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SOLAR ACTIVITY DEPENDENCE OF EFFECTIVE WINDS DERIVED FROM IONOSPHERIC DATA AT WUHAN

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ABSTRACT

The solar cycle variability of thermospheric circulation is one of the outstanding questions involving the upper atmosphere. However, it needs to be identified due to the latitude and longitude dependence of neutral winds. This article examines the solar activity trends in the vertical component of equivalent winds (VEWs) derived from ionosonde data during 1966-1985 over Wuhan (114.4° E, 30.6° N, 45.2° dip) of China. The monthly median data of routine ionosonde measurements in published tables are used to derive VEWs which are contributions from both neutral winds and zonal electric fields. The solar activity trends of VEWs over Wuhan have an obvious local time and seasonal dependence. Over Wuhan, the magnitudes of VEWs decrease with increasing solar activity around midnight for all seasons and around midday in winter and autumn. In contrast, little variation is found throughout the solar cycle around midday in summer and spring. The magnitudes of daily means and amplitudes of diurnal and semidiurnal components of VEWs over Wuhan decrease with solar activity, which also confirms that it is not a feature of a particular location. There is a more pronounced decrease in diurnal amplitudes of VEWs than other harmonic components over Wuhan. The decrease in diurnal amplitudes with increasing solar activity can be reasonably explained, if the greater ion drag at solar maximum compensates for pressure gradients due to the greater EUV input.

INTRODUCTION

Understanding the variation of thermospheric circulations is an important subject involving the coupling system of the upper atmosphere and ionosphere. The solar cycle variability of thermospheric circulations has been studied with measurements and theoretical and empirical model techniques for years. Current models and measurements show that, although neutral compositions and temperature in the thermosphere clearly and strongly depend on the level of solar activity, the solar activity variations of thermospheric meridional winds are complex and different at particular sites (Hedin et al., 1994). It is reported that, with increasing solar activity, the diurnal amplitudes of meridional winds decrease at some locations. But opposite trends are found in some seasons and some locations (e.g., Duboin and Lafeuille, 1992; Aruliah et al., 1991, 1996; Arriagada et al., 1997). At a high-latitude site, Kiruna (67.8°N, 20.4°E) of Sweden, a higher solar flux results in the magnitude of the FPI meridional winds being larger for each season (Aruliah et al., 1991, 1996). Hedin et al. (1994) found the winds at

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mid-latitudes have no clear dependence on the solar activity level. The meridional neutral winds from the EISCAT radar show an F107 dependence: the mean winds are larger during low solar activity periods, while the trends are opposite in the semidiurnal components (Witasse et al., 1998). Decrease in diurnal amplitudes of the derived winds with solar activity levels is found at a mid-latitude station, Boulder (40.0°N, 254.7°E) (Buonsanto, 1991). While at another mid-latitude station in the southern hemisphere, King George Island (62.2°S, 58.8°W), the amplitudes of winds decrease from low to high solar activity levels in spring and summer, but increase in winter (Arriagada et al., 1997). Thus the details of the solar cycle and/or seasonal analyses differ from study to study (Hagan, 1993) and from location to location.

Until now, there are few investigations on the solar activity trend of winds in China, and the pattern is not clear yet. Thus it needs to be identified due to the latitude and longitude dependence of neutral winds. This article investigates the solar activity level trends of vertical equivalent winds deduced from monthly median ionospheric data during 1966-1985 over Wuhan (114.4° E, 30.6° N, dip 45.2°), China.

DATA AND METHOD OF ANALYSIS

The ionosphere above Wuhan has been routinely measured for a long time. In this work, the monthly median ionospheric data in published tables during 1966-1985 is utilized to derive the vertical component of equivalent winds (VEWs) around the peak of F-layer over Wuhan. Based on the sensitivity of magnetic meridional winds, the height and critical frequency of the F peak can be used to estimate the vertical component of equivalent winds along the magnetic meridian throughout day and night (Hedin et al., 1994; Titheridge, 1995). Unfortunately, there are no electric field measurements over Wuhan. To avoid introducing false information, we do not estimate true winds with a correction of electric fields but conduct investigation on VEWs directly.

