Estimating Wind Speed at an Urban Reference Height

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In many applications, standardized urban wind observations are requested. Measurements recorded at any urban site should be comparable with other simultaneously measured urban or rural wind speeds and be representative as wind input data for dispersion modeling. Therefore, urban reference heights are currently in discussion. However, available urban data are usually not from a 'reference' height.

The recently suggested procedure of the European COST 715 Action (Rotach *et al.*, 2004) uses three simple steps to estimate wind speed at any 'reference' height from any other measurement height in the urban roughness sublayer.

This procedure has been thoroughly and independently tested with data from the Basel Urban Boundary Layer Experiment (BUBBLE). Long-term wind and turbulence profile measurements over 8 months allow the validation of the procedure with various input configurations. The calculated 'reference' wind speeds have been compared to wind speeds directly measured at 'reference' height.

Table 1: The two urban measurement sites selected for the verification of the COST 715 procedure. The towers were deployed in the city centre of Basel, Switzerland during BUBBLE:

	Basel-Sperrstrasse	Basel-Spalenring
Tower height	32 m	38 m
No of sonics	6	6
No of cup anemometers	12	5
Mean building height h	14.6 m	15.0 m
Roughness length z_0	2.1 m	1.4 m
Plan area density λ_P	54 %	37 %

Step 1.

Estimate z_d and z_*.

In the first step of the COST 715 procedure, the urban zeroplane displacement z_d and the roughness sublayer height z_* are estimated from mean building height h using empirical relationships.

The determination of z_d with the 'rule-of-thumb' (0.7h) delivers reasonable estimates at both BUBBLE towers. z_d determined by different empirical relationships with morphometric data from a digital building model as well as the neutral logarithmic wind profile result both in typical values for z_d between 0.7 and 0.8h.

z_* is a more problematic input parameter. Various experiments demonstrated, that local Reynolds stress u_* changes with height and shows a maximum between 1.5 and 2h. In the COST 715 procedure, z_* is interpreted as the height, where maximum local Reynolds stress is observed, rather than the height where the spatial inhomogeneities vanish. The height of the maximum u_* is surprisingly constant around 1.6h for different flow situations at both urban towers.

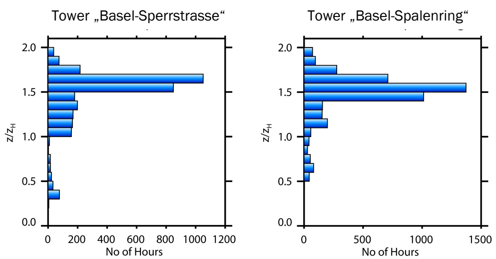

Figure 1: The histograms illustrate the height of maximum u_* at the two urban towers. Data include all stabilities and all wind directions. In the majority of all cases, maximum u_* is measured close to 1.6h. A cubic spline interpolation was performed between measurement levels to enhance the height resolution.

Step 2.

Calculate the profile of local u_*.

The following parameterization for the vertical profile of local $u_*(z)$ has been proposed by Rotach (2001), where a and b are empirical constants:

$$\left(\frac{u_*(z)}{u_*(z_*)}\right)^b = \sin\left(\frac{\pi}{2}\frac{z-z_d}{z_*-z_d}\right)^a \quad for \quad z_d \leq z \leq z_*$$

$$u_*(z) = u_*(z_*) \quad for \quad z \geq z_*$$

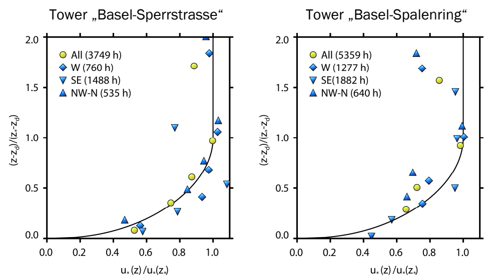

Figure 2: Parameterization of the u_* profile (black line) in comparison with measured values of $u_*(z)/u_*(z_*)$ for the different wind direction classes. "W" is the main synoptic wind, "SE" denotes the direction of the main cold air drainage flow, "NW-N" is a convective summertime wind. Observational data are processed with an individual h for each of the wind sectors, a z_d of 0.7h and a z_* of 1.55h.

