the afternoon because of strong cooling by the dense electron density. Around the equatorial anomaly region the electron temperature increased at high altitude in the evening because of the competing effects of plasma cooling and the plasma movements. Since the ionospheric plasma zonal $E \times B$ drift is eastward near the sunset (where E is ionospheric electric field and B is magnetic field) and the vertical drift is downward, the high-altitude dayside hot plasma can enter into the topside *F* region in the premidnight. The computer simulations were directly compared with the Hinotori satellite data. The simulation results were consistent with the equatorial electron density and temperature observed by the Hinotori satellite.

1. Introduction

In the equatorial ionospheric *F* region, plasma production and loss as well as transport and diffusion are important for the structure of electron and ion densities and temperatures.

Martyn [1947] discussed a formation of equatorial anomaly which comes out the combined effects of $E \times B$ drift and ambipolar diffusion. During the day an eastward electric field generated in the *E* region of the ionosphere through dynamo action [Matsushita, 1967] causes *F* region plasma to drift upward with a velocity of $\vec{E} \times \vec{B}/B^2$. At the same time, gravitational and pressure gradient forces move the plasma downward along the magnetic field line. The plasma is transported away from the magnetic equator toward higher latitudes. The equatorial fountain is thus responsible for the plasma density crests that are formed at north and south of the magnetic dip equator.

Several theoretical investigations have shown that the $E \times B$

drift is the basic mechanism in generating the equatorial anomaly. Time-independent plasma continuity equation including production and loss of plasma and the $E \times B$ drift which provides the upward or the downward motion of plasma at the magnetic equator was solved by Bramley and Peart [1965], Hanson and Moffett [1966], and Bramely and Young [1968]. Their results showed that the electron density distribution with peaks at $\pm 20^\circ$ magnetic latitude are formed for an $E \times B$ drift velocity of 15 m/s. Baxter and Kendall [1968] used time-dependent continuity equation to qualitatively explain the daily variation of the equatorial anomaly. By using a simple equatorial plasma drift model in which the plasma drifted upward during the day and downward at night, they found that the crests began forming at 1000 LT, reached their maximum development at 1700 LT and disappeared by 0200 LT. A drift amplitude of 20 m/s produced crests at $\pm 16^\circ$ dip latitude. Abur-Robb and Windle [1969] and Sterling *et al.* [1969] included a neutral wind in the time-dependent continuity equation and showed that the latitudinal positions of the crests are controlled only by the $E \times B$ drift velocity and not on the neutral wind velocity. They also demonstrated the effectiveness of an equatorward neutral wind in maintaining the nighttime low-latitude F_2 plasma densities. These results were carried out under a centered dipole magnetic field whose dipole axis

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Figure 1. A model of an $E \times B$ plasma drift and a neutral wind used in the simulations. The upward and eastward drifts are plotted for 400, 600, and 800 km altitude. The neutral winds model are shown at 400 km altitude.

aligned with the Earth's rotational axis. Anderson [1973a, b] used a realistic geomagnetic field model to investigate the longitudinal differences of the equatorial ionosphere. His simulations including the $E \times B$ drift, the neutral wind and the production and the loss of plasma showed the differences of equatorial ionosphere between the American and the Asia sectors. Time-dependent continuity equation was also solved with the energy equations of electrons and ions in the midlatitude ionospheric F region [Bailey, 1980, 1983]. Bailey [1980] showed the counterstreaming of H^+ and O^+ and the temperature difference between them. Bailey [1983] has presented also the effect of $E \times B$ drift on the plasma temperature.

The Hinotori satellite was launched on February 1981 from Kagoshima Space Center of the Institute of Space and Astronautical Science in Japan for investigations of the solar flare and the Earth's ionosphere during the solar maximum. The satellite was put at ~ 600 km altitude with an inclination of 30° . An impedance probe [Oya *et al.*, 1986] and an electron temperature probe [Oyama *et al.*, 1988] onboard the Hinotori satellite measured the density and temperature respectively of the electrons.

In this paper, we have carried out a three dimensional computer simulation of the equatorial F region based on time-dependent numerical solutions of the coupled ion and electron continuity, momentum, and heat balance equations. Results are presented as three-dimensional structures of electron and ion temperatures and densities that are compared with the observations made by the Hinotori satellite.