The Dudeney (1983) method is used for estimating hmF2 from the monthly median foF2, M3000F2 and foE. The VEWs are deduced from ionospheric data with the method of Liu et al. (2003a, 2003b) and Luan et al. (2002). The effective winds are found to be well agreeable with actual measurements (e.g. FPI, Millstone Hill Incoherent Scatter radar data) and the servo method. The neutral parameters are provided from the MSIS model.

The winds are often represented by one mean and three harmonic components with periods of 24, 12, and 8 hours, which also be called diurnal, semi- and ter-diurnal components. A least-square harmonic analysis has been performed the derived VEWs over Wuhan for each month during 1966-1985 using the following equation (e.g. Duboin and Lafeuille, 1992; Witasse et al., 1998):

$$W(t) = W_0 + A_{24}\cos[\omega_{24}(t-t_{24})] + A_{12}\cos[\omega_{12}(t-t_{12})] + A_8\cos[\omega_8(t-t_8)] + \ell(e), \quad (1)$$

where $\omega_{\mathrm{n}} = 2\pi/\mathrm{n}$, $\mathrm{n} = 24, 12, 8$, $\ell(e)$ is the corresponding error term.

RESULTS

Over Wuhan the derived VEWs have distinct local time and seasonal variations. In general, the VEWs are larger downward during the daytime and smaller upward at some intervals in the nighttime. The local time patterns are very similar with those of hmF2.

To investigate the solar cycle trend of VEWs for seasons, the deduced VEW data for 1966-1985 are sorted into season as follows: summer months are from May to August; winter months are November, December, January and February; spring months are March and April; and autumn months are September and October (Buonsanto, 1991). To obtain more detailed information of their trends, the data are shown over the full range of solar activity and not sorted into two solar activity levels (solar minimum and maximum). This is different from previous studies.

An interesting and significant feature is that the solar cycle trend of VEWs over Wuhan depends on local time.

Figure 1 illustrates the solar cycle trend and correlation coefficients (r) of VEWs around midday (local time 11-13 h) and midnight (local time 23-1 h) for four seasons during the period of 1966-1985 over Wuhan. Positive values correspond to upward vertical velocities, or southward neutral winds. Around midnight over Wuhan, the magnitudes of VEWs tend to decrease with increasing solar activity for four seasons. The trend with solar activity is obvious around midnight for all seasons and more significant is found in summer and spring. With higher solar activity, the magnitudes of VEWs decrease around midday in winter and autumn. In contrast, little change throughout the solar cycle is found around midday in summer and spring (r only -0.16 and -0.12). The solar activity trends of VEWs are most distinct in winter around both midday and midnight (Figure 1).

A harmonic analysis of VEWs is performed as a function of local time for each month. Figures 2-4 show the daily means and amplitudes of three harmonic components of VEWs over Wuhan with periods of 24, 12 and 8 h as a function of solar activity for seasons. The harmonic results show some features of the solar activity variability. The seasonal behavior of VEWs over Wuhan and how it is influenced by the levels of solar flux can be investigated with the daily mean values depicted in Figure 2. The daily mean VEWs are downward for all seasons except in summer (r = 0.03). The downward mean VEWs are larger in autumn than in spring. The magnitudes of daily mean VEWs decrease with increasing solar activity except in summer. The decrease in magnitudes of mean VEWs is found most obvious in autumn, much smaller in spring, and little solar activity variation is found in summer.

An obvious reduction in diurnal amplitudes of VEWs with increasing solar activity is found during all seasons. The solar activity variation of diurnal amplitudes in winter is more significant than those in other seasons. And the solar dependence of diurnal amplitude in spring is smaller than in other seasons. In contrast, the solar cycle variation of the diurnal amplitudes in summer is smaller than that in other seasons at Boulder (Buonsonto, 1991).

It is interesting to note from Figure 4 that the semi- and ter-diurnal amplitudes of VEWs also decrease with increasing solar activity for all seasons except in winter. Little change in semidiurnal amplitudes is found in winter.

DISCUSSION AND SUMMARY

The wind behavior as a function of solar flux is not yet to be understood comprehensively. In this article VEWs derived from ionosonde measurements during 1966-1985 over Wuhan are analyzed to investigate the influence of solar fluxes. Solar cycle variability of VEWs from Chinese ionospheric data for such a long period is reported for the first time. Although VEWs can be deduced only at the peak of F layer, due to very high viscosity at altitudes above 200 km, there should be small height variation of thermospheric winds above that height. Thus the VEWs derived at the peak of the ionospheric F-layer which varies with solar activity should not have serious influences on the conclusion of the investigation presented above.

