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Variations of electron density and temperature in ionosphere based on the DEMETER ISL data*

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Abstract Observations of the Langmuir Probe Instrument (ISL, Instrument Sonde de Langmuir) onboard the DEMETER satellite during four years from 2006 to 2009 were used to analyze the tempo-spatial variations of electron density (N_e) and temperature (T_e) in the ionosphere. Twenty four research bins with each covering an area with 10° in longitude and 2° in latitude were selected to study the spatial distributions of N_e and T_e. The results indicate that both N_e and T_e have strong annual variations in the topside ionosphere at 660 km altitude. The semiannual anomaly and equinoctial asymmetry which are usually well known as the features of F-layer also exist in the topside ionosphere at low- and mid-latitudes. The yearly variation of N_e is opposite to the peak electron density of the F2-layer (NmF2) at higher latitudes in daytime and both are similar in nighttime. Also the yearly variations of T_e at low-latitude are contrary to that at 600 km in daytime and similar in nighttime. An interesting feature of nighttime T_e at low-latitude is an obvious annual variation in the northern hemisphere and semiannual variation in the southern hemisphere. The yearly variations of T_e in daytime have negative and positive correlation with N_e at mid- and high-latitudes, respectively. Both N_e and T_e in the neighborhood bins at the same latitude have a high correlation. In ionospheric events analyzing, this information may help to understand the characteristics of the variation and to distinguish the reliable abnormality from the normal background map.

Key words: **seasonal variation; annual variation; spatial distribution; N_e; T_e; DEMETER satellite**
CLC number: P315.72 **Document code**: A

1 Introduction

DEMETER satellite is the first satellite, which specially serves to earthquake studying and volcanic monitoring. Its scientific goal is to detect abnormality that might exist in the ionosphere before earthquake occurrence or volcano eruption. At present, studies using the DEMETER satellite data on the anomalous phenomena in the ionosphere relating to earthquakes have been published, including case studies and statistic studies (Parrot et al, 2006; Sarkar et al, 2007; Zhu et al, 2008; Rozhnoi et al, 2008; Nemec et al, 2009; Akhoondzadeh et al, 2010). From these researches, it can be seen that the important work in extracting abnormal information is to know the variation of the ionospheric background.

Now, there are many researches reported on ionosphereic background. Both ground and space data are use (e.g. Zhao et al, 2007; Oliver et al, 2008; Liu et al, 2006, 2007a, b, 2009a, b). These studies show that the variations in ionosphere are extraordinary complicated and many anomalous structures have been explored. And the anomalies defined by the observed values were significantly deviated from the predicted solar zenith angle dependence. The main anomalies type were characterized by Zou et al (2000), including the 'winter or seasonal anomaly' which expresses the daytime values of mid-latitude NmF2 in northern hemisphere are much greater in winter than that in summer, but this anomaly disappears at night; 'semiannual anomaly' which represents the NmF2 at equinox greater than that at solstice; 'annual anomaly or non-seasonal anomaly' which describes the NmF2 (in the whole world) in December is greater than in June during both daytime and night; 'equinoctial asymmetry' which presents the electron density is higher at on equinox than that at the other. These phenomena were detected in the 1930s and most

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were described by the end of the 1950s; for historical details see Rishbeth (1998). Recent researches have shown that variations in ionosphere have a significant altitude dependency (e.g., Chen et al, 2009; Liu et al, 2007a; Balan et al, 2000; Bailey et al, 2000; Su et al, 1998), that is to say, the feature of the ionospheric variation changes with altitude.

As complexity of the ionospheric variation and the unique of measure instrument, though more studies have been done, these results cannot be directly applied to analyzing the data recorded by another instrument. In this paper, we will use N_e and T_e data from Langmuir Probe (ISL, Lebretona et al, 2005) which onboard DEMETER satellite to analyze the ionospheric variation at DEMETER orbit altitude and to provide useful information for the earthquake or volcano abnormality recognizing. At present, the DEMETER satellite has been successfully running for about six years and a large number of observation data have been accumulated. That provided a wealth of data for the background research.

