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Effects of zonal and meridional neutral winds on the electron density and temperature at the height of 600 km

By

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Abstract : Electron temperature (Te) and density (Ne) data which were obtained with equator-orbiting satellite Hinotori in 1981-1982 at the height of 600 km are used to study the local time, latitude, longitude, and seasonal variations of the topside ionosphere at low latitudes. The study shows that difference of behavior of the daytime Te and Ne between two hemispheres is well understood by the effect of neutral wind.

Electron density in the summer hemisphere is higher than that in winter hemisphere due to meridional wind component (seasonal variation) which blows from summer hemisphere to winter hemisphere and consequently electron temperature is lower in summer hemisphere than in winter hemisphere. In addition to this effect, effect of the zonal wind component (diurnal change) is superposed at the regions where magnetic meridian plane tilts. Especially in the American sector、 where magnetic meridian plane tilts about 20 degrees westward, zonal wind effect is comparable to the meridional wind effect.

Key words : Ionosphere (Neutral wind and plasma interaction; Electron density and temperature; Topside ionosphere)

1. Introduction

The efforts to revise International Reference Ionosphere (IRI) are still being continued based on the observations. The IRI reproduces Te and Ne of bottomside ionosphere basically well, whilst model of Ne and Te in the topside ionosphere is still very poor because only small amount of data are used to construct the model. For example, IRI predicts plasma density much higher than the real one in the topside ionosphere.

Past Te observations which are used to construct IRI model are from AE-C at 300 km and 400 km (Brace and Theis, 1981), from AEROS at 600 km (Spenner and Plugge,1979), from ISIS - 2 at 1400km (Brace and Theis,1981) , and from ISIS-1 at 3000km (Brace and Theis, 1981). In spite of the existence of many satellite measurements, especially Te data is not well archived to improve the IRI and it is still difficult for us to draw the realistic picture of basic parameters of topside ionosphere from the IRI .

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In February 1981, Japan's first sun observation satellite was launched with the inclination of 31 degrees at a circular orbit of 600km. Electron temperature probe (Hirao and Oyama, 1970; Oyama and Hirao, 1982) was put at the end of one of the solar cell paddles and a cylinder probe for Ne (Oya et al., 1986) was put at another end of the solar cell paddle which was orthogonally placed to the solar cell paddle for the electron temperature probe. When a solar flare was detected, the data recorder onboard was totally allocated to store transient flare phenomena and Ne/Te data were not recorded. However Ne/Te data of 3 to 4 satellite passes are recorded per day until the spacecraft stopped the operation in June ,1982 due to a battery problem.

The Ne/Te data thus obtained turned out to be the most beautiful data set at the height of 600 km and many papers have been published (Watanabe and Oya, 1986; Takahashi et al, 1987; Oyama and Schlegel 1988; Schlegel et al., 1989; Oyama 1991, 1994; Oyama et al., 1993, 1996a; Watanabe and Oyama, 1995; Watanabe et al., 1995a; Watanabe and Oyama, 1996; Su et al, 1995, 1996a, 1996b; Balan, 1997, Dabas et al.,2000).

In 1996, we had reported longitudinal variation of Te alone (Watanabe and Oyama,1996). In this paper we describe features of both Te and Ne at two different longitude zones for three seasons in order to show the significant role of both zonal and meridional winds. Data for these three seasons are equinox (February, March , April in 1981 and 1982, September and October in 1981, denoted as E.Q.X hereafter) summer in the northern hemisphere (May, June in 1981 and 1982, and July in 1981, denoted as M.J.J hereafter), and summer in the southern hemisphere (November, December and January, denoted as N.D.J hereafter). The results which are summarized here are expected to contribute to the revision of the IRI of Te/Ne and to serve as a reference to other Te/Ne observations at the height of 600 km in the equatorial region (within 30 degrees in geomagnetic latitudes). The results can also be used for educational purpose because they show very clear and ideal neutral wind effects on the topside ionosphere. In chapters 2, 3, and 4, data which are processed irrespective of solar flux F10.7 are used because the number of the data otherwise becomes insufficient for the discussion. However brief description is given about the solar flux dependence in chapter 5 ,because the effect of solar flux intensity F10.7 can be seen in spite of the small range of the solar activity variation during the satellite observation.

2. Local time variation of Ne at three seasons in two longitude zones

Figures 1a, 1b, and 1c show the local time variation of Ne for three seasons for the longitude zone of 210-285 degrees where magnetic meridional plane tilts about maximum 10 degrees toward east. Ne values which are plotted in the figure are the data averaged during individual 3 seasons. One feature which is common to all three figures is that Ne takes minimum value around 4 local time which is right before sunrise, increases toward daytime, and finally reduces in the evening.

It is noted in these figures that two equator clefts of both hemispheres are smeared out as a result of averaging many satellite passes.

During the equinox (upper panel) when wind blows toward high latitudes, local time variation is roughly symmetric in the northern and southern hemispheres. It is, however, noted that Ne around 7-11 LT is higher in the northern hemisphere than in the southern hemisphere and higher in the southern hemisphere than in the northern hemisphere around 17-20 LT. During northern summer season (middle panel), Ne in the northern hemisphere is higher than in the southern hemisphere.

Whilst in northern winter, Ne in the southern hemisphere is higher than in the northern hemisphere. Among the three panels, Ne is the lowest in northern summer, which shows the seasonal anomaly.

