British Journal of Applied Science & Technology
16(1): 1-8, 2016, Article no.BJAST.26096
ISSN: 2231-0843, NLM ID: 101664541

SCIENCEDOMAIN *international*
www.sciencedomain.org

Diurnal Variation of Midlatitiude Thermospheric Zonal Winds during a Period of Low Solar Activity

William Tafon Sivla[1*], Olakunle Ogunjobi[2] and Virginia Sule[3]

[1]Department of Physics, Benue State University, P.M.B. 102119, Makurdi, Nigeria.
[2]Department of Physics, Federal University, Lokoja, Kogi State, Nigeria.
[3]Department of Physics, Kogi State University, P.M.B. 1008, Anyigba, Nigeria.

Authors' contributions

This work was carried out in collaboration between all the three authors. Author WTS designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed literature searches. Authors WTS, OO and VS managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/26096
Editor(s):
(1) Joao Miguel Dias, Habilitation in Department of Physics, CESAM, University of Aveiro, Portugal.
Reviewers:
(1) Abubakar Yakubu, University Putra, Malaysia.
(2) A. Ayeshamariam, Khadir Mohideen College, India.
Complete Peer review History: http://sciencedomain.org/review-history/14576

Original Research Article

Received 31st March 2016
Accepted 29th April 2016
Published 11th May 2016

ABSTRACT

The seasonal behaviour of thermospheric zonal winds speeds between geomagnetic latitudes 30-40 degrees north and south from 2006 to 2007 has been studied using zonal wind data recently generated from CHAMP measurements using an iterative algorithm. The period, which falls under the declining phase of the recent solar cycle minimum, is characterized by low magnetic activity and low solar flux levels. Seasons are classified into, June solstice, December solstice, March and September equinoxes. No significant differences are observed between north and south mid-latitude wind variation during the equinox seasons. The switch from westward to eastward direction is observed at about 1500 MLT for all the seasons. Large zonal wind speeds are observed at and after dawn in both hemispheres. The significant difference observed in morning winds at the two mid-latitude bands during the solstices may be attributed to the differences in the solar irradiation.

Keywords: Mid-latitudes; zonal winds; CHAMP satellite.

**Corresponding author: E-mail: sivla_w@yahoo.com;*

1. INTRODUCTION

The neutral winds are an important parameter in nearly all electrodynamic and plasma physics processes in the mid- and low-latitude ionosphere-thermosphere [1]. The thermosphere can be considered as a linear dissipative oscillatory system, which suppresses the small-scale and short-term structures more effectively than the large-scale and long-term ones [2]. Thermospheric variability can be externally or internally generated. External sources arise from geomagnetic activity, solar EUV(extreme ultraviolet) radiations, tides and wave disturbances from the lower layers of the atmosphere while internal variability arise from the coupling between ionized species and the neutral gas. Under very quiet geomagnetic conditions, clear thermospheric and ionospheric signatures of magnetospheric processes are mostly observed at high geomagnetic latitudes [3]. Electrodynamics of the mid-latitude thermosphere are extensively influenced by magnetospheric processes, and in particular, electric fields of magnetospheric origin which penetrate throughout the mid-latitude thermosphere to cause perturbations in the ionosphere-thermosphere system [4].

During geomagnetic storms the increases in high latitude heating generate travelling atmospheric disturbances which propagate across midlatitudes to the equatorial region. This high latitude forcing contributes to the energy and momentum of the Earth's thermosphere. According to [5], the ionospheric ion velocity and thermospheric neutral wind are related to the effective ionospheric electric field and Earth's magnetic field as by

$$E_{eff} = (\vec{v} \times \vec{B}) + (\overrightarrow{u} \times \vec{B}) \tag{1}$$

where E_{eff} is the ionospheric electric field, v the ionospheric ion velocity, u the neutral wind speed and B the Earth's magnetic field. Zonal wind flow in the upper thermosphere is regulated by ion drag. The pressure gradient force balances ion drag in the low and mid-latitude upper thermosphere. Ion drag results from the collision interactions of the neutral gas with the plasma. Ignoring all the forces that contribute in driving thermospheric circulation, the change in wind velocity according to [6] is given by

