Hemispheric and Annual asymmetry of Nmf2 observed by FORMOSAT-3/COSMIC Radio Occultation observations

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ABSTRACT

Introduction

Globally, the hemispheric averaged NmF2 values in December solstice are significantly higher than those at June solstice at all longitudes. This is known as F_2 - layer annual asymmetry. This phenomenon was observed and reported several decades ago but the possible mechanisms are not yet clearly understood. Four types of anomalies, equatorial ionization anomaly, winter or seasonal anomaly, semiannual anomaly and annual anomaly or annual asymmetry, are often found in the F2 layer. Apart from the above four anomalies, recently Liu et al. (2009) and Chen et al. (2010) reported two different anomalies. Those are Weddell Sea Anomaly (WSA) and Mid-latitude summer night-time anomaly (MSNA). All the above anomalies are well understood except annual anomaly. Few studies on annual asymmetry can be found in the literature [Yonezawa, 1971; Su et al., 1998; Rishbeth and Muller-Wodarg, 2006; Mendillo et al., 2005, Liu et al., 2007, Zhen Zeng et al., 2008]. All the above studies show that the asymmetry has significant local time, longitudinal and solar cycle variations. One possible mechanism is the varying sun-earth distance (about 0.983 AU for December and 1.017 AU for June). But varying Sun – Earth distance can explain only 25% of the total observed asymmetry. Lei et al. (2013) found similar asymmetry in thermospheric neutral density and they attributed this to the varying Sun – Earth distance. But, ionospheric behavior is different from the thermosphere because of its complex electrodynamics and transport processes involved. Zeng et al. [2008] found significant longitudinal variations in the asymmetry values. Their case controlled simulation indicate that the solstice difference of Sun-Earth distance, offset between geomagnetic and geographic center and the tilt of geomagnetic pole will play important role on the annual asymmetry, however, the detailed physical mechanisms of how the geomagnetic configurations effects the annual asymmetry were still unexplained. There were no detailed studies on effects of thermospheric neutral winds on the annual asymmetry. Hence, the main objective of this paper is to study the local time, longitudinal and solar activity variations of annual asymmetry and its responsible neutral and electrodynamic mechanisms.

Data and Results

FORMOSAT – 3/ COSMIC is a constellation of 6 satellites, primarily dedicated to GPS radio occultation experiment to study the Earth’s atmosphere and ionosphere. To study the annual asymmetry, we used NmF2 data from the vertical electron density profiles provided by UCAR (http://www.cosmic.cdar.edu). A 41-day period that centered on June 21 and December 21 is used to represent the complete solstice of June and December, respectively, from 2008 to 2012. Solstice differences of 41-day mean F10.7 values from 2008 to 2012 are -0.9405, 3.6317, 6.6449, 39.4982 and -22.897 respectively (+ve means December is more). In order quantify the annual asymmetry, the asymmetry index suggested by Rishbeth et al. (2006) by averaging the corresponding summer and winter hemispheric NmF2 values is computed using equation-1. Figure 1 shows the local time and latitudinal variation of the zonally averaged NmF2 and asymmetry index. During the solstices, EIA crest in the winter hemisphere is stronger than the summer hemisphere during the morning to noon. However, around noon to early afternoon hours, the EIA crest in summer hemisphere become stronger than the winter EIA crests and higher electron density in summer hemisphere is maintained throughout the afternoon to midnight.

$$AI = \frac{\text{NmF2Dec}(\text{N}+\text{S})_{avg} - \text{NmF2Jun}(\text{N}+\text{S})_{avg}}{\text{NmF2Dec}(\text{N}+\text{S})_{avg} + \text{NmF2Jun}(\text{N}+\text{S})_{avg}} \quad \ldots\ldots (1)$$

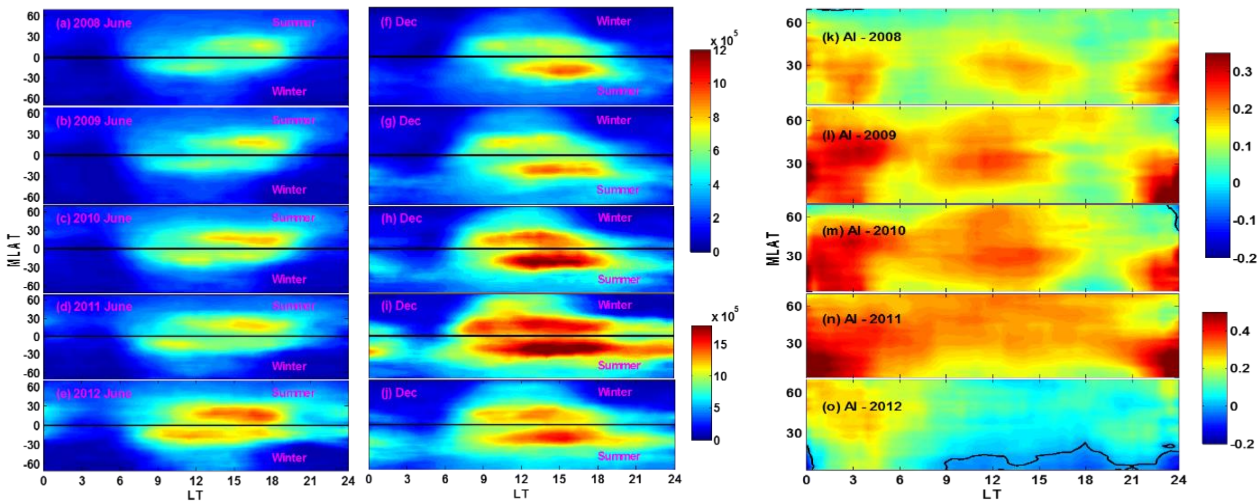

Fig 1: Local time and latitudinal variations of the zonally averages NmF2 during June and December solstices (left and middle panels) and the Asymmetry Index (AI) (right panel) from 2008 to 2012. Solid black lines in right panels indicate the contour line corresponding to zero AI.

