Lower and Upper thermosphere wind variations during magnetically quiet days.

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Abstract.

The mesosphere/lower thermosphere and thermospheric F-regions are dynamically coupled through thermospheric winds, tides and waves. The regular fluctuations in the earth's magnetic field on quiet days are caused by dynamo-induced currents which flow in the ionosphere/thermosphere system. This paper presents simultaneous mesosphere/lower thermosphere and upper thermospheric region wind observations during a quiet magnetic period using data from TIMED and CHAMP satellites. The upper thermospheric winds from two time local sectors are observed to be faster than the lower thermospheric winds.

1. Introduction

Based on thermal considerations the thermosphere is the layer located above the mesosphere. The thermosphere lies above the mesopause at above an approximate height of 90 km. The thermosphere ends at the boundary with the exosphere, approximately 500-700 km, where atoms can escape freely from the atmosphere (Kane, 2005). Unlike the mesosphere, temperature increases with height in the thermosphere. The thermosphere is often considered in a first approximation as a linear stable dissipative oscillatory system, which suppresses the small-scale and short- term structures more effectively than the large-scale and long-term ones (Kazimirovsky,2005). Much of the sun's X-rays and UV radiations are absorbed in the thermosphere. These radiations, in addition to ionizing radiations from outer space, ionize neutral species in the mesosphere and thermosphere forming the ionosphere. The ionosphere extends from about 60 to 800 km, and using electron density is subdivided into; the D region (70-90 km), E-region (90-150 km) and F-region (150-700 km). The terrestrial thermosphere and ionosphere form the most variable part of the Earth's atmosphere (Kazimirovsky and Vergasova, 2009).

Pressure gradients resulting from diurnal and latitudinal variations of neutral gas heating together with Coriolis effect, generate meridional and zonal winds in the earth's upper atmosphere. Ion drag resulting from collisions between ions and the neutral particles contributes in establishing the general pattern of the winds especially in the F-region thermosphere. The effect of molecular diffusion in the thermosphere becomes important at heights above about 110 km. Above this height there is rapid decrease in the densities of heavier molecular species.

The general heating for the Thermosphere-Ionosphere system comes from the interaction of the solar UV photons and energetic particles. Ion drag which brings about differential motion between the neutrals and ionized species is also an energy source for the thermosphere. Frictional heating of the neutrals and ions in the high latitudes caused by electric field driven currents is a major source of heat at the high latitudes. Figure 1 below shows the energy changes that take place between the thermosphere/Ionosphere system and the surroundings. Ions and atoms which are likely products from photoionisation and dissociation, and electron impact and ionization may be converted to different species in the thermosphere. These species may eventually recombine in reactions which are exothermic.

