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The solar cycle variation of plasma parameters in equatorial and mid latitudinal areas during 2005–2010

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Abstract

Based on the ISL data detected by DEMETER satellite, the solar cycle variation in electron density (Ne) and electron temperature (Te) were studied separately in local daytime 10:30 and nighttime 22:30 during 2005–2010 in the 23rd/24th solar cycles. The semi-annual, annual periods and decreasing trend with the descending solar activity were clearly revealed in Ne. At middle and high latitudes, there exhibited phase shift and even reversed annual variation over Southern and Northern hemisphere, and the annual variation amplitudes were asymmetrical at both hemispheres in local daytime. In local nighttime, the annual variations of Ne at south and north hemispheres were symmetrical at same latitudes, but the annual variation amplitudes at different latitudes differed largely, showing obviously zonal features. As for Te, the phase shift in annual variations was not as apparent as Ne with the increase of latitudes at Southern and Northern hemisphere in local daytime. While in local nighttime the reversed annual variations of Te were shown at low latitudinal areas, not at high latitudes as those in Ne. The correlation study on Ne and Te illustrated that, in local daytime, Ne and Te showed strong negative correlation at equator and low latitudes, but during the solar minimum years the correlation between Ne and Te changed to be positive at 25–30° latitudes in March 2009. The correlation coefficient *R* between Ne and Te also showed semi-annual periodical variations during 2005–2010. While in local nighttime, Ne and Te exhibited relatively weak positive correlation with R being about 0.6 at low latitudes, however no correlation beyond latitudes of 25° was obtained.

Keywords: Electron density; Electron temperature; DEMETER satellite; Solar cycle variation

1. Introduction

Many papers have shown a negative correlation between the electron density (Ne) and electron temperature (Te) during daytime (Bilitza, 1975; Bilitza and Hoegy, 1990; Bailey et al., 2000; Zhang and Holt, 2004). However, a positive or less negative correlation between Ne and Te under certain conditions has been recently reported. For example, Lei et al. (2007) have concluded that the positive correlation between Ne and Te accompanying an increase of solar flux, a positive correlation observed at 850 km in the longitude region between 180 and 270°E during the December solstice (Ren et al., 2008), and a weak one measured by the incoherent scatter radar at Millstone Hill in June (Zhang and Holt, 2004). By using the Hinotori satellite data, Kakinami et al. (2011b) found that when the daytime Ne is significantly high (>10^6 cm^{-3}), the correlation turned to positive irrespective of latitude, longitude, season, solar flux levels and magnetic levels. And the most clear positive correlation was during LT 1100-1500 around the dip equator (|MLat| < 10°).

DEMETER satellite had been operated during 2005–2010, when the 23rd solar cycle was at its descending branch in 2005, to its minimum in 2008–2009, and began to ascending since 2010 into the 24th cycle. It provided a good opportunity to study the temporal variation features of plasma parameters in ionosphere under such low solar

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activities. DEMETER satellite, at the altitude about 660–710 km, was designed as a sun-synchronous orbit, with descending and ascending orbits crossing the equator at LT (local time) 10:30 and 22:30, respectively. The scientific payload of Langmuir Probe was installed on the satellite to detect the in situ electron density (Ne) and electron temperature (Te) (Lebreton et al., 2006). In this paper, the solar-cycle periodical variations in parameters of Ne and Te were analyzed separately at first during 2005–2010, the descending branch of the 23rd solar cycle and the beginning of 24th cycle, and then their relationship in local daytime and nighttime was discussed at the low latitudinal areas.

2. Solar cycle variations of plasma parameters

DEMETER satellite, launched on 29 June 2004, had a circular orbit of a period of 90 min and inclination 98.3°. The orbits covered invariant latitudes within ±65° (Cussac et al., 2006). The altitude at 710 km was adjusted to 660 km in December 2005. Taken account of the totally different variation features in local daytime and nighttime, the plasma parameters were selected separately according to the down-orbits (in local daytime with sub-orbit number 0) and up-orbits (in local nighttime with sub-orbit number 1). As the movement of electrons at these altitudes is controlled by geomagnetic field, the geomagnetic coordinate was used in this paper, so the following latitudes all meant magnetic latitudes.

