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Thermospheric neutral winds over Abuja, Nigeria

Sivla W. T.[1*], Ogunjobi O.[2], Okoro E. C.[1], Ugonabo O. J.[1] and Orji P. O.[1]

[1]Department of Physics and Astronomy, Faculty of Physical Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria.
[2]Department of Physics, Faculty of Sciences, Federal University, Lokoja, Kogi State, Nigeria.

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We present nighttime variation of thermospheric winds estimated from the Fabry-Perot interferometer (FPI) which was recently deployed at Abuja in Nigeria. These results apply to the thermosphere region around 250 km and were obtained during the period of weak solar activity with solar flux values generally below 70 s.f.u. The results presented cover three months, from October 2017 to December 2017. The high geomagnetic activity level zonal winds generally lag the low geomagnetic activity level winds. Low geomagnetic activity level wind speeds are maintained between 80 and 100 m/s. High activity zonal wind speeds revealed minimum speed values between 0030 LT to about 0330 LT. We also present comparison between our observations and the latest version of the horizontal wind model (HWM14). The model predictions are generally in good agreement with our zonal wind observations. Our limited data used in the investigation is likely responsible for the significant discrepancies observed in the meridional winds.

Key words: Equatorial thermosphere, Low solar activity, thermospheric dynamics, meridional and zonal winds.

INTRODUCTION

Energy in the Earth's upper thermosphere is redistributed by complex processes which are driven by solar and geomagnetic activities. The regular and irregular variability of solar activity significantly modulates the structure and the evolution of the earth's thermosphere-ionosphere (TI)-system (Liu et al., 2011). The upward propagation of internal atmospheric waves (planetary waves, tides and gravity waves) from the troposphere and stratosphere is an essential source of energy and momentum for the TI system (Kazimirovsky, 2002). Thermospheric composition, neutral winds, electric fields and temperatures play a key role in the TI coupling (Kervalishvihi and Lühr, 2014). The neutral winds have a pronounced effect on ionospheric plasma in the low and middle latitudes due to the geometry of the Earth's geomagnetic field. Here the thermospheric winds have a significant component aligned with the direction of the magnetic field lines (Fisher et al., 2015). The F-region meridional winds dominant component is parallel to the magnetic field (Heelis, 2004), while the zonal winds are predominantly in the perpendicular direction.

On a global scale thermospheric neutral wind circulation is driven by pressure gradient force, ion drag, convection, coriolis force and viscosity. Maruyama and Watanabe (2013) examined in detail the importance of ion drag processes in the upper thermosphere using a three

*Corresponding author. E-mail william.sivla@unn.edu.ng.

dimensional coupled ionosphere-thermosphere model. With simulations performed at equinox, moderate solar activity (F10.7=150) and magnetically quiet condition (Ap=7), their model also revealed the general observed characteristic of the global TI system. In the general observed feature of the Walliam TI system, the motion of ions parallel to the earth's geomagnetic field is a source of momentum to the thermosphere. The spatial heating of the earth's upper atmosphere by the Sun gives a general pattern of thermospheric wind behaviour, with the zonal winds generally westward during the day and eastward at night. For meridional winds, flow is generally equator ward at night during periods of normal geomagnetic activity. The ionized particles act as breakers on zonal wind flow in the upper atmosphere but can enhance wind speeds when accelerating in the same direction. In addition to the normal diurnal pattern, the zonal wind also varies with changes in the seasons, geomagnetic activity and the solar cycle.

The thermospheric neutral winds remain one of the most undersampled state parameters in the earth's upper atmosphere as there is limitation of coverage in terms of location, time and geophysical conditions (Fisher et al., 2015). Ground based Fabry-Perot interferometers (e.g Biondi et al., 1999; Martinis et al., 2001; Meriwether et al., 2011; Makela et al., 2012; Fisher et al.,2015) have provided thermospheric wind data sets using the optical technique. Useful thermospheric data sets on a global scale obtained from accelerometer readings on satellites have also been used in number of investigations (King-Hele and Walker, 1983; Sutton et al., 2005; William, 2006; Doornbos et al., 2010; Zhang et al., 2018). Although most of the space science investigations have focused on periods of high solar activities and severe geomagnetic storms the study of the TI system during periods of low solar activity conditions is also very essential (Liu et al., 2011). A good understanding of the thermosphere under minimum solar conditions will further enhance our knowledge of contributions to thermospheric variability from anthropogenic sources. For example, rising greenhouse gas concentrations are likely contributing to the cooling and contraction of the planet's upper atmosphere (Laštovička et al., 2006).

