

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

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

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

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

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

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

where v_{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

66 can be used for wind measurements at all altitudes. Mid-latitude thermospheric wind studies
67 have been carried out in the last two decades using Fabry-Perot interferometers, incoherent
68 scatter radar, ground-based ionosonde, satellite data and general circulation models [10-
69 12,13; 14-16; 17-18;19;20]. Data from new observational initiatives from space, such as
70 CHAMP and GRACE missions; [21] and ground instruments, such as the newly developed
71 Optimized Fabry-Perot interferometer [22], are being used to address and update the much
72 needed information regarding variations of neutral winds, ion drifts and electric fields.
73 CHAMP wind data has been used for detailed wind studies in the equatorial latitudes recently
74 by [23-24, 9]. [8] in their study, presented thermospheric wind patterns at Polar Regions
75 around the June solstice using wind data from CHAMP. [25] used CHAMP wind data to
76 study thermospheric response to the driving forces of large scale magnetospheric convection
77 that results from solar wind and interplanetary magnetic field (IMF) interactions with the
78 magnetosphere. The latitudinal structure of zonal winds at low and mid-latitudes has been
79 investigated by [26] using CHAMP satellite wind data and Dynamic Explorer-2 (DE-2)
80 measurements.

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

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2. 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.

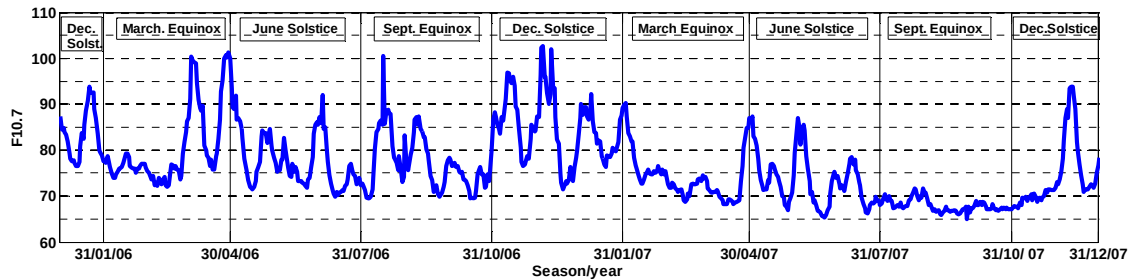


Figure 1. Variations of the solar flux proxy F10.7 with seasons from 2006 to 2007.

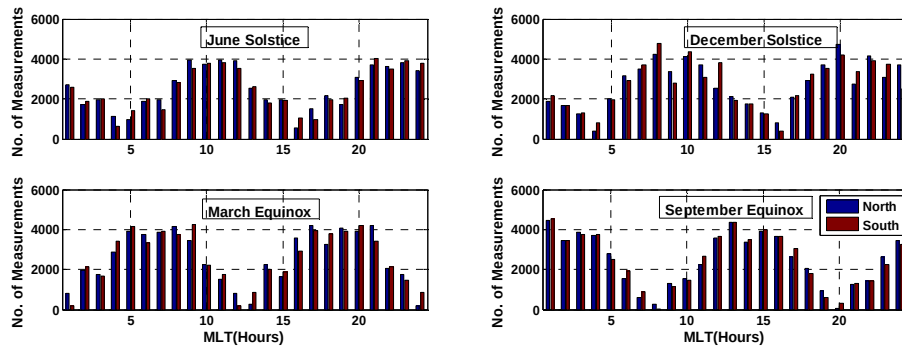


Figure 2. Number of measurements in each local time bin for each of the seasons in the mid-latitude northern hemisphere (North) and southern hemisphere (South).

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, $A_p < 8$. Figure 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. Figure 2 shows the number of measurements in each magnetic local time bin for each of the seasons.

3. Results.

Figure 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. Figure 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.

3.1 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 0400-0600MLT, 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 0600-0800MLT.

3.2 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 1000MLT. The switch in wind direction from westward to eastward occurred at 1500MLT. 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 200m/s encountered from 0800 to 0900 MLT. Peak eastward speeds occur about 2000MLT. Peak westward wind speeds going above 250 m/s occur around 0800 MLT in the southern hemisphere. 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.

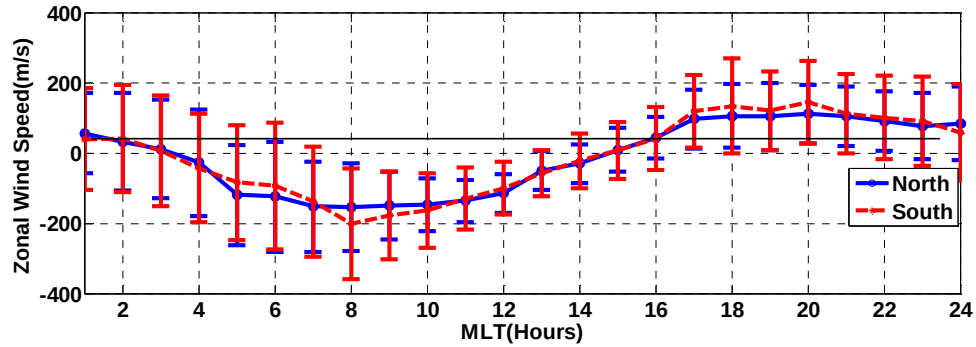


Figure 3. Zonal winds in the northern (North) and southern (South) mid-latitudes averaged all seasons. The wind is averaged within 30°- 40° N and 30°- 40° S geomagnetic latitudes. The error bars correspond to the standard deviation of the observations for each bin.