Taking into account that the altitude of the DEMETER satellite orbits has been adjusted to be 660 km from 710 km in December 2005, data from January 1, 2006 to the end of 2009 was used in this paper.

2 Data and preliminary analysis

The French DEMETER satellite was launched on June 29, 2004. It has a nearly circular sun-synchronous orbit (10.30LT in day sector, 22.30LT in night sector). The orbital altitude is about 710 km (adjusted to 660 km at the end of 2005) and the orbital inclination is 98°. The scientific instruments perform measurement between –65° and +65° in geomagnetic latitude (Cussac et al, 2006). The two main parameters measured by ISL are electron density (N_e) and electron temperature (T_e). The accepted accuracy is ±15% for T_e and ±30% for N_e (Lebretona et al, 2005).

The orbital repeat period of DEMETER satellite is about 16 days; that is to say, the satellite will revisit the orbit once every 16 days. The distance between the adjacent orbits is about 2 500 km at low latitudes. To make sure that the research area had observation data everyday, the 20° resolution in longitude is necessary. The DEMETER satellite had a high resolution in latitude. To construct a high resolution background map, we divided the world map into 90×36 bins of 2° (latitude)×10° (longitude). For each bin, we collected all data recorded by ISL in four years and calculated the averages by day. Then we sorted the averages by time. Thus the yearly variation of each bin was established. As limited by the size of bins, two averages can be gained about every three days. Figure 1 gives an example of the yearly variation of N_e and T_e in one bin which is located in near the geomagnetic equator (10°N–12°N, 105°E–115°E). As shown in the Figures 1b and 1c, black lines are 60 days moving average and gray lines indicate the observed data in this bin. The smooth curve can represents well the feature of the variation in this bin. So in the following analysis, only the smooth data were used.

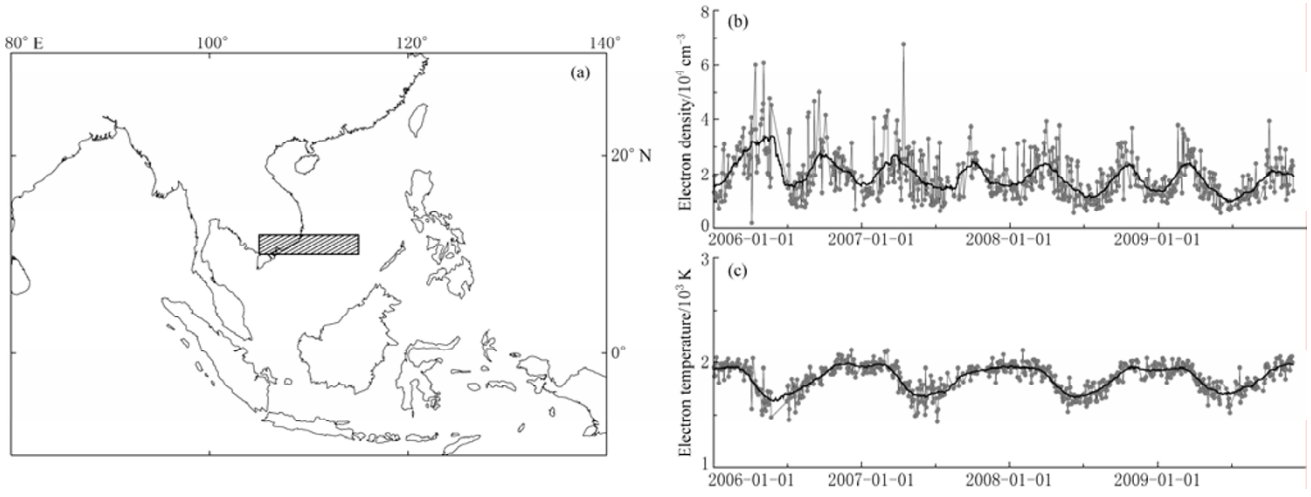


Figure 1 Locations of the research bins and the yearly variations of N_e and T_e. (a) Research area represented by the shaded rectangle; (b) Yearly variation of electron density (N_e); (c) Yearly variation of electron temperature (T_e).