The general characteristics of thermospheric neutral winds over Africa have not been established due to lack of ground-based Fabry-Perot interferometer observations. The first wind observations over Africa were reported by Vila et al. (1998). They presented some nighttime observations of neutral wind variations at F2 layer levels near the dip equator, measured by the Fabry-Perot interferometer set up in 1994 at Korhogo (Ivory Coast, geographic latitude, 9.25°N longitude 355°E, dip latitude-2.5°). The very short lived campaign showed complex behaviour of nighttime equational F2 layer during regular measurements from 1994-1995. Of recent observations of thermospheric winds over Ethiopia have been carried out using the imaging Fabry-Perot interferometer deployed in Bahir Dar University (Tesema et al., 2017). Their first results of six months on nightime monthly averaged thermospheric winds and temperatures for the equatorial east African sector near the geomagnetic equator revealed significant night-night variation in the zonal and meridional winds, temperatures and relative intensities. With support from the Nigeria Space Research and development Agency a William Fabry-Perot Interferometer has been installed in Abuja (Wu, 2016). In this study we attempt to analyze the new observational results over three months from this instrument. With the short available data set we have group the winds into two geomagnetic activity levels of solar cycle 24. The ongoing observations cover the minimum of solar cycle 24. The study will augment the previous two studies in the equatorial latitudes of Africa and stimulate further research with the much expected wind data sets to be obtained from the two available sites. The results are compared with predictions from the recent version of the horizontal wind model (HWM14). Using satellite and ground based observations, improvements to the parameter evaluation steps, together with model formulation; the Horizontal model has been upgraded to provide improved specification of thermospheric general circulation (Drob et al., 2015).

INSTRUMENTATION AND DATA ANALYSIS

Figure 1 shows the location of the FPI deployed at Abuja in Nigeria, Africa (9.06°N, 7.5°E). This Fabry-Perot interferometer started observing the 630.0 nm nightglow emission since September 2017. The instrument measures thermospheric winds by recording the wind induced Doppler shift in the OI 630 nm nightglow emission from ~250 km. It has a 5 cm clear aperture etalon with 2 cm gap. The reflectivity of the coating is 80%. The instrument has a single mirror rotator; which allows it to sample the four cardinal directions with an elevation angle of 45°. The exposure time for each of the direction is 600 s. The instrument also uses a neon lamp to monitor the instrument drift. The wind error is signal intensity dependent and varies widely from a few meters per second to larger values. Thermospheric winds can be deduced by measuring the Doppler shifts and broadening of the emission's line shape at high resolution.

The cloud sensor which covers a field of view of 80° reports the observing conditions. It measures the infrared radiation from the sky to ascertain the value of the sky temperature and this when compared with ambient ground temperature gives the cloud coverage (Makela et al., 2012). For values of approximately -20°C or less the sky is mostly clear while for higher values the skies are cloudy. Values for cloudy skies are excluded from the data analysis. Measurements are sorted into 1 h bins. For each bin, the weighted mean and standard deviation are computed. Desiring to obtain geomagnetic activity trends during low solar activity period, measurements are sorted into a high geomagnetic activity level (Ap>8) and a low geomagnetic activity level (Ap≤8)(Table 1).

RESULTS

Data were collected in Abuja from October 2017 to December 2017. Technical hitches and cloudy skies prevented operations for a long period of time, thus