In Figures 2a, 2b, and 2c Ne profiles are shown for the longitude zone of 285-360, where magnetic meridional

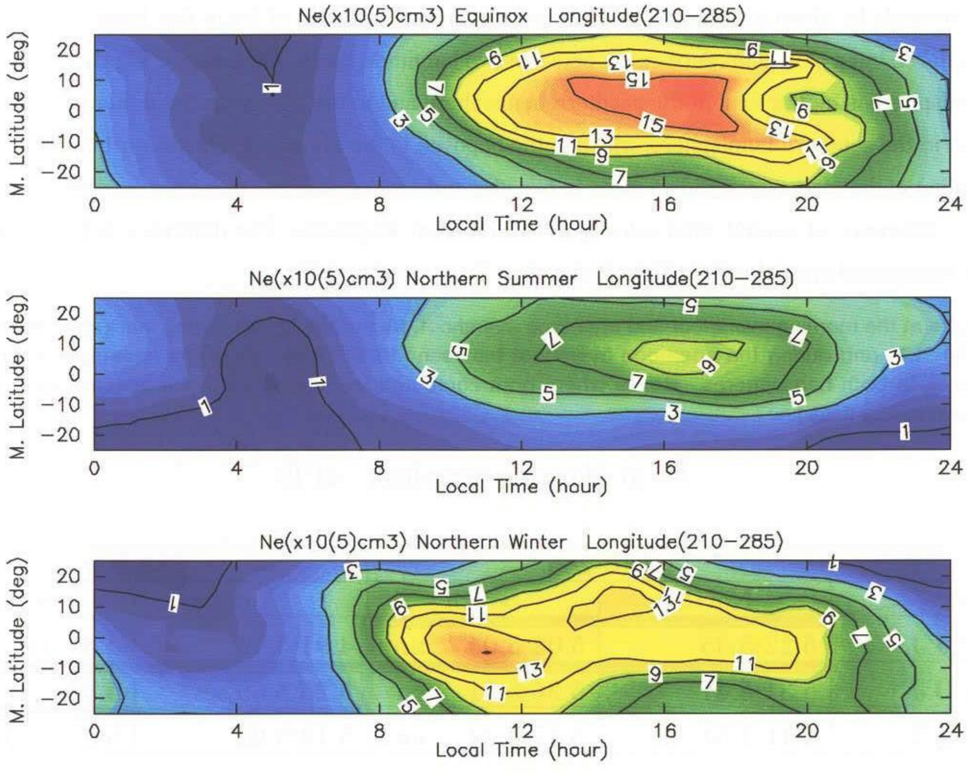

Figure.1 Local time variation of Ne for three seasons; (a) equinox, (b)summer in northern hemisphere and (c) winter in northern hemisphere for the longitude zone of 210-285.

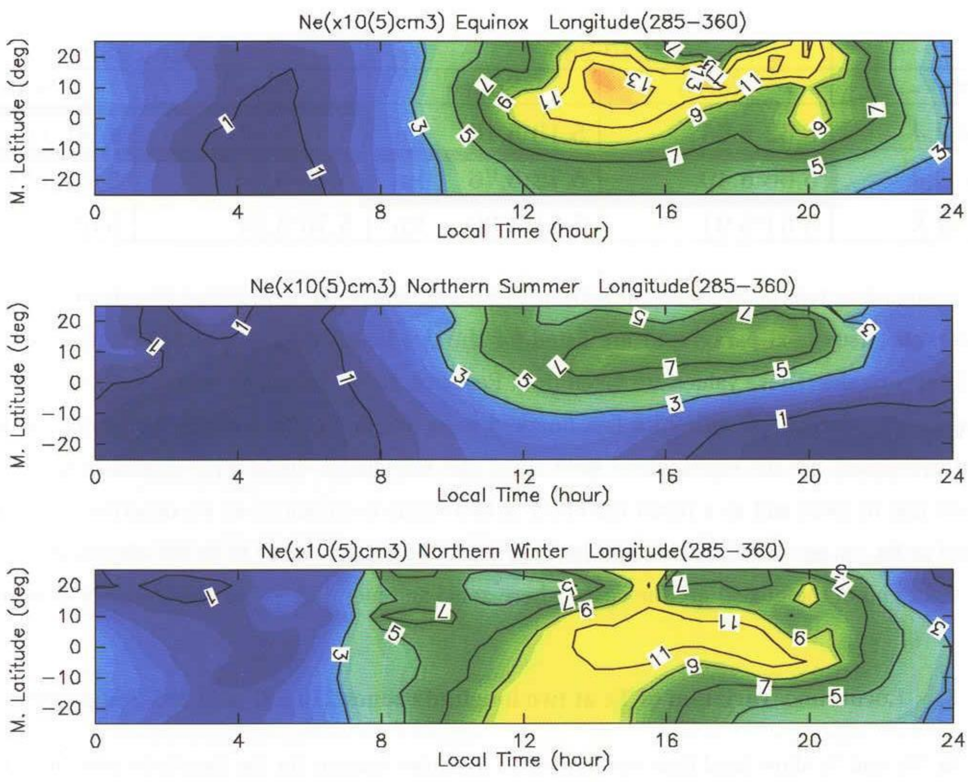

Figure.2 Same as figure 1 but for the longitude zone of 285-360

plane tilts westwards by about a maximum of 20 degrees. General behavior of Ne in this latitude zone is nearly the same as for 210-285,but a clear difference exists between two longitude zones. For example Fig.2a (equinox) Ne in the southern hemisphere is higher than in the northern hemisphere and in the afternoon Ne in the northern hemisphere is higher than in the southern hemisphere, which is the opposite to the Figure 1a. This is attributed to the difference of the declination of the magnetic meridian plane in two longitude zones. Another factor for the difference of Ne might be due to the difference of neutral wind velocity at two different longitudes. The difference between two longitude zones can be recognized more clearly in Te behavior than Ne as we show later.

Table 1 $Log_{10}Ne$ at the morning overshoot and afternoon overshoot. Ne are the values during morning overshoot between 6-7:30 LT and during the afternoon overshoot between 16:30-18:00 LT at the geomagnetic latitudes of 20 degrees in both hemispheres. Boxes where both zonal and meridional wind components are enhanced are surrounded by thick line .