$$\frac{d\vec{u}}{dt} = -\nu_{in}(\vec{u} - \vec{v}) \tag{2}$$

where ν_{in} is the ion-neutral collision frequency. In the mid-latitude upper thermosphere neutral winds are driven by pressure gradient, ion drag, viscous and coriolis forces. Ion drag resulting from collisions between ions and the neutral particles contributes in establishing the general pattern of winds observed in the Earth's upper thermosphere. This ion drag is also an important energy source for the thermosphere. Thermospheric winds blow in great circular paths along the pressure gradient from the high pressure on the day side to the low pressure on the night side. At mid-latitudes the pressure variation in the thermosphere which is dominated by solar heating gives rise to the observed diurnal circulation pattern [7]. The mid-latitude thermosphere parameters exhibit irregular behavior on a time scale of hours [4].

Today thermospheric winds are observed using three main techniques namely; the Incoherent Scatter Radar technique, the optical technique and the satellite drag technique. Although a number of important features have been derived from datasets obtained from Fabry-Perot interferometer wind observations, the interferometer technique has its limitations such as uncertainty in emission height, restriction to dark hours, clear sky and reduced moon phases [8]. The physical assumptions in radar technique measurements break down under disturbed conditions [9]. The satellite technique provides wind measurements globally and can be used for wind measurements at all altitudes. Mid-latitude thermospheric wind studies have been carried out in the last two decades using Fabry-Peot interferometers, incoherent scatter radar, ground-based ionosonde, satellite data and general circulation models [10-20]. Data from new observational initiatives from space, such as CHAMP and GRACE missions; [21] and ground instruments, such as the newly developed Optimized Fabry-Perot interferometer [22], are being used to address and update the much needed information regarding variations of neutral winds, ion drifts and electric fields. CHAMP wind data has been used for detailed wind studies in the equatorial latitudes recently by [23,24,9]. [8] in their study, presented thermospheric wind patterns at Polar Regions around the June solstice using wind data from CHAMP. [25] used CHAMP wind data to study thermospheric response to the driving forces of large scale magnetospheric convection that results from solar wind and interplanetary magnetic field (IMF) interactions with the magnetosphere. The latitudinal structure of zonal winds at low and mid-latitudes has been investigated by [26] using CHAMP satellite wind data and Dynamic Explorer-2 (DE-2) measurements.

Compared to previous satellites, AE-E and DE-2, CHAMP measurements provide large zonal wind datasets that can be used for detailed studies of wind behavior at very quiet and disturbed times. The prolonged minimum in solar activity between solar cycles 23 and 24 is unique, and the resulting quiet state of the thermosphere has never been observed in the past cycles. In this study we use zonal wind data derived by [27] from the CHAMP accelerometer readings using an iterative algorithm to study diurnal wind variation in the mid-latitudes during quiet times in the declining phase of the solar cycle 23. This algorithm which is improved and generally applicable works independently of the orientation of the instrument in space. In this procedure the modelled aerodynamic force is varied until it coincides with the observed acceleration [28]. The procedure in this model avoids the restrictions and sources of errors in the direct method. Data from this model has successfully been used in an earlier study by [29] to study zonal wind variations at two solar flux levels in the mid-latitudes from 2002 to 2004 during the equinoxes. This study at solar minimum when the sun is the ground state will augment the previous ground observations in mid-latitudes wind behavior and improve our understanding of wind climatology in the mid-latitudes.

1.1 Data Selection and Processing

The satellite CHAMP, an acronym for challenging minisatellite payload, was launched in July 2000 [30]. CHAMP is in a near-circular, polar orbit, and provides coverage of all local times and latitudes every 130 days [9]. From its initial altitude at 456 km when it was launched, CHAMP orbit decayed to about 350 km during the first five years [28]. With 15 orbits per day, the CHAMP satellite crosses any mid-latitude band 15 times during its ascending motion and 15 times during its descending motion. CHAMP provides pole- to-pole latitudinal coverage. This takes place at different longitudes due to the rotation of the earth. For a single day, the relative position of the sun and the satellite changes very little; therefore, satellite measurements at the same geomagnetic latitude, although at different longitudes are within a small range of Local Solar Time. The inclination of the CHAMP satellite orbit and latitudes determine the actual local solar time coverage at given latitude. Although the data for a single day at given geographic latitude are within a short range of local solar time, the corresponding geomagnetic latitudes and universal times of these data are different at different longitudes.

