The asymmetrical features of plasma density during extreme solar minimum in 2008-2009

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Abstract

The variations of plasma density in topside ionosphere during 23rd /24th solar cycle minimum attract more attentions in recently years. In this analysis, we use the data of electron density (Ne) from DEMETER (Detection of Electromagnetic Emissions Transmitted from Earthquake Regions) satellite at the altitude of 660—710 km to investigate the solstitial and equinoctial asymmetry at LT(local time) 1030 and 2230 during 2005—2010, especially in solar minimum years of 2008—2009. The results reveal that □Ne (Dec.—Jun.) is always positive over southern hemisphere and negative over northern part whatever at LT 1030 or 2230, and it becomes smaller with the declining of solar flux from 2005 to 2009. The □Ne between September and March is completely negative during 2005—2008, but in 2009, it turns to be positive at latitudes of 20° S—40° N at LT 1030 and 10° S —20° N at LT 2230. Furthermore, the solstitial and equinoctial asymmetry index (AI) are calculated and studied respectively, which all depends on local time, latitude and longitude. The notable differences occur at higher latitudes in solar minimum year of 2009 with those in 2005—2008. The equinoctial AI at LT 2230 is quite consistent with the variational trend of solar flux with the lowest absolute AI occurring in 2009, the extreme solar minimum, but the solstitial AI exhibites abnormal enhancement during 2008 and 2009 with bigger AI than those in 2005—2007.

1. Introduction

The temporal and spatial variations of the plasma parameters at the peak layer and topside ionosphere have been widely studied for many years from the ground-based and satellite observation, and some anomalous phenomena in ionosphere have been revealed in many researches, such as the annual asymmetry in plasma density between winter and summer, and equinoctial asymmetry between two equinoxes [1-2]. DEMETER satellite had been operated for more than 6 years with a sun-synchronous orbit at the altitude of 660—710 km from June in 2004 to the early Dec. in 2010, which covered the extreme solar minimum in the 23rd /24th solar cycles. From this satellite, topside plasmas were continuously detected by ISL (Instrument Sonde de Langmuir) instruments [3] at LT 1030 and 2230, which provides a good opportunity for studying the asymmetrical features at difference seasons over Southern and Northern Hemispheres in solar minimum.

2. The asymmetrical characteristics in electron density

2.1 The solstitial asymmetry in Ne

In order to reflect the solar cycle variations in asymmetrical feature of Ne, the longitudinal averaged data at different latitudes are calculated in June—July and December—January in next year to represent the two solstices in each year from 2005 to 2009. In order to avoid the effects of geomagnetic storms, days with Kp>=3+ have been removed. The results during 2005-2009 exhibit that, in daytime around LT 1030, the differences □Ne by (December—June) are always positive over Southern Hemisphere and negative over Northern one, and the “winter anomaly” only occurs at magnetic latitude of 0-10° N. Moreover, the amplitude of □Ne is obviously larger at Southern Hemisphere. With the decrease of

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solar flux from 2005 to 2009, the amplitude of □Ne reduced at both hemispheres, which illustrates the reducing of annual asymmetry and the decreasing of solar zenith angle effect on the topside ionosphere during solar minimum. Over Northern Hemisphere, □Ne even approaches to zero at middle latitude of 20° N—45° N during 2008—2009, which means that daytime Ne in winter season is equivalent to that in summer season at middle latitudes in this solar minimum.

In local nighttime around 2230，it is found by the differences between two solstices that, the anti-symmetrical feature in nighttime is more obvious in 2005, with similar amplitude of □Ne at similar latitudes over two hemispheres and almost no winter anomaly occurring. With the decrease of solar flux since then, the amplitude of □Ne reduces too as that at LT 1030, but inter-hemispheric asymmetry becomes apparent with much larger □Ne over Southern Hemisphere around 0—20° S and beyond 40° S. In local nighttime 2230, the latitudinal dependence of □Ne is much complicated, especially over Southern Hemisphere with two typical peaks of □Ne occurring at high latitudes and 10° S and one minimum at 30° S, while □Ne near to -10^4 cm^{-3} beyond 40° N at Northern Hemisphere, even larger than that at LT 1030.