3 Results and discussion

In this paper, five bins distributed in the same latitude and 20 bins which are located in the same longitude were selected for analysis. By comparing the variations in these bins, we hope to explore the characteristics of the tempo-spatial variation of N_e and T_e.

3.1 Spatial distribution along latitude

For low resolution in longitude of the DEMETER satellite, it is difficult to obtain observed data in a small research region. To detect whether the adjacent orbit data can be as a proxy or not when the data is missing or there is no data, five comparable bins, labeled by '*A*' to '*E*' from left to right, respectively, were chosen to analyze the spatial distribution of yearly variation on the same latitude. The yearly variations of N_e and T_e in five bins are all plotted in Figure 2, which made it convenient for us to compare each other and easy to find the characteristic of distribution along latitude.

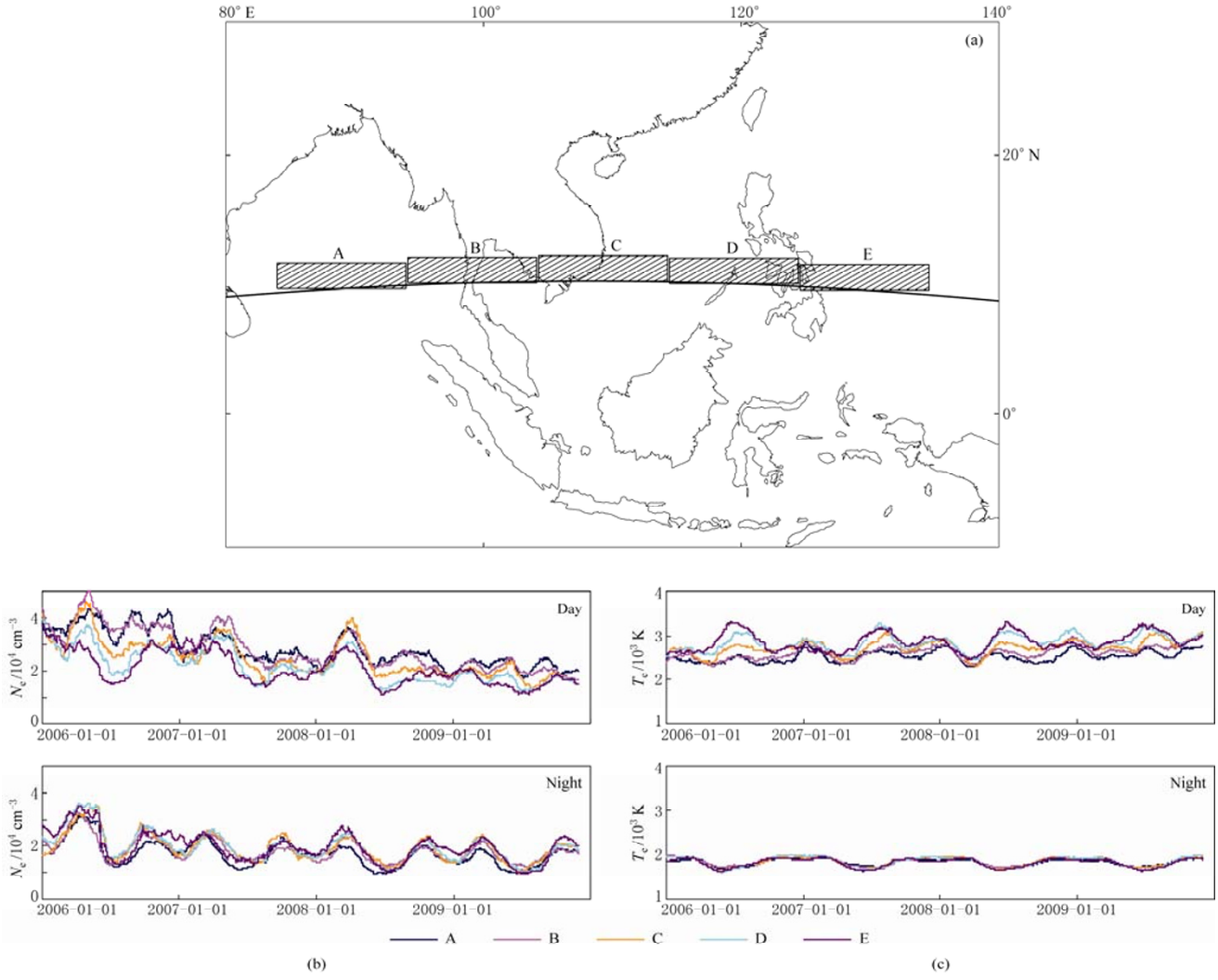


Figure 2 Locations of the five comparable bins and the yearly variations of N_e and T_e. (a) Research area represented by the shaded rectangle and the black line indicates the geomagnetic equator; (b) Yearly variations of electron density; (c) Yearly variations of electron temperature.

Figures 2b and 2c show yearly variations of N_e and T_e in comparable bins. Both yearly variations of N_e and T_e in these areas nearly show the same varying characteristics in nighttime. But they did not agree well with each other in daytime. To analyze the feature along the longitude, we calculate correlation coefficients of the yearly variation between the '*A*' bins and the other four bins. The results are presented in Figure 3. The correla-