Ne at Morning overshoot of Te

	210-285		285-360	
Season	North	South	North	South
M.J.J	5.22-5.35	5.02-5.04 an	4.91-5.19	4.81-5.03 bn
N.D.J	5.31-5.41	5.36-5.51 cn	5.25-5.59	5.38-5.58 dn
E.Q.X	5.11-5.34	5.17-5.24 en	5.18-5.22	5.07-5.25 fn

Ne at Afternoon overshoot of Te

	210-285		285-360	
Season	North	South	North	South
M.J.J	5.62-5.65	5.13-5.16 gn	5.57-5.85	4.90-5.03 hn
N.D.J	5.66-5.40	5.72-5.76 in	5.79-5.84	5.73-5.86 jn
E.Q.X	5.81-5.91	5.81-5.90 kn	5.76-5.81	5.69-5.78 ln

Table 1 summarizes typical Ne values in both hemispheres, where Ne at morning overshoot of Te as well as at afternoon overshoot (see next paragraph) are listed for the two longitude zones of 210-285 degrees and 285-360 degrees for three seasons. These values are taken from Research Note (Watanabe et.al., 1995b; Oyama et al., 1994). Two boxes which are surrounded with thick line (marked as **an** and **dn** for the morning overshoot and **hn** and in for the afternoon overshoot) are the cases where both zonal and meridional winds drive plasma to the same direction along magnetic line of force and as a result the effect of two winds is enhanced as we describe in section 3. Other boxes (marked as **bn, cn, en,** and **fn** for the morning overshoot and **gn ,jn kn,** and **ln** for the afternoon overshoot in the boxes at the right end of the boxes) are the cases where zonal and meridional wind components weaken their effect each other.

3. Local time variation of Te at two longitude zones 210-285 and 285-360 degrees

Figures 3a, 3b, and 3c show local time variation of Te for three seasons for the longitude zone of 210-285 degrees corresponding to Ne shown in Figures 1a,1b, and 1c.

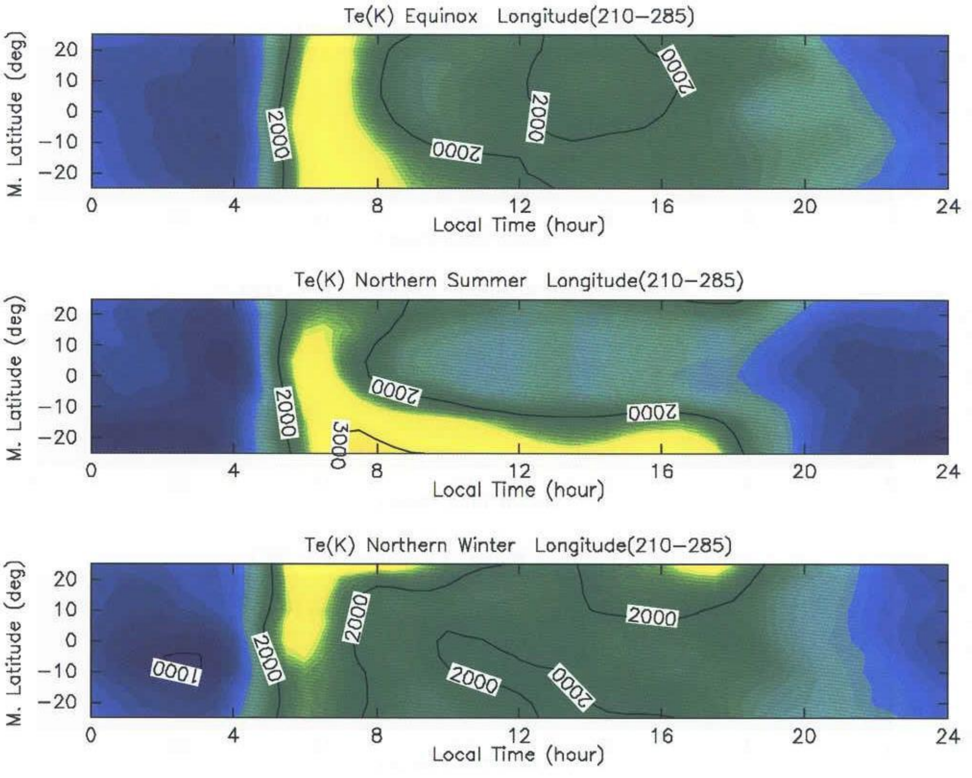

Figure.3 Local time variation of Te for the longitude zone of 210-285;(a) equinox,(b) summer in northern hemisphere, and (c) winter in northern hemisphere

General features of local time variation of Te are as followings. Te shows the lowest value around 4:00 LT, rising steeply, and takes the peak value at about 6 LT (which is, well known "morning overshoot"). After the morning overshoot, Te decreases, and again takes the high value around 16 LT; the peak value increases as we move to the higher latitude (hereafter, we call "afternoon overshoot"). As shown in Figure 3a(equinox), high Te region in the northern hemisphere is smaller than in the southern hemispheres. In the northern summer (Fig. 3b), there is a single peak in northern hemisphere and an extended period (06LT to 18 LT) of high temperature in the southern hemisphere, whereas in the northern winter (Fig. 3c) there appears to be two peaks in the northern hemisphere and only one in the southern hemisphere.

Figures 4a, 4b, and 4c show Te in the same format as for Figure 3 for three seasons but in the longitude zone of 285-360, corresponding to the Ne behaviors which are shown in Figures 2a,2b,and 2c. Although the gross features are same as for the longitude zone of 210 - 285 degrees, a slight, but still geophysically meaningful difference of Te exists between two longitude zones. Te at the morning overshoot as well as afternoon overshoot as typical examples of the difference are summarized in table 2 for two longitude zones and for three seasons. Similar to table 1, boxes which are surrounded by thick line (marked as **at** and **dt** for the morning overshoot and **it** and **ht** for the afternoon overshoot at the end of the boxes) indicates the cases where both meridional and zonal wind components drive plasma to the same direction and consequently two effects is enhanced, while other boxes (marked as **bt, ct ,et,** and **ft** for the morning overshoot and **gt, jt, kt** and **lt** for the afternoon overshoot in the boxes) show the cases where two wind components suppress the effects each other.

