Determination of surface layer parameters at the edge of a suburban area

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Abstract

Main goal of this work is to examine a possibility of application of Monin-Obukhov (M-O) similarity theory for the wind speed estimation in the lower part (at 2 m height) of the atmospheric surface layer (ASL) using routine weather elements. For this purpose the meteorological data at the Zagreb-Maksimir Observatory, located in suburban environment for the year 2005 is used. The effective roughness length z_0 concept is used in order to take into account the influence of different surface roughness (mainly due to urbanization) dependent on wind direction (Fig. 2 and 3). The value z_0 is reflected on the vertical wind speed profile as well as other meteorologically relevant profiles. At the same time, it represents an average effect of all obstacles of several kilometers in the upwind direction. In other words, it means that the wind speed measured at one place represents actually "the weighted average" wind speed over a wider area in the upwind direction. Such "average" wind speed is usable for application at grid raster in atmospheric models with resolution of several kilometers, especially over suburban and urban areas. Surface roughness classification according to wind direction provides the more accurate wind speed extrapolation at 2 m height as well as at heigher levels in comparison to case when the dependence of z_0 on wind direction is not taken into account. These extrapolations are used for the purposes of atmospheric modeling, in civil engineering, etc.

1. Introduction

The intention of this paper is to estimate the wind speed at 2 m because hourly observations of this parameter are usually not made, although hourly data can be useful for many practical applications (e.g. in agriculture, surface transportation, etc.). A comprehensive method is presented, which gives hourly estimates of the wind speed at 2 m from routine weather data. The data consist of 10-min average of wind speed with the prevailing wind direction, air temperature for two levels (2m and 10 m) as well as the corresponding wind gust during 10-min periods for 10 m above the ground. The corresponding air pressure refers to the measurements in the Observatory building ~ 50 m to the south from the meteorological observing site (Fig. 1).

2. Methodology

In the absence of turbulence measurements we have to derive the surface layer parameters (friction velocity u_*, temperature scale for turbulent heat transfer θ_* and M-O lenght L) from other available data. For estimation of M-O length an iterative and empirical procedure are used. In the iterative procedure the computation starts with estimates for u_* and θ_* with assumption about neutral atmospheric stability ($\zeta = z/L \rightarrow 0$). Using new values of u_* and θ_* an updated value of M-O length is calculated. Depending on the sign of M-O lenght, new values of u_* and θ_* enter the calculation where appropriate stability corrections are intoduced. Taking into account these new, improved values of u_* and θ_*, the new improved value of M-O length is obtained, and so on. It appears that usually not more than three iteration steps are needed to achieve a sufficient accuracy of 1% in successive values of M-O length.
For L < 0 (unstable conditions) the following stability correction functions are used (Paulson, 1970; Dyer, 1974):

$$\psi_m\left(\frac{z}{L}\right) = 2\ln\left(\frac{1+x}{2}\right) + \ln\left(\frac{1+x^2}{2}\right) - 2\tan^{-1}(x) + \frac{\pi}{2}$$

$$\psi_h\left(\frac{z}{L}\right) = 2\ln\left(\frac{1+x^2}{2}\right)$$

where

$$x = \left(1 - 16\frac{z}{L}\right)^{\frac{1}{4}}$$

For L > 0 (stable conditions) after Beljaars and Holtslag (1991):

$$-\Psi_m = \frac{az}{L} + b\left(\frac{z}{L} - \frac{c}{d}\right)\exp\left(-\frac{dz}{L}\right) + \frac{bc}{d}$$

$$-\Psi_h = \left(1 + \frac{2}{3}\frac{az}{L}\right)^{\frac{3}{2}} + b\left(\frac{z}{L} - \frac{c}{d}\right)\exp\left(-\frac{dz}{L}\right) + \left(\frac{bc}{d} - 1\right)$$

where a = 1, b = 0.667, c = 5 and d = 0.35.

Empirical procedure

$$Ri = \frac{\frac{g}{\bar{\theta}}\frac{\partial\theta}{\partial z}}{\left(\frac{\partial u}{\partial z}\right)^2} \approx \frac{g}{T(z_1)} z_m \ln(z_2/z_1)\frac{\Delta\theta}{(\Delta u)^2}$$

$$z_m = \sqrt{z_1 z_2}$$

Ri – bulk Richardson number
z_m – geometric mean height
$T(z_1)$ – absolute air temperature at the first level

Fig. 1 The meteorological observing site at the Zagreb-Maksimir Observatory including anemometer masts of 2 m (1) and 10 m (2) of heights, respectively.