2. Model

2.1. Ion Continuity, Momentum, and Heat Balance Equations

The electron density and the electron and ion temperatures in the equatorial ionosphere are simulated by the following equations:

$$\frac{\partial N_i}{\partial t} + \frac{1}{A} \frac{\partial AN_i V_i}{\partial s} = P_i - L_i, \quad (1)$$

$$\begin{aligned} \frac{3}{2} N_i k \frac{\partial T_i}{\partial t} + \frac{3}{2} N_i k V_i \frac{\partial T_i}{\partial s} + \frac{N_i k T_i}{A} \frac{\partial AV_i}{\partial s} \\ - \frac{1}{A} \frac{\partial}{\partial s} \left(A \kappa_i \frac{\partial T_i}{\partial s} \right) = Q_i, \end{aligned} \quad (2)$$

$$\begin{aligned} \frac{\partial V_i}{\partial t} + V_i \frac{\partial V_i}{\partial s} = +g \sin I - \frac{k}{N_i m_i} \frac{\partial N_i T_i}{\partial s} - \frac{k}{N_e m_i} \frac{\partial N_e T_e}{\partial s} \\ - \sum_j v_{ij} (V_i - V_j) - \sum_n v_{in} (V_i - U_n \cos \hat{I}) = 0, \end{aligned} \quad (3)$$

where N_i is ion density, N_e is electron density, V_i is field-aligned velocity, P_i is production rate, L_i is loss rate, A is cross-sectional area of magnetic flux tube, T_i is temperature, Q_i is heating and cooling rate, κ_i is thermal conductivity, k is the Boltzmann constant, m_i is ion mass, g is gravitational acceleration, v_{ij} is the collision frequencies between i th and j th

Figure 2. Three-dimensional simulations of electron density, electron temperature, and O^+ temperature at the magnetic equator. The exospheric temperatures are 1560 and 1200 K respectively for the diurnal maximum and minimum values. The simulations include the effects of $E \times B$ plasma drift and neutral wind. The contour number (n) in density plot represents the number density of 10^n cm^{-3} and the number in temperature shows $n \times 100 \text{ K}$.

particles, U_n is neutral wind velocity, I is magnetic dip angle, t is time, and s is arc length along magnetic field line. The i and j variables represent electron, oxygen ion O^+ and hydrogen ion H^+ , and n represents oxygen atom, hydrogen atom, oxygen molecule, and nitrogen molecule. The electron density is calculated from the summation of ion density, $N_e = N_{O^+} + N_{H^+}$. This is a good approximation in the ionospheric F region. For the electron velocity V_e we assume that there are no field-aligned currents,

$$N_e V_e = N_{O^+} V_{O^+} + N_{H^+} V_{H^+}. \quad (4)$$

Equations (1)–(3) are numerically solved for O^+ , H^+ along a magnetic field line under an $E \times B$ drift and a neutral wind. Equations (2) and (4) are used for electrons. The calculation grids on a magnetic field line can move to a different magnetic field line with the different altitude and local time by the $E \times B$ drift. About 100 magnetic field lines are used in order to make three-dimensional structures of densities and temperatures. The simulation procedure involves the calculations of (1) the O^+ and H^+ field-aligned velocities from equation (3) and the electron field-aligned velocity from equation (4); (2) the O^+ and H^+ densities from equation (1); and (3) the O^+ , H^+ and electron temperatures from equation (2). Those equations are solved by the implicit method and iteration. The nonlinear terms of Q_i are calculated with the previous density and tem-

perature before one iteration. The iteration is carried out until all parameters such as densities and temperatures converge.

2.2. Boundary Conditions

At the lower boundary of 120 km altitude we take ion density to be in chemical equilibrium,

$$P_i = L_i. \quad (5)$$

Since the production and loss of O^+ and H^+ by the chemical reaction with other ions are not important in the ionospheric E and F region, the equation (5) is enough condition to calculate the densities for O^+ and H^+ of these regions.

We take the ion and electron temperatures to be the same as the neutral temperature at the lower boundary.

3. Atmospheric Model

In our computer simulations of the equatorial ionospheric F region, the neutral atmosphere is calculated with Jacchia model but the hydrogen concentration is calculated with Kockarts-Nicolet model. The calculated plasma density and temperature structure are not sensitive for hydrogen concentration near F region because the simulation is carried out in the solar maximum condition.