As described above, there are large local time and seasonal variations and relatively smaller solar cycle dependence in the VEWs derived from ionospheric data at Wuhan. The solar activity trends of VEWs over Wuhan have obvious local time and seasonal dependence. The magnitudes of VEWs decreases with increasing of solar activity around midnight for all seasons and around the midday in winter and autumn. In contrast, it is not obvious around midday in summer and spring. Over Millstone Hill, the magnitudes of the nighttime winds during solar maximum are also remarkably smaller than those of solar minimum nighttime winds, but the daytime trend is opposite (Hagan, 1993). Therefore there are different trends between daytime winds at Wuhan and Millstone Hill.

The daily mean and amplitudes of tidal components of VEWs decrease with the increasing solar activity. The present work shows that there are more pronounced solar trends of diurnal amplitudes of VEWs than other harmonic components over Wuhan. In contrast, the solar cycle variability in the Millstone Hill daily mean winds is more pronounced (Hagan, 1993). And the seasonal dependence of solar cycle variation of the diurnal amplitude over Wuhan is also different from that at Boulder (Buonsanto, 1991). Consistency is found between the present results and previously found trends of decreasing amplitude of the diurnal variation with increasing solar activity level. This work confirms that the above trend is not a feature of a particular location (Hedin et al., 1994).

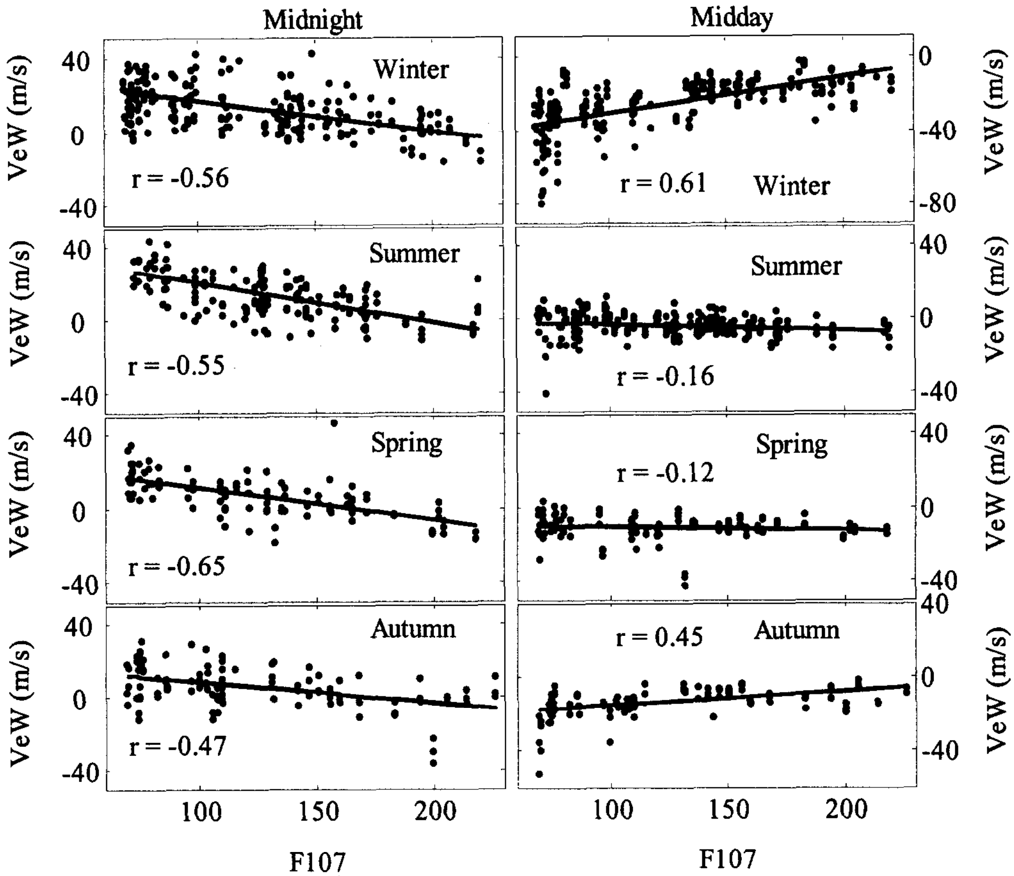

Fig. 1. Midday and midnight VEWs (upward positive) versus F107 for seasons during 1966-1985 over Wuhan. The correlation coefficient, r, is also shown in each panel. The individual points represent the values for each month.