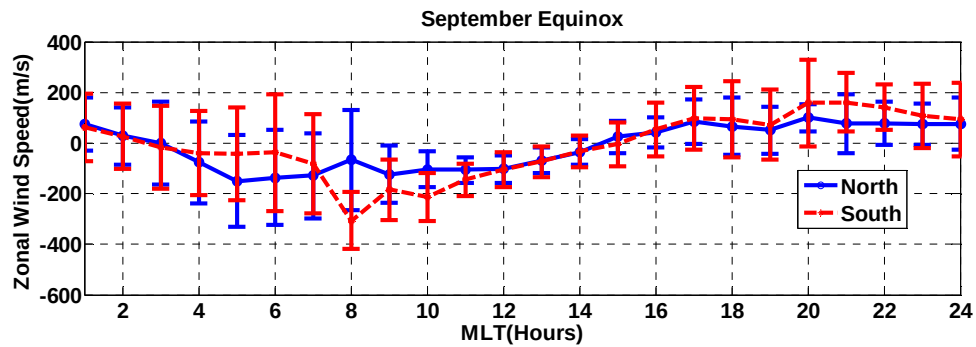
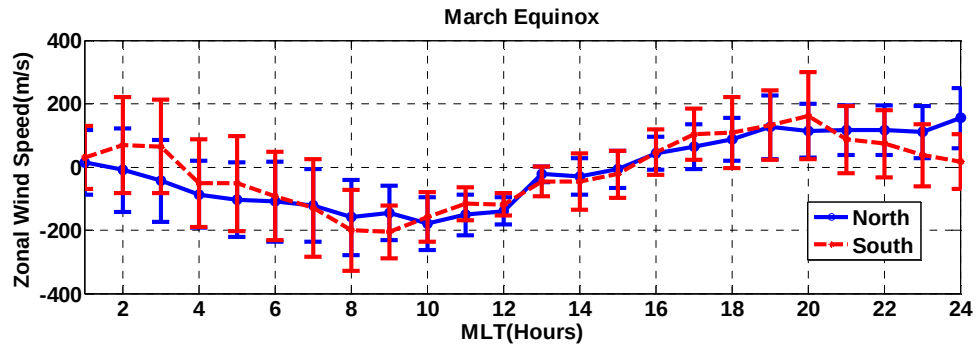
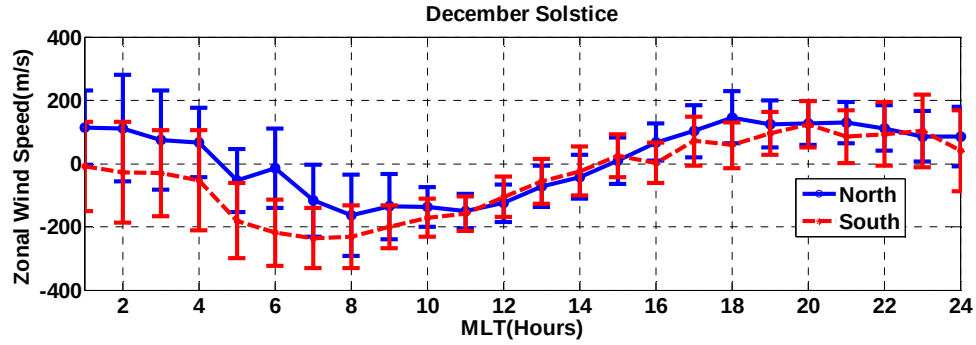
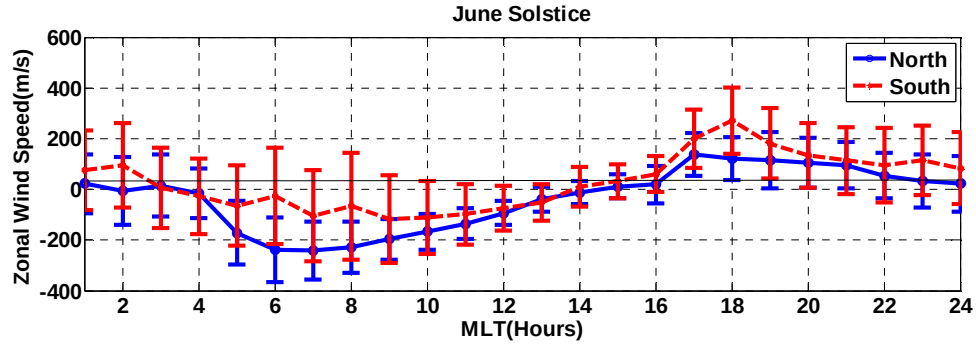


Figure 4. Zonal wind in the upper thermosphere for different seasons. Blue curves represent wind variation in the northern mid-latitudes (30° N- 40° N) and the dashed one is for variation southern mid-latitude (30° S- 40° S). The error bars correspond to the standard deviation of the observations of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

4. 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 2000MLT September equinox mean wind values may be extreme as enough measurements were not used in averaging. The error bars in figures 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 300km 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 1300LT while for CHAMP this change is observed at about 1500MLT. 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.

5. 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.

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