Figure 3. Three-dimensional simulations of electron density, electron temperature, and O^+ temperature in 1400 LT. The parameters used here are same to Figure 1.

3.1. Plasma Drift and Neutral Wind Velocities

The upward drift velocity induced by the ionospheric electric field for equinox conditions is modeled as

$$V_{up} = 20 \times \cos \left((LT - 11) \frac{\pi}{12} \right) + \frac{40 \times \exp [-(LT - 19)^2/3]}{1 + \exp [(h - 1000)/300]} - 10 \times (\exp [-(LT - 4)^2/16] + \exp [-(LT - 21)^2/16]) \text{ m/s} \quad (6)$$

on a basis of radar observation in Jicamarca [Fejer, 1981], where LT is local time in hour and h is height in kilometers. We use the eastward plasma drift by Coley and Heelis [1989], the zonal neutral wind by Wharton *et al.* [1984] and the meridional neutral wind by Herrero *et al.* [1988].

Figure 1 shows the plasma drift and the neutral wind models used in the simulations. The upward and eastward drift velocities are plotted for 400, 600, and 800 km altitudes. The neutral wind model are also plotted in the bottom panel for 400 km altitude.

3.2. Ion Chemistry

Oxygen ions O^+ in the equatorial ionospheric F region are produced from the photoionization of atomic oxygen by the solar EUV radiation. The production rate q_{euv} of O^+ was shown by Anderson [1973b]

$$q_{euv} = q_{\infty} N_O e^{-\tau}, \quad (7)$$

$$\tau = 9 \times 10^{-18} N_O H_O Ch(r, \chi, H_O) + 1.5 \times 10^{-17} N_{N_2} H_{N_2} Ch(r, \chi, H_{N_2}), \quad (8)$$

$$q_{\infty} = 2.4 \times 10^{-7} (1 + 0.0124 F_{10.7}), \quad (9)$$

where N_O and N_{N_2} are the atomic oxygen and the molecule nitrogen number densities, Ch is the Chapman function, r is height, χ is the solar zenith angle, H_O and H_{N_2} are the oxygen atom and the nitrogen molecule scale heights, and $F_{10.7}$ is the solar flux intensity.

The loss of O^+ is due to reactions with molecular nitrogen and molecular oxygen with rate coefficient of $2 \times 10^{-11} \text{ cm}^3 \text{ s}^{-1}$ and $7 \times 10^{-13} \text{ cm}^3 \text{ s}^{-1}$, respectively. The O^+ is also produced from H^+ according to the charge exchange reaction:

with a rate coefficient of $2.3 \times 10^{-11} T_H^{0.5} N_O \text{ sec}^{-1}$ where T_H is the hydrogen ion temperature and N_O is the oxygen atom number density. The loss of O^+ to produce H^+ is according to the charge exchange reaction:

with a rate coefficient of $2.5 \times 10^{-11} T_n^{0.5} N_H \text{ s}^{-1}$, where T_n is the neutral temperature and N_H is the atomic hydrogen number density. Those reaction rates are given by Banks and Kockarts [1973].

Figure 4. Three-dimensional simulations of electron density, electron temperature, and O^+ temperature at 600 km altitude. The parameters used here are same to Figure 1.

3.3. Collision Frequency

The collision frequencies for momentum transfer described by *Raitt et al.* [1975] are used as

$$\nu_{O^+,n} = 3.42 \times 10^{-11} N_O T_e^{0.5} \times (1.04 - 0.064 \log_{10} T)^2 + 6.66 \times 10^{-10} N_{O_2} + 6.68 \times 10^{-10} N_{N_2}, \quad (12)$$

$$\nu_{H^+,n} = 6.61 \times 10^{-11} N_O T_{H^+}^{0.5} \times (1 - 0.047 \log_{10} T_{H^+})^2 + 3.2 \times 10^{-9} N_{O_2} + 3.36 \times 10^{-9} N_{N_2} + 1.37 \times 10^{-10} N_H T_e^{0.5} \times (1.4 - 0.117 \log_{10} T)^2, \quad (13)$$

