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SEASONAL BEHAVIOR OF EQUIVALENT WINDS OVER WUHAN DERIVED FROM IONOSPHERIC DATA IN 2000-2001

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ABSTRACT

The equivalent winds are derived from digisonde measurements over Wuhan (114.4°E, 30.6°N, 45.2° dip) to investigate their seasonal behavior during the years 2000-2001. The results show that the diurnal pattern of the vertical equivalent winds (VEWs) has a prominent seasonal variation. The VEWs are larger upward in summer and larger downward in winter. The VEWs over Wuhan show an equinox asymmetry, i.e., VEWs in vernal equinox have smaller magnitudes than those in autumn equinox. Midnight descent of VEWs is more distinct in fall and winter, but not obvious in spring. The rise occurs in the early morning for all seasons. The VEWs are decomposed to investigate the seasonal difference of the tidal components. Neutral winds estimated from the VEWs are compared with those predicted by the empirical neutral wind model, HWM93. It shows reasonable agreement except for some local time intervals. © 2003 COSPAR. Published by Elsevier Ltd. All rights reserved.

INTRODUCTION

Investigating the variation of thermospheric neutral winds has great significance in understanding dynamics of the thermosphere and ionosphere. Great efforts have been made to conduct investigations on the seasonal behavior of neutral winds for various locations (de Medeiros et al., 1997; Herrero et al., 1988; Hagan, 1993; Hari and Murthy, 1995). In East Asia, investigations are mainly concentrated on the measurements at some Japanese stations with the MU radar (Oliver, 1990) and ionosondes (Igi et al., 1995, 1999), but up to now only Zhang et al. (1995) investigated neutral winds with Chinese monthly median ionosonde data.

The present work investigates the vertical equivalent winds (VEWs) derived from ionospheric measurements with an ionosonde (DGS256) over Wuhan (114.4°E, 30.6°N, 45.2° dip) in the years 2000-2001. The results represent the situation for high solar activity. The VEWs are the projections in the vertical plane of the ion velocities driven by horizontal neutral winds and the electromagnetic drifts induced by the zonal electric fields. A harmonic analysis is performed to study the seasonal difference in the tidal components of the derived VEWs over Wuhan. Neutral winds estimated from the VEWs with the aid of an empirical electric field model (Fejer, 1997) are compared with those from the horizontal wind model HWM93 (Hedin et al., 1996) and with other investigations for high solar activity, but we only focus on the features of the seasonal and local time variations.

DATA AND METHOD OF DERIVING EQUIVALENT WINDS

Measurements with a DGS-256 digisonde over Wuhan during the years 2000-2001 under quiet to moderate magnetic activity are collected for this investigation. A point different from previous studies is that the hmF2 data in

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this analysis is provided by UMLCAR SAOExplorer (ionograms have been manually scaled), a software for autoscaling ionospheric parameters and analyzing electron profile, not the statistical relationship between hmF2 and foF2, M3000F2 and foE. We choose months from March to April as spring, May to August as summer, September to October as fall, November, December, January and February as winter. Data during geomagnetic disturbances are rejected, and the periods during spread-F, which severely influence the accuracy of deducing the electron profile, are also ruled out. Thus the numbers of remainder days are 92, 125, 83, and 205, respectively. Severe spread-F events occurred frequently in summer, thus the valid database in summer is much smaller than in other seasons. The average values of F10.7 index for each season are 168, 162, 174, and 153, respectively.

