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Solar activity variations of nocturnal thermospheric meridional winds over Indian longitude sector

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ABSTRACT

The night time F-layer base height information from ionosondes located at two equatorial stations Trivandrum (TRV 8.5°N, 77°E) and Sriharikota (SHAR 13.7°N, 80.2°E) spanning over two decades are used to derive the climatology of equatorial nocturnal Thermospheric Meridional Winds (TMWs) prevailing during High Solar Activity (HSA) and Low Solar Activity (LSA) epochs. The important inferences from the analysis are 1) Increase in mean equatorward winds observed during LSA compared to HSA during pre midnight hours; 25 m/s for VE (Vernal Equinox) and 20 m/s for SS (Summer Solstice), AE (autumnal Equinox) and WS (Winter Solstice). 2) Mean wind response to Solar Flux Unit (SFU) is established quantitatively for all seasons for pre-midnight hours; rate of increase is 0.25 m/s/SFU for VE, 0.2 m/s/SFU for SS and WS and 0.08 m/s/SFU for AE. 3) Theoretical estimates of winds for the two epochs are performed and indicate the role of ion drag forcing as a major factor influencing TMWs. 4) Observed magnitude of winds and rate of flux dependencies are compared to thermospheric wind models. 5) Equinoctial asymmetry in TMWs is observed for HSA at certain times, with more equatorward winds during AE. These observations lend a potential to parameterize the wind components and effectively model the winds, catering to solar activity variations.

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1. Introduction

Measurements of TMWs have been scarce owing to the complexities involved in the measurement process. In the recent years long-term datasets and increased number of measurements has made TMWs a subject matter of intense theoretical as well as experimental studies. Nighttime meridional wind reversal and its linkage to Midnight Temperature Maximum (MTM) were studied using optical and radar instruments (Harper, 1973; Sastri et al., 1994). Burnside and Tepley (1989) performed wind measurements using a FPI at Arecibo in the south-American longitude sector and partly due to measurement uncertainties at the time, did not record any significant solar activity dependences. The solar and magnetic activity dependence of meridional neutral winds at 300 km altitude have been studied from the data obtained using 15 years of measurements by the incoherent scatter facility at Saint-Santin (France) by Duboin and Lafeuille (1992). They report an increase in poleward wind magnitude with increasing solar activity in the daily mean winds obtained. The Horizontal Wind Model, an empirical model, was developed based on integration of measurements from different platforms such as FPI, Incoherent Scatter radar and satellites (Hedin et al., 1988, 1991). A co-ordinated analysis of mid latitude data carried out by Hedin et al. (1994) however, revealed poleward shift in winds with increasing solar activity that could not be accounted by HWM. Buonsanto and Witasse (1999) using Incoherent Scatter Radar observations of meridional winds at Millstone hill observatory report an increase in equatorward winds during 2000–2400 h local time with decreasing solar activity. Later on, studies from the south-American sector using an extended database of three solar cycles using FPI measurements by Tepley et al. (2011) and Brum et al. (2012) report solar activity dependences.

Apart from incoherent scatter technique and FPI technique, another way to determine TMWs are using ionosonde F layer heights. A technique to derive thermospheric wind from ionosonde h'F measurements was developed by Krishna murthy et al. (1990). The winds thus obtained were validated through rocket measurements by Sekar and Sridharan (1992). Further, the seasonal variations of thermospheric winds during high solar activity were discussed by Hari and Krishna murthy (1995). Nogueira et al. (2011) investigated the response of thermospheric meridional wind during geo-magnetic storm events over Brazil using a similar technique of obtaining winds. Important studies using ionosonde

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derived TMWs from East-Asian sector also explore responses of TMWs to seasonal/solar activity and MTM related abatement (Maruyama et al., 2008; Liu et al., 2003a, 2003b; Luan et al., 2004). Equinoctial asymmetry in winds is also reported (Maruyama et al., 2009).

It is important that a data base of the thermospheric meridional winds under different geophysical conditions is generated especially in view of the fact that there is a scarcity of wind measurements in the equatorial region. Meridional winds have an impact over the magnitude of Equatorial Ionization Anomaly (EIA) crests depending on the season and time of day (Bramley and Young, 1968; Rishbeth, 1972). The upward/downward movement of ionization along the magnetic field lines due to the effects of thermospheric meridional wind causes increase/decrease of EIA strength in low latitudes as reported by Tulasiram et al. (2009). Also in the night-time F region, TMWs are having significant impact over the sustenance of Equatorial Spread F (ESF) below a critical height of F layer (Devasia et al., 2002; Manju et al., 2007; Madhav Haridas et al., 2013). The Equatorial Temperature and Wind Anomaly (ETWA) setup by TMWs due to the temperature changes caused by increased ion-drag at the EIA crests have significant impact over the vertical winds at magnetic equator (Sastri, 1990; Raghavarao et al., 1991).