The data in this study covers the period from 1st January 2006 to 31st December 2007, a total of 730 days. Zonal wind speeds are considered in the geomagnetic mid-latitudes, 30-40°N and 30-40°S. Wind speeds are then sorted for geomagnetic activity index, Ap< 8. Fig. 1 shows the variation of the solar proxy F10.7 during the period of study from 1st January 2006 to 31st December 2007. Our period of study falls under the solar minimum of solar cycle 23 and the solar flux values can be seen to vary between 102 s.f.u and 65 s.f.u.

The data is grouped into seasons, the June solstice (May, June, July), December solstice (November, December, January) and March equinox (February, March, April) and September equinox (August, September, October). The data in each of the seasons is binned and averaged over magnetic local time (MLT) and geomagnetic latitudes. Fig. 2 shows the number of measurements in each magnetic local time bin for each of the seasons.

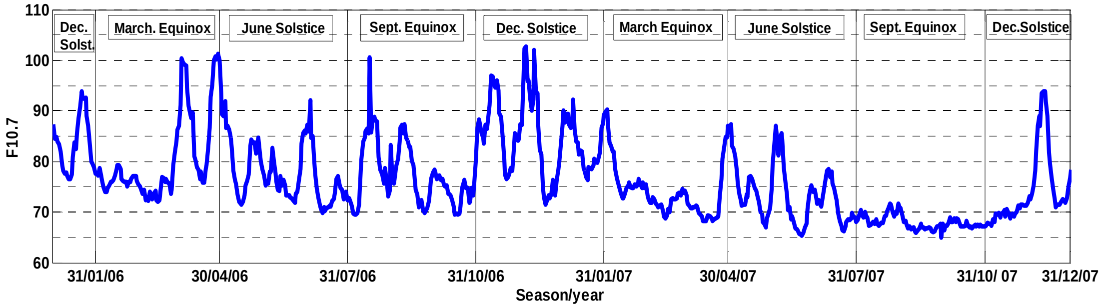


Fig. 1. Variations of the solar flux proxy F10.7 with seasons from 2006 to 2007

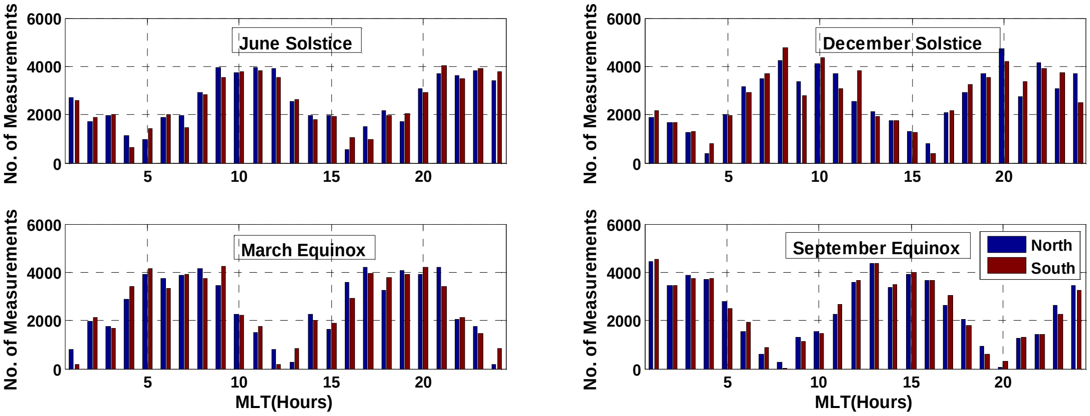


Fig. 2. Number of measurements in each local time bin for each of the seasons in the mid-latitude northern hemisphere (North) and southern hemisphere (South)