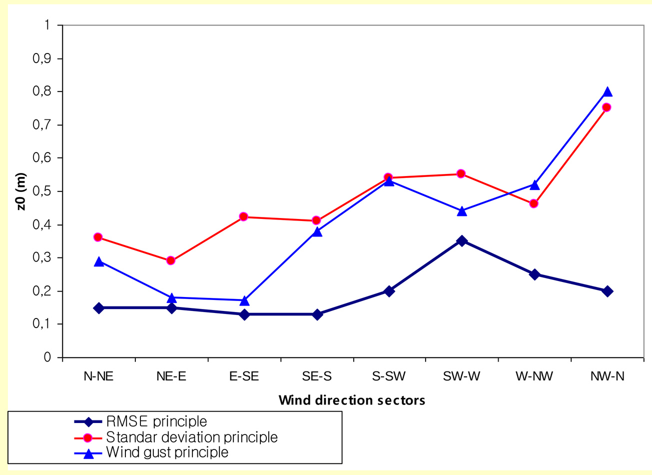

Fig. 2 Comparion of effective roughness length estimation using three principles: wind gusts in 10-min period and standard deviations for the same period, both for wind at 10 m above the ground, and minimum RMSE of estimation of 10-min average at 2 m above the ground for the Zagreb-Maksimir Observatory.

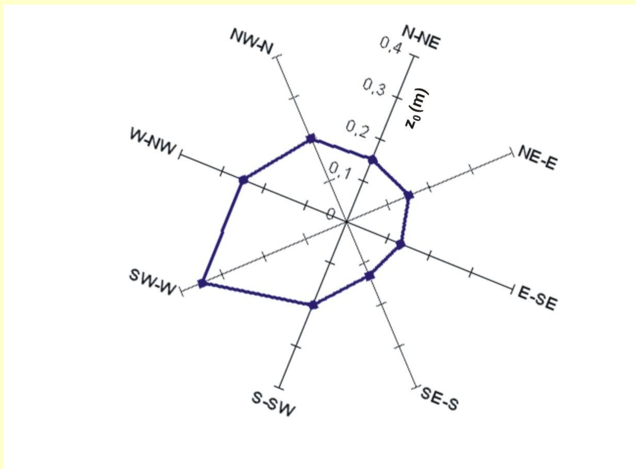

Fig. 3 Effective roughness length rose in dependence on the wind direction sector. Values of z_0 have been estimated using root mean squared errors (RMSE) principle.

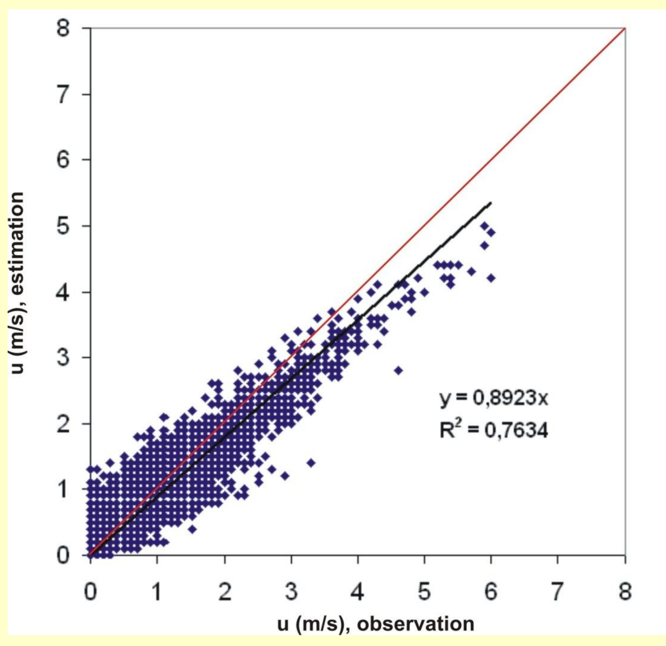

Figure 4 a

Fig. 4 a Comparison between estimated (using gradient method) and observed values of wind speed at 2 m above the ground for the Zagreb-Maksimir Observatory; dependence of z_0 on wind direction is neglected (R^2 = 0.76). Figure 4 b the same as in Fig. 4 a but taking into account the dependence of z_0 on the wind direction sector (R^2 = 0.85).