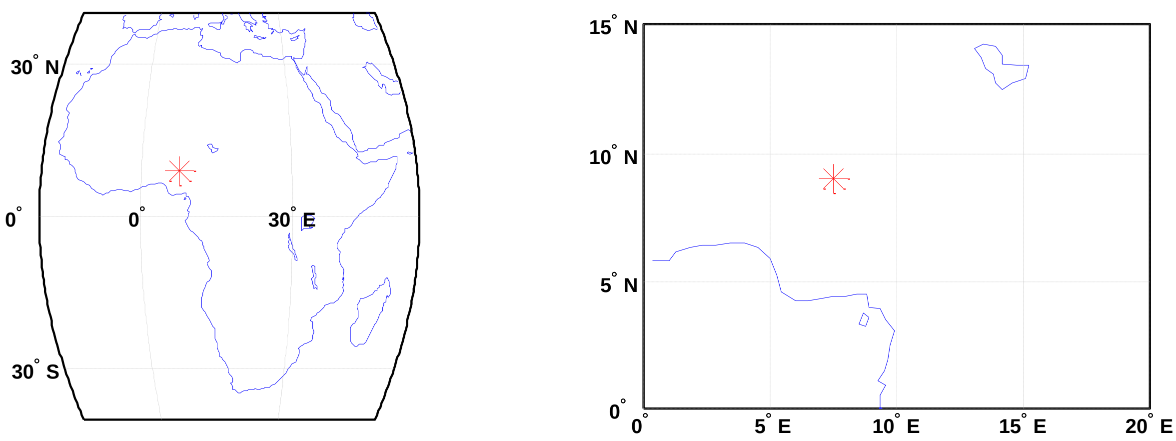

Figure 1. Map of Africa and section of Nigeria showing Abuja where the FPI is located.

Table 1. Number of nights in each month and the corresponding averaged solar flux and geomagnetic index Ap.

Month Averaged F10.7	Nights	Respective Ap
October 68.31	1, 2,4,6,7,9,11,12,13,14,15,16,17,18,19,21	11,5,5,8,3,1,28,26,37,30,25,8,5,4,12,8
November 63.62	1,2,4,9,10,11,13,14,15,16,17,21,23,27	2,8,8,18,18,20,6,11,11,11,14,4,27,8,4
December 62.52	1,2,5,15,17	7,3,28,3,23

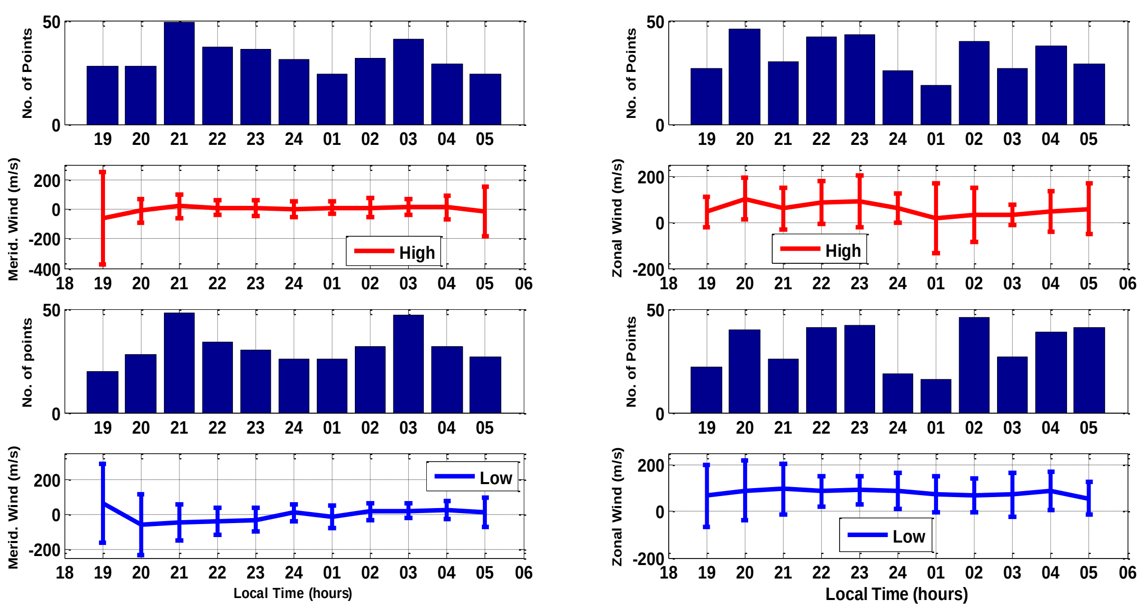

Figure 2. Averaged thermospheric winds and standard variations at high and low geomagnetic activity levels. Top panels of each diurnal variation show the number of data points in each 1-hour bin.

limited data is available for analysis. Table 1 lists the number of nights for each of the three months and the corresponding averaged solar flux (F10.7) and geomagnetic activity index Ap. The considered time interval from October 2017 to December 2017 is characterized by low solar flux values, generally varying between 60 and 70 s.f.u.