This distinct hemispheric behavior is consistently observed throughout the ascending phase of solar cycle 24, indicating that this feature is independent of solar flux changes. Coming to the asymmetry index, the overall positive AI values indicate that the global Nmf2 values are significantly higher during December solstice than in June solstice, confirms the existence of annual anomaly throughout the ascending phase of solar cycle 24. The local time variation of AI from Figure 1 indicates that the annual asymmetry is significantly enhanced during noon and midnight with two distinct peaks, one around $20^0 – 50^0$ MLAT during noon and another stronger midnight peak at low-latitudes during the years 2008 to 2010. In the year 2011, AI values are substantially larger, which could be due to larger F10.7 in December-2011 than in June-2011. During the year 2012, though the overall asymmetry is positive (December is larger than June) the AI values are significantly smaller than the years 2008 – 2011. This decrease in AI can be attributed to the decrease in F10.7 flux values from June 2012 (134.8 sfu) to Dec 2012 (111.9 sfu). With a view to examine the detailed latitudinal and longitudinal distributions of the observed noon and midnight enhancements in the annual asymmetry, we estimated the solstice difference (Dec - Jun) of NmF2 values (ΔNmF2 = NmF2_dec – NmF2_june) during noon and mid-night. Figure 2 shows the longitudinal and latitudinal variation of ΔNmF2 values during noon and mid-night. The large positive values of ΔNmF2 at noon time indicate that the overall ionization in December is significantly larger than in June solstice throughout the globe with a major part of noon-time asymmetry comes from EIA crest regions due to inter-solstice differences in the EIA crests. Further, one can observe the high values of ΔNmF2 at south Atlantic (~-60^0 to 0^0), Pacific (~-120^0 to -60^0) and European-Asian (~0^0 to 120^0) longitudes. This observed longitudinal and local time variations in the annual asymmetry will be discussed through the geomagnetic field configuration, inter-hemispheric neutral winds, longitudinal variability of vertical ExB drifts and Weddle sea anomaly using detailed model simulations.

Conclusion

A detailed investigation is carried out by using a long term data set of COSMIC GPS-RO during 2008 – 2012 to understand the physical mechanism of annual asymmetry. The complex physical processes that involved in the Annual asymmetry of NmF2 were discussed through detailed analysis of observations and model simulations. This study makes a decent attempt to explain the possible interlink between thermospheric neutral winds and the complex electrodynamics to explain the local time and longitudinal variability of annual asymmetry.

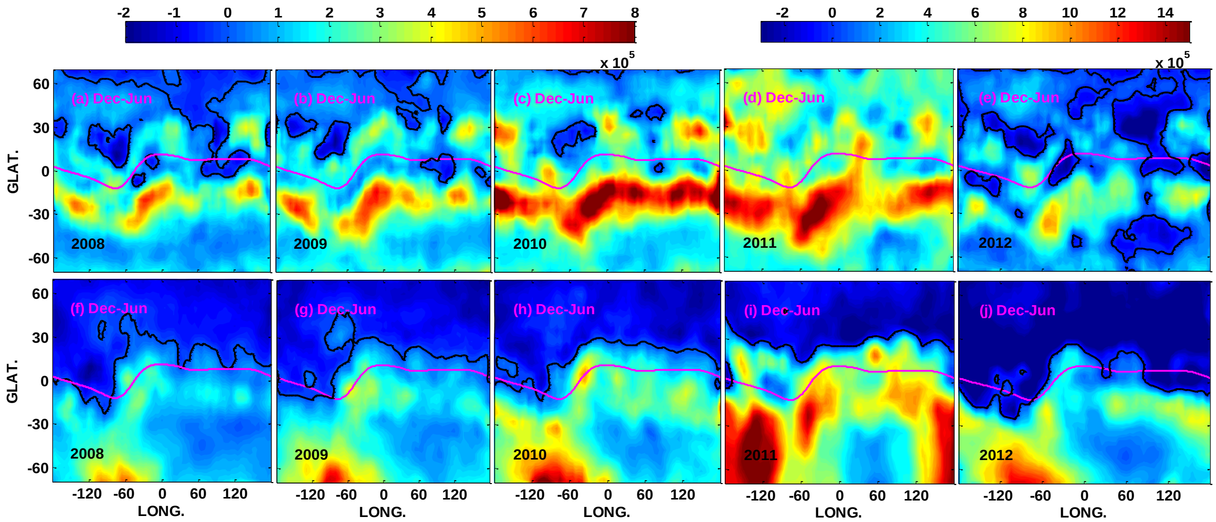

Fig2: Longitudinal and Latitudinal variation of the solstice difference (Dec - Jun) of Nmf2 during noon (a-e) and mid-night (f-g) from 2008 to 2012 (Zero contour line is represented by black solid line)

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