The parameterization suggests to interpret any measured u_* above z_* as $u_*(z_*)$. The observations show, that the measured profile of u_* above z_* is in many cases decreasing, especially at 'Basel-Spalenring'. By taking the topmost measurement level as input for both u_* and u, the procedure results therefore in an underestimation of $u(z)$ typically in the order of 10%.

No urban u_* measured?

If Reynolds stress u_* is not measured directly in the city, the parameterization of Hanna and Chang (1992) may be applied or measurements from a rural site can be used to estimate $u_*(z_*)$ according to Bottema (1995), where α is an empirical factor:

$$\frac{z_{0urban}}{z_{0rural}} = \left(\frac{u_*(z_*)_{urban}}{u_{*rural}}\right)^\alpha$$

In order to test this scenario, data from the rural site 'Village Neuf' which is located 4 km North of the city in an ideal area with agricultural land use is taken as input.

Figure 3 shows flow situations, when the rural site is in the upwind direction of the city. In this case, applying the parameterization leads to a systematical underestimation of the urban $u_*(z_*)$ by 30%. The underestimation is remarkably stronger in periods when the rural site lies downwind of the city. This suggests, that beside local effects at the urban site, the procedure gives only reasonable results, when the wind flow at the rural site is undisturbed by the city.

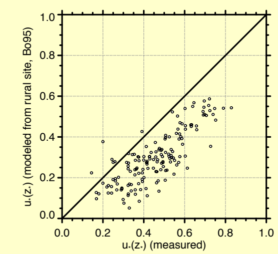

Figure 3: Comparison of measured urban Reynolds stress at z_* and its modeled values.

Step 3.

Numerically integrate the wind profile.

The wind at reference height is calculated by numerically integrating the logarithmic wind profile equation. For each integration step, the local Reynolds stress from step 2 is taken. ϕ_m is calculated with local Obukhov length, and sensible heat flux is assumed to be constant with height.

$$\frac{\partial u}{\partial z} = \frac{u_*(z)}{k(z-z_d)}\phi_m$$

Table 2: Comparison between modeled wind speed at a 'reference height' (z_d + 10 m, 24.6 m) and measured (interpolated) values at same height for "Basel-Sperrstrasse". The table lists overall statistics for different input configurations in terms of the slope of a linear regression (a, with $u_{modeled} = a\, u_{measured}$), the square of the linear Pearson correlation coefficient between measurement and modeled wind speed (r^2) and the RMS error in m/s.

Input wind speed		Urban input u_*			Rural input u_*		
z	z/h	a	r^2	RMS	a	r^2	RMS
31.7 m	2.17	0.93	0.73	0.66	1.22	0.71	0.97
22.4 m	1.53	0.95	0.97	0.20	1.02	0.72	0.64
17.9 m	1.23	1.03	0.97	0.25	0.89	0.68	0.87
14.7 m	1.01	1.00	0.90	0.62	0.52	0.47	1.31
11.3 m	0.77	1.08	0.41	3.90	0.16	0.16	1.62

In general, modeled values with an urban input u_* and input parameters from below reference height result in a good estimate, but in some cases overestimate the reference wind speed slightly. The overestimation is most pronounced when an overall wind direction along the canyon axis is observed. The associated flow channeling within the street canyon increases local wind speed and u_* close to the roofs and in the upper canyon part relatively to the horizontal average. As a consequence the resulting reference wind speed is overestimated when integrating upwards.

The calculations with rural u_* values (see box left) result in higher scatter between the modeled and in-situ measurements. The modeled urban $u_*(z_*)$ is in many cases strongly underestimated, which in consequence lowers the local gradients $\partial u / \partial z$. Calculations with numerical integration downwards result in a strong overestimation and the ones with an upward integration show an underestimation.

Conclusions.

Overall, the results of the procedure are encouraging, and most configurations result in reasonable estimates of the wind speed at the reference height. However, input data from the street canyon below h should be avoided. The performance of the procedure is strongly dependent on how representative the input wind measurements $u(z)$ are in the horizontal average. Larger errors are associated with rural measurements and flow directions that have strong inhomogeneities and a highly variable building height.

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