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Simulation of vertical wind profile under neutral conditions

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After analysing formulations of the horizontal wind velocity above a non-uniform underlying surface, it is found that the mean height of roughness elements, fractional vegetation cover and leaf area index are the most essential parameters of vertical wind profile under neutral conditions. By using Landsat-5 data, every-10-days observed data in the field, the every-10-days Normalized Difference Vegetation Index (NDVI) data from NOAA-14 meteorological satellite, 1:10000 land-use data, and 1:10000 topographical data, the mean height, leaf area index and fractional vegetation cover of wheat at Yucheng Integrated Agricultural Experiment Station are simulated as functions of NDVI. Then, hourly horizontal wind velocity at a height of 4 m during the period from 21:05 on 5 March 2000 to 7:05 on 24 May 2000 is calculated, for which hourly observed horizontal wind velocity at a height of 2 m is first used to simulate the wheat parameter of the dimensionless constant. The results show that the simulated velocity is almost identical to the observation velocity at a height of 4 m.

1. Introduction

Wind plays an important role in ecosystem changes. Wind is the dominant disturbance to patterns of vegetation recovery (Schumacher et al. 2004). Many herbaceous species rely on wind as their most important dispersal vector (Schippers and Jongejans 2005). Wind is also one of the major dynamic factors that cause extensive damage to ecosystems (Beinhauer and Kruse 1994, Gardiner et al. 2000, Blennow and Sallnäs 2004). This paper focuses on simulation of the horizontal wind velocity above a non-uniform underlying surface.

Under thermally neutral conditions, steady-state flow over horizontally bare soil can be described by the well known logarithmic law (Sutton 1953, Mihailovic et al. 1999, Baldauf and Fiedler 2003)

$$u(z) = \frac{u^*}{k} \ln \frac{z}{z_0}$$

where $u(z)$ is the horizontal velocity at height $z$; $u^*$ is the friction velocity for a bare soil, which physically represents the shear stress $\tau = \rho u^2$, where $\rho$ is the air density; $k$ is the von Karman’s constant taken to be 0.41; and $z_0$ is the roughness length of a bare soil.

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The popular saying (Wieringa 1993) ‘$z_0$ is the height at which the wind speed becomes zero’ is therefore true in a purely algebraic sense only according to equation (1). Research results from Blackadar and Tennekes (1968) show that the logarithmic wind profile was not a feature of the lower few metres over homogeneous terrain only, but rather was a consistent description of any surface layer wind field up to heights of 30 m to 100 m. Consequently, the roughness length $z_0$ is the optimal parameter for specifying terrain effects on wind (Wieringa 1981).

For vegetative surfaces (Sutton 1953)

$$u(z) = \frac{u_*}{k} \ln \frac{z-d}{z_0}$$

where $u_*$ is the friction velocity over the vegetation surface; $d$ is a zero-plane displacement, which is the mean height of the vegetation on which the bulk aerodynamic drag acts; and $z_0$ is the roughness length. According to this expression, the wind speed is zero at height $d+z_0$, but the logarithmic profile cannot be extrapolated that far downwards. When the quantities $d$ and $z_0$ are known, the whole profile above a vegetative surface as well as the ratio $\frac{u_*}{k}$ can be obtained if the wind at a single level is known.

Apparently, transfer of momentum between short grass and the atmosphere does not differ so much from the corresponding exchange when bare soil is the underlying surface (Mihailovic et al. 1999). Over tall grass, the transfer of momentum into the atmosphere is more intensive since $u_*$ becomes greater than $u_{*g}$. The difference in these velocity scales physically is from a displacement effect and an increase in $z_0$.

Equation (2) is not valid when height $z$ is between the height of the vegetation $h$ and some height $z^*$ representing the lower limit of inertial sublayer. Its order of magnitude can vary between $z^* = d + 10z_0$ and $z^* = d + 20z_0$ (De Bruin and Moore 1985). Since $z_0$ is around 10% of the canopy height then the thickness of the roughness sublayer can vary between one and two canopy heights. In models of biosphere–atmosphere exchange, when the underlying vegetative surface consists of patches of bare soil and plant communities with different morphological parameters, the level of inhomogeneity in the cover has to be taken into account in addition to a spatially varying displacement height (Mihailovic et al. 1999).

