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Nighttime thermospheric meridional neutral winds inferred from ionospheric $h'F$ and $hpF2$ data

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Abstract

Nighttime thermospheric meridional winds aligned to the magnetic meridian have been inferred using $h'F$ and $hpF2$ ionosonde data taken from two equatorial stations, Manaus (2.9°S, 60.0°W, dip latitude 6.0°N) and Palmas (10.17°S, 48.2°W, dip latitude 6.2°S), and one low-latitude station, Sao Jose dos Campos (23.21°S, 45.86°W, dip latitude 17.26°S), during geomagnetic quiet days of August and September, 2002. Using an extension of the ionospheric servo model and a simple formulation of the diffusive vertical drift velocity, the magnetic meridional component of the thermospheric neutral winds is inferred, respectively, at the peak ($hpF2$) and at the base ($h'F$) heights of the F region over Sao Jose dos Campos. An approach has been included in the models to derive the effects of the electrodynamic drift over Sao Jose dos Campos from the time derivative of $hpF2$ and $h'F$ observed at the equatorial stations. The magnetic meridional winds inferred from the two methods, for the months of August and September, are compared with winds calculated using the HWM-90 model and with measurements from Fabry–Perot technique. The results show varying agreements and disagreements. Meridional winds calculated from $hpF2$ ionospheric data (servo model) may produce errors of about 59 m/s, whereas the method calculated from the F-region base height ($h'F$) ionospheric data gives errors of about 69 m/s during the occurrence of equatorial spread-F.

Keywords: Thermospheric neutral winds; F region; Atmospheric models; Digital ionosonde

1. Introduction

Several studies have shown that many of the upper atmosphere phenomena can be explained and attributed to the effects of thermospheric neutral winds. Hanson and Moffett (1966) appear to be the first to show that neutral winds can account qualitatively for the day-to-night changes in the height and density of the ionospheric $F2$-peak. They reported that the component of the wind blowing along the magnetic meridian can move the plasma along the magnetic field lines causing vertical ionization drifts, thereby altering the electron density distribution at F-region heights.

In the face of a better knowledge of the various phenomena involved in the thermosphere–ionosphere system, at different latitudes, several methods have been developed to determine the meridional neutral winds. Direct measurements of airglow emissions at ionospheric heights can be made through ground-based optical techniques to determine the neutral wind velocities (see e.g., Meriwether et al., 1973; Sahai et al., 1992; Emmert et al., 2003). However, indirect methods are the most used to derive the meridional winds, and have been exploited in several investigations in the last decades. As examples, the technique using incoherent scatter radars can provide the meridional winds from measurements of ion velocity (see e.g., Burnside et al., 1983; Griffin et al., 2004), meridional winds

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can be derived from satellite measurements of airglow emissions (Bittencourt et al., 1976; Bittencourt and Tinsley, 1977) or can also be estimated using ionospheric *F*-region height parameters scaled from ionograms recorded by ground-based ionosondes (Bittencourt and Sahai, 1978; Miller et al., 1986; Murthy et al., 1990; Richards, 1991; Titheridge, 1995; Buonsanto et al., 1997; Liu et al., 2003a,b,c; Luan et al., 2004). In general, due to the attribution of some basic assumptions, these indirect methods are subject to a number of uncertainties, but they have been used successfully from several studies to describe the main morphological features of the wind component that affects the behavior of the ionosphere at *F*-region heights.

The use of ionospheric height parameters data coupled to simple numerical approaches has been extensively devised to derive the meridional neutral winds. One of these approaches, developed by Rishbeth (1967), uses simplified servo equations, which are still useful to describe the behavior of the *F2*-peak. These equations, further detailed by Rishbeth et al. (1978) and Ganguly et al. (1980), have been used by innumerable authors to explain changes in the *F2*-layer due to vertical drifts caused by the effects of winds and electric fields at mid-latitudes (McDonald et al., 1985; Yagi and Dyson, 1985; Miller et al., 1986; Buonsanto, 1990). Also, using the servo model, Foppiano et al. (2003) have calculated thermospheric winds for middle to high latitudes, and Sridharan et al. (1991), Gurubaran and Sridharan (1993), and deMedeiros et al. (1997) for low-latitudes.