2.2 The equinoctial asymmetry in Ne

The asymmetry between the March equinox (with data in March and April) and September equinox (with data in September and October) in local daytime of 1030 is also studied. It can be found that, at the descending branch of solar activity in 2005—2008, the September equinoctial Ne is always smaller than that the March one almost globally, while the amplitude of △Ne reduces gradually. In the solar minimum of 2009, the September equinoctial Ne exceeds the March one over most latitudes firstly. And then when the solar flux begins to increase in 2010, September equinoctial Ne becomes small again at -20—40° N, but still maintains larger value at other latitudes.

In local nighttime around 2230, the analysis on Ne in two equinoxes reveals that, at the descending branch of solar activity since 2005 to 2008, the Fall equinoctial Ne is approximate to the Spring one over Southern Hemisphere, but obviously smaller at low latitudes over Northern Hemisphere. It is interesting that the smallest △Ne occurs in 2007, not in 2008, at the minimum position of 10°S —20°N. In the solar minimum of 2009, the shape of △Ne curve varies a lot, with big positive differences appearing at Southern Hemisphere of 20°S —0°N. And then in the ascending branch of solar cycle of 2010, the positive difference enlarges over Southern Hemisphere, and also the negative difference over Northern Hemisphere reoccurs, which illustrates that Ne increases much quickly in September equinox over Southern Hemisphere with the enhancement of solar activity.

2.3 Asymmetry index in solstices

To give a quantitative description of the annual asymmetry, the asymmetry index (AI) is calculated by $AI = \frac{(Ne_i^N + Ne_i^S)_{December} - (Ne_i^N + Ne_i^S)_{June}}{(Ne_i^N + Ne_i^S)_{December} + (Ne_i^N + Ne_i^S)_{June}}$ from *Mendillo et al.* [4], in which *N* and *S* represent Ne at Northern and Southern Hemisphere, and *i* is the same geomagnetic latitude at both hemispheres.

The results show that, solstitial AI at LT 1030 reduces with the latitude from about 0.3 near the equator to 0.05 at high latitude in 2005. And in 2006, AI decreases from 0.15 near equator to 0.05, and even to 0.01 in 2007 at high latitudes, being the minimum. In 2008, the solar minimum year, AI becomes wholly larger than that in 2007 almost at all latitudes, and in 2009, AI presents peak values at latitude around 50°N. So the daytime solstitial AI is totally different in the descending solar branch of 2005-2007 with those in low solar activity in 2008 and 2009. The similar feature in these 5 years is that AI values are all larger than 0, which illustrates that the global December solstitial Ne is substantially larger than the June one in local daytime. Compared with Figure 2, it can be found that the highest Ne in Dec. over Southern Hemisphere has a decisive impact on the positive values of solstitial AI.

The solstitial AI in local nighttime around 2230 is the smallest with most values less than 0.08 in 2005, significantly different with that in daytime. During 2006—2009, the shapes of nighttime AI are similar, presenting bigger values at latitudes less than 10°, which means that nighttime Ne is enhanced around December solstice at equatorial areas. And also at latitude beyond 55°, AI becomes bigger with the decrease of solar flux, so the high latitudinal AI reverses with the solar activity. In local nighttime, AI exhibits the minimum at latitudes of 30—50°，showing the well interhemispheric symmetry feature of Ne at two solstices around LT 2230.

2.4. Equinoctial asymmetry index

With the same consideration, the asymmetry index (AI) is calculated by

$$AI = \frac{(Ne_i^N + Ne_i^S)_{September} - (Ne_i^N + Ne_i^S)_{March}}{(Ne_i^N + Ne_i^S)_{September} + (Ne_i^N + Ne_i^S)_{March}}$$

in equinoxes since 2005 to 2010 at LT 10:30 and 22:30 respectively. Compared with the results in solstitial AI, it can be found that equinoctial AI values at LT 1030 are all less than 0 since 2005 to the solar minimum 2008, which is opposite to the solstitial AI values. And the global Ne in March is generally larger than that in September during 2005-2008. In 2009, daytime AI becomes larger than 0 totally, while nighttime equinoctial AI is also bigger than 0 at low latitudes of less than 20°. In 2010, the ascending year of solar activity, daytime and nighttime equinoctial AI are opposite to each other, with daytime AI less than 0 while nighttime AI larger than 0 at low latitudes, and daytime AI bigger than 0 while nighttime AI smaller than 0 at middle and high latitudes. The results illustrates that September equinoctial Ne is always smaller than the March one during the `solar descending segment whatever in local daytime or nighttime, but during solar minimum and ascending solar years, nighttime total Ne in September equinox becomes larger than that in March equinox at low latitudes, and daytime total Ne in September equinox continued to be enhanced at middle and high latitudes.