Experimental evidence indicates that estimates of momentum transfer coefficient, $K_m$, above a vegetative surface were 1.5–2.0 times larger than a simple application of equation (2) would indicate. Thus equation (2) can be modified as

$$u(z) = \frac{u_*}{a_G k} \ln \frac{z-d}{z_0}$$

where $a_G$ is a dimensionless constant estimated to be between 1.5 and 2.0 (Raupach and Thom 1981, Massman 1986). Equation (3) can be valid for the lower part of the roughness sublayer only (Mihailovic et al. 1999).

Above a non-uniform underlying surface, non-uniformity is expressed by the surface vegetation fractional cover $\sigma$, which takes values from 0 when the ground surface is bare soil to 1 when the ground surface is totally covered by plants. Suppose that the underlying surface is a combination of only two homogenous portions characterized by $\sigma$ and $1-\sigma$, the wind profile can be formulated as (Mihailovic et al. 1999)
where $u(z)$ is the horizontal velocity at height $z$; $z_0$ is the roughness length; $u^*$ is a friction velocity above the non-homogeneous surface; $k$ is the von Karman’s constant taken to be 0.41; $d$ is the displacement height, which is the mean height in the vegetation; and $\alpha$ is a dimensionless constant representing a correction to the mixing length in the roughness sublayer.

In terms of equation (4), roughness length $z_0$, zero-plane displacement height $d$, dimensionless constant $\alpha$ and vegetation fractional cover $\sigma$ are the most important parameters of the horizontal velocity $u(z)$.

2. Estimation of the parameters

2.1 The dimensionless constant $\alpha$

Comparing model simulations with observations, Laric (1997) found that for short grass

$$\alpha^2 = (6.4 \text{LAI})^b$$

for tall grass

$$\alpha^2 = (6.4 \text{LAI})^s$$

and for forest

$$\alpha^2 = (3.2 \text{LAI})^s$$

where LAI is leaf area index.

For wheat, as an extension of the dimensionless constants of short grass and tall grass, $\alpha$ is generally expressed as

$$\alpha = (6.4 \text{LAI})^b$$

where $b$ is the wheat parameter of the dimensionless constant to be simulated.

LAI is the one-side foliage area per ground area (m$^2$ m$^{-2}$) (White et al. 2000). The simplest and most practical way is to investigate the relationships between LAI and values of various vegetation indices by means of regression models (Asrar et al. 1985, Price and Bausch 1995, Wulder 1998, Brown et al. 2000, Qi et al. 2000, Vaesen et al. 2001, Chen et al. 2002). These vegetation indices include the simple ratio vegetation index (Nemani et al. 1993), the reduced simple ratio vegetation index (Nemani et al. 1993), the perpendicular vegetation index (Wiegand and Richardson 1987), the weighted difference vegetation index (Clevers 1989), the normalized difference vegetation index (Goward et al. 1985, Yue et al. 2002), the soil adjusted vegetation index (Huete 1988), the atmospherically resistant vegetation index (Kaufman and Tanre 1992), the soil and atmospherically resistant vegetation index (Kaufman and Tanre 1992), the modified normalized difference vegetation index (Liu and Huete 1995), and the feedback-based vegetation index (Huete et al. 1997). These relationships between LAI and the vegetation indices have the following generalized formulations:

$$\text{LAI} = a \text{VI}^3 + b \text{VI}^2 + c \text{VI} + d$$

(9)
LAI = a VI^b + c \tag{10} \\
LAI = a \ln(b VI + c) \tag{11}

where VI is a vegetation index; \(a, b, c,\) and \(d\) are empirical parameters and vary with vegetation types.

In addition to the relationships between LAI and vegetation indexes, the LAI-2000 instrument was used in different vegetation types to derive LAI indirectly (Colombo et al. 2003, Gower and Norman 1991), i.e.

\[
LAI = -2 \int_{0}^{\pi} \ln P(\theta) \cos \theta \sin \theta d\theta \tag{12}
\]

where \(P(\theta)\) is a gap fraction in five zenith angle \(\theta\) ranges with midpoints at 7°, 23°, 38°, 53°, and 67°.

### 2.2 Vegetation fractional cover \(\sigma\)

The fractional vegetation cover, the mean vertically projected canopy area per unit ground area is formulated as (Kellerer 1983, Jasinski and Crago 1999)

\[
\sigma = 1 - \exp \left\{ - \frac{n A_t}{A_p} \right\} \tag{13}
\]

where \(n\) is the number of roughness elements; \(A_t\) is the mean vertically projected canopy area of a single roughness element, \(A_p\) is the unit area such as the pixel area.