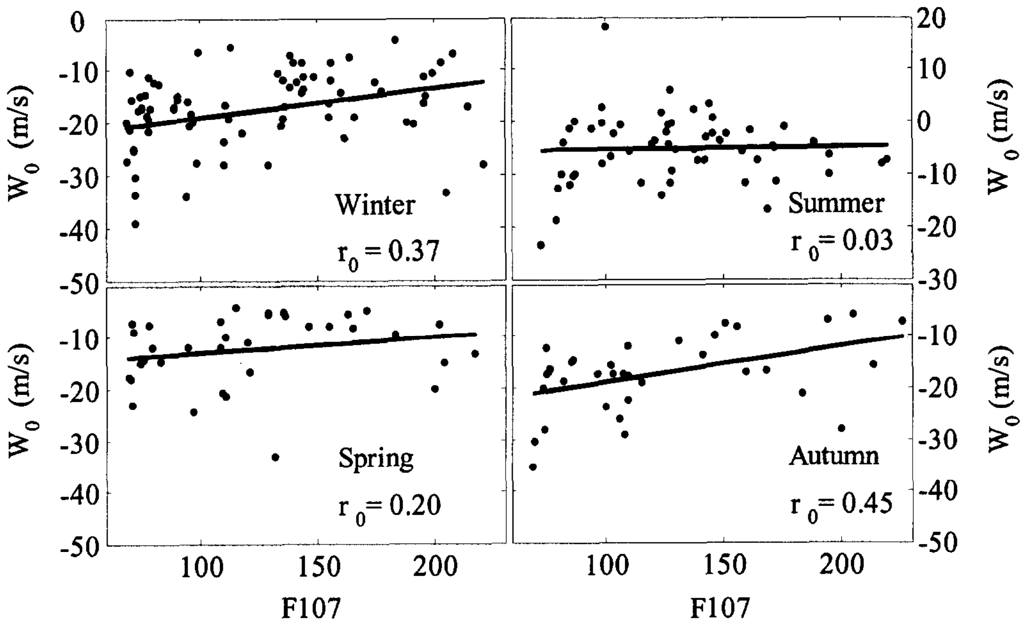

Fig. 2. Daily mean of VEWs versus F107 for seasons during 1966-1985. Solid line shows the linear fitting trend. r_0 labeled in each panel are the related correlation coefficients.

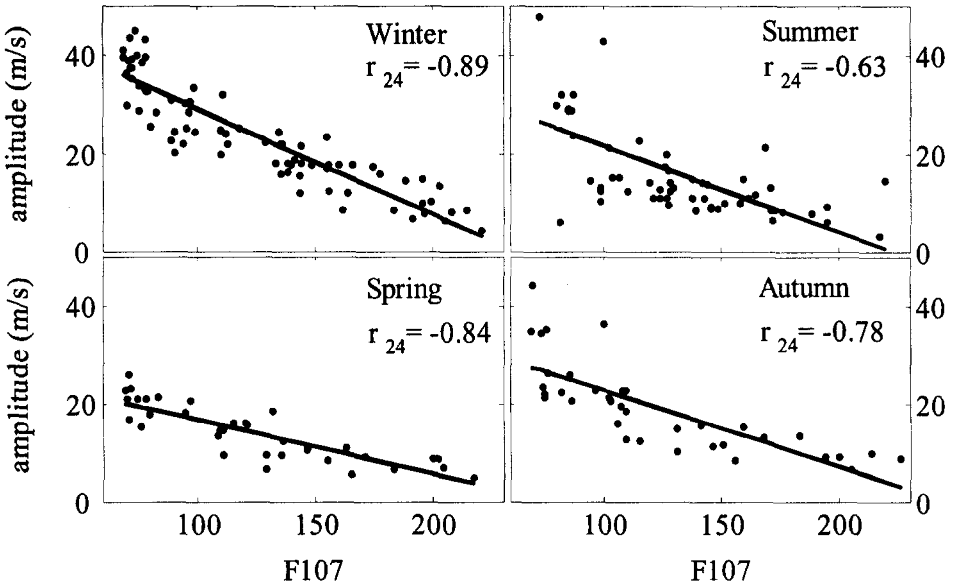

Fig. 3. Same as Fig. 2 but for the amplitudes of diurnal (24h) component.

