WN4 Variability in the Topside Ionosphere

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Introduction

WN4

A wave-number 4 oscillation (WN4) along the magnetic equator has been observed in several parameters including total electron content (TEC), zonal winds, [O]/[N_2] ratio, distribution of NO, the equatorial electrojet current density, and ion density. A WN4 pattern has four peaks equally spaced in longitude when viewed in a constant local time frame.

Bankov et al. [2009] compared F13, F15, and DEMETER ionospheric measurements during fall equinox 2004, at local times near 5:45 (F13), 9:30 (F15), 10:30 (DEMETER), 17:45 (F13), 21:30 (F15), and 22:30 (DEMETER.) They found that WN4 was almost a regular feature in O + at the local times examined, as well as in H+ in evening through pre-midnight hours and in He+ in the morning. Hartman and Heelis [2007] considered ion drift measurements made by F15 in 2001 and 2002 near 9:30 LT. They attributed a seasonally-dependent longitude variation to hemispheric differences in the dynamo current due to the different orientation of magnetic meridians to the day-night terminator. They also saw a WN4 pattern present throughout the year, but especially apparent during equinox. Pedetella et al. [2011] looked at seasonal and local time variations in daytime TEC measurements from COSMIC and GIP-TIEGCM simulations, to examine the effects of non-migrating tides (WN4.) They found that the WN4 pattern based on GIP-TIEGCM simulation was strongest at 8-14 LT, and that the phase of DE3 changes 90° in longitude per 24 hours local time. Tidal signatures at low latitudes near 600 km have been observed by ROCSAT-1 in ion densities [Kil et al., 2008] and ExB drift [Kil et al., 2007; Ren et al., 2009; Fejer et al., 2008].

DE3

There is strong evidence that WN4 patterns in the ionosphere/thermosphere are associated with the DE3 non-migrating tide which originates in the lower atmosphere. DE3 stands for the diurnal (24-hour period) component of an eastward propagating tide with zonal wave number 3. Non-migrating tides do not follow the apparent motion of the Sun. DE3 has three peaks equally spaced in longitude when viewed in a fixed-universal time frame. DE3 is thought to be generated by latent heat release of evaporation during cloud formation [Hagan and Forbes, 2002], as the atmosphere responds to periodic absorption of solar radiation.

Immel et al. [2006] proposed a physical mechanism for the propagation of DE3 into the F-region based on the ExB drift. They suggested that **upward-propagating tides modulate the dynamo electric fields in the E-layer, which determine the ExB drift of plasma lifted up into the F-region.** This effect would be maximized at equinox, when the meridional component of E-region neutral winds at low latitudes is not dominated by inter-hemispheric flows. Jin et al. [2008] simulated DE3 effects on the longitudinal structure of F-region zonal electric fields, in order to investigate how this tide might modify the vertical ExB drift. They noted that under a realistic geomagnetic field configuration, longitude sectors with large declination angles would show a larger hemispheric difference in the phase of DE3.

There is some evidence for additional coupling mechanisms. Winds associated with non- migrating tides at F-region altitudes can push plasma along field lines and modify the F-region dynamo [England et al., 2010, Park et al., 2010.] Non-migrating tides have also been shown to modify the [O]/[N_2] ratio, which affects the concentration of O^+ since an increase in [O] allows more production of O^+ at a given altitude, and decreases in [N_2] increase the lifetime of O^+ [Zhang et al., 2010.]

Although many migrating and non-migrating tides are produced at lower altitudes and propagate upward, **DE3 has a particularly significant impact on higher altitudes because it has a large amplitude, and because it propagates upward very efficiently.** The efficient propagation of DE3 is due to its long vertical wavelength, which is possible because its origin in convective clouds extends throughout the troposphere [Williams and Avery, 1996]. Hagan and Forbes [2002, 2003] found that DE3 and SW6 are the largest amplitude non-migrating tides that should reach the upper mesosphere/lower thermosphere using the Global Scale Wave Model (GSWM). They also showed that the DE3 tide would be very effective at modifying the E-region dynamo because the DE3 wavelength is large compared to the Hall conductivity layer and has a symmetric latitudinal structure. **As tides propagate upward and the atmospheric density decreases, they are expected to increase in amplitude [Williams and Avery, 1996].**

Data

The **DMSP satellites orbit at ~800 km** above the Earth, well above the peak electron density (above the F peak.) They fly in sun-synchronous orbits, i.e. at a nearly constant local time (LT). Total ion density was obtained from the scintillation meter, and fractional O^+ from the retarding potential analyzer (RPA).