tion coefficients of N_e and T_e gradually reduce with the distance increasing at nighttime, but they are still at a high level. While the correlation coefficients decrease rapidly at daytime. The high correlation coefficients between these bins at nighttime indicated that the data in adjacent bins at the same latitude could be used as a proxy. This result is consistent with the conclusion of Zhang's work (Zhang et al, 2008) who found that the adjacent orbit data within 2 000–4 000 km in longitude at the same latitude have a high correlation on the same day. But this result can not apply to the daytime data.

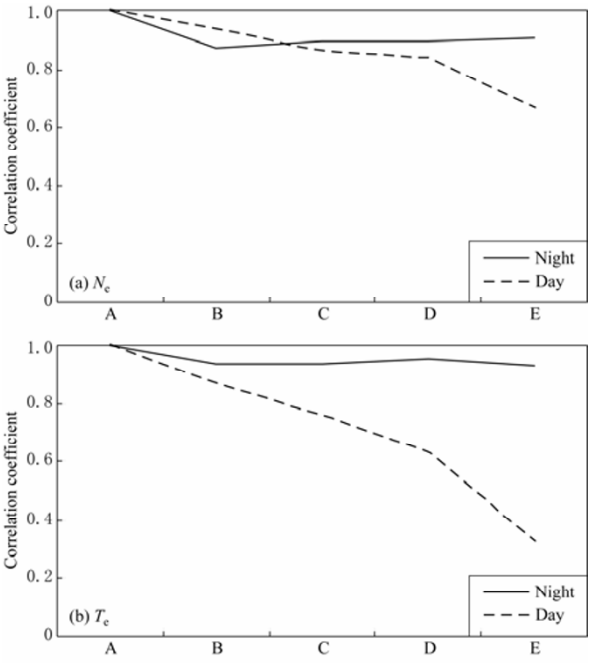


Figure 3 Correlation coefficients of electron density and electron temperature between '*A*' bin and the other four bins.

3.2 Spatial distribution along longitude

To analyze the spatial distributions of N_e and T_e along longitude, 20 bins were selected (see Figure 4). Considering ionosphere is very dynamic at low latitudes, more bins were chosen in equator range than that in mid- and high-latitude. These bins are located in different latitude along the same geomagnetic longitude. The yearly variations of these bins are presented in Figure 5 and they are labeled by geomagnetic latitudes of these bins' center. And the analyzing results are also displayed as follows.