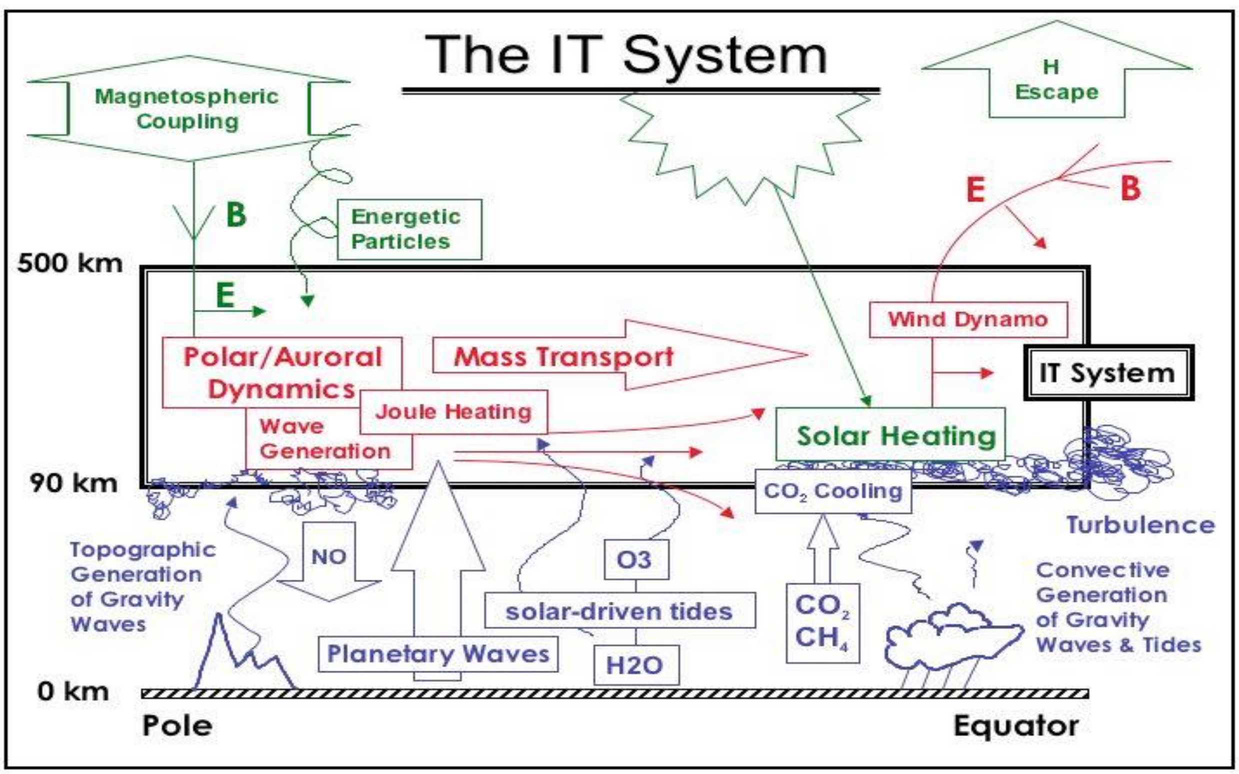

Figure 1. Energy input, conversion and transport processes in the Ionosphere-Thermosphere system (Forbes, 2007).

The aim of this paper is an attempt to compare wind variation in the lower and upper thermospheric regions during a quiet period using satellite data. Wind data for the month of September, 2003 from the TIMED and CHAMP satellites has been used for this study. The month of September, 2003 was a relatively quiet month. Quiet time disturbances (Q-disturbances) can either be positive or negative. Positive Q-disturbances occur under slightly enhanced auroral activity when high latitude heating increases and damps the solar driven poleward thermospheric circulation (Mikhailov et al., 2009). Negative Q-disturbances occur under so called ground state of the thermosphere which corresponds to very low geomagnetic activity with an unconstrained solar-driven thermospheric circulation characterized relatively strong daytime poleward wind and relatively low atomic oxygen concentrations at middle and sub-auroral latitudes (Mikhailov et al., 2007a).

The lower and upper thermospheres with the embedded ionosphere form a coupled system. Influences that originate at one height have influences elsewhere in the system. Ionospheric dynamo is driven by neutral winds, but operations of these winds in the E and F-layers are different. The E-layer and F-layer dynamos are linked by geomagnetic field lines, which act as highly conducting 'wires' because electrons can move freely along them to neutralize parallel electric field (Rishbeth, 1997).

2. Data Sources

The TIMED Doppler Interferometer (TIDI) is a wind measuring instrument on board the TIMED satellite. It measures horizontal wind vector winds in the mesosphere and lower thermosphere from an altitude of 70 km to 120 km. The TIDI telescopes perform limb scan simultaneously in four orthogonal directions: two at 45^0 forward but on either side of the spacecraft's velocity vector and two at 45^0 rearward of the spacecraft (Talaat et al., 2003). An image of the TIDI geometry is shown in figure 2 below. The TIMED satellite orbits an altitude of 625 km and the total inclination is 74.1^0; TIDI measures the horizontal vector wind field with an accuracy of 3 m/s and a vertical resolution of 2 km (Killeen et al., 2006). TIDI measures wind by measuring the Doppler shift of the atmospheric emission features.