The present work addresses the solar activity variability aspect of TMWs, which has been hitherto unexplored with a significant database in the Indian longitude sector. In the present study, using a vast database of ionosonde data from the two stations located at Trivandrum and SHAR, conclusive evidence of solar cycle dependence of the night time meridional winds are brought out. Further, mechanisms involved in the reduction of wind magnitudes are examined and the role of the ionization distribution through the ion drag locally modulating the thermospheric meridional winds is found to be a significant factor contributing to the observed solar flux differences. This study also brings out the need to improve upon the existing wind models that do not fully account for the observed solar activity variabilities in TMWs. The observations are compared with the Horizontal Wind Model (Hedin et al., 1991) and the TIEGCM model (Roble et al., 1977; Dickinson et al., 1981; Qian et al., 2014) and their effectiveness in reproducing the observations is discussed.

2. Data and method of analysis

The meridional wind estimation is done using ionosonde data from TRV (geographic lat/long: 8.5°N77°E; dip 0.9° ; Dec -2.6°) and SHAR (13.5°N 80.2°E; dip 13.2° ; Dec -1.6°) following the method developed by Krishna murthy et al. (1990).

The method is based on the fact that at the magnetic equator during night-time, the F-region vertical drift is due to $E \times B$ (where E is the east-west electric field and B is the magnetic induction) while at locations away from it, the meridional component (U) of the neutral wind also has a contribution to it apart from diffusion (Rishbeth et al., 1978). An equatorward (poleward) wind pushes the ionization up (down) along the field lines. The vertical drift V at a location such as SHAR is given as

$$V = V_D \cos I - U \cos I \sin I - W_D \sin^2 I \tag{1}$$

Where V_D is the electrodynamic ExB drift, U is the meridional component of neutral wind, I is the dip angle and W_D is the plasma drift due to diffusion. In view of the fact that the two stations are not widely separated, the assumption is that east/west electric field is constant in that limited region and so is the ExB drift at the two stations. Since the magnetic dip at SHAR is high enough the meridional neutral wind also contributes significantly to V. Simplifying Eq. (1), the meridional wind can be estimated from the expression (2).

$$U = \left[\frac{2(V_D \cos I - V)}{\sin 2I}\right] - W_D \tan I \tag{2}$$

The observed vertical drift velocities are initially derived from the rate of change of h'F, (d(h'F)/dt)). For Trivandrum and SHAR it is denoted by V_T and V_S respectively. The true vertical drift is obtained from the observed vertical drift after removing apparent drift due to recombination.

$$V_D = V_T - \beta_T H_T \tag{3}$$

$$V = V_S - \beta_S H_S, \tag{4}$$

where the suffixes T and S denote the parameters at Trivandrum and SHAR respectively, β is the effective recombination coefficient and H is $[N^{-1}\,dN/dh]^{-1}$, N representing the electron density and h the height. Substituting for V_D and V in Eq. (2), the meridional component of the neutral wind is obtained as,

$$U = \left[\frac{2(V_D \cos I - V)}{\sin 2I}\right] - \frac{2(\beta_T H_T \cos I - \beta_S H_S)}{\sin 2I} - W_D \tan I \tag{5}$$

The recombination coefficient β is given by

$\beta = K_1[N_2] + K_2[O_2]$, where K_1 K_2 are the reaction rates of $[N_2]$ and $[O_2]$ (Anderson and Rusch, 1980). $[N_2]$ and $[O_2]$ are the number densities of N_2 and O_2 respectively obtained from MSIS model (Hedin et al., 1988). It is to be noted that the winds thus obtained are based on the estimates of contribution to magnetic meridional direction near the magnetic equator.

The plasma drift due to diffusion W_D is given by,

$$W_D = \frac{1}{m_i \upsilon_{in}}\left\{\frac{1}{N} * \frac{d}{dh}\left[Nk(T_i + T_e)\right] + m_i g\right\} \tag{6}$$

Here N is electron density, m_i is ionic mass, k is Boltzmann's constant and υ_{in} is the ion-neutral collision frequency and Te and Ti are electron and ion temperatures. TIEGCM simulations reveal that the F_2 layer is isothermal considering both ion and electron temperatures in the altitude regions of interest in this study. Accordingly, the W_D expression reduces to the second term in Eq. (6) that is, g/υ_{in}.

The first term in Eq. (5) is obtained from ionogram data, while the second and third terms are derived using atmospheric models. The meridional wind U is thus estimated from Eq. (5). A mammoth effort was undertaken to scale each ionogram of 15 min cadence for the years spanning 1989 to 2008 from two stations. A sum total of ∼650 days of data have gone into the mean for low solar activity years (1993–1998, 2003–2008; SFU < 130) and ∼300 days for high solar activity years (1989–1992; 1999–2002; SFU ≥ 150) making it a large database of meridional wind. Periods contaminated due to spread F are eliminated from all the data. Previous references chose the level of Ap < =70 as quiet conditions as far as impact on meridional winds were concerned (Krishna murthy et al., 1990). However, we have adopted the cut-off of Ap < 18 to represent magnetically quiet days since monthly mean values of winds having more number of days with higher Ap levels are seen to bias the observations. The sources of error in wind estimation are from the ambiguity in ionosonde h'F determination (first term of Eq. (5)), errors in model estimation of β (second term of Eq. (5)) and error due to diffusion. The error due to β increases for days with low h'F while simultaneously, the error in diffusion decreases and vice versa. Also, the maximum limit of error in the estimation of a single wind time series is calculated to be ± 25 m/s. However, the mean is taken for a number of such points and over several years

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