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Journal of Atmospheric and Solar-Terrestrial Physics 69 (2007) 1419–1430

Journal of ATMOSPHERIC AND SOLAR-TERRESTRIAL PHYSICS

www.elsevier.com/locate/jastp

A statistical analysis of longitudinal dependences of upper thermospheric zonal winds at dip equator latitudes derived from CHAMP

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Received 1 November 2006; received in revised form 16 March 2007; accepted 2 April 2007
Available online 25 April 2007

Abstract

New observations, obtained by the accelerometer onboard the CHAMP satellite, reveal a detailed picture of the thermospheric zonal wind. Based on three years of data (2002–2004) we have studied the longitudinal dependence of the zonal delta wind (deviations from the zonal average) at the dip equator. The large number of passes (~33 750) allows to consider several aspects of the wind characteristics at the same time. For this analysis we derived the longitudinal variation of the zonal delta wind at about 400 km altitude and investigated its dependence on solar flux, magnetic activity, and season. Major longitudinal dependences are confined to the morning hours, 03-09 local time (LT). The amplitude of the delta wind is approximately proportional to the latitudinal displacement of the magnetic dip equator from the geographic equator. The direction of the delta wind reverses sign between the June and December Solstices. During Equinox seasons these large scale features are almost absent. The flux level of solar EUV has no significant influence on the longitudinal variations. A dependence on magnetic activity could only be found during the post-sunset hours, 18-21 LT. Performing a Fourier transform of our delta wind velocities revealed a dominance of the wavenumber 4 in the Equinox data at some LT sectors. The wave-4 structure is a prevailing feature in the slowly precessing satellite frame, which has been recently reported, e.g. in nonmigrating tidal temperature measurements of the SABER instrument on the TIMED satellite in the Mesosphere Lower Thermosphere (MLT) region. Therefore, this statistical study of zonal wind longitudinal dependences provides new observational evidence for the coupling of the various atmospheric layers by nonmigrating tides.

Keywords: Thermospheric winds; Thermosphere–ionosphere interaction; Atmospheric tides; Equatorial zonal wind

1. Introduction

Thermospheric winds play an important role for the electrodynamics of the upper atmosphere due to the ion/neutral interaction. Nevertheless, our knowledge about details of the winds is quite sparse because of the lack of sufficient measurements. A climatology of the equatorial zonal winds derived from CHAMP (CHAllenging Minisatellite Payload) data at an altitude of 400 km was recently presented by Liu et al. (2006). As expected, there is a dominant diurnal variation comprising winds blowing away from the afternoon density maximum, westward in the morning and eastward in the evening

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1364-6826/$ - see front matter
doi:10.1016/j.jastp.2007.04.004

sector. The authors show that there is a strong dependence of the wind velocity on the solar flux, F10.7, but little dependence on the magnetic activity index, Kp. For high solar activity (F10.7$\geqslant$140) the wind is directed westward from 06–12 LT during all seasons and directed eastward for the rest of the day. In the case of low solar activity (F10.7$<$140) the zonal wind switches to westward direction about 2 h earlier (between 03-04 LT) and keeps that direction until 12 LT and then turns eastward again for the remaining day.

Longitudinal dependences of zonal winds in the upper thermosphere have been reported by Wu et al. (1994). The authors analyzed Dynamical Explorer 2 (DE 2) measurements of thermospheric neutral temperatures and horizontal wind components at equatorial latitudes between $\pm 9^{\circ}$ over an altitude range of 200–400 km. However, the majority of the DE 2 wind and temperature spectrometer (WATS) data were taken within the altitude range of 300–400 km (Wharton et al., 1984). Their main focus was on the longitudinal dependence of these quantities on the duskside, dayside, and nightside for active and quiet geomagnetic conditions. The time interval 16–19 LT (duskside) was sampled between November 1, 1982 and January 31, 1983. The dayside (09–11 LT) measurements were taken between September 1 and November 30, 1981 and the nightside (00–02 LT) samples came from January 1 to February 14, 1983. For the zonal wind under quiet conditions they found that on the dayside at 0° longitude the westward wind component is reduced to about -10 m/s compared to -75 m/s at 120°W. The predicted zonal wind from the vector spherical harmonic (VSH) model shows no significant longitudinal dependence. Furthermore, no distinct longitudinal dependence on the duskside and nightside were found. However, the derived longitudinal variations from DE 2 on the nightside are less reliable because of sparse data coverage. For the reduction of the dayside zonal wind near 0° longitude Wu et al. (1994) suggested the influence of the South Atlantic Anomaly (SAA) as one possible cause. Due to a higher level of ionization the ion drag on the neutral particles should result in a deceleration of the wind within the longitude range of the SAA (-90°–0°E.)

Longitudinal dependences of the wind velocity in the MLT region can be caused by the presence of nonmigrating tides (Forbes et al., 2003). Together with migrating tides, nonmigrating tides are a part of global-scale oscillations in temperature, wind, and density at periods that are harmonics of a solar day (e.g. Chapman and Lindzen, 1970; Forbes, 1995). Migrating tides follow the apparent westward motion of the sun. The zonal wavenumber, s, is equal to the frequency (in cycles per day). Depending on the altitude, migrating solar atmospheric tides are either thermally forced by the absorption of solar radiation by tropospheric H_2O, by stratospheric and lower mesospheric O_3, by lower thermospheric O_2 and N_2, and by O in the upper thermosphere (Hagan et al., 1995). For the nonmigrating tides the zonal wavenumber, s, is not equal to the frequency (in cycles per day), which means that they can either propagate westward ($s<0$), eastward ($s>0$) or remain standing ($s=0$) in an Earth-fixed frame. Zonal asymmetries (i.e. topography, land–sea differences, longitudinal dependences in absorbing species) (Forbes et al., 2003) or nonlinear interactions between the migrating diurnal tide and planetary waves (Hagan and Roble, 2001) or gravity waves (McLandress and Ward, 1994) are some mechanisms that may agitate diurnal nonmigrating tides. Furthermore, latent heat release in the tropical troposphere can be an important source of nonmigrating tides, too. This was confirmed by Hagan and Forbes (2002) who investigated the effect of tropospheric latent heat release to the migrating and nonmigrating diurnal tides in the MLT region with the global-scale wave model (GSWM). The eastward propagating diurnal tide with zonal wavenumber 3 (DE3) dominates the GSWM diurnal amplitude maxima response to latent heating. Its amplitude maxima surpass the amplitude maxima of the westward propagating tide with wavenumber 1 (DW1) during 9 months of a year although the DW1 is the most persistent major component of the GSWM latent heating solutions (Hagan and Forbes, 2002). The strong influence of the DE3 tide on the tidal variability in the MLT region was confirmed by Forbes et al. (2006). Analyzing temperature measurements taken by SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) on the TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) satellite revealed an apparent wave-4 structure in longitude. For satellite instruments measuring at constant local time at a specific latitude and orbit node, the observed wavenumber is Doppler-shifted (Oberheide et al., 2003). This implies that the observed wave-4 pattern is either caused by the DE3 or by the DW5 tidal component.