As shown in Figures 5a and 5b, the yearly variations of daytime N_e at mid- and low-latitudes both in northern and southern hemispheres had similar characteristic that they have maxima around the equinoxes and

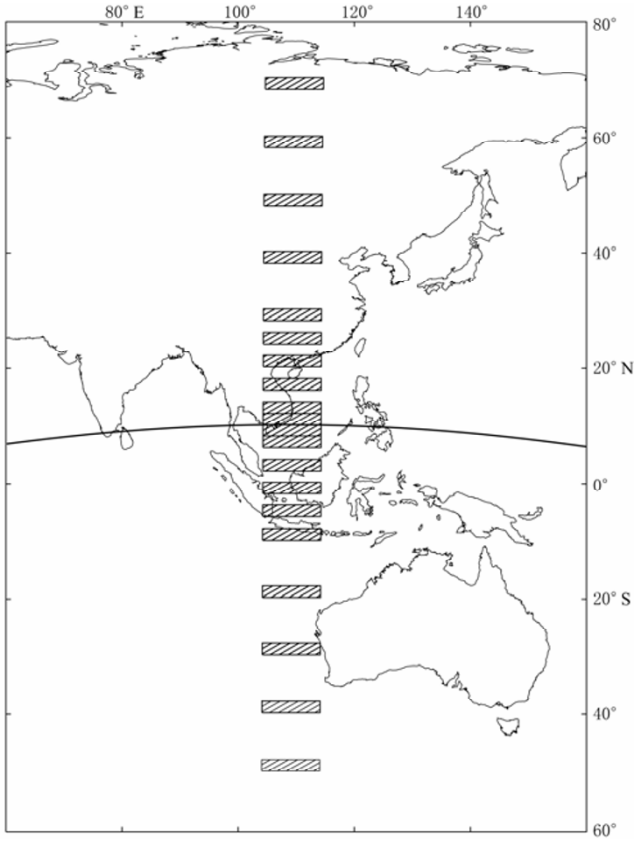


Figure 4 Locations of the selected bins represented by shaded rectangle and the solid line indicates the geomagnetic equator.

minima around the solstices in four years. This feature is the 'semiannual anomaly' which generally exists in the ionospheric F-layer (Torr and Torr, 1973). With the latitude increasing, the daytime N_e in the southern hemisphere rise much more rapidly than that in the northern hemisphere and the peaks of daytime N_e in the northern hemisphere around the March/September equinox begin to shift towards the summer. When it comes to higher latitudes, the two peaks disappeared and were replaced by one peak around July solstice. This is opposite to the NmF2 which has a minimum around July solstice, but the nighttime N_e in both hemispheres is similar to Zou's result (Zou et al, 2000). The 'annual anomaly' is not obviously both in the southern and northern hemispheres. The low solar activity level in the four years might be the main reason because the plasma density in the topside ionosphere is dependent on solar activity level (e.g. Liu et al, 2007a; Bailely et al, 2000; Su et al, 1998). The 'equinoctial asymmetry' also can be seen in low- and mid-latitudes where daytime N_e is higher at March equinox than at September equinox. This is consistent

