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Mid-latitude thermospheric zonal winds during the equinoxes

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Abstract

The diurnal variation of the mid-latitude upper thermosphere zonal winds during equinoxes has been studied using data recently generated from CHAMP measurements from 2002 to 2004 using an iterative algorithm. The wind data was separated into two geomagnetic activity levels, representing high geomagnetic activity level ($Ap > 8$) and low geomagnetic activity level ($Ap \leqslant 8$). The data were further separated into two solar flux levels; with $F10.7 > 140$ for high and $F10.7 \leqslant 140$ for low. Geomagnetic activity is a correlator just as significant as solar activity. The response of mid-latitude thermospheric zonal winds to increases in geomagnetic disturbances and solar flux is evident. With increase in geomagnetic activity, midday to midnight winds are generally less eastward and generally more westward after the about midnight transitions. The results show that east west transitions generally occurred about midnight hours for all the situations analyzed. The west to east transition occurs from 1400–1500 MLT. Enhanced westward averaged zonal wind speeds going above 150 ms^{-1} are observed in the north hemisphere mid-latitude about sunrise hours (~0700–1100 MLT). Nighttime winds in the north hemisphere are in good agreement with previous single station ground observations over Millstone Hill. Improved ground observations and multi satellite observations from space will greatly improve temporal coverage of the Earth's thermosphere.

Keywords: Thermospheric zonal winds; Equinoxes; Geomagnetic activity; Mid-latitudes

1. Introduction

The Earth's thermosphere together with the imbedded ionosphere forms an intermediary region between the magnetosphere and the neutral atmosphere below. The thermosphere is often considered to a first approximation 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 (Kazimirovsky et al., 2006). Thermospheric variability can be externally or internally generated. The reason for the extreme variability of the thermosphere-ionosphere system is its rapid response to external forcing from various sources, i.e. solar ionizing flux, energetic particles and electric fields imposed through interaction between solar wind, magnetosphere and ionosphere as well as coupling from below (meteorological influences) (Kazimirovsky and Vergasova, 2009). The thermosphere-ionosphere system response varies from minutes to several hours depending on the sources and the distances from these sources. Under disturbed geomagnetic conditions, thermospheric neutral winds at F-region heights exhibit large deviations from the quiet time climatological behavior. Under quiet geomagnetic conditions the F-region thermosphere is at ground state with a relative low atomic oxygen concentration as compared to concentration during active periods. The mid-latitude thermosphere at F-region heights is generally under the influence of solar EUV and UV forcing during geomagnetic quiet times but is strongly influenced by high latitude heat and momentum sources during geomagnetic disturbances (Hernandez and Roble, 1984).

The neutral winds are an important driver or a critical parameter in nearly all electrodynamic and plasma physics

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processes in the mid- and low-latitude ionosphere–thermosphere (Larsen and Fesen, 2009). 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 is dominated by in situ solar heating, giving rise to a diurnal circulation pattern (Emery, 1977). The mid-latitude thermosphere exhibits irregular behavior on a time scale of hours (Walker, 1988). The thermosphere is stably stratified so the factors that give rise to the irregular behavior are likely different from those in the troposphere. The negative temperature gradient in troposphere lead to convection which contributes to irregular behavior in this lower layer of the atmosphere, while irregular behavior in the upper layer, the thermosphere, with a positive temperature, is due to influences from the incoming solar radiation.

Many of the interactions of the Earth's thermosphere with the imbedded ionosphere govern how it interacts with the UV and EUV radiations. The present day concept of the thermosphere-ionosphere interaction is based on two circulation systems; solar driven and storm-induced interactions (Mikhailov et al., 2009). The thermosphere and the ionosphere overlap but describe two different particle populations, the neutral and ionized species. The ionospheric F-region and the thermosphere exist as a closely coupled system through neutral-ion interactions. These layers are divided because the factors which influence the motion and structure of one do necessarily affect the other in a similar way.

Much of the earliest ideas concerning thermospheric dynamics were inferred from observations of the ionosphere (Babcock, 1978). Zonal winds were first studied by analyzing their effect on satellite orbits which was termed "superrotation" of the atmosphere (King-Hele, 1964) and was estimated using measurements of satellite inclination. Today thermospheric winds are observed using three main techniques namely; the Incoherent Scatter Radar technique, the optical technique and the satellite drag technique. Most of the upper atmosphere wind analysis has been carried out using the relatively large database of optical and radar observations. Although a number of important features have been derived from data sets obtained from Fabry–Perot interferometer wind observations , the interferometer technique has its limitations (e.g. uncertainty in emission height, restriction to dark hours, clear sky and reduced moon phases) (Lühr et al., 2007). The radar technique is not reliable under disturbed conditions. The satellite technique provides wind measurements globally and can be used for wind measurements at F-region heights and above. Earlier analyses of neutral winds from accelerometer data were scarce but this has changed drastically with the extended wind data base made possible by winds obtained from CHAMP accelerometer readings.

Studies of mid-latitude winds during quiet times reveal a general pattern of solar EUV-driven day-to-night circulation with zonally averaged winds directed from the summer to the winter hemisphere, and a seasonal transition which the NCAR-TGCM predicted to occur abruptly near the equinoxes (Roble et al., 1977). Mid-latitude thermospheric wind studies have carried out in the last two decades using Fabry–perot interferometers, incoherent scatter radar, ground-based ionosonde , satellite data and general circulation models (Balan et al., 2004; Bounsanto, 1991; Burns et al., 1995; Duboin and Lafeuille, 1992; Emery et al., 1999; Fejer et al., 2002; Fesen et al., 1995; Fuller-Rowell et al., 1994, 1996; Hedin et al., 1991; Kawamura et al., 2000;Titheridge, 1995). It is the neutral wind parameter that has most lacked attention in regard to the many issues pertaining to the forecasting of ionospheric weather (Meriwether, 2006).

Data from new observational initiatives from space (e.g. CHAMP and GRACE missions) and ground (e.g., the newly developed Optimized Fabry–Perot interferometer) are being used to address and update the much needed information regarding variations of neutral winds, ion drifts and electric fields. Recent analysis of wind data from CHAMP satellite has provided an excellent statistical behavior of thermospheric zonal winds. CHAMP wind data has been used for detailed wind studies in the equatorial latitudes recently by Häusler et al. (2007), Liu et al. (2006), Häusler and Lühr (2009). In the study by Häusler et al. (2007) at dip equator latitudes for the combined equinoxes, the statistical analysis revealed the largest longitudinal dependence of the CHAMP zonal delta winds during morning hours, 03:00–09:00 local time. The study also revealed that the influence of solar flux level was insignificant. Liu et al. (2006) presented a climatology of CHAMP zonal winds in the equatorial region using data from 2002–2004. Their results confirmed the diurnal variation with westward winds and eastward winds in the morning and evening sectors, respectively. The zonal winds generally revealed little dependence on magnetic activity but the effect of solar flux was significant. In their study Häusler and Lühr (2009) presented the annual variation of the prominent wave-4 structure in the zonal wind at 400 km altitude, using 4 years of CHAMP accelerometer measurements from 2002–2005. The studies showed the observed wave-4 structure in the upper thermospheric wind can be attributed to the pressure of the eastward propagating diurnal tide with zonal wavenumber $s = 3$ (DE3). The studies also revealed that the largest amplitudes of DE3 are found along the dip equator. Lühr et al. (2007), in their study, presented thermospheric wind patterns at Polar Regions around the June solstice using wind data from CHAMP. Förster et al. (2008) used CHAMP wind data to study thermospheric response to the driving forces of