The VEWs are derived from ionospheric measurements with the method of Libo Liu et al. (A new approach to the derivation of dynamic information from ionosonde data, submitted to *Ann. Geophysicae.*, 2002) and Luan et al. (2002), which is an improved method of Rishbeth et al. (1978). The equation for deriving VEWs from ionospheric parameters can be written as follows

$$W = \frac{dh_m}{dt} + (a-1)\frac{q_m H}{N_m} + (a'_{O_2} - ac)\beta_{O_2} H + (a'_{N_2} - ac)\beta_{N_2} H + W_d \sin^2 I. \quad (1)$$

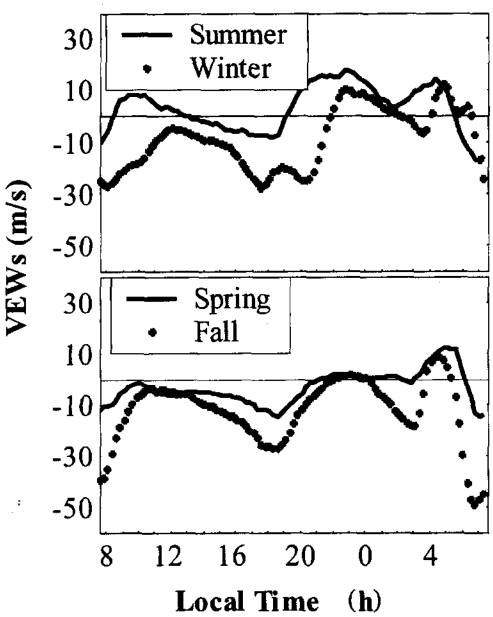

Fig. 1. The diurnal variation of vertical equivalent winds (VEWs) for 4 seasons.

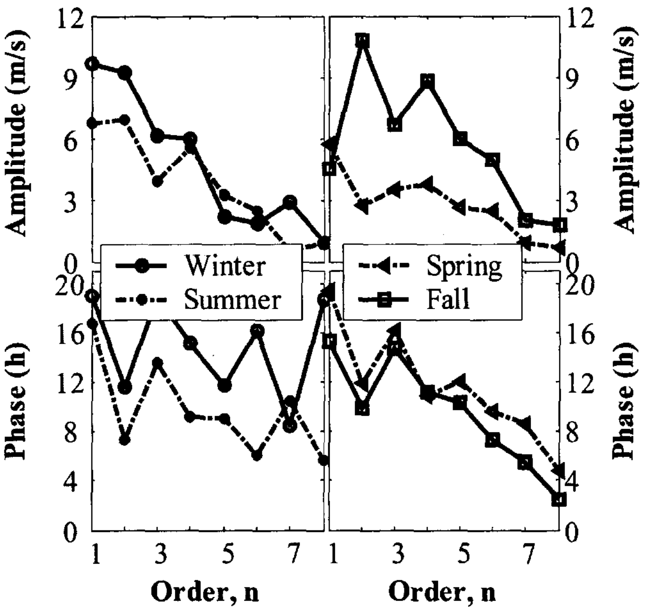

Fig. 2. Amplitudes and phases of tidal components of VEWs versus the harmonic order n for seasons.

Here h_m is the peak height, W_d is diffusion velocity, I is magnetic dip, H is scale height of neutral O atom. N_m, q_m, β_{N_2} and β_{O_2} are the electron density, production rate, and loss coefficients due to N_2 and O_2 at the peak of F layer, respectively. a, a'_{O_2} and a'_{N_2} are integral factors, which depend on the shape of electron density profile at the topside ionosphere. The profiles are reasonably approximated by a Chapman-α layer. Thus $a = 2.8214$, $a'_{O_2} = 0.4641$, and $a'_{N_2} = 0.5217$. c is a servo constant. We take c=1.73×0.75 for night, and c=1.33×0.75 for day (Bounsanto, 1997). And the values of c during the transition period between day and night are interpolated. W is the VEW, which can be related with the meridional neutral wind (U) and electric field drift ($V_{N\perp}$) by the expression:

$W = U \sin I \cos I + V_{N\perp} \cos I$. In the subsequent calculations, neutral densities and neutral temperature are provided by the MSIS90 model (Hedin, 1991), and ion and electron temperature by the IRI90 model (Bilitza, 1990).