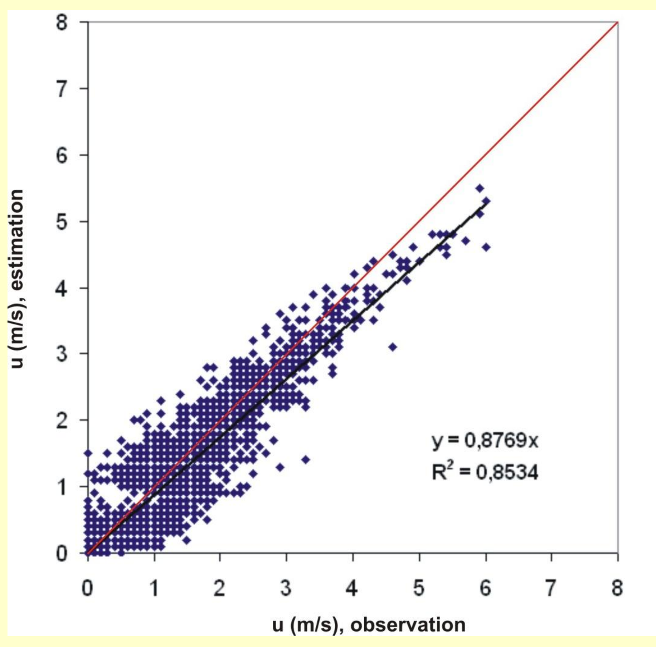

Figure 4 b

Lee (1997) – empirical procedure for calculation of stability parameter z/L

a) Unstable conditions

$$\frac{z}{L} = \frac{1}{c}\left(\frac{z}{z-z_0}\right)\ln\left(\frac{z}{z_0}\right)\left(\frac{Ri}{1-\beta^* Ri}\right)$$

b) Stable conditions

$$\frac{z}{L} = \left(\frac{z}{z-z_0}\right)\ln\left(\frac{z}{z_0}\right)\times\left(\frac{Ri + 13Ri^2 - 15Ri^3 + 3.3Ri^4}{1 - 0.6Ri^2 + 0.1Ri^4}\right)$$

for z/z_0= 10

$$\frac{z}{L} = \left(\frac{z}{z-z_0}\right)\ln\left(\frac{z}{z_0}\right)\times\left(\frac{Ri + 5Ri^2 - 7Ri^3 + 2.1Ri^4}{1 - 0.6Ri^2 + 0.1Ri^4}\right)$$

za $z/z_0=10^4$

If wind speed is available at the height z_2, then, an estimation of wind speed at other level in the surface layer can be obtained using:

$$u(z_1) = u(z_2)\frac{\left[\ln\left(\frac{z_1}{z_0}\right) - \psi_m\left(\frac{z_1}{L}\right)\right]}{\left[\ln\left(\frac{z_2}{z_0}\right) - \psi_m\left(\frac{z_2}{L}\right)\right]}$$

where z_1 = 2 m, z_2 = 10 m.

Effective roughness length estimation

$$\frac{\sigma_u}{\bar{u}} = \frac{1}{\ln(z/z_0)}$$

σ_u – standard deviation of wind speed

$\bar{u}$ – mean wind speed

Wind gust factor – ratio of maximum wind gust and average wind speed during the period that the gust u_{max} appered.

$$G \equiv \frac{u_{max}}{\bar{u}}$$

Median of wind gust factor:

$$\langle G \rangle = 1 + \frac{1.42 + 0.3013\ln\left((990/\bar{u}t) - 4\right)}{\ln z/z_0}$$

3. Results

Verification parameters

$$BIAS = \frac{1}{N}\left[\sum_{i=1}^{N}(F_i - O_i)\right]$$

$$MAE = \frac{1}{N}\left[\sum_{i=1}^{N}|F_i - O_i|\right]$$

$$RMSE = \sqrt{\frac{1}{N}\left[\sum_{i=1}^{N}(F_i - O_i)^2\right]}$$

F_i (i=1,2,...,N) – estimated values, O_i – observed values

	Verification parameters			
Wind direction sectors	**Z_{0m} (m)**	**BIAS (m/s)**	**MAE (m/s)**	**RMSE (m/s)**
N-NE	0.15	-0.09	0.30	0.40
NE-E	0.15	-0.07	0.24	0.20
E-SE	0.13	0.00	0.14	0.15
SE-S	0.13	0.01	0.24	0.28
S-SW	0.20	-0.06	0.33	0.41
SW-W	0.35	-0.04	0.33	0.41
W-NW	0.25	0.00	0.25	0.39
NW-N	0.20	0.01	0.18	0.19
Mean	0.20	-0.03	0.25	0.31
All directions	0.18	-0.11	0.32	0.41

4. Conclusions

•Results obtained using both procedures are in excellent agreement except in case of very stable conditions when Ri > 1.

•Limitation of presented method in reproducing intermittent turbulence is directly caused by the use of a stability functions.

•The classification of z_0 according to wind direction (z_0 values obtained are higher for western than for eastern quadrants of wind direction)

•In average, considered wind speed estimation errors, which refer to wind direction sectors are about 10% lower than in case when estimations of wind speed are made regardless of wind direction sectors (Figures 4 a and 4 b).

23rd Symposium on Boundary Layers and Turbulence/21st Conference on Air –Sea Interaction, 11-15 June 2018, Oklahoma City, Oklahoma, USA