2. RESULTS

Fig. 3 shows the zonal wind averaged over all seasons for the northern and southern hemisphere mid-latitude bands. The averaged winds started to blow westward at 0300 MLT. Fig. 4 displays the diurnal wind variation for June and December solstices, and, March and September equinoxes in the north and south mid-latitudes. The switch of direction from westward to eastward occurred at about 1500 MLT for winds in the two hemispheres whilst there is no statistically significant differences between the north and south hemispheres, a larger eastward wind is observed in the southern hemisphere mid-latitude band from around 1700-2300 MLT. The southern hemisphere wind is more westward during the day from about 0400-0700 MLT. Peak westward and eastward winds were observed in the southern hemisphere mid-latitude zonal winds at 0800 and 2000 MLT respectively.

2.1 June and December Solstices

The mid-latitude June solstice zonal wind started to blow eastward at around 1500 MLT in the northern hemisphere. A difference is observed between the north and south mid-latitude zonal winds around 1700-2000 MLT. Peak eastward winds occurred at 1700 MLT and 1800 MLT for north and south mid-latitudes respectively. The switch of the wind direction from eastward to westward occurred at about 0400 MLT. Peak westward winds are encountered around 0700 MLT for both northern and southern hemisphere mid- latitudes. In the northern hemisphere mid-latitude change in wind direction from east to west occurs at 0400-0600 MLT, while in the south the change occurs about midnight during the December solstice. The switch in direction from west to east occurred around 1500 MLT in both hemispheres. Maximum westward speeds going above 200 m/s are observed in the southern hemisphere from 0600-0800 MLT.

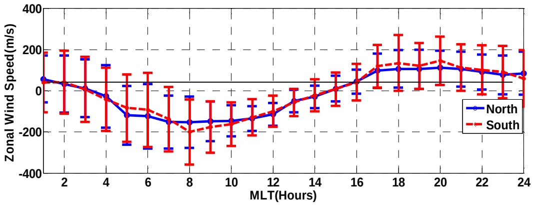
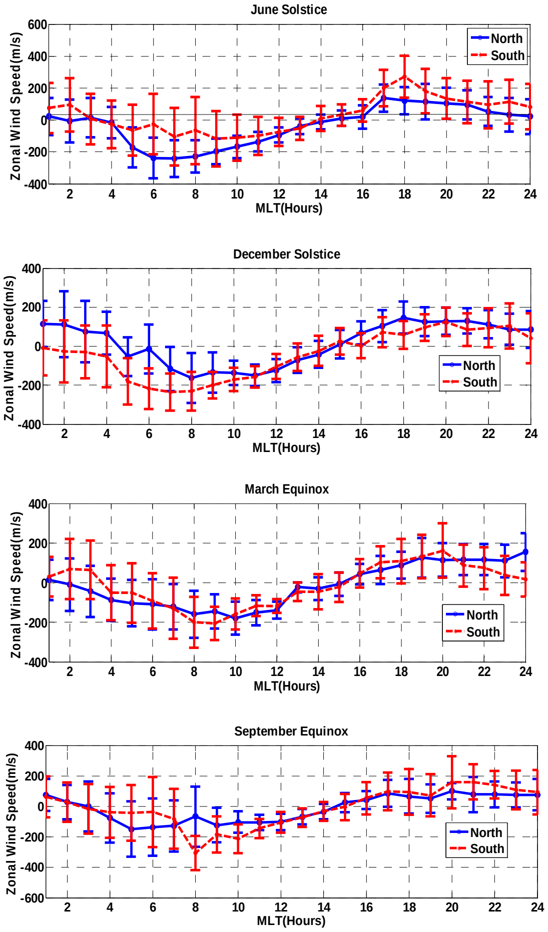


Fig. 3. Zonal winds in the northern (North) and southern (South) mid-latitudes averaged all seasons. The wind is averaged within 30°- 40°N and 30°- 40° S geomagnetic latitudes. The error bars correspond to the standard deviation of the observations for each bin

2.2 Equinoxes

March equinox zonal winds are westwards from 0200 to 1500 MLT in the northern hemisphere. Peak speeds going above 150 m/s are observed around 1000 MLT. The switch in wind direction from westward to eastward occurred at 1500 MLT. Peak eastward winds are encountered in the evening around midnight. In the southern hemisphere switch in direction to westward was at 0330 MLT with maximum speeds of about 200 m/s encountered from 0800 to 0900 MLT. Peak eastward speeds occur about 2000 MLT. Peak westward wind speeds going above 250 m/s occur around 0800 MLT in the southern hemisphere.