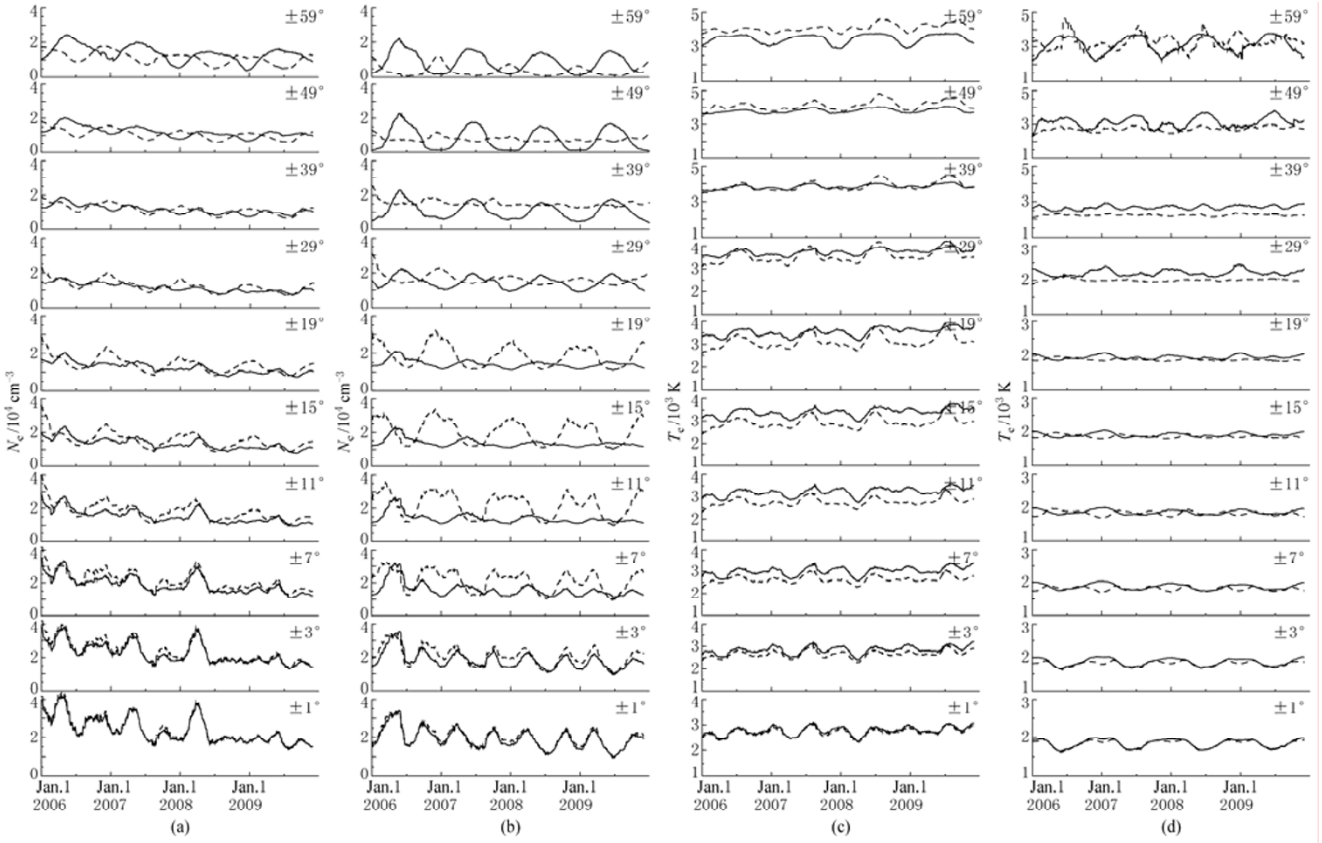


Figure 5 The yearly variation of electron density in daytime (a); The yearly variation of electron density in nighttime (b); The yearly variation of electron temperature in daytime (c); The yearly variation of electron temperature in nighttime (d). The dashed lines represent the variation in southern hemisphere and the solid lines show the variation in northern hemisphere.

with the result at 600 km altitude (Bailey et al, 2000). In the southern hemisphere and greater latitudes, the feature disappears gradually with latitude. The 'equinoctial asymmetry' is obviously distinctions among the four years. It is more significant in 2006 and decrease in the following years. As the averages of F107 in the four years are 80.0, 73.1, 69.0 and 70.6, the distinctions may be controlled by the solar activity (e.g. Liu et al, 2006). The 'semiannual anomaly' and the 'equinoctial asymmetry' also apply to the yearly variations of nighttime N_e in the northern hemisphere. The latitude-dependent nighttime N_e is also corresponding to Suo's conclusion (Suo et al, 1989). Suo et al used nighttime observational data from five ground-based ionosonde stations located in China from south to north, to study the F-layer of the ionosphere.