$$\nu_{O^+,H^+} = 0.084 N_{H^+} T_{H^+}^{-1.5}, \quad (14)$$

$$\nu_{H^+,O^+} = 1.35 N_O T_{H^+}^{-1.5}, \quad (15)$$

where

$$T = (T_n + T_{O^+})/2. \quad (16)$$

3.4. Thermal Conductivities

For O^+ , H^+ ions, and electrons the thermal conductivities given by *Banks and Kockarts* [1973] are

$$\kappa_{O^+} = 1.15 \times 10^4 (N_{O^+}/N_e) T_{O^+}^{2.5}, \quad \text{eV s}^{-1} \text{ cm}^{-1} \text{ deg}^{-1} \quad (17)$$

$$\kappa_{H^+} = 4.6 \times 10^4 (N_{H^+}/N_e) T_{H^+}^{2.5}, \quad \text{eV s}^{-1} \text{ cm} \text{ deg}^{-1} \quad (18)$$

$$\kappa_e = \frac{\kappa_{ei} \kappa_{en}}{\kappa_{ei} + \kappa_{en}}, \quad \text{eV s}^{-1} \text{ cm}^{-1} \text{ deg}^{-1} \quad (19)$$

where

$$\kappa_{ei} = 7.7 \times 10^5 T_e^{2.5}, \quad \text{eV s}^{-1} \text{ cm}^{-1} \text{ deg}^{-1} \quad (20)$$

$$\kappa_{en} = 3.2 \times 10^7 \frac{T_e N_e}{\nu_{en}}, \quad \text{eV s}^{-1} \text{ cm}^{-1} \text{ deg}^{-1} \quad (21)$$

ν_{en} is the electron-neutral momentum collision frequency described by *Schunk and Nagy* [1978],

$$\begin{aligned} \nu_{en} = & 8.9 \times 10^{-11} N_O (1 + 5.7 \times 10^{-4} T_e) T_e^{0.5} \\ & + 4.5 \times 10^{-9} N_H (1 - 1.35 \times 10^{-4} T_e) T_e^{0.5} \\ & + 1.82 \times 10^{-10} N_{O_2} (1 + 3.6 \times 10^{-2} T_e^{0.5}) T_e^{0.5} \\ & + 2.33 \times 10^{-11} N_{N_2} (1 - 1.21 \times 10^{-4} T_e) T_e. \end{aligned} \quad (22)$$

3.5. Heating Rates

In the ionospheric F region the photoelectrons produced by the solar EUV radiation heat the ambient electrons. The electron heating rate (Q_{pe}) by the photoelectron is written as

$$Q_{pe}(s) = \int_0^\infty \left(\frac{d\phi}{dE} \right) \left(\frac{dE}{ds} \right) dE \quad (23)$$

where ϕ is the photoelectron flux, E is the photoelectron energy in eV and dE/ds ,

$$\left(\frac{2E}{m_e} \right)^{1/2} \frac{dE}{ds} = \frac{dE}{dt} \cong -\frac{10^{-5}}{E^{1/2}} N_e, \quad \text{eV s}^{-1} \quad (24)$$

Figure 5. Three-dimensional simulations of electron density, electron temperature, and O^+ temperature at 600 km altitude. The exospheric temperatures are 1040 and 800 K respectively for the diurnal maximum and minimum values. The simulations include the effects of $E \times B$ plasma drift but the neutral wind effect is not included.

is the energy loss of photoelectrons due to elastic collisions with ambient electrons [Banks, 1969]. The photoelectron flux model has been obtained as the two-stream approximation by Banks and Nagy [1970]. Since the nonlocal heating by the photoelectron is important especially near sunrise or sunset, the photoelectron heating based on two-stream approximation is included in our computer simulations of ionospheric F region.

The other collisional heat transfer rates Q_i (i = electron, ions) used in our simulations are listed by Bailey and Sellek [1990].

4. Simulation Results

Equations (1)–(4) are solved in the equinox conditions for the centered dipole magnetic field lines; the dipole axis is aligned with the Earth's rotational axis.