The fractional vegetation cover, an important element of climate models, was first introduced by Deardorf (1978). Its specification from field-observations has been problematical (Zeng et al. 2000). It is a relatively simple parameter to obtain by means of satellite remote sensing, which was mostly formulated as (Baret et al. 1995, Wittich and Hansing 1995, Wittich 1997, Gutman and Ignatov 1998, Zeng et al. 2000)

\[
\sigma(i, j) = 1 - \left( \frac{N_v(i, j) - N(i, j)}{N_v(i, j) - N_s(i, j)} \right)^b \tag{14}
\]
or

\[
\sigma(i, j) = \frac{N(i, j) - N_s(i, j)}{N_v(i, j) - N_s(i, j) + (1 - d(i, j))(N(i, j) - N_v(i, j))} \tag{15}
\]

where \(N(i, j) = [\lambda_{NIR}(i, j) - \lambda_{RED}(i, j)]/[\lambda_{NIR}(i, j) + \lambda_{RED}(i, j)]\), \(\lambda_{RED}(i, j)\) is the spectral reflectance of the visible red band; \(\lambda_{NIR}(i, j)\) is the spectral reflectance of the near-infrared band; \(d(i, j) = [(\lambda_{NIR}(i, j) + \lambda_{RED}(i, j)), s]/[(\lambda_{NIR}(i, j) + \lambda_{RED}(i, j)), s];\)
the subscripts \(v\) and \(s\) denote values over 100% vegetation cover and bare soil, respectively; \(b\) is a parameter to be simulated.

Zeng et al. (2000) modified the formulation of fractional vegetation cover so that the fractional vegetation cover is independent of season and represents the annual maximum green vegetation fraction for a given pixel. The modified formulation was expressed as

\[
\sigma(i, j) = \frac{N_{\max}(i, j) - N_s(i, j)}{N_v(i, j) - N_s(i, j)} \tag{16}
\]
where $N_{\text{max}}(i, j)$ is the annual maximum value of the normalized difference vegetation index $N(i, j)$.

Many other studies (Scanlon et al. 2002, Defries et al. 1999, 2000) classified the fractional cover into three broad categories: $\sigma_b(i, j)$, a portion of the land surface that always remains as bare soil, $\sigma_w(i, j)$, a portion of the fractional cover that is woody vegetation, and $\sigma_{g/b}(i, j)$, a remaining portion that consists of bare soil and herbaceous vegetation cover. Their relationship is formulated as (Scanlon et al. 2002)

$$\langle \sigma_b(i, j) \rangle + \langle \sigma_w(i, j) \rangle + \langle \sigma_{g/b}(i, j) \rangle = 1$$

where $\langle \rangle$ operator represents spatial averaging; the subscripts $b$, $w$ and $g/b$, respectively represent the portion of the land surface that always remains as bare soil, the portion of the fractional cover that is woody vegetation, and the remaining portion that consists of bare soil and herbaceous vegetation cover.

The temporal mean of the observed NDVI at each pixel is equal to the sum of the NDVI weighted by the fractional cover types

$$N_b(i, j)\langle \sigma_b(i, j) \rangle + N_w(i, j)\langle \sigma_w(i, j) \rangle + N_{g/b}(i, j)\langle \sigma_{g/b}(i, j) \rangle = \overline{N}(i, j)$$

where $\overline{\phantom{0}}$ operator represents temporal averaging; the subscripts $b$, $w$ and $g/b$, respectively represent the portion of the land surface that always remains as bare soil, the portion of the fractional cover that is woody vegetation, and the remaining portion that consists of bare soil and herbaceous vegetation cover.

For homogeneous canopies, the relation between fractional vegetation cover and leaf area index was formulated as (Choudhury et al. 1994, Baret et al. 1995, Wittich 1997)

$$\sigma(i, j) = 1 - e^{-c \text{LAI}(i, j)}$$

where LAI is leaf area index; $c$ is a constant to be simulated.

### 2.3 Roughness length $z_0$ and zero-plane displacement height $d$

The most common geometric approach is to use the mean height of roughness elements to estimate zero-plane displacement height $d$ and roughness length $z_0$ (Grimmond and Oke 1999). The relations between the mean height of roughness elements and $d$ and $z_0$ are formulated as

$$d = A_d H$$

$$z_0 = A_0 H$$

where $H$ is the mean height of roughness elements; $A_d$ and $A_0$ are constants to be simulated.