The variations of T_e are displayed in Figures 5c and 5d. The yearly variations of T_e in daytime have maxima around the solstices and minima around the equinoxes at low latitude. This is contrary to Bailey et al's (2000) conclusion which used the Hinotori satellite data to study the ionospheric variation at 600 km altitude. But the results agree well when the latitude is greater 15° both in southern and northern hemispheres. The yearly variations of nighttime T_e at low latitude have a very interesting feature that the annual component dominates the variation in northern hemisphere (the maxima at December solstice and the minima around the July solstice) and the semiannual component is the basis in southern hemisphere (there are two peaks around the March and September equinox), except two bins on both sides of the geomagnetic equator where the T_e variations are similar. The variation of nighttime T_e between 30° and 40° latitude in southern hemisphere have a special phenomena that the feature of the seasonal and annual variations can hardly be identified. As a result, the yearly variation of daytime T_e has a negative correlation with daytime N_e at mid-latitude, but it has a positive correlation when it comes to high latitude.

To investigate the distribution characteristic of the N_e and T_e in different seasons (Spring: February to April; Summer: May to July; Autumn: August to October;

Winter: November to January), we collect all the data in each bins (there are 65 bins from geomagnetic −65° to geomagnetic 65°) along 181° geomagnetic longitude and calculate the average of them. Then the average of the N_e and T_e as a function of the geomagnetic latitude are constructed, as shown in Figure 6.