2.5 Longitude effects of the asymmetry index of Ne in solar minimum

To study the longitudinal effects on the solstitial and equinoctial asymmetry, the data over four longitude sectors are averaged at 30°E, 120°E, 210°E and 285°E with a bandwidth ±27°and the corresponding AI is calculated. Figure 1 exhibits the latitudinal variations in these four longitude sectors of AI at LT 1030 and 2230 in 2009. It can be seen that

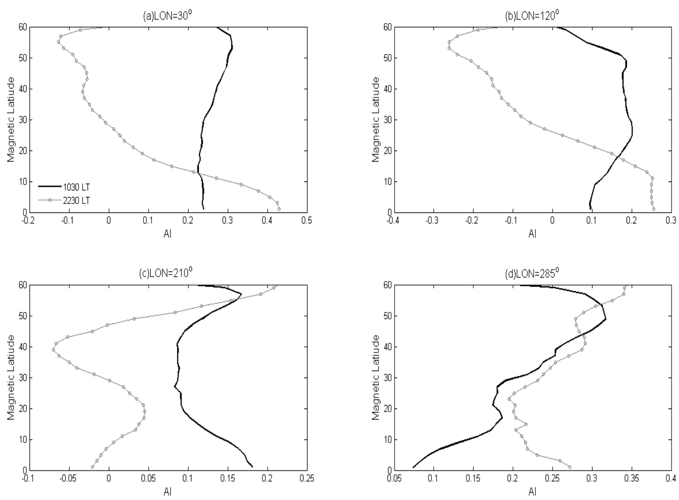

Figure 1. The latitudinal curves of solstitial AI of Ne in the four longitude zones of (a) 30° ±27° , (b) 120° ±27° , (c) 210° ±27° , and (d) 285° ±27° at LT 1030 and 2230 in solar minimum year of 2009

the longitude effects of AI are very intensive. In local daytime all solstitial AIs are larger than 0, but the distribution of AI at 120°E is reverse to that at 210°E at 20-50°latitudes, and AI at 280°E exhibits the biggest latitudinal variation amplitude from 0.07-0.3. In local nighttime, the solstitial AI curves change significantly, especially at 210°E and 285°E with most latitudinal AI values being positive. Compared with the Ni results at same four longitude sectors in 2002[5], big differences exist at 210°E in nighttime and at 285°E both in daytime and nighttime, which illustrates the difference of longitude effects in plasma density in solar maximum and minimum.

3. Conclusion

In this paper, the asymmetrical features in electron density at LT 1030 and 2230 have been analyzed in two solstices and equinoxes respectively during 2005—2010 from DEMETER at the altitude of 660—710 km, especially in solar minimum years of 2008—2009. In summary, it can be concluded as follows: (1) The December Ne is always larger than the June one over Southern Hemisphere while most northern Ne is bigger in June solstice than in December during 2005—2009 at LT 1030 and 2230; "Winter anomaly" only occurs at 0-10° N magnetic latitude with Ne in Dec. larger than that in Jun.; (2) Solstitial □Ne reduces over both hemispheres with the declining solar flux since 2005 to 2009, especially at the northern part, but the inter-hemispheric difference of .□Ne becomes more apparent during solar minimum; (3) The September Ne is globally lower than the March one during 2005—2008, however in 2009, it reverses at latitudes of 20° S —40° N in daytime and 10° S —20° N in nighttime; (4) Both solstitial and equinoctial AI depend on local time, latitude and longitude and the latitudinal AI curves over four longitude bands are different obviously in the solar minimum year.

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