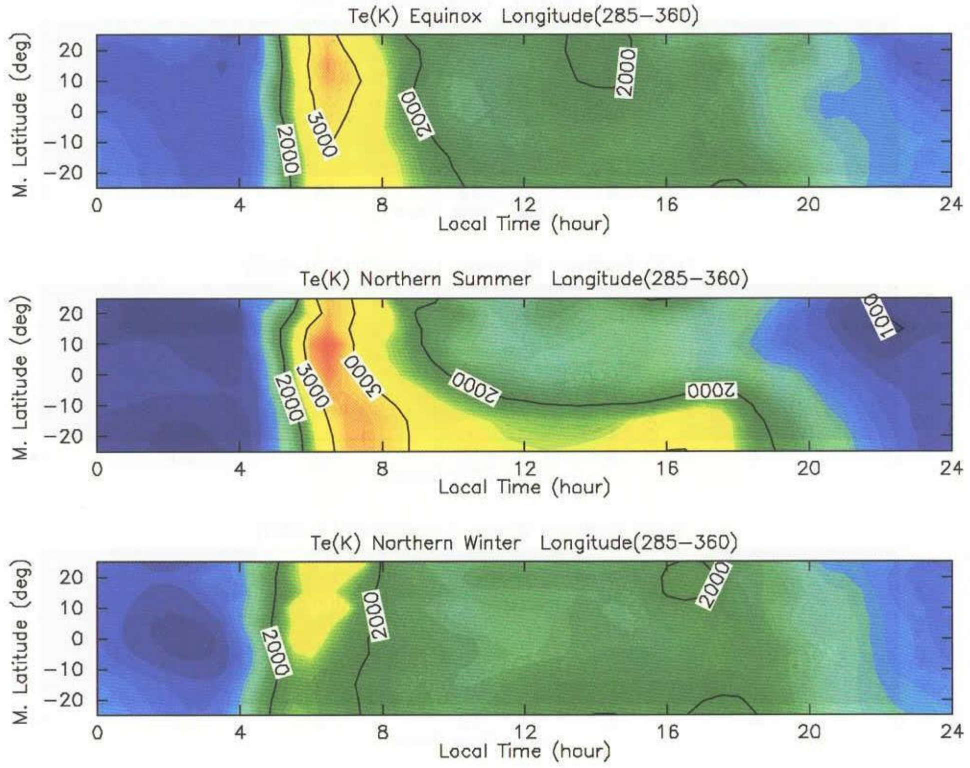

Figure.4 Same as Figure 3 but for the longitude 285-360

Table 2 Te at morning overshoot and afternoon overshoot at two longitude zones. Columns surrounded by thick lines indicate that both zonal and meridional winds drive plasma in the same direction and as a result the effects of two winds is enhanced.

Te (K) at Morning overshoot

	210-285		285-360	
Season	North	South	North	South
M.J.J	2170	3140 at	3250	3300 bt
N.D.J	2960	2320 ct	2950	2290 dt
E.Q.X	2630	2860 et	3200	2900 ft

Te(K) at Afternoon overshoot

	210-285		285-360	
Season	North	South	North	South
M.J.J	2070	2870 gt	2040	3010 ht
N.D.J	2650	2000 it	2050	2040 jt
E.Q.X	2020	1990 kt	1900	2030 lt

4. Effect of neutral wind on Ne / Te

Basic chemical reactions which are working in the topside ionosphere are:

$O^{+}+O_2 \rightarrow O_2^{+}+O$

$O_2^{+}+e \rightarrow O+O \quad k_1 \quad (1)$

$O^{+}+N_2 \rightarrow NO^{+}+N \quad k_2=6.0\times10^{-13}(600/T_i)\ cm^3s^{-1} \quad (2)$

$NO^{+}+e \rightarrow N+O \quad \alpha_1 \quad (3)$

Detail value of α_1 is given by M.Torr and D. Torr (1979) and roughly is expressed as $\alpha_1=(4.3)\times10^{-7}(Te/300)^{-0.83}\ cm^3\ s^{-1}$. The features of Ne which appeared in Figures 1a,1b,and 1c and 2a,2b,and 2c can be well explained by the effects of neutral wind which blows at the height which we are discussing. Major effect is produced by meridional wind component, which generates the difference between two hemispheres depending on seasons ,while zonal wind component produces the difference between two longitude zones. Figure 5 shows schematic picture on the effect of meridional wind components on the plasma motion, (a) winter in northern hemisphere, (b) equinox, and (c) summer in northern hemisphere . In the Figure 5, B is an earth magnetic field. V_M is the horizontal wind component in the wetward tilted magnetic meridian plane. V_{BM} is the velocity component along the geomagnetic line force.

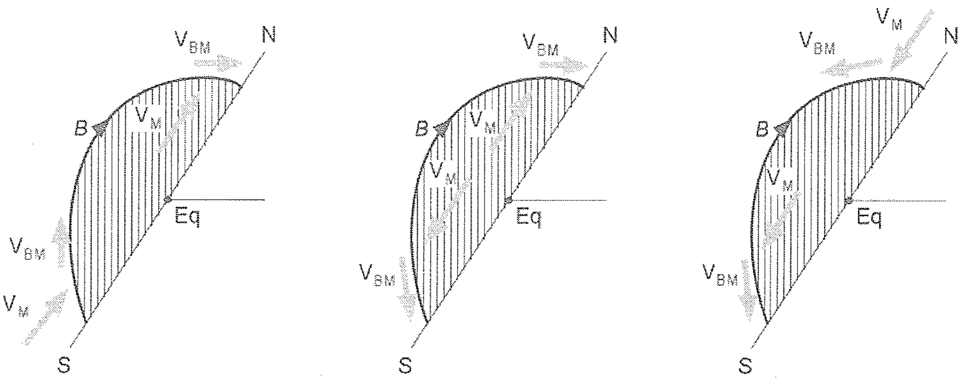

Figure.5 Effect of the meridional wind on the electron density increase /decrease in the topside ionosphere : (a) northern winter,(b) equinox, and(c)northern summer. Arrows indicate the direction of neutral wind V_M and plasma drift V_{BM} along geomagnetic line of force.

In the following we discuss the effect of meridional and zonal winds following the treatment of Hedin et al., (1991) for wind system in 10-30 degrees latitude. For northern summer season when the neutral wind blows from the northern hemisphere to the southern hemisphere as shown in Figure 5a,the ions are pushed up to the high altitude in the northern hemisphere along the magnetic line of force by the force which is generated as a result of the collision between ions and neutral particles. Consequently, recombination of neutral nitrogen reduces and as a result electron density increases because recombination of the reactions (2) and (3) is less. Whilst in the southern hemisphere, ions are pushed down along the geomagnetic line of force, and as the result electron density decreases because the reactions (2) and (3) becomes more effective.