Figure 2 shows the averaged results of the meridional and zonal winds for the three months (October to December, 2017) at high and low geomagnetic activity

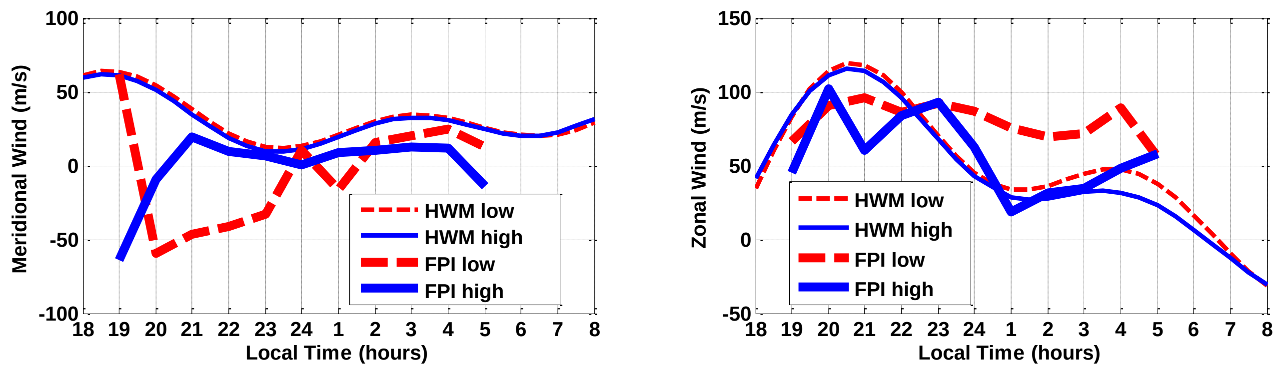

Figure 3. Geomagnetic activity levels variation in thermospheric winds at Abuja: Meridional winds (positive north) and zonal winds (positive east). Also shown are the HWM14 model results. The averaging bin period of the model results is 30 min.

levels with the standard deviations and the corresponding number of data points in each local time bin. The standard deviations display the variability of the wind speeds. The standard deviation is large for the zonal winds at the two considered geomagnetic activity levels. In general the standard deviation of the meridional winds at high and low activity levels is fairly consistent from 20:00 LT to 03:00 LT, with average values of σ=+/−50 m/s for high activity and about σ=+/−70 m/s for the low activity winds as shown in left panel of Figure 2.The standard deviation is not consistent for the zonal winds as shown in the right panel. The inconsistency appears more pronounced in the high activity level winds.

The high activity meridional wind speeds maintain values between 0 and 20 m/s northwards from 09:30LT to 04:30 LT as displayed in left panel of Figure 2. The low activity winds are southwards from 1930 LT to about 24:00 LT. Zonal wind speeds are generally eastward throughout the period of study with low activity wind speeds maintained between 80 and 100 m/s as shown in Figure 2. The high activity winds generally lag low activity winds. The difference is consistent from 23:00 to 05:00 LT as displayed in Figure 3.

DISCUSSIONS

Figure 3 shows a comparison of the winds in Figure 2 at the two considered geomagnetic activity levels for the meridional and zonal winds. The Horizontal wind model (HWM14) at the two geomagnetic activity levels is also included for comparison. The primary driver of upper atmospheric winds in the equatorial regions is the pressure gradient force. This force increases in the eastward direction towards sunset and together with the reduced ion drag account for the relatively large zonal winds experienced in the early evening before midnight. According to Fisher et al. (2015), the ion drag force which results from collisions between the neutrals and F-region plasma, partly balances the eastward pressure gradient force during solar minimum conditions. Influence of ion drag force is less pronounced during low solar activity period (Hsu et al., 2016). Rapid rising of the ionosphere by the evening prereversal enhancement of eastward electric fields reduces the influence of ion drag force (Anderson and Roble, 1974; Maruyama and Watanabe, 2003). Most of the investigations carried out on equatorial latitude upper thermospheric winds (Biondi et al., 1999; Meriwether et al., 2011; Tesema et al., 2017) have revealed nighttime patterns similar to those in our observations. Our zonal wind speeds in the West African sector revealed maximum speeds generally below 100 m/s which is generally in agreement with the investigations of Tesema et al. (2017) in the east African sector FPI which is also close to the magnetic equator. The early evening peak meridional wind speeds observed in the west African winter months (Tesema et al., 2017) is not reflected in our study, however around the midnight hours there is some resemblance. With more coverage studies will be carried out to fully understand the interhemispheric flow from the summer to winter hemisphere.