June Solstice

December Solstice

March Equinox

September Equinox

Fig. 4. Zonal wind in the upper thermosphere for different seasons. Blue curves represent wind variation in the northern mid-latitudes (30° N-40° N) and the dashed one is for variation southern mid-latitude (30° S-40° S). The error bars correspond to the standard deviation of the observations of each bin

The switch in direction from westward to eastward occurred at 1500 MLT in both hemispheres. Peak eastward winds are encountered about 2000 to 2100 MLT in both hemispheres.

3. DISCUSSION

The period of study 2006 to 2007 falls within the declining phase of solar cycle 23 minimum. The latest solar minimum marks one of the lowest EUV production and longest duration in the recent cycles. Although the individual samples of the data measurements were taken at different times, the hourly mean values of the zonal wind speed were calculated by considering the whole ensemble of measurements falling within the bin.

In the process of applying the selection criteria for magnetic activity some bins were left with small number of measurements, especially during the equinoxes. The mean wind values in some of these cases may not represent typical observed values. The 0800 MLT and 2000 MLT September equinox mean wind values may be extreme as enough measurements were not used in averaging. The error bars in Figs. 3 and 4 which correspond to the standard deviation indicate the scattering of zonal wind speed in each corresponding magnetic local time bin.

Very quiet geomagnetic conditions correspond to a ground state of the thermosphere with relatively low atomic oxygen concentration at the middle and sub-auroral latitudes [31]. The solar EUV radiation directly heats the mid-latitude upper thermosphere in the northern hemisphere mid-latitude during the June solstice and southern hemisphere mid-latitude likewise during the December solstice. The zonal velocities especially during the solstices are observed to be large after dawn. Sunrise and sunset are processes which do not occur gradually. The sunrise process is an abrupt event which is usually followed by rapid increases in electron temperatures and densities and its onset could eventually generate gravity waves with speeds greater than that of the Sun [7]. The magnitudes of the dawn and after dawn winds are different in each of the mid-latitude hemisphere during the solstices. During the June solstice when the sun is the northern hemisphere the magnitude of north mid-latitude wind at and after dawn is more than that of the south mid-latitude. A similar scenario is observed for south mid-latitude winds during the December solstice when the sun is the southern hemisphere. The situation in each case is likely due to the overhead sun which gives rise to large zonal pressure gradients. These pressure gradients in turn drive large westward zonal winds at dawn.

Our results compare favourably with model results of [32] at 300 km over Wuhan (30.6°N, 114.4°E). Our results generally agree with the HWM90 predictions of [19]. Around the June solstice (summer), CHAMP measurements and HWM predictions show significant differences in direction. The HWM winds in the southern hemisphere during summer are westward for most of the diurnal variation and eastward winds are only encountered within a short interval from about 1600-2000 MLT. In the northern hemisphere summer wind direction is western for all day and most of the night with a small eastward switches from about 1800 to 2200 MLT. The eastward switches during equinoxes occur about 1500 LT just like in the CHAMP measurements. The change in wind direction for December solstice model winds is at about 1300 LT while for CHAMP this change is observed at about 1500 MLT. In all cases the CHAMP winds and HWM winds generally blow westward for most of the day and eastward for most of the night. The differences observed in the model predictions and CHAMP winds can be attributed to number of factors ranging from the data used, prevailing conditions and the difference in latitude bands. [7] deduced the quiet-time thermospheric circulation pattern above the Millstone Hill (42.6°N, 71.5°W) incoherent scatter radar facility for the years of 1970 and 1971 using measured values of ionospheric drift, temperatures and densities. The deduced zonal winds were eastwards at dusk and westwards at dawn. Zonal velocities were particularly large after dawn. These results compare favourably with our results which were also generally eastwards at dusk and westwards at dawn.