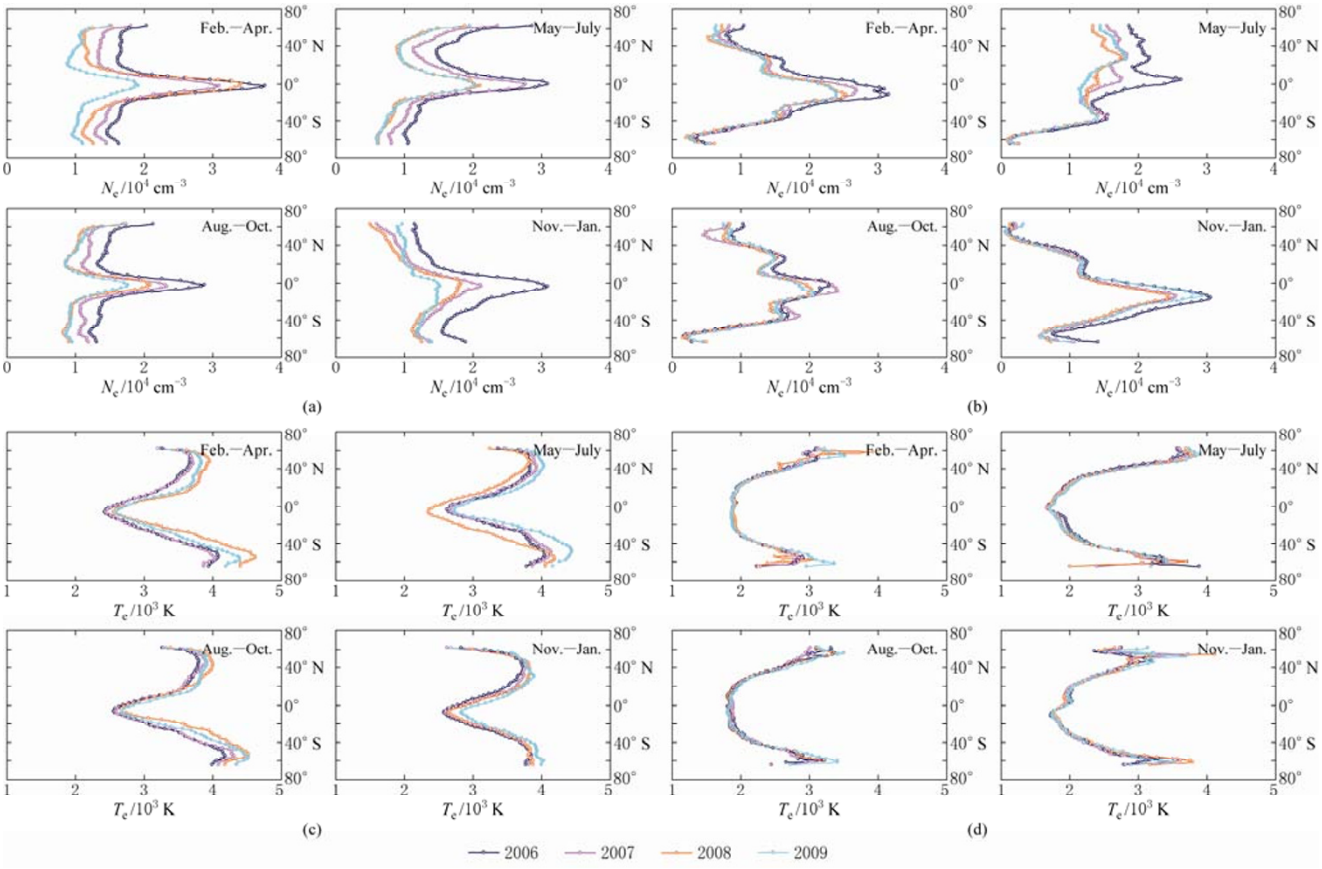


Figure 6 Distribution of N_e and T_e along the same longitude in four seasons. (a) and b) are respectively N_e in daytime and nighttime; (c) and (d) are T_e in daytime and nighttime.

As shown in Figure 6, N_e has one peak centered close to the magnetic equator both in daytime and nighttime. While in nighttime an asymmetrical distribution about the magnetic equator is observed in summer and winter season, and the shift in mid-latitude can be seen in spring and autumn. The daytime T_e has minima around the magnetic equator and maxima at higher mid-latitude. While the nighttime T_e increase with the latitude. The result is consistent with the conclusion of Ouyang et al's (2008) work.

The ionosphere at low latitudes is highly dynamic. Previous works have shown that the equatorial fountain effect causes the well-known EIA structure, which is characterized by two off-equator peaks of plasma density in the NmF2 region (e.g. Bailey et al, 1981). However, only a single peak centered close to the geomagnetic equator is observed at 660 km altitude. Since more factors (including local time, season, altitude, solar activity level, spatial position and the other unknown factors) contribute to the variation of topside ionosphere, it is essential to do more work to make these variations clear.

4 Discussion and conclusions

After carefully analyzed on the yearly variations of N_e and T_e in 24 given research bins, the conclusions are summarized as follows.

1) There are significant seasonal and annual variations in the variations of N_e and T_e.

2) The variations of N_e and T_e in neighboring bins with the same latitude have high correlation.

3) The semiannual anomaly and equinoctial asymmetry exist in the topside ionosphere at low- and mid-latitudes.

4) The yearly variation of N_e in daytime is opposite to NmF2 at higher latitudes, but in nighttime they are similar.

5) The yearly variation of daytime T_e at 660 km altitude is contrary to that at 600 km (Bailey et al, 2000) at low latitude.

6) The nighttime T_e has an obvious annual variation in the northern hemisphere and semiannual variation in the southern hemisphere.

7) The yearly variation of daytime T_e has a negative correlation with daytime N_e at mid-latitude and has a positive correlation with it at high latitudes.

As the variations of the ionosphere are sophisticated, they are subject to diurnal, seasonal, solar cycle, spatial variations and the other unknown factors. To understand and explain these variations, more works are needed to do. The information presented in this paper may help to understand the characteristics of ionospheric variation, to identify and extract the abnormality from the background in events analyzing.

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