Garratt’s result (1992) showed that $A_d = 0.67$ and $A_0 = 0.10$ were good overall mean values for land surfaces. Raupach (1992) noted that for field crops and grass canopies $A_d = 0.64$ and $A_0 = 0.13$, for forests $A_d = 0.8$ and $A_0 = 0.06$. Jasinski and Crago (1999) compared the various roughness estimates for the Landes Forest (Gash et al. 1989, Parlange and Brutsaert 1989, Raupach 1994, Jasinski and Crago 1999) and concluded that $A_0$ values usually lie between 0.02 and 0.2 and $A_d$ values mostly between 0.6 and 0.9. In dispersion modelling over urban areas,
Hanna and Chang (1992) suggested that $A_d = 0.5$ and $A_0 = 0.10$ were useful approximations. Although this parametrization ignores many aspects, it does capture the most important parameter influencing turbulence near the surface and provides a basis for comparisons with more sophisticated models (Yang and Friedl 2003).

A key plant parameter is the frontal area index $\lambda$, which is defined as the ratio of frontal area of roughness elements from the mean wind direction per unit ground area. It can be formulated as

$$\lambda = \frac{nA_f}{A_p}$$

where $n$ is the number of roughness elements; $A_f$ is the mean frontal area of an individual roughness element, $A_p$ is the unit area such as the pixel area.

For isotropically oriented elements, the relationship between the frontal area index $\lambda$ and canopy area index $A$, the total (single-sided) area of all canopy elements over unit ground area, can be formulated as $A = 2\lambda$. The canopy area index includes all canopy elements, transpiring ones (living leaves and stems) and non-transpiring ones (dead leaves and stems), while leaf area index includes only transpiring surfaces. $A_d$ and $A_0$ are formulated as (Raupach 1992, 1994)

$$A_d = 1 - \frac{1 - \exp(-\sqrt{c_{d1}/A})}{\sqrt{c_{d1}/A}}$$

$$A_0 = (1 - A_d)\exp\left(-k\frac{u_h}{u_*} - \Psi_h\right)$$

where $c_{d1}$ is a free parameter; $k$ is the von Karman’s constant; $\Psi_h$ is the roughness-sublayer influence function; $u_*$ is the friction velocity; $u_h$ is the mean velocity at height $h$. When $\lambda > \lambda_{max}$, $\frac{u_h}{u_*}$ is nearly constant at 0.3, where $\lambda_{max}$ is the point at which adding further roughness elements to the surface does not affect the bulk drag because additional elements merely shelter one another. When $\lambda < \lambda_{max}$, $\frac{u_h}{u_*}$ is the solution of equation

$$\gamma = \frac{u_h}{u_*} = \left(\frac{\exp(\lambda_{max}/4)}{(C_S + C_R\lambda_{max})^{\frac{1}{2}}}\right)$$

where $C_S$ is the drag coefficient of the substrate surface at height $h$ in the absence of roughness elements (about 0.003); $C_R$ is the drag coefficient of an isolated roughness element mounted on the surface.

In addition to the geometric approach and the frontal area index, there have been many well-documented experimental determinations of the roughness over various surfaces, ranging from mobile surfaces (sea, moving sand or snow) to vegetations and towns based on the data of land cover types.

It can be concluded that the mean height of roughness elements ($H$), fractional vegetation cover ($\sigma$) and leaf area index (LAI) are the most essential parameters of the vertical wind profile under neutral conditions. Currently, wind speed models require either field validation of simulated LAI, $\sigma$ and $H$, or remotely sensed estimates of LAI, $\sigma$ and $H$ to initiate them (Running et al. 1999). LAI, $\sigma$ and $H$ measurements are critical for improving the performance of such models over large
areas and this has prompted investigations into the relationship between ground-measured LAI, $\sigma$ and $H$ and spectral vegetation indexes derived from satellite-measured data (Colombo et al. 2003).