In the northern winter hemisphere, ions are pushed up in the southern hemisphere and pushed down in the northern hemisphere and consequently electron density increases in the southern hemisphere and decreases in the northern hemisphere.

In addition to the meridional wind effect, zonal wind influences on the behaviors of plasma density.

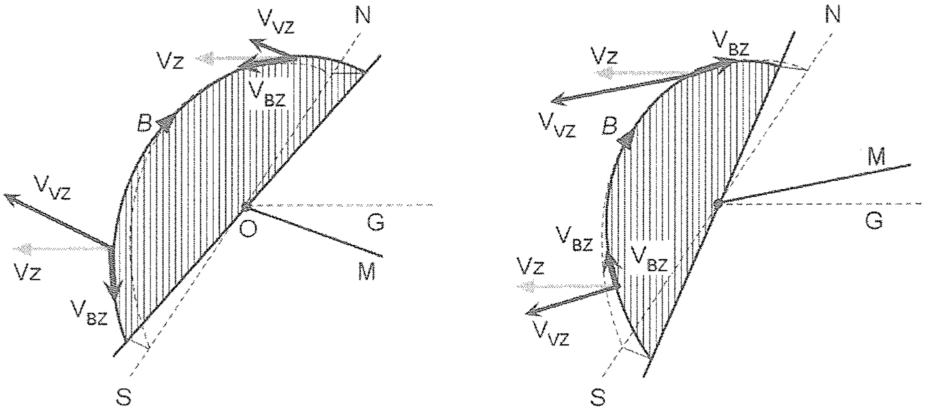

Figure.6 Effect of the declining magnetic meridional plane caused by zonal wind in the morning at two different longitude zones (a) longitude 210-285,and(b) longitude 285-360.

Table 3 Effect of meridional and zonal winds on the Ne at 600 km. ⬆ and ⬇ shows the upward(downward) motions of ions caused by meridioal wind ⇧ and ⇩ show the upward (downward)motion caused by zonal wind .

Morning

	210～285		285～360	
Hemisp. \ Season	North	South	North	South
M.J.J	⬆ ⇧	⬇ ⇩ ad	⬆ ⇩	⬇ ⇧ bd
N.D.J	⬇ ⇧	⬆ ⇩ cd	⬇ ⇩	⬆ ⇧ dd
E.Q.X	⬇ ⇧	⬇ ⇩ ed	⬇ ⇩	⬇ ⇧ fd

Afternoon

	210～285		285～360	
Hemisp. \ Season	North	South	North	South
M.J.J	⬆ ⇩	⬇ ⇧ gd	⬆ ⇧	⬇ ⇩ hd
N.D.J	⬇ ⇩	⬆ ⇧ id	⬇ ⇧	⬆ ⇩ jd
E.Q.X	⬇ ⇩	⬇ ⇧ kd	⬇ ⇧	⬇ ⇩ ld

Figure 6 a and b show the effect of tilting angle of the magnetic meridian plane, where V_Z is the zonal wind velocity, V_{VZ} is the component of zonal wind V_Z, which is vertical to the magnetic meridian plane and V_{BZ} along the magnetic field line, respectively. When the neutral wind blows westward (that is, from east to west) in the early morning in the Asian sector where magnetic meridional plane tilts toward eastward as shown in Figure 6a,ions are pushed up in the northern hemisphere and pushed down in the southern hemisphere. By the same chemical reactions as mentioned for meridional wind component, electron density increases in the northern hemisphere and reduces in the southern hemisphere. When the wind blows eastward(that is ,from west to east), ions are pushed up in the southern hemisphere and pushed down in the northern hemisphere. Consequently electron density increases in the southern hemisphere and reduces in the northern hemisphere.

Magnetic meridional plane tilts toward westward in the latitude range of 285-360. When wind blows westward in the morning as shown in Figure 6b, ions are pushed down in the northern hemisphere and pushed up in the southern hemisphere. Consequently electron density increases in the southern hemisphere and reduces in the northern hemisphere. When the wind blows eastward in the afternoon, electron density changes are just the other way.

In order to summarize the description above, the combined effects of zonal and meridional winds for two different longitude zones is tabulated in Table 3.

The same direction of black and white arrows in the Table 3 indicate that both zonal and meridional winds drive plasma in the same direction and, therefore, enhances the increase of electron density or the decrease, depending on the angle between geomagnetic field and neutral wind direction.

In the morning hours two cases exist, (**ad** and **dd**) of Table 3, where both meridional and zonal winds drive plasma in the same direction. The first one, denoted as ad in the column is northern summer season in the longitude zone of 210-285, where plasma is pushed up in the northern hemisphere and pushed down in the southern hemisphere. As a result plasma density increases in the northern hemisphere and reduces in the southern hemisphere. Therefore it is predicted that difference of Ne between northern hemisphere and southern hemisphere becomes the highest in the morning in May,June and July in 210-285 longitude .

The second case, denoted as **dd** is N.D.J season in the longitude zone of 285-360, where both zonal and meridional winds push the plasma down in the northern hemisphere and push it upward in the southern hemisphere.

For afternoon hours,two cases exist where both zonal and meridional winds drive plasma in the same direction (columns **id** and **hd**) and difference of Ne between both hemispheres should be enhanced. The first case denoted as **id** in the longitude zone of 210-285, where plasma is pushed down in northern hemisphere, and pushed up in the southern hemisphere by both winds. The second case, denoted as **hd** occures in M.J.J season in the longitude zone of 285-360 . The plasma is pushed up in the northern hemisphere and pushed down in the southern hemisphere. In other columns (**bd, cd, ed**, and **fd** for the morning overshoot and **gd ,jd, kd**, and **ld** for the afternoon overshoot), two neutral wind components suppress the effect each other.