SEASONAL CHARACTERISTICS OF VERTICAL EQUIVALENT WINDS

Figure 1 presents the diurnal variations of VEWs averaged for each season. It shows a marked seasonal difference. In summer VEWs have larger upward magnitudes during the night, smaller downward during the day, and the daily prevailing wind is 2.9 m/s. In contrast, the VEWs in winter are smaller upward during nighttime and larger downward blows during the day, with the mean flow of -9.2 m/s. In all seasons, the typical magnitudes of the seasonal averaged VEWs are from -30 to 10 m/s, and the related peak heights concentrate on 280-350 km. The patterns of VEWs in summer and winter agree with those of meridional neutral winds which blow mainly equatorward in summer and polarward in winter. The downward flows dominate in both spring and fall. The amplitudes and diurnal variations of VEWs in spring are much smaller than those in other seasons, and the mean of VEWs is -3.4 m/s. In fall large downward flows are present. The VEWs in fall act more similar with that in winter than in spring, also between in spring and in summer. The relatively large flows in all seasons occur during the sunset and sunrise. The maximum magnitude of VEWs is found in fall, -49.4 m/s, and the smallest in spring, -15.2 m/s.

The seasonal mean VEWs tend to flow downward in the daytime and upward during night, while the duration that the wind blows in the same direction varies with seasons. The night upward VEWs last longest in summer and shortest in fall. The upward peak in VEWs appears in the night. It is noticeable that comparable upward twin-peaks appear in summer and winter with magnitudes of about 17 m/s and 12 m/s, respectively. In summer the late afternoon transition from the downward to upward flow is at about 19:00 LT, which is about 2.5 hours earlier than other seasons. In summer VEWs reach the first upward peak at 21:00 LT and persist about 2 hours at that level. The first upward peak in winter and fall is reached at about 22:30 LT and begins to descend immediately after that time. The morning transition from the upward to downward winds occurs at about 5:30-6:30 LT.

Midnight descent in VEWs over Wuhan takes place obviously in summer, fall, and winter, beginning at about the same time around 23:00LT, while it is not obvious in spring. The descent maximum is at around 3:00-3:30 LT with the largest in fall. The VEWs during descent in summer are upward, and the decent reaches the maximum about 2 hours earlier than in other seasons. The VEWs descend more intensely and the descent lasts longer in winter and fall than in summer. It suggests that this phenomenon occurs more frequently in fall and winter. After the descent, a sharp rise appears in the early morning for every season. The rise starts earlier in summer and later in winter. The midnight descent combined with the early morning rise form two upward peaks in VEWs during the nighttime for all seasons except spring. Study from the AE-E satellite measurements reported that the midnight descent occurs earlier and more rapidly in summer than in winter at latitudes between $\pm 18^\circ$ (Herrero et al., 1988). Midnight descent is suggested to be influenced by the semidiurnal component in the neutral winds (Crary, 1986).

FOURIER DECOMPOSITION OF EQUIVALENT WINDS

A least-square harmonic analysis has been performed on the derived VEWs for each season to investigate their seasonal variations using the following equation:

$$W(t) = W_0 + \sum_{n=1}^{8} W_n \cos(n\omega t - \Phi_n) + l(e), \qquad (2)$$

where n is the order of tidal components, W_n and Φ_n are the amplitude and initial phase of the n-th order component, $\omega = 2\pi / 24$ is the diurnal frequency. W_0 is the prevailing component or seasonal mean of VEWs. $l(e)$ is the corresponding error term. The harmonic analysis reveals that the amplitudes and initial phases of the main tidal components in summer have similar variations to those in winter. Figure 2 shows the amplitudes and initial phases (expressed in time) of the first 8 order components of VEWs for all seasons.

We note that the amplitudes of the first three tidal components in winter are 2-3 m/s larger than those in summer, and the initial phases in winter are later than those in summer. The differences between the initial phases in both seasons increase with the order n for the fist four components. The semidiurnal component is dominant in fall, and the diurnal component is dominant in spring. The amplitudes of tidal components of VEWs are generally larger in winter and fall, smaller in summer and spring. In most of previous investigations, the patterns of neutral winds during vernal equinox and autumn equinox were often treated as similar. However, the discrepancy in fall and spring reveals the equinoctial asymmetry in neutral winds. According to Zhang et al. (1995), large downward plasma drifts at sunrise time in September are also found in Yamagawa (30.5°N, 130.6°E) in 1982, and drifts in March have small magnitudes, while drifts there in June have larger downward components than those in December. The VEWs during two equinox seasons are different: the initial phases of tidal components of the VEWs in spring are a little later than those in fall, and the amplitudes in fall are obviously larger than those in spring (Figure 2).