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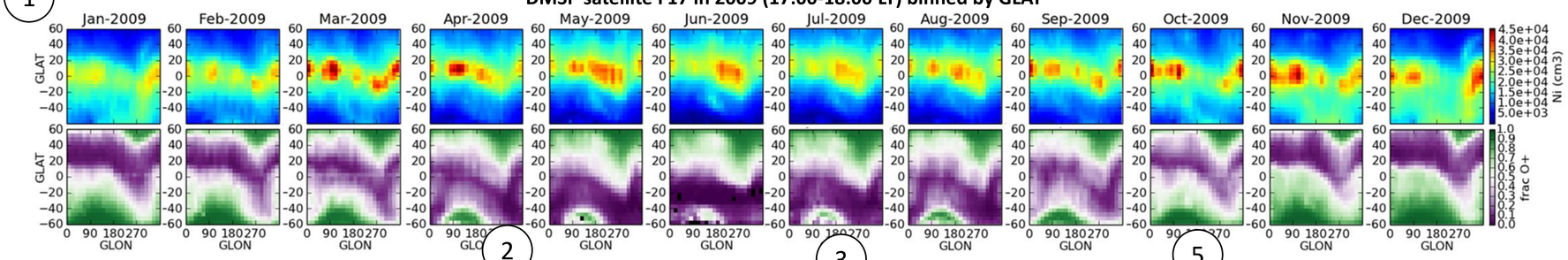
Results

Seasonal Variations

DMSP satellite F17 in 2009 (17:00-18:00 LT) binned by GLAT

1



(1) Monthly averages of total ion density (Ni) and fractional O^+, filtered for low geomagnetic activity (Kp<3) and binned by geographic latitude and longitude, showing the general shape of WN4 over a whole year, at solar minimum and a near-constant local time.

(2) Monthly averages of Ni measured by DMSP satellite F17 at 17:00-18:00 LT, binned by magnetic latitude and geographic longitude and averaged over March, June, September, and December months.

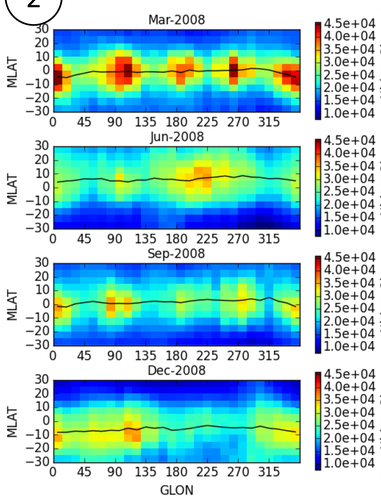
(3) 90-degree running medians of the data in (2) to emphasize longitudinal effects separate from WN4.

A line approximating the center of the WN4 structure, as a function of geographic longitude (GLON), was computed using the equation:

$$Center\ MLAT_i = \frac{\sum_{-30}^{+30}({N_{ij}}^3 \times j)}{\sum_{-30}^{+30}({N_{ij}}^3)}$$

where i is an index over GLON, j is an index over MLAT from -30 to +30, and N_{ij} is total ion density at i,j. This is similar to the general equation for a centroid, but weighted by N^2.