4. CONCLUSION

In this paper we presented diurnal zonal wind variations in the mid-latitudes using data derived from CHAMP using a new iterative algorithm. Our studies have revealed a shift in direction from westward to eastward at 1500 MLT for all the seasons. June solstice winds were significantly more westwards during the day morning hours in the north hemisphere mid-latitude than the south hemisphere mid-latitude. December solstice winds are more westwards from about mid-night to day morning day hours in the south hemisphere mid-latitude. There is a bright future, as 24 hour ground observations of thermospheric have been reported by [22] using newly developed Second-generation, Optimized, Fabry-Perot interferometer (SOFDI). Since CHAMP was not designed for thermosphere wind as part of the primary mission objective, [27] have made some suggestions that can improve the development of future thermospheric missions with the aim of reducing wind error. Although satellites such as CHAMP do offer global thermospheric coverage, they suffer from limited local time sampling, as they take so many days to cover all local times.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Larsen MF, Fesen CG. Accuracy issues of the existing thermospheric wind models: can we rely on them in seeking solutions to the wind driven-driven problems? Annales Geophysicae. 2009;27:2277-2284.
2. Kazimirovsky ES, Kokourov VD, Vergasova GV. Dynamical climatology of the upper mesosphere, lower thermosphere and ionosphere. Surveys in Geophysics. 2006;27:211-255.
3. Rees D. Observations and modeling of ionsopheric and thermospheric disturbances during major geomagnetic storms: A review. Journal of Atmospheric and Terrestrial Physics. 1995;57:1433-1457.
4. Walker JCG. The mid-latitude thermosphere. Planetary Space Science. 1988;36:1-10.
5. Aruliah AL, Griffin EM, McWhirter I, Aylward AD, Ford EAK, Charalambous A, Kosch MJ, Davis CJ, Howells VSC. First tristattic studies of meso-scale ion-neutral dynamics and energetics in the high-latitude upper atmosphere using collocated FPIs and EISCAT radar. Geophysical Research Letters. 2004;31:L03802. DOI: 10.1029/2003GL018469
6. Nozawa S, Brekke A. Studies of the E-region neutral wind in the disturbed auroral ionosphere. Journal of Geophysical Research. 1995;100:14717-14734.
7. Emery BA. Seasonal wind variations in the mid-latitude thermosphere. ScD. Thesis, Department of Meteorology, Massachusetts Institute of Technology, USA; 1977.
8. Lühr H, Rentz S, Ritter P, Liu H, Haüsler K. Average thermospheric wind patterns over the Polar Regions, as observed by CHAMP. Annales Geophysicae. 2007;25: 1093-1101.
9. Liu H, Lühr H, Watanabe S, Kohler W, Henize V, Visser P. Zonal winds in the equatorial upper atmosphere. Journal of Geophysical Research. 2006;3:A07307. DOI: 10, 1029/2005 JA01145
10. Balan N, Kawamura S, Nakamura T, Yamamoto M, Fukao S, Igarashi K, Murayama Y. Simultaneous mesosphere/ lower thermosphereand thermospheric F

region observations during geomagnetic storms. Journal of Geophysical Research. 2004;109:A04308.
DOI: 10.1029/2003JA009982