Figure 2 shows one of the three dimensional simulation results of electron density and electron and ion temperatures at magnetic equator. The exospheric temperatures are 1560 and 1200 K respectively for the diurnal maximum and minimum values. This condition corresponds to the $F_{10.7} = 250$. The simulations can include the effects of an $E \times B$ plasma drift and a neutral wind. The increasing of electron temperature (morning overshoot) occurs above the F region density peak in the morning of ~ 0600 local time (LT). The high electron temperature region seen in Figures 2 and 3 is found to

be confined at ~ 300 km altitude near noon. The region is localized around magnetic equator as shown in Figure 3 where the density and temperatures are displayed in altitude-magnetic latitude space at 1400 LT. We can also see the hot region in the topside of F region during a daytime. The daytime hot plasma at high altitudes can expand to evening region due to small cooling rate (see Figure 2).

Figure 4 shows the density and temperatures at a fixed altitude of 600 km where the Hinotori satellite observed the electron density and temperature. The equatorial ionization anomaly starts developing at ~ 1000 LT and continues to midnight. The morning overshoot for electron is seen around 0600 LT. However, there is no O^+ temperature increase at that time. The heated region is localized between $\pm 30^\circ$ magnetic latitudes centered at magnetic equator. The electron temperatures increase in midlatitudes in the afternoon. These electron temperature enhancements occur clearly when the meridional neutral wind velocity is large. The poleward winds produce the reduced electron densities at these latitudes which result in the enhanced temperature as can be verified by comparing the top and the middle panels of Figure 4. The electron density and temperature distributions at 600 km altitude is sensitive to the input parameters used in the simulation. Figure 5 presents an example of results from a simulation run that used lower exospheric temperatures (that is, 1040 and 800 K respectively for the diurnal maximum and minimum values of T_∞). In these

Figure 6. Three-dimensional simulations of electron density, electron temperature and O^+ temperature in 2100 LT. The parameters used here are same to Figure 5.

results, the hot plasma regions that protrude from the dayside into the nightside has latitudinal structure better developed than in Figure 4, which seems to be capable of better accounting for the equatorial T_e and electron density enhancements around 2100 LT often observed in the large number of latitude-longitude crossings of the Hinotori satellite. (Further details on such aspects of equatorial anomaly will be discussed elsewhere.) Figure 6 shows the results in the 2100 LT. In the topside F region ionosphere, the temperature structure shows the arch shape. The structure is due to the competing of plasma cooling and the plasma movements. Since the ionospheric plasma zonal $E \times B$ drift is eastward near the sunset and the vertical drift is downward, the high-altitude dayside hot plasma can enter into the topside F region in the premidnight and diffuses along the magnetic field line.

5. Comparison Between Simulations and Observations

One of the examples of electron density and temperature observed by the Hinotori satellite in the equatorial region is shown in Figure 7 where UT is universal time, LT is local time at the satellite position, LON is longitude, LAT is latitude, MLAT is magnetic latitude, and ALT is altitude. The data were obtained on April 8, 1982. The electron densities increase in the magnetic latitudes of $\sim \pm 12^\circ$ (1626 and 1637 UT) where the electron temperatures increase up to ~ 200 K from background temperature. The enhancements are associated with the equatorial anomaly. Enhanced electron temperature oc-

curs between 1600 and 1624 UT in the mid-latitude region. The electron temperature enhancement of ~ 3000 K that occurs at 1530 UT, is the morning electron temperature overshoot that arises from photoelectron heating. The calculated electron density and temperature are also plotted in Figure 7, where the exospheric temperatures are 1430 and 1100 K respectively for the diurnal maximum and minimum values. The drift and neutral wind models described in section 3.1 are used for bold lines. Dashed lines show the results without the evening enhancement of equation (6), and dotted lines show the condition of the neutral wind velocity equal to 0. From the comparison around 1520 UT the simulation results without the evening enhancement of upward plasma drift are consistent with the data. However, if we consider the more realistic case of the presence of an evening drift enhancement, the model electron densities show maximum departures from observed values in two longitude sectors, one centered around $190^\circ E$ and the other around $35^\circ E$. These differences could be arising from the centered dipole magnetic field model used by us that do not account for the magnetic declination angle variations.