5. Solar activity dependence of Te/Ne profile

In order to see the solar activity dependence of Te/Ne, we have grouped Te/Ne data into two solar flux levels, (a) F10.7 flux is less than 200 and (b) when it is larger than 200. As shown in Figures 7 and 8 for Ne and Te, respectively, Te is sensitive even to a slight variation of electron density, which is produced by the difference of solar flux intensity. In Figures 7 and 8, we have plotted the Ne/Te variations for three seasons (M.J.J, N.D.J and E.Q.X) including all longitudes. Two features are seen clearly from these figures. First, the morning overshoot is enhanced over equator for larger solar flux especially for two seasons, N.D.J and M.J.J. During the equinox period, the morning overshoot is less remarkable than other two seasons (Oyama et al., 1996b). The second feature is that the difference between northern and southern hemispheres becomes larger as solar flux increases.

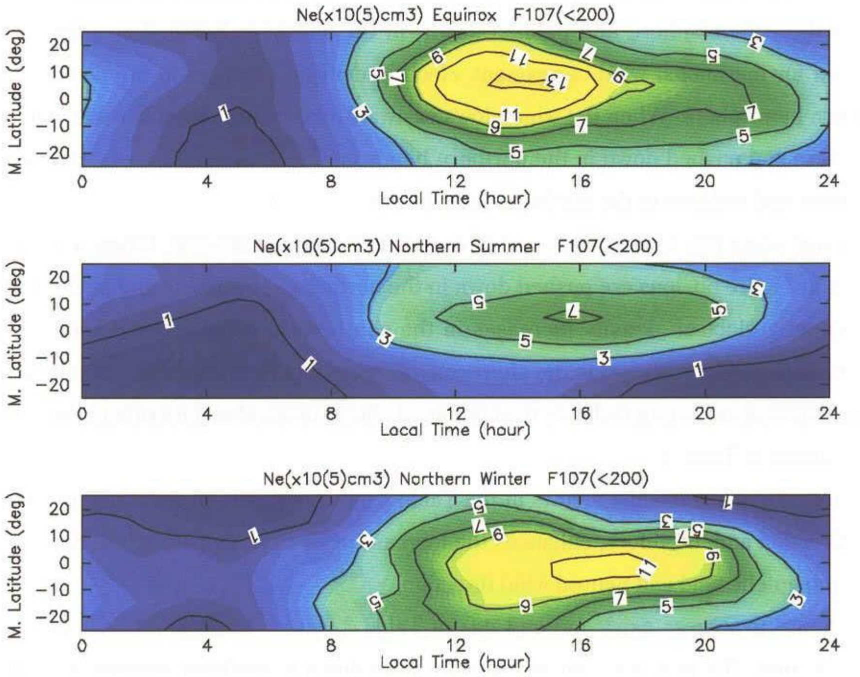

Figure.7(a) Local time variation of Ne for the solar flux , F10.7 smaller than 200 for three seasons: from the top to the bottom of each figures, equinox, northern summer, and northern winter.

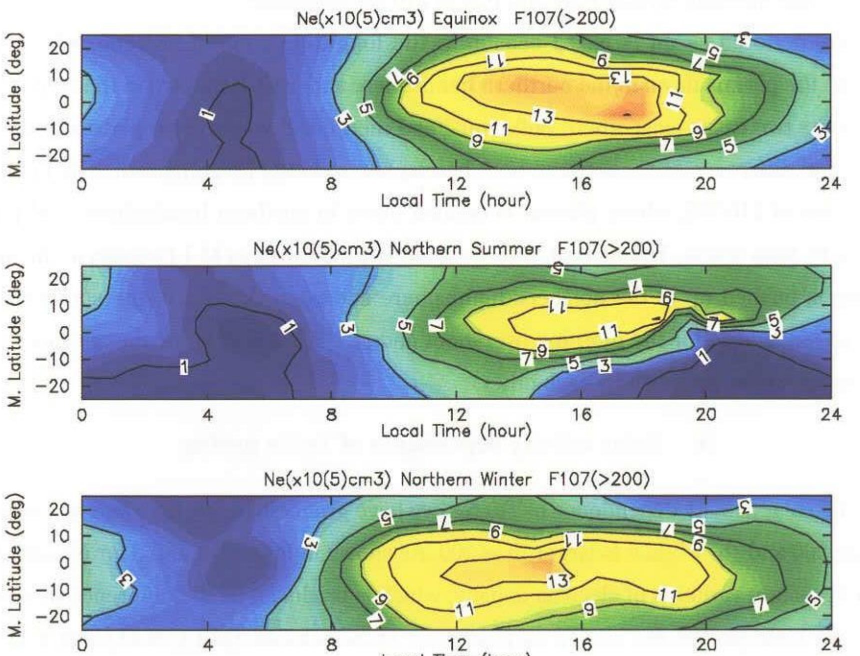

Figure.7(b) The same as Figure 7(a) but for F10.7 larger than 200.

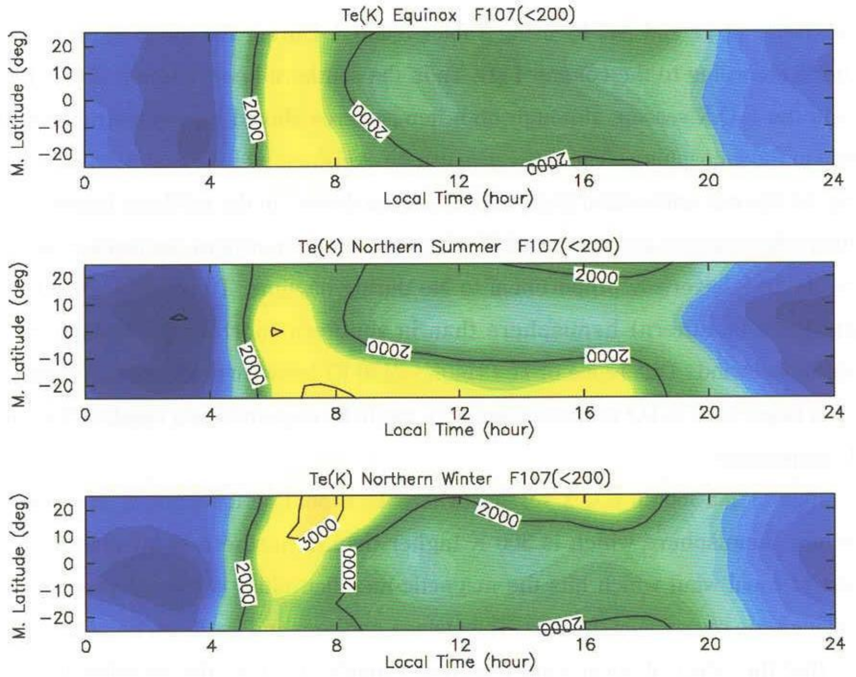

Figure.8(a) Local time variation of Te for F10.7 less than 200 for three seasons:from the top to the bottom of each figures, equinox, northern summer, and northern winter.