11. Bounsanto MJ. Neutral in the thermosphere at mid latitudes over a full solar cycle: A tidal decomposition. Journal of Geophysical Research. 1991;96:3711-3724.
12. Burns AG, Killeen TL, Deng W, Carignan GR, Roble RG. Geomagnetic storm effects in the low- to mid-latitude upper thermosphere. Journal of Geophysical Research. 1995;100:14673-14692.
13. Duboin ML, Lafeuille M. Thermospheric dynamics above saint-Santin: Statistical study of the data set. Journal of Geophysical Research. 1992;97:8661-8671.
14. Emery BA, Lathuillere C, Richards PG, Roble RG, Bounsanto MJ, Knipp DJ, Wilkinson P, Sipler DP, Niciejewski R. Time dependent thermospheric neutral response to the 2-11 November 1993 storm period. Journal of Atmospheric and Solar Terrestrial Physics. 1999;61:329-350.
15. Fejer BG, Emmert JT, Sipler DP. Climatology and storm time dependence of nighttime thermospheric neutral winds over Millstone Hill. Journal of Geophysical Research. 2002;107(A5):1052.
DOI: 10.1029/2001JA000300
16. Fesen CG, Roble RG, Duboin ML. Simulations of seasonal and geomagnetic activity effects at Saint-Satin. Journal of Geophysical Research. 1995;100:21397-21407.
17. Fuller-Rowell TJ, Codrescu MV, Moffet RJ, Quegan S. Response of thermosphere and ionosphere to geomagnetic storms. Journal of Geophysical Research. 1994;99:3893-3914.
18. Fuller-Rowell TJ, Codrescu MV, Risbeth H, Moffet RJ, Quegan S. On the seasonal response of the ionosphere and thermosphere to geomagnetic storms. Journal of Geophysical Research. 1996;101:2343-2354.
19. Hedin AE, Biondi MA, Burnside RG, Hernandez G, Johnson RM. Revised global model of thermospheric winds using satellite and ground – Based observations. Journal of Geophysical Research. 1991;96:7657-7688.
20. Kawamura S, Otsuka Y, Zhang SR, Fukao S, Oliver WL. A climatology of middle and upper atmosphere radar observations of thermospheric winds. Journal of Geophysical Research. 2000;105:12777-12788.
21. Lühr H. The CHAMP Mission, GFZ German Research Centre for Geosciences; 2010
22. Gerrard AJ, Meriwether JW. Initial daytime and nighttime SOFDI observations of thermospheric winds from Fabry-Perot Doppler shift measurements of the 630-nm OI line-shape profile. Annales Geophysicae. 2011;29:1529-1536.
23. Häusler K, Lühr H. Nonmigrating tidal signals in the upper thermospheric zonal wind at equatorial latitudes as observed by CHAMP. Annales Geophysiccae. 2009;27: 2643-2652.
24. Häusler K, Lühr H, Rentz S, Köhler W. A statistical analysis of longitudinal dependencies of upper thermospheric zonal winds at dip equator latitudes derived from CHAMP. Journal of Atmospheric and Solar Terrestrial Physics. 2007;69:1419-1430.
25. Förster M, Rentz S, Köhler W, Liu H., Haaland SE. IMF dependence of high-latitude thermospheric wind pattern derived from CHAMP cross-track measurements. Annales Geophysicae. 2008;26:1581-1595.
26. Liu H, Watanabe S, Kondo T. Fast thermospheric wind jet at the Earth’s dip equator. Geophysical Research Letters. 2009;36:L08103.
DOI: 10.1029/2009GL037377
27. Doornbos E, Van den Ijssel J, Luhr H, Forster M, Koppen-wallner G. Neutral density and crosswind determination from arbitrarily oriented multiaxis accelerometers on satellites. Journal of Spacecraft and Rockets. 2010;47:580-589.
28. Ritter P, Lühr H, Doornbos E. Substorm-related thermospheric density and wind disturbances derived from CHAMP observations. Annales Geophysicae. 2010;28:1207-1220.
29. Sivla WT, McCreadie H. Mid-latitude thermospheric zonal winds during the equinoxes. Advances in Space Research. 2014;54:499-508
30. Reigbe RC, Bock R, Förste C, Grunwaldt L, Jakowski N, Lühr H, Schwintzer P, Tilgner C. Scientific tech Rep STR96/13, CHAMP phase B executive summary. GeoForschungsZentrum; 1996.

31. Mikhailov AV, Depuev VH, Depueva AH. Synchronous NmF2 and NmE daytime variations as a key to the mechanism of quiet-time F2-layer disturbances. Annales Geophyicae. 2007; 25:483-493.
32. Lei J, Liu L, Luan X, Wan W. Model study on neutral winds in the ionospheric F-region and comparison with the equivalent winds derived from the Wuhan ionosonde data. Terrestrial Atmospheric and Oceanic Sciences. 2003;14:1-12.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/14576