At near-equatorial latitudes another simple approach, described by Murthy et al. (1990), has also been used to derive the meridional winds from experimental values of the *F*-region base height ($h'F$).

In the present paper, we derive nighttime thermospheric meridional neutral winds over a low-latitude station using experimental values of ionospheric $h'F$ and *hpF2* data obtained from three digital ionosonde measurements. The models used to determine the meridional wind velocity from its effect to the *F*-region peak and base heights are reviewed in Section 2. The observational data and the methods used to calculate the meridional winds are described in Section 3. The results obtained from the different methods are discussed in Section 4, which also points other relevant aspects directly arising from the calculations. Finally, in Section 5 we summarize the relative importance of the two approaches used to determine the magnetic meridional component of the neutral winds.

2. Models used to infer the thermospheric meridional winds

2.1. The servo model of the nighttime F2-peak layer

The servo model developed by Rishbeth (1967) and Rishbeth et al. (1978) provides a physically simple description of conditions at the peak of the ionospheric *F2*-layer (Titheridge, 1995). According to the model, in the absence of any applied forcing that causes ionization drift, the nighttime *F2*-peak forms in a ‘stationary height’ h_S where the loss rate due to plasma recombination equals the rate of plasma diffusion. Hence, this ‘stationary height’ occurs when:

$$\beta_S = \frac{kD_S \sin^2(I)}{2H^2(kac-1)}, \quad (1)$$

where β_S and D_S represent, respectively, the chemical loss coefficient and the ambipolar plasma diffusion coefficient that apply to the ‘stationary level’ h_S, I is the magnetic dip angle, H denotes the scale height of the dominant constituent at *F2*-peak heights, k is a loss scale height factor proportional to the ratio of the molecular to the atomic masses, a is a layer shape factor and c is a empirical constant that adjusts the relative importance of the transport processes and the loss terms at the *F2*-peak.

This ‘stationary height’ changes with time to a new ‘equilibrium level’ if a time varying vertical drift due to electric fields or neutral winds is applied to the *F2*-peak. The actual peak height h_m tends exponentially towards this ‘non-zero drift equilibrium level’ at a rate determined by diffusion and loss in the ‘stationary level’, and its approach is governed by the following servo equation (Rishbeth et al., 1978):

$$W = H\left[\frac{dz_m}{dt} + \frac{D_S \sin^2(I)}{2H^2}\left(e^{z_m} - e^{-kz_m}\right)\right], \quad (2)$$

where z_m is the ‘reduced height’ of the actual peak height measured in units of H, and W is the vertical plasma drift applied by neutral winds or electric fields, being given by

$$W = V_E \cos(I) + U_M \cos(I)\sin(I), \quad (3)$$

where V_E is the ion drift velocity component perpendicular to the Earth’s magnetic field B and related to the component of the electrostatic field E by $V_E = E_{\perp east}/B$, and U_M is the horizontal component of the thermospheric neutral wind (positive northward in the southern hemisphere) aligned with the local geomagnetic field.

An equation to calculate the magnetic meridional component of the neutral winds can be obtained coupling the Eq. (3) to the servo mechanism controlling the *F2*-peak height demonstrated by the servo equation (2):

$$U_M = \frac{dz_m}{dt}\frac{H}{\cos(I)\sin(I)} - \frac{D_S}{2H}\frac{\sin(I)}{\cos(I)}\left(e^{-kz_m} - e^{z_m}\right) - \frac{(E/B)}{\sin(I)}. \quad (4)$$

As pointed in previous works (Buonsanto et al., 1989, 1997), the first term of the right-hand side of Eq. (4) is generally small and can be neglected, but for a more realistic calculation its contribution will not be omitted in our analysis. The contributions of the second and third terms to U_M are the most significant and depend mainly upon local time, but also on seasons and different solar activity levels (deMedeiros et al., 1997).