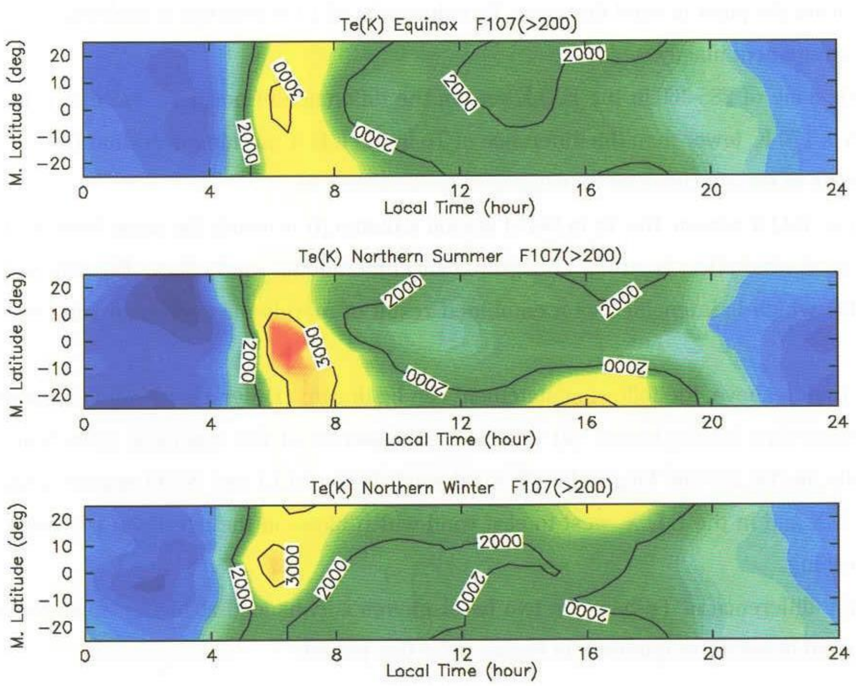

Figure.8(b) The same as Fig.8(a) but for F10.7 larger than 200.

6. Discussion

We discuss the behavior of Te and Ne, by using Tables 2 and 3. During the morning overshoot period, in the longitude zone of 210-285,according to the column (**et**), Te in the southern hemisphere is 230 K higher than in the northern hemisphere in the E.Q.X season, although both hemispheres should be symmetric from the point of the solar energy absorption in the ionosphere. The difference can be explained by the zonal wind, which blows from east to west in the morning. As one can understand from table 3, plasma density in the northern hemisphere increases and decreases in the southern hemisphere and as a result Te decreases in the northern hemisphere and increases in the southern hemisphere, as Te is inversely proportional to Ne during daytime. Te of M.J.J (N.D.J) season which is higher (lower) in northern (southern) hemisphere than in southern (northern) hemisphere is qualitatively understood by the meridional wind. Difference of Te (3140K - 2170 K) between northern and southern hemispheres in M.J.J season, which is larger than N.D.J season(column ct), might be explained as a result of the combined effect of meridional and zonal components.

In the longitude range of 285-360, in E.Q.X season (where Te should be the same if no zonal wind component exist), Te of the northern hemisphere which is 300 K higher than in northern hemisphere (column **ft**) can be explained by the effect of zonal wind which hits the magnetic meridian tilting it toward west as about 10 degrees larger than in 210-285 longitude region. Nearly equal Te between northern and southern hemispheres in M.J.J season (column **bt**) suggests that the effect of zonal wind is strong enough to cancel the meridional wind effect. Large difference of Te between two hemispheres in N.D.J season(column **dt**) is consistent with the enhanced combination of zonal and meridional wind components.

For the afternoon overshoot in the longitude range of 210-285, nearly equal Te between northern and southern hemispheres in the E.Q.X season (column **kt**) suggests that in the afternoon zonal component is smaller than in the morning. In N.D.J season (column **it**) Te in the northern hemisphere is higher than in the southern hemisphere, which is consistent from the point of wind direction. Te behavior in M.J.J season(**gt**) is understood from table 3 as due to meridional wind component mainly.

In the longitude zone of 285-360,in the E.Q.X season the difference of northern /southern hemispheres is 130 K(column **lt**),which is 170 K lower than the difference of Te in the E.Q.X morning overshoot(**ft**) This again suggests that zonal wind is weak in the afternoon as we suggested from column **kt**.

In contrast to the E.Q.X season, the Te in N.D.J season (column **jt**) is nearly the same between two hemispheres, which means that zonal wind effect is strong enough to cancel meridional wind effect. Big difference of Te between two hemispheres(**ht**) which is intensified as a combined result of meridional and zonal wind effects supports the above statement.

From the description above, the following statement can be drawn; (1)meridional wind component produces the Te difference between two hemispheres, (2) effects of declination of the magnetic meridional plane on Te is detectable, especially, in the 285-360 longitude. (3).zonal wind during M.J.J and N.D.J season (column it, and ht) is stronger than in E.Q.X and in the E.Q.X, west to east wind which blows in the afternoon is weaker than the east to west wind in the morning.

The fact that the difference of Te between two hemispheres is enhanced at higher solar activity suggests that meridional neutral wind blows more intensely in higher solar flux period.