3. Simulation of vertical wind profile

3.1 Retrieval of the essential wheat parameters at Yucheng Integrated Agricultural Experiment Station, Chinese Academy of Sciences, Shandong Province

In north China, the period from the first 10-days of March to the first 10-days of April is the optimum time for identifying wheat among other crops because wheat is the sole crop that has become green in this period. According to available NDVI data and Landsat TM data from archives, Landsat-5 data on 30 March 2000 are selected to identify wheat land-use type, of which projection is chosen as Albers Conical Equal Area. Observation data in the field and other auxiliary data include: (1) every-10-days observed data of mean height, leaf area index and fractional vegetation cover of the wheat at Yucheng Integrated Agricultural Experiment Station, Chinese Academy of Sciences, Shandong Province (36°49′52″N, 116°34′17″E) in 2000 (table 1); (2) the every-10-days NDVI data from NOAA-14 meteorological satellite; (3) 1:10,000 land-use data; (4) 1:10,000 topographical data.

The data pre-processing includes the following steps: (1) to collect 41 control points on the 1:10,000 topographical map and to geometrically correct the Landsat TM image (figure 1); (2) to conduct resampling by means of the proximity-element method in order to easily classify the image and keep the relatively proportional relation of grey gradations of the original image, (3) to create 25 m × 25 m corrected Landsat TM data; (4) to conduct projection transformation of the every-10-days NDVI data from Lambert homolographic projection to Albers Conical homolographic projection; (5) to conduct registration of the every-10-days NDVI data with the 1:10,000 land-use map of Yucheng, Shandong province; (6) to fit the original image by means of a quadratic polynomial.

Table 1. Observation values of relative parameters in 2000 (source: Yucheng Integrated Agricultural Experiment Station, Chinese Academy of Sciences, Shandong Province).

<table>
<thead>
<tr>
<th>Observation date (2000)</th>
<th>Stem height (cm)</th>
<th>Leaf area index</th>
<th>Fractional vegetation cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 March</td>
<td>13.5</td>
<td>2.18</td>
<td>20</td>
</tr>
<tr>
<td>15 March</td>
<td>21.6</td>
<td>2.58</td>
<td>25</td>
</tr>
<tr>
<td>20 March</td>
<td>22.6</td>
<td>3.3</td>
<td>33</td>
</tr>
<tr>
<td>25 March</td>
<td>24.2</td>
<td>3.58</td>
<td>36</td>
</tr>
<tr>
<td>30 March</td>
<td>29.2</td>
<td>4.58</td>
<td>39</td>
</tr>
<tr>
<td>4 April</td>
<td>35.4</td>
<td>4.61</td>
<td>44</td>
</tr>
<tr>
<td>9 April</td>
<td>45.4</td>
<td>4.88</td>
<td>50</td>
</tr>
<tr>
<td>14 April</td>
<td>55</td>
<td>4.97</td>
<td>62</td>
</tr>
<tr>
<td>19 April</td>
<td>73.6</td>
<td>4.98</td>
<td>70</td>
</tr>
<tr>
<td>24 April</td>
<td>84.5</td>
<td>5.04</td>
<td>90</td>
</tr>
<tr>
<td>29 April</td>
<td>85</td>
<td>4.98</td>
<td>95</td>
</tr>
<tr>
<td>4 May</td>
<td>93</td>
<td>3.76</td>
<td>95</td>
</tr>
<tr>
<td>9 May</td>
<td>93</td>
<td>3.29</td>
<td>95</td>
</tr>
<tr>
<td>14 May</td>
<td>93.2</td>
<td>2.93</td>
<td>90</td>
</tr>
<tr>
<td>19 May</td>
<td>93.2</td>
<td>2.38</td>
<td>88</td>
</tr>
<tr>
<td>24 May</td>
<td>93.2</td>
<td>1.55</td>
<td>80</td>
</tr>
</tbody>
</table>
The simulation results show that

\[
\text{LAI} = \begin{cases} 
-51.915 + 11.603 \ln(NDVI) & \text{when } NDVI \text{ increases (correlation coefficient is 0.889)} \\
-51.751 + 11.077 \ln(NDVI) & \text{when } NDVI \text{ decreases (correlation coefficient is 0.860)}
\end{cases}
\]

\[
H = \begin{cases} 
-238.753 + 2.251 NDVI_s & \text{when } NDVI_s \text{ increases (correlation coefficient is 0.868)} \\
93.2 \text{ cm} & \text{when } NDVI_s \text{ decreases}
\end{cases}
\]

\[
\sigma = \begin{cases} 
\text{e}^{28.308 + 5.679 \ln(NDVI)} & \text{when } NDVI \text{ increases (correlation coefficient is 0.920)} \\
\text{e}^{-3.712 + 0.733 \ln(NDVI)} & \text{when } NDVI \text{ increases (correlation coefficient is 0.889)}
\end{cases}
\]

where \( NDVI_s = 100(NDVI + 1) \); LAI is leaf area index; \( H \) is the mean height of wheat; and \( \sigma \) is the fractional vegetation cover.