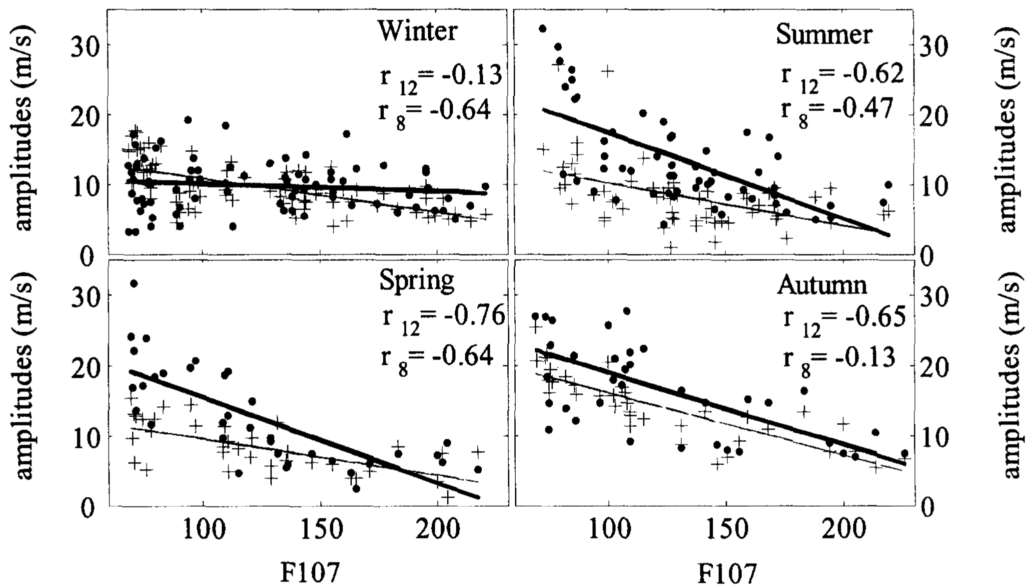

Fig. 4. Same as Fig. 2 but for the semidiurnal (dot points) and terdiurnal (plus symbols) components. Heavy and thin lines are the linear fit for semidiurnal and terdiurnal components, respectively. r_{12} and r_8 are correlation coefficients.

The thermospheric wind is primarily driven by pressure gradients generated by the solar radiations (mostly in the equatorial regions during the daytime) and auroral heating (in aurora regions) (Titheridge, 1995). The motion of the atmosphere is retarded mainly by ion drags and Coriolis forces. Although each is solar cycle dependent, the effects of solar heating and ion drag appear to cancel each other out. The factors whether in rough balance or not determine the winds with little or significant solar activity. The absence of an obvious solar cycle variation is explained by the competing effects of increased energy input and ion drag at solar maximum. While with the decrease in solar activity it is reasonable to think that the wind will be less poleward as a result of relatively smaller effect of pressure gradients (Witasse et al., 1998). In contrast, increased ion drag during solar maximum may play an important role in the interpretation of the decrease in diurnal amplitude of winds with increased solar activity. Ion drag is strongest during daytime when F region densities are higher; thus the winds are slower during the day in comparison to nighttime. With the enhancement of solar activity, if the ion drag increases so greater not only to compensate for the greater pressure gradients, the diurnal amplitude will decrease.

The outstanding limitations involving this investigation are as follows: (1) The investigation is conducted on the VEWs rather than the true winds because estimated electric fields are not subtracted to estimate the true winds. (2) Geomagnetic activities may have significant effects on winds. In the present study the VEWs are derived from the monthly median values of ionospheric data which may partly include the influence of geomagnetic disturbances. How much the geomagnetic storms included may distort the results over Wuhan needs further studies.

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