2



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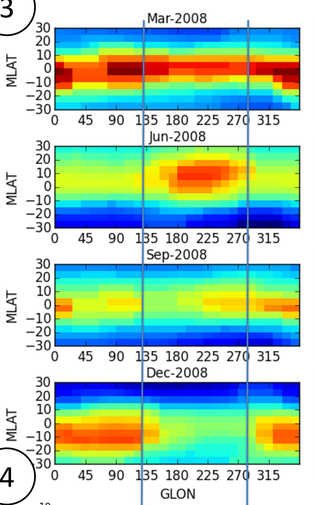

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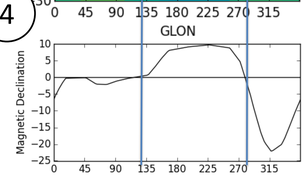
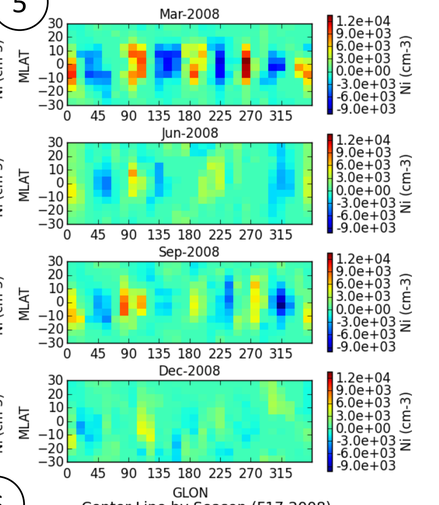


(4) Magnetic declination along the magnetic equator. Ni in June shows an increase in regions of positive declination; Ni in December shows a decrease in this same region.

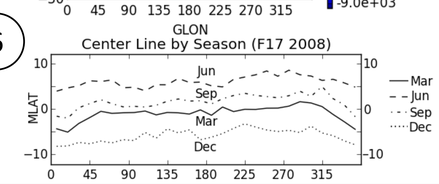
(5) Deviations from the running median. ((2) – (3)) WN4 is strongest in equinox months (March and September.)

5



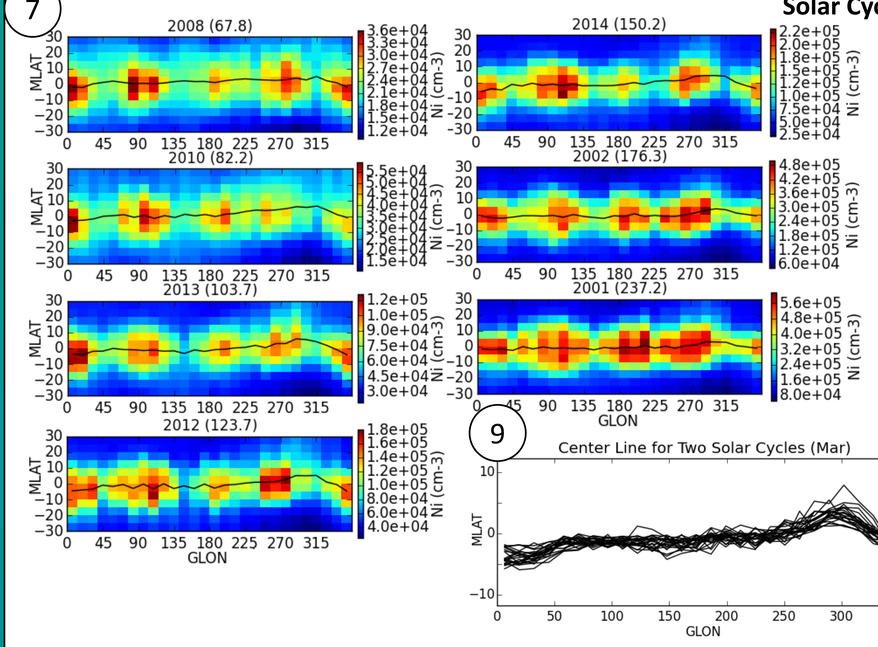
(6) A line through the center of the WN4 structure moves north in northern summer, south in northern winter.