Figure 8 shows the average electron temperature at the satellite altitude of ~ 600 km as the functions of local time and geomagnetic latitude. The data were selected in the equinox conditions from February 1981 to May 1981 and from September 1981 to November 1981. The average $F_{10.7}$ was 205 in these periods. The electron temperature values were averaged for bins of 30 min in local time and 5° in geomagnetic latitude. Electron temperature enhancements occur in the morning

Figure 7. An example of electron density and temperature observed by the Hinotori satellite. The data were obtained on April 8, 1982. The calculated electron density and temperature are also plotted where the exospheric temperatures are 1430 and 1100 K respectively for the diurnal maximum and minimum values. The drift and neutral wind models described in section 3.1 are used for bold lines. Dashed lines show the results without the evening enhancement, and dotted lines show the condition of the neutral wind velocity is equal 0.

(~0600 LT) with the peak temperature at the magnetic equator and in the midlatitude in the afternoon (~1800 LT).

The result from computer simulation of equatorial ionosphere is shown in Figure 9 where the electron temperature of Figure 4 displayed with the same format of Figure 8. We can see a good correlation between observations and the simulation results.

Effects of the meridional neutral wind and $E \times B$ drift effects for electron temperature are shown in Figure 10 and 11 where the observed and calculated electron temperatures are plotted for magnetic equator region and 25° magnetic latitude region at 600 km altitude, respectively. The observed electron temperature are plotted with the mark of box. The large dashed

and small dashed lines show the calculated electron temperatures with neutral wind and without neutral wind, respectively. The dotted lines show the calculated temperature with large plasma drift where $10 \times \cos[(LT - 11)\pi/12]$ is added in the plasma drift model of equation (6). It is noted that the afternoon enhancement of electron temperature in the mid-latitude region are strongly affected by both the neutral wind and $E \times B$ drift.

6. Discussion and Summary

Electron temperatures observed by the Hinotori satellites show the temperature structure in the equatorial ionospheric F

Figure 8. Electron temperature in the local time–geomagnetic latitude space at ~600 km altitude. The data were selected in the equinox conditions from February 1981 to May 1981 and from September 1981 to November 1981. The average $F_{10.7}$ was 205 in these periods.

Figure 9. Simulated electron temperature in the local time–geomagnetic space at 600 km altitude. The electron temperature of Figure 4 are displayed with the same format of Figure 8.

region. The elevated electron temperature were observed in the morning, in the midlatitude in the afternoon. The temperatures showed enhancements associated with the solar radio flux intensity.

Three-dimensional computer simulations shown here were carried out by method similar to that of Bailey *et al.* [1973], Bailey and Moffett [1978, 1979], and Bailey [1980, 1983]. However, we have used more realistic inputs of ionospheric plasma drifts and neutral winds based on models representing results from DE 2 and AE-E satellites and the photoelectron flux model. The simulation results show that the structure of equatorial ionospheric *F* region is strongly affected by the plasma drift, which is induced by the ionospheric electric field, neutral wind, exospheric temperature, and solar flux intensity variations.

The simulations showed the electron temperature enhancements around the equator in the morning, in the midlatitude in the afternoon and around the equatorial anomaly region from afternoon to midnight. The enhancements in the morning is due to photoelectron heating which is well known as the morning overshoot. The afternoon enhancements in the midlatitude comes from the balance of heating and cooling. When no neutral wind is included in this simulation, the electron temperature did not show remarkable enhancements because of strong cooling by the dense electron density in the midlatitude region. Around the equatorial anomaly the electron temperature increased at high altitudes in the evening. Since the ionospheric plasma near sunset drifts upward and eastward by the $E \times B$ force and the time scale for the ion cooling is large at high altitudes, the high altitude dayside hot plasma can enter into the premidnight region. These results were consistent with the equatorial electron density and temperature observed by the Hinotori satellite. This latter aspect, especially, is rather sensitive to the combination of the values used, as the input for

Figure 10. Comparison between simulated electron temperature at 600 km altitude and the electron temperature observed by the Hinotori satellite at the magnetic equator. The large-dashed and small-dashed lines show the electron temperature with the neutral wind effects and without the effects, respectively. The dotted lines show the temperature when the plasma drift of $10 \times \cos[(LT - 12)\pi/12]$ is added in equation (6).

Figure 11. Same as Figure 10. The electron temperatures at 25° magnetic latitude are plotted.

the model, for the exospheric temperature and plasma drift and neutral wind.

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