The scaled NDVI, \( NDVI_s \), is derived from NOAA-14 data. \( NDVI_s \) increases from early March to early May and decreases from early May to June. \( NDVI_s \) ranges from 90 to 160 at Yucheng Integrated Agricultural Experiment Station, Chinese Academy of Sciences in Shandong province.

3.2 Simulation of horizontal wind velocity above the wheat surface at Yucheng Integrated Agricultural Experiment Station, Chinese Academy of Sciences, Shandong Province

According to equations (4) and (8) as well as discussions on roughness length and displacement height, horizontal wind velocity at height \( z \) and at time \( t \) is formulated
as

\[
\begin{align*}
   u(z, t) &= \frac{2.44u_* (t)}{\sigma(t) \left( (6.4 \text{LAI}(t))^b - 1 \right) + 1} \left[ \frac{\sigma(t) \left( (6.4 \text{LAI}(t))^b - 1 \right) + 1}{(0.13H(t)) \left( (6.4 \text{LAI}(t))^{2b} \right)} \right] z - 0.64H(t)\sigma(t)(6.4 \text{LAI}(t))^b \\
   &\text{where } u_* (t) \text{ is the friction velocity over the wheat surface; LAI} (t) \text{ is the leaf area index; } H(t) \text{ is the mean height of wheat; } \sigma(t) \text{ is the fractional vegetation cover of wheat; } b \text{ is the wheat parameter of the dimensionless constant to be simulated.}
\end{align*}
\]

The simulation result most fits the observation of horizontal wind velocity at a height of 2 m when \( b = 0.39 \) (figure 2). The horizontal wind velocity is expressed as

\[
\begin{align*}
   u(z, t) &= \frac{2.44u_* (t)}{2.06\sigma(t)(\text{LAI}(t))^{0.39} + (1 - \sigma(t))} \ln \left[ \frac{2.06\sigma(t)(\text{LAI}(t))^{0.39} + (1 - \sigma(t))}{0.55H(t)(\text{LAI}(t))^{0.78}} \right] z - 1.32H(t)\sigma(t)(\text{LAI}(t))^{0.39} \\
   &\text{The hourly horizontal wind velocity at a height of 4 m during the period from 21:05 on 5 March 2000 to 7:05 on 24 May 2000, which is simulated by means of equation (30), is almost identical to the observation ones (figure 3). The correlation coefficient between the simulation results and the observation values is 0.998.}
\end{align*}
\]

4. Conclusion

Our review of studies on wind profile shows that horizontal wind velocity above a non-uniform underlying surface is determined by roughness length, zero-plane displacement height, dimensionless constant and vegetation fractional cover. Roughness length and zero-plane displacement height can be expressed as a mathematical function of the mean height of roughness elements; the dimensionless constant can be formulated as a function of leaf area index. Therefore, the mean height of roughness elements, fractional vegetation cover and leaf area index are involved in the formulation of horizontal wind velocity as the most essential parameters. The case-study at Yucheng Integrated Agricultural Experiment Station, Chinese Academy of Sciences, Shandong Province shows that the mean height of roughness elements, fractional vegetation cover and leaf area index are closely related to the normalized difference vegetation index (NDVI). They are retrieved

![Figure 2. Hourly observation of horizontal wind velocity at height 2 m during the period from 21:05 on 5 March 2000 to 7:05 on 24 May 2003 at Yucheng Integrated Agricultural Experiment Station (when observation time is 21:05 on 5 March 2000, \( T_s = 1 \); when observation time is 7:05 on 24 May 2000, \( T_s = 1929 \).)
from the scaled NDVI. A model of vertical wind profile (MVWP), the relationship between horizontal wind velocity and NDVI is finally established. The simulated horizontal wind velocity is almost the same as the observed one at the Yucheng Integrated Agricultural Experiment Station, which means that MVWP is applicable to formulate horizontal wind velocity under thermally neutral conditions.

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References


BLENNOW, K. and SALLNÄS, O., 2004, WINDA—a system of models for assessing the probability of wind damage to forest stands within a landscape. Ecological Modelling, 175, pp. 87–99.


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