6



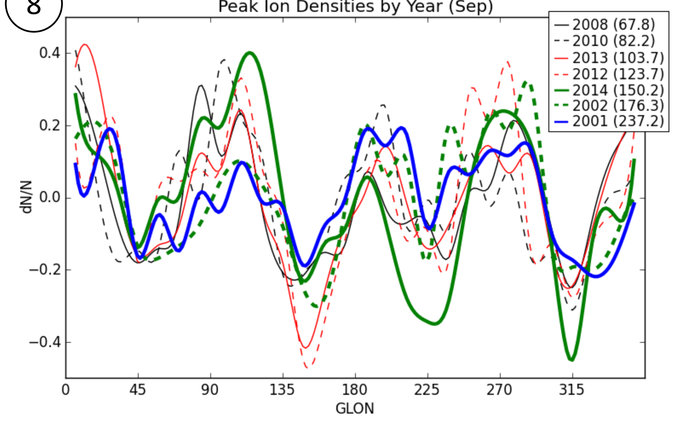
Solar Cycle Variations

7



(7) Monthly averages for September Ni measured by DMSP satellites (F13 before 2007, F17 2007 and later) at 17:00-18:00 LT, for 7 different years, with average F10.7 value labeled in parentheses. The latitude, longitude, and relative intensity of the WN4 peaks do not change significantly with solar cycle.

8



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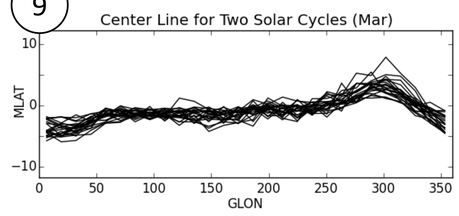
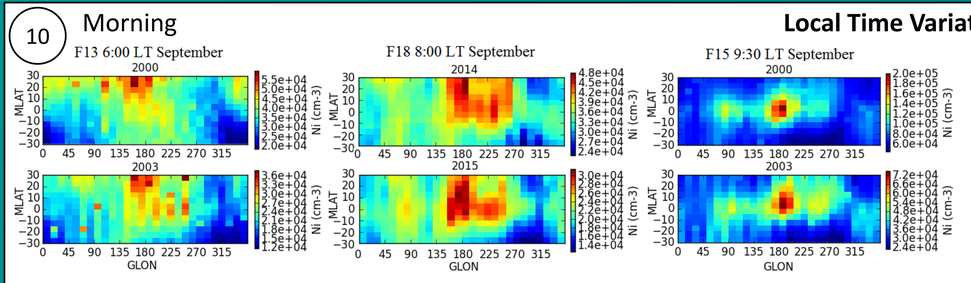


(8) dN/N of the same months/years shown in (7), along a line through the center of the WN4 structure. dN/N of WN4 does not show a dependence on solar cycle.

(9) A line through the center of the WN4 structure for March of the same years shown in (7). While there is some variation in latitude, there is not a clear trend with solar cycle, and these variations are much smaller than the seasonal variations (see (6).)

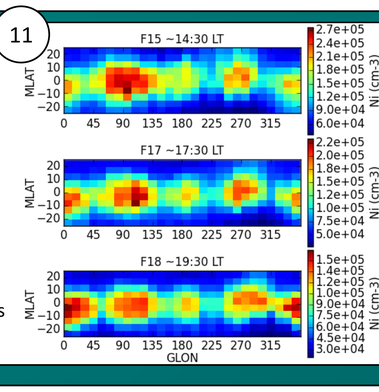
Local Time Variations

10



Afternoon/Evening

11



(10) Ion densities (Ni) for September measured at different local times by 3 DMSP satellites, showing the development of WN4 in the morning. Two examples are shown for each LT. Note that the plots are to different scales. Unfortunately, no DMSP data is available in late morning or around noon.

(11) Ni in September 2014 showing WN4 throughout the afternoon and evening. The latitude, longitude, and relative intensity of the peaks does not change significantly over these times.

Conclusions

- ✓ WN4 is clearest at equinox. During northern summer, there is an increase in Ni at longitudes where there is a positive magnetic declination. In northern winter, this effect is reversed. Additionally, the WN4 structure in Ni moves northward in northern summer, and south in southern winter.
- ✓ The latitude, longitude, relative strength of WN4 peaks, and dN/N do not appear to change significantly with solar cycle, at least at the local time examined (17:00-18:00 LT) when WN4 is particularly strong.
- ✓ The positions and relative strengths of WN4 peaks change rapidly in the morning, but stay very constant throughout the afternoon and evening.