Thermospheric wind is obtained from the 'Spatial Tri-axial Accelerometer for Research' (STAR) on board the Challenging Mini-Payload Satellite (CHAMP). The STAR accelerometer measures the non-gravitational accelerations acting on the satellite. Figure 3 shows the STAR and spacecraft reference frames. The orbital plane of the low Earth orbiting (LEO) spacecraft precesses by 1h of local time (LT) in 11 days, thus after 131 days all local times are covered (Ritter et al., 2010). Sutton et al. (2007) adapted the method used by Liu et al. (2006) to process the accelerometer dataset into density and wind datasets. During the month of September, 2003 the CHAMP satellite altitude varied between 390 km and 425 km. This range falls within the F-region of the embedded ionosphere.

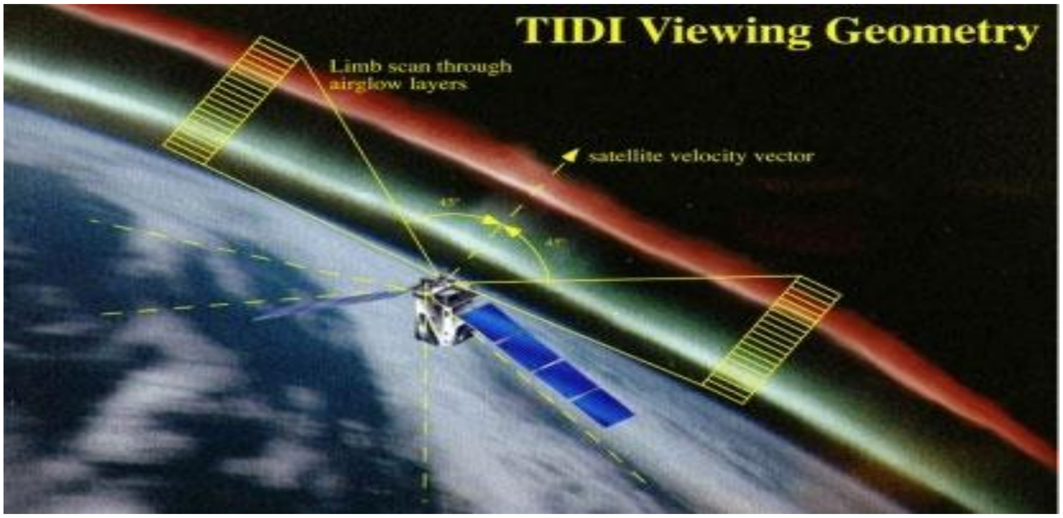

Figure 2. Illustration of TIDI viewing geometry (Killeen, 2002).

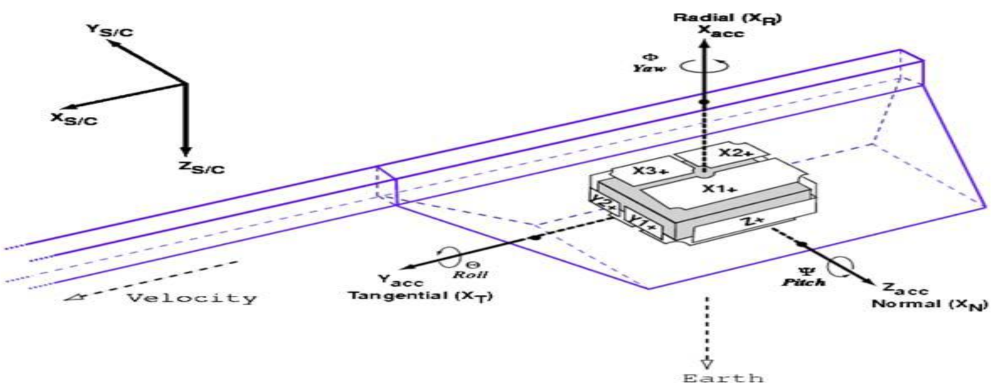

Figure 3. The STAR reference frame with respect to the fixed Spacecraft frame (Bruinsma et al., 2003).