2.1. Variation characteristics of electron density

2.1.1. Temporal variations of Ne in local daytime

As shown in Fig. 1, the Ne curves were plotted for 6 years during 2005–2010, with the latitude separated by 5°. The Ne curves were exhibited in different colors, with red ones representing those at Southern hemisphere and blue over Northern hemisphere. It can be seen that, the most significant temporal feature in Ne is the annual variation. Another feature is that, the annual amplitude decreased since 2005, to the minimum during June months of 2009, and then increased again in 2010, which was related to the solar cycle. At the equator, the minimum Ne occurred in June months and two Ne peaks in Equinoxes in each year. Around the latitudes of 5°N and 5°S, the curves of Ne almost coincide with each other, which were also similar with that at equator. At the latitudes of 10°N and 10°S, a little phase shift occurred among the peaks and valleys in each year over Southern and Northern hemispheres. At the latitudes of 15–25°, the phase shift became more obvious, and in Southern hemisphere the annual variations were much larger than those at Northern hemisphere. At the latitudes of 30–55°, the annual variations in Northern hemisphere were not so clear as those in Southern hemisphere, and the phase of annual variation was reversed at two hemispheres, with the valley Ne in December solstice in Northern hemisphere corresponding to the peak Ne in Southern hemisphere. This phase shift in yearly variation and asymmetrical features over Northern and Southern hemispheres have also been found in other observations, such as DMSP satellite (Liu et al., 2007), COSMIC radio occultation observation (Zeng et al., 2008), and MU radar (Balan et al., 1997). Liu et al. (2012) found that stronger decrease in Ne was more perceptible in the afternoon hours and at altitudes above hmF2 during 2008–2009 than that in 1996–1997, the preceding solar minima, over Jicamarca (12°S, 283.2°E). The Ne data recorded by CHAMP and GRACE satellites exhibited a decreasing trend during 2005–2009 within a much longer observing time period of 2001–2010. These decreasing phenomena in Ne in the 23rd solar cycle were consistent with the results by DEMETER in this paper.

2.1.2. Temporal variation of Ne in local nighttime

By using the same data processing method, the local nighttime Ne at different latitudes was plotted in Fig. 2. Compared with those in Fig. 1, it could be summarized that, (1) the values of Ne in local nighttime was very close with those in local daytime at different latitudes, except for the latitudes beyond 45° with much smaller Ne than that in local daytime at same latitudes; (2) the amplitude of annual variations in Ne at local nighttime was larger than that in local daytime, especially at the latitudes beyond 45°; (3) the phase of the annual period was reversed beyond the latitude of 15°; (4) the amplitude of annual variations in Northern hemisphere was similar with that at same latitude over Southern hemisphere, so the asymmetrical feature between Southern and Northern Ne disappeared in local nighttime, which was significantly different with that in local daytime.

The similar feature about the Ne curves as shown in Figs. 1 and 2 were the progressive decline in the absolute Ne with increase in latitude at the Southern hemisphere, especially in the June months of each year, which might be consistent with the ionospheric midlatitude trough with large-scale electron density depletion structure in the middle latitude F region (Kersley et al., 1997). According to the research of Lee et al. (2011) in N_mF_2 by COSMIC data during solar minimum, in J-month of 2008, the deep trough formed between 60° and 80°in the Northern and Southern hemispheres during the nighttime period on all altitude slices, and N_mF_2 over Southern trough was much smaller than that over Northern one. In this paper, the Ne was located within ±55° magnetic latitude, which did not reach the mid-latitude trough at both hemispheres, so it could be understandable of the decline Ne with increase latitudes.

A strange phenomenon in Ne by DEMETER was the disappearance of diurnal variation, in which the peak values of Ne were very close to each other in local daytime and nighttime as presented in Figs. 1 and 2. According to the research of Bhuyan et al. (2002) on SROSS-C2 satellite at 500 km altitude, the electron density at LT 10:00 was always larger than that in LT 22:00 with at least an order of magnitude, except for the data around latitude 10°N in June months with bigger Ne in local nighttime. Liu