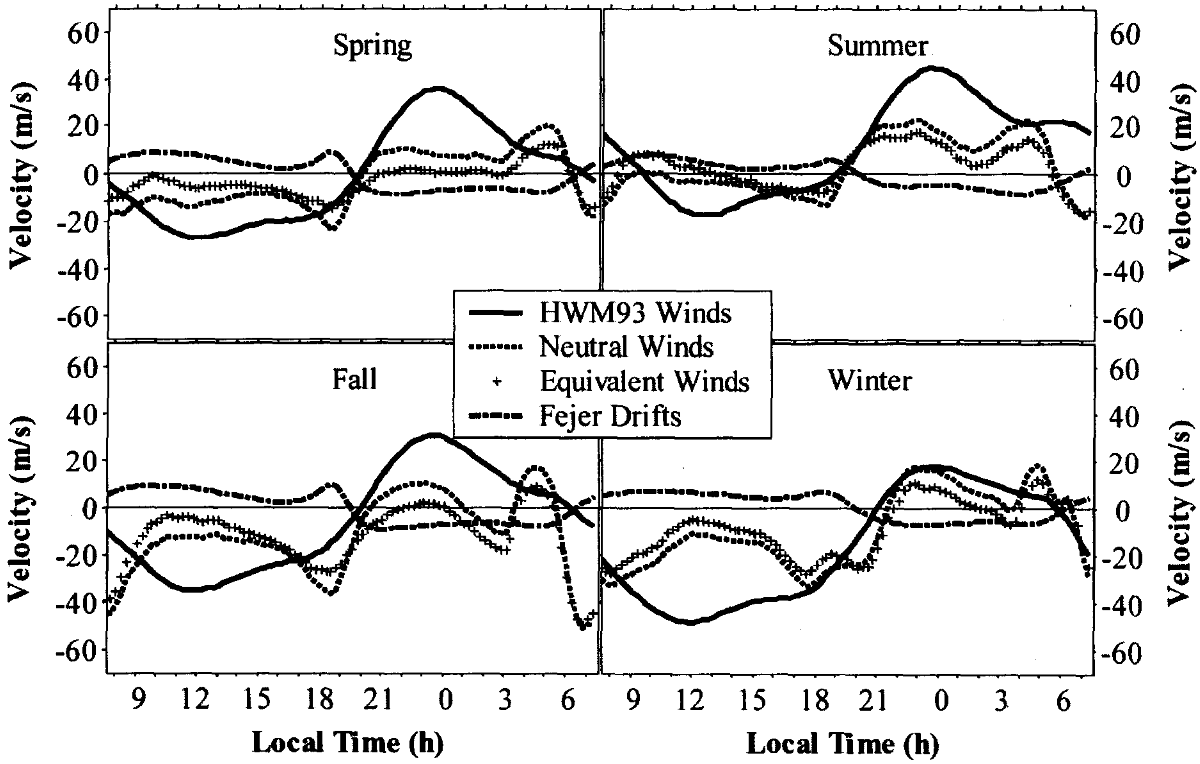

Fig. 3. VEWs and the vertical projection of neutral winds of HWM93 Model for all seasons. Fejer Drifts denote the vertical projection of drifts induced by the electric fields estimated by Fejer (1997) model. Neutral Winds represent the contribution of neutral winds embodied in VEWs.