3. Results and Discussion

The solar and geophysical conditions that prevalied during the period of study, the month of September, are shown in figure 2. The Dst index represents the axially symmetric disturbance magnetic field from large-scale magnetospheric current systems observed at the dipole equator on the Earth’s surface (Ritter et al.,2004). The Dst index varied between 35nT and -67nT. The global Kp index is the mean value of the disturbance levels observed at 13 selected mid-latitude stations during three-hour time intervals. According to a quasi-logarithmic scale it covers the range from 0 to 9. The highest Kp index values are recorded between 15^{th} and 20^{th}. The highest Ap value is observed within these days.

The solar flux varied with minimum values of about 90 s.f.u and maximun values going up to about 140 s.f.u recorded towards month end.

Figure 5 shows the latitudinal variation of the zonal and meridional winds with local time. (a),(b) and(c) represent zonal wind distributions at 90 km, 100 km and 110 km respectively while (d), (e) and (f) represent meridional wind distributions at 90 km,100 km and 110 km respectively. Figure 6 shows the zonal wind distribution in the upper thermospheric during the early morning sector and late afternoon sector.

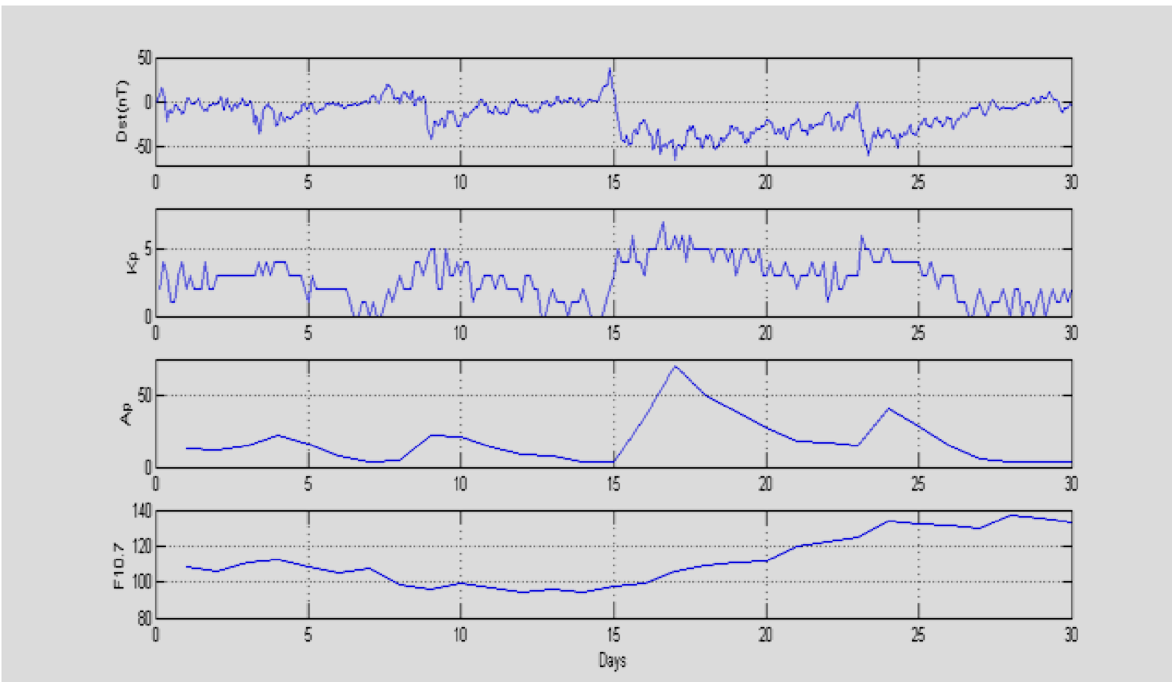

Figure 4. Solar (F10.7) and geomagnetic activity (Dst, Kp and Ap) conditions during the month of September 2003.