Our study on the limited data has revealed geomagnetic activity influence on the two components of the thermospheric wind variation. The effects of geomagnetic activity generally originate from high latitudes (Liu et al., 2006) and the propagation of the disturbance to low latitudes is better facilitated at night (Fuller-Rowell et al., 1994, 1996). Difference in the zonal winds at the two levels is significant as shown in Figure 3. Increase in ion drag from midnight to dawn during periods of high solar activity may account for the significant difference in the wind speeds. Increasing geomagnetic activity weakens the post midnight zonal winds. Increase in geomagnetic activity strengthens the meridional winds in early evening hours from 19:30 to 23:30 LT.

Biondi et al. (1999) studied the solar effect on equatorial nighttime thermospheric winds for different seasons under quiet geomagnetic conditions. Their wind for the combined equinox and December solstice are more equator ward than our corresponding variations at two geomagnetic activity levels. Our limited data did not cover the whole September and December solstice winds thus making it likely for some differences to be observed.

Comparison to a horizontal wind model

Comparisons of the neutral wind variations at different levels of geomagnetic activity using HWM14 are shown in Figure 3. Ground based measurements from Brazil and PARI through 2013 were used in updating the latest version of the climatological wind model, HWM14 (Fisher et al., 2015). The HWM14 agree perfectly well for the meridional wind at both levels of geomagnetic activity. The HWM14 model zonal winds agree for most of the interval at both levels of activity with slight disagreement observed from 00:30-07:00LT. We also compare the model predictions with our own results. In general, zonal wind speeds in our study compare quite well with the HWM results for the two levels of geomagnetic activity considered. Some significant disagreements are quite visible for some time intervals in the meridional wind variation; 19:00-21:00 LT for high and 19:00-23:30 LT for low. The HWM14 model meridional values for the high and low activity levels closely resemble the FPI measurements from 21:00-04:00 LT and 24:00- 05:00LT respectively. The high activity and low activity meridional winds display significant discrepancies from 19:00 to 21:00 LT and 19:00 to 24:00 LT respectively. The horizontal wind model (HWM) which is an empirical model integrates various data of thermospheric neutral wind observations. They will likely reveal a more representative observations of upper thermospheric than our measurements spanning over a short interval of three months. Since no ground-based neutral wind measurements over Africa were used in the construction of HWM14 the FPI data from the installed FPIs in Morocco (Fisher et al., 2015), Ethiopia, and now from Abuja will contribute immensely to the validation of the latest HWM version.

Conclusions

We have presented nighttime observations from the recently installed Fabry-Perot Interferometer in Abuja, Nigeria. Our observations for two geomagnetic activity levels during the low solar activity period of cycle 24 revealed general variations generally similar to previous investigations in other equatorial longitude sectors. The climatology we have presented is the first of this kind from the West African sector. From our investigation we draw the following conclusions:

1. The maximum eastward zonal winds are generally in agreement with results from the East African sector. The zonal winds at both activity levels are eastward with large amplitudes in the early night sector. This has also been observed in the South American sector.
2. High activity zonal winds lag the low activity winds for most of the night. Difference in wind speeds for the different levels is more pronounced in the zonal winds.
3. The latest version of HWM14 compares favourably well with our zonal wind observations. Discrepancies are noticed in the early evening meridional winds at high and low activity levels before 21:00 LT and from 19:00-23:30LT respectively.

With more coverage expected further investigations will be carried out to argument previous low latitude studies and stimulate a better understanding of wind climatology over the equatorial latitudes of West Africa.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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