7. Conclusions

Diurnal, latitudinal, and longitudinal variations of Te/Ne in the equatorial ionosphere at 600 km during daytime are discussed. Even a small difference of both parameters in two different longitude zones 210-285 and 285-360, where magnetic meridional plane tilts eastward and westward, respectively, are explained by the effect of neutral wind . Especially the effect of zonal wind is almost comparable to the effect of meridional wind in the longitude zone of 285-360. Present study suggests the possibility to calculate thermospheric neutral wind system from the Te/Ne data (Su et al., 1995). The Te data set which was used here are available from NSSDC.

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References

Balan,., K.-I. Oama, G.J. Bailey, S. Fukao,S. Watanabe, and N.A. Abdu, A plasma temperature anomaly in the equatorial ionosphereJ.Geopjhys.Res.,102,7485-7492,
1997.

Brace, L.H., and R.F.Theis, Global empirical models of ionospheric electron temperature in the upper F-region and plasmasphere based on in situ measurements from Atmosphere Explorer C, ISIS-1 and ISIS-2 satellites, J.Atmos. Terr. Phys.**43**, 1317-1343, 1981.

Dabas,R.S.,B.M.Reddy,K.-I.Oyama,Study of anomalous electron temperature variation in the topside ionosphere using HINOTORI satellite, J.Atmos. Terr. Phys., 62, 1351-1359, 2000.

Hedin,A.E., M.A.Biondi, R.G.Burnside, G.Hernandez, R.M.Johnson, T.L.Killeen, C.Mazaudier, J.W.Meriwether, J.E.Salah, R.J.Sica, R.W.Smith, N.W.Spencer, V.B.Wickwar, and T.S.Virdi, Revised Global model of thermosphere winds using satellite and ground - based observations, JK. Geophys. Res. **96**, A5, 7657-7688, 1991.

Hirao, K. and K.- I.Oyama, An improved type of electron temperature probe, J.Geomag Geoelectr., **22**, 239-402, 1970.

Oya, H., T.Takahashi, and S.Watanabe, Observation of low latitude ionosphere by the impedance probe on board the HINOTORI satellite, J.Geomag.Geoelectr., 38, 111-124, 1986.

Oyama, K.-I. and K.Hirao, Electron temperature probe on board Japan's 5 th scientific satellite HINOTORI , Proc. 13th ISTS Symp., 1982.

Oyama K.-I.,and K.Schlegel, Temperature structure of plasma bubbles in the lower latitude ionosphere around 600Km altitude, Planet. Space. Sci., **36**, (6)553-567, 1988.

Oyama, K.-I., Electron Temperature measurements carried out by Japanese scientific satellites, Adv. Space Res., **11**, (10) 149-(10)158,1991.

Oyama,K.-I., S.Watanabe, and H.Oya, Energetics of the plasma bubble, Adv.Space Res., **13**, (1) 293-(1) 297, 1993.

Oyama K.-I., Verification of IRI plasma temperature at great altitude by satellite data Adv. Space Res., **14**,(12)105-(12)113, 1994.

Oyama K.-I., S. Watanabe, and T. Takahashi, Table of electron temperature at 600Km altitude during 1981-1982. First step towards IRI revision, ISAS RN575, 1995.

Oyama K.-I., S.Watanabe, Y.Z.Su, T.Takahashi, and K. Hirao, Season local time, and longitudinal variations of electron temperature at the height of ~600Km in the low latitude region, Adv. Space Res., **18**(6), 269-278, 1996a.

Oyama K.-I., N. Balan, S. Watanabe, T. Takahashi, F. Isoda, G.J. Baily and H. Oya, Morning overshoot of Te enhanced by downward plasma drift in the equatorial topside ionosphere, J. Geomag. Geoelectr., **48**, 959-966, 1996b.

Schlegel,K., K.-I. Oyama,and T.Takahashi, Global morphology of plasma bubbles in the lower ionosphere, AGARD Conference prceedings, No.44, 8/1-8/5, 1989.

Spenner,K., and R.Plugge, Empirical model of global electron temperature distribution between 300 and 700 km based on data from AEROS-A, J.Geophys. **46**, 43-56, 1979.

Su Y.Z.,K.-I.Oyama, and G.J. Bailey, Comparison of satellite electron density and temperature measurements at low latitudes with a plasmasphere-ionosphere model, J. Geophys Res., **100**, 14591-14604, 1995.

Su Y.Z.,K.-I.Oyama, and G.J. Bailey, Longitudinal variation of the topside ionosphere at low latitudes : Satellite measurements and mathematical modellings, J.Geophys Res., **101**,17191-17205,1996a.

Su Y.Z.,K.-I.Oyama, and G.J. Bailey, T.Takahashi, and S.Watanabe, Spatial and temporal variation of the electron temperature at equatorial anomaly latitudes, Adv. Space Res., **18**(6), 83-86, 1996b.

Takahashi T., H. Oya, and S.Watanabe, Ionospheric disturbances induced by substorm associated electric field in the low latitude F region, J.Geomag. Geoelectr., **39**, 187-209, 1987.

Torr.D.G. and M.R.Torr, Chemistry of the thermosphere and ionosphere, J.Atmos. Terr.Phys., **41**, 797-839, 1979 .

Watanabe.S., and H.Oya, Occurrence characteristics of low latitude ionosphere irregularities observed by impedance probe on boad the HINOTORI satellite, J.Geomag. Geoelectr., **38**, 125-150, 1986.

Watanabe S., and K.-I. Oyama, Seasonal and local time dependence of electron temperature, Ann. Geophys., **14**, 290-296, 1996.

Watanabe S., K.-I. Oyama, and M.A .Abdu, A computer simulation of electron and ion densities and temperatures in the equatorial F region and comparison with HINOTORI results, J.Geophys. Res., **100**, 14581-14590, 1995a.

Watanabe S.,and K.-I. Oyama, Dynamic model and observation of the equatorial ionosphere Adv. Space Res. **15**, 109-112, 1995.

Watanabe S., T. Takahashi, H. Oya, and K.-I. Oyama, Table of electron density at 600Km altitude during 1981-1982, First step towards IRI revisions, ISAS, RN579, 1995b.

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