The meridional wind illustrates clear latitudinal structures. The winds are generally equatorwards for most of the day. Polewards winds are observed for the most of the evening to morning hours. At high latitudes in the northern hemisphere strong equatorward winds are experienced with speeds going above 150 m/s. Speeds up to 250 m/s are experienced at 90 km altitude. The zonal winds do not show any clearly defined structure at 90 and 100 km altitudes.

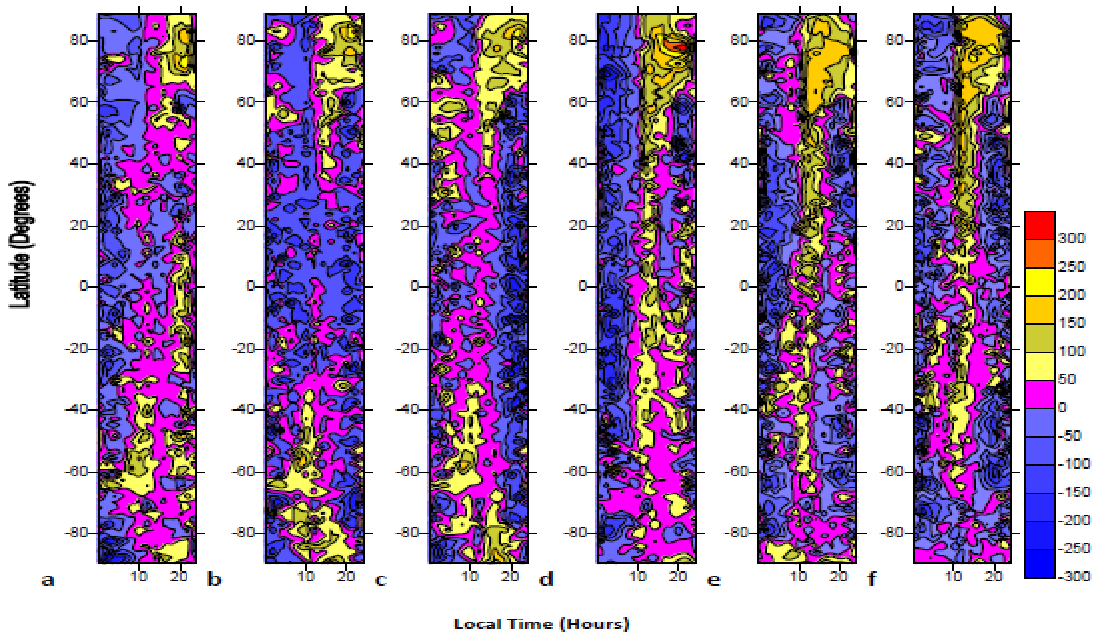

Figure 5. Zonal wind distribution at (a) 90 km (b) 100 km (c) 110 km and meridional wind distribution at (d) 90 km (e) 100 km (f) 110 km