COMPARISON WITH NEUTRAL WINDS

The VEWs contain contributions from neutral winds and electric fields. First, we try to compare the equivalent winds (Figure 1) with meridional winds under the similar solar activity conditions, assuming the equatorward (poleward) wind is consistent with the upward (downward) equivalent wind. In Arecibo, the winter meridional wind from FPI measurements (Biondi et al., 1999) agrees well with the derived equivalent winds in the trend of the amplitude variation and the local times at which the peak in winds appeared under the condition that the F10.7 index is between 100 and 300 units. In Kokubunji (35.7°N, 139.5°E), the meridional wind derived from ionosonde measurements (Igi et al., 1999) shows a similar amplitude variation in summer, and its amplitude in winter night is also comparable to that in Wuhan. The long time equatorward wind in spring and fall, and the trend of early morning rise in the amplitudes at about 4:00 LT at all seasons also agree well with those in equivalent winds over Wuhan. It is noticeable that the amplitudes of VEWs in winter over Wuhan will be 1.5-2 times larger than those in Kokubunji and in Arecibo, when the relationship between the horizontal winds and their vertical projections are taken into account.

Second, we estimate neutral winds from VEWs via subtracting the contribution from electric field drifts, which are estimated with the Fejer (1997) model. The projection of neutral winds from HWM93 is also presented in Figure 3 for comparisons. Our derived neutral winds and those from HWM93 show reasonable agreements in main phase and amplitude, especially in the transition from the late afternoon downward to the early night upward flow. Relatively greater discrepancies generally occur in three local time intervals: (1) hours around noon (11:00-14:00 LT), (2) during midnight descents (23:00-2:00 LT), and (3) at sunrise (6:00-8:00 LT). The local times of great discrepancy occurrence depend on seasons. For the first time interval the greatest discrepancy appears in winter with the magnitude of 35 m/s; for the second, in all seasons except for winter with the magnitude of 20 m/s, and for the last, in summer and fall with the magnitudes of about 40 m/s. It is noticeable that the meridional component should be two times of the neutral vertical component due to the magnetic inclination over Wuhan. The local time of great discrepancies occurring in summer and winter agree well with the results of the similar comparison for the meridional winds in Kokubunji (35.7°N, 139.5°E) by Igi et al. (1995), but there are 20~30 m/s discrepancies in magnitude. However, no double peaks are found at night in Kokubunji. The discrepancies partly suggest the deficiency of HWM93 Model at some local time over Wuhan. As pointed out by Titheridge (1995), there are no data for latitudes north of 34°S at longitudes between 20°E and 210°E, and the errors in the HWM winds can reach 50-100 m/s at some local times.

SUMMARY

The vertical equivalent winds (VEWs) derived from ionosonde measurements over Wuhan, China during the years 2000-2001 have a prominent seasonal variation. Neutral winds estimated from VEWs in general agree with those predicted by HWM93, but there are more tidal components in VEWs, especially the amplitude of the semidiurnal component is more distinct. The principal features are summarized below:

(1) The VEWs have a diurnal pattern of downward during the daytime and upward at night. This is consistent with the general pattern of meridional neutral winds, i.e., equatorward at night and poleward during the daytime. The local time variation of the VEWs in summer is like that in spring, also between winter and fall.

(2) The harmonic analysis shows that the amplitudes of the first three tidal components of VEWs in winter are larger than those in summer, and the initial phases in winter are later than those in summer. Different features in tidal components of the VEWs during two equinox seasons reflect an equinox asymmetry.

(3) Midnight descent is found for all seasons except in spring. This is more distinct in fall and winter. A rise of VEWs follows in the early morning for all seasons. It is also similar with the results of Kokubunji (Igi et al., 1999). The rise starts earlier in summer and later in winter. Comparable upward twin-peaks are found with magnitudes of about 17 m/s in summer and 12 m/s in winter.

The VEWs reflect the vertical movement of plasma around the peak height of F layer. They are induced by both neutral meridional winds and electric drifts. Over Wuhan, the VEWs are mainly contributed by neutral winds because the average contributions from electric fields are much smaller (based on the estimation of electric fields from the Fejer model). Thus the results of VEWs in this analysis can be also applied to neutral winds over Wuhan. We will utilize the routinely scaled ionospheric parameters from Chinese ionosondes to extend our information on neutral winds in further studies.

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