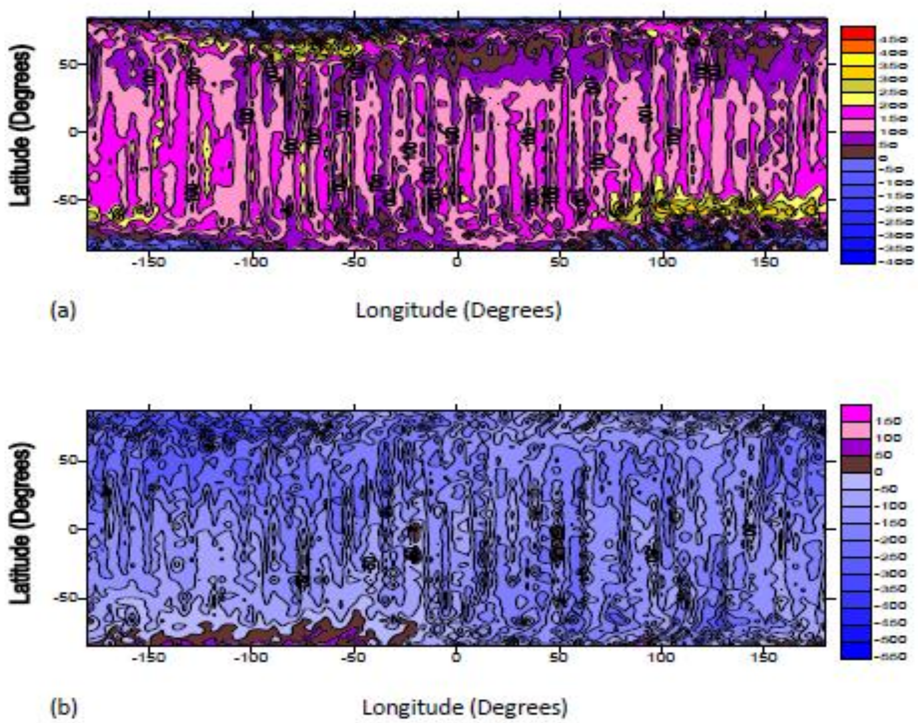

Figure 6. Latitude/longitude distribution of zonal wind from CHAMP at two hours local time sectors. (a) 1500-1900, (b) 0300-0700.

At high latitudes in the northern hemisphere evening winds are eastwards with speeds going above 150 m/s. At 90 km altitude pre-dawn winds are westwards (towards west) with speeds in excess of 200 km experienced in some locations. The CHAMP zonal winds are westward during the morning hours as shown in the local time sector (0300-09000) figure in 6b.

Early morning winds in this local time sector within the longitude band (-50 to -150 degrees) in the southern hemisphere high latitude are eastward (towards east) with speeds less than 50 m/s. Also within this longitude band in the North Pole winds with speeds up to 350 m/s are observed in the west direction. Wind direction in the afternoon to early evening local time sector (1500-1900) is generally westwards.

Under magnetically quiet conditions at mid-latitudes, meridional winds in the lower thermosphere are generally equatorward (towards equator) during daytime and poleward (towards poles) at night (Balan et al., 2004). From the distribution in figure 5, there is some agreement as the meridional winds presented in the lower thermosphere seem to follow this pattern. The F-region zonal winds in the mid-latitudes are generally westward before local noon and eastward in the afternoon, with a nighttime transition that occurs during the early morning hours in local winter and near midnight in local summer (Roble, 1983). Our winds in the presented sectors agree with this variation. The E-layer and F-layer wind systems are very different, the F-layer winds being generally faster and having less vertical structure than E-layer winds, because of the greater molecular viscosity (Rishbeth, 1997). From our distributions in figures 5 and 6 zonal winds in the upper thermosphere as observed in the two local time sectors are faster than the E-region winds observed by the TIMED satellite.

The lower thermosphere dynamics at quiet times is different from what is observed at the F-region. In addition to the difference with optical depth, the lower thermosphere is strongly influenced by tides, gravity waves and planetary waves from the lower atmosphere. In the F-region circulation is primarily governed by solar EUV heating at low and middle latitudes, at high latitudes it is strongly controlled by ion drifts associated with magnetospheric convection (Roble, 1983). Under very quiet geomagnetic conditions, clear thermospheric and ionospheric signatures of magnetospheric processes are only seen at high geomagnetic latitudes (Rees, 1995).

4. Summary and Conclusion

During magnetically quiet times, meridional wind in the lower thermosphere is generally equatorward during daytime and poleward at night. The zonal winds in the lower thermosphere are generally westward. Early morning local time sector upper thermospheric zonal winds are westward, while the late afternoon local time winds are eastwards.

The upper thermosphere winds in the early morning and late afternoon local time sectors are faster than zonal winds in the lower thermosphere. The datasets used may not reveal a good comparison as data is obtained from the two satellites by two different methods. Upper themospheric winds from CHAMP are derived from the accelerometer readings while Lower thermospheric winds are obtained from the Doppler interferometer. There is need to consider the plasma effect and the field line structure.

Simultaneous measurements need to be carried out at several points in the thermosphere to overcome the uncertainty associated with single satellite measurements.

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