Determination of Thermal Roughness Length for Complex Urban Areas with High Resolution Meterological Stations

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1-The Importance of Thermal Roughness Length

This study of **urban micrometeorology** aims to gain a better understanding of **heat flux** mechanisms in cities. During a measurement campaign over the EPFL campus (see Fig. 1), a **dense network of weather stations** was deployed and several parameters were measured to get the best estimate of the **thermal roughness length** z_{0h}, a measure of how well the sensible heat fluxes take place between the surface and the atmosphere.

Figure 1: The EPFL Campus

2 – Monin-Obukhov Similarity Theory

Within the atmospheric surface layer, you can use the Monin-Obukhov Similarity Theory to predict the behavior of variables like the air temperature or the wind speed. One of the objectives of this study is to test if this theory holds well in complex areas like cities.

Thermal roughness length z_{0h}

$$\theta_s - \bar{\theta} = \frac{H}{\rho c_p k u_*}\left[\ln\left(\frac{z-d_0}{z_{0h}}\right) - \Psi_h\left(\frac{z-d_0}{L}\right) + \Psi_h\left(\frac{z_{0h}}{L}\right)\right] \quad \text{(Eqn 1)}$$

Surface roughness z_0

$$\bar{u} = \frac{u_*}{k}\left[\ln\left(\frac{z-d_0}{z_0}\right) - \Psi_m\left(\frac{z-d_0}{L}\right) + \Psi_m\left(\frac{z_0}{L}\right)\right] \quad \text{(Eqn 2)}$$

Table 1: Important parameters involved in this study and how they are determined.

Parameter	Symbol	How *measured* / calculated	Refer to poster section
thermal roughness length	z_{0h}	iterative loop from Eqns 1 and 2	6
surface roughness	z_0	Large Eddy Simulations (LES) *Sound Detection and Ranging (SODAR)* and Eqn 2	3 4
zero-displacement height	d_0	LES	3
skin temperature	θ_s	*weather stations network*	4, 5
air temperature	θ	*Radio Acoustic Sound System (RASS)*	4
sensible heat flux	H	iterative loop from RASS data	6

3 – Large Eddy Simulations of the EPFL Campus

Simulation details

1) scale-dependant Lagrangian Smagorinky coefficient calculation
2) buildings simulated using the Immersed Boundary Method
3) grid resolution: 100 x 100 x 80

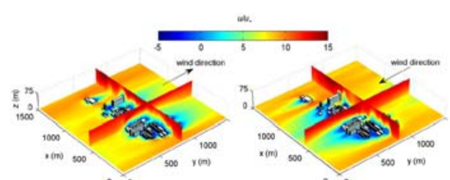

Figure 2: Normalized velocity fields based on LES data.

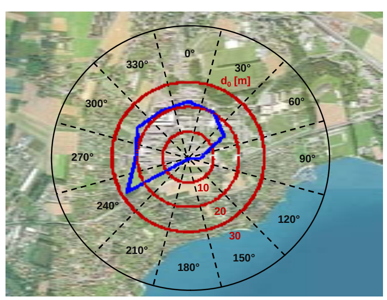

Figure 3: Distribution of zero-displacement height d_0 based on LES data.

4 – High Resolution Meteorological Stations

Sensorscope weather stations

Parameter measured: skin temperature (among others)
Number of stations: 100
Area covered: 0.3 km²
Period of operation: Nov. 2006 to May 2007
Sampling time: 2 min

Figure 4: A Sensorscope weather station.

SODAR / RASS

Parameters measured: wind and temperature profiles
Location: south of the campus
Period of operation: Jun. 2006 to Jul. 2007
Sampling time: 30 min

5 – Getting Representative Values of Skin Temperature Distribution

Several factors can affect the spatial distribution of skin temperature, which in turn influences the sensible heat flux. Some of these factors are the surface type and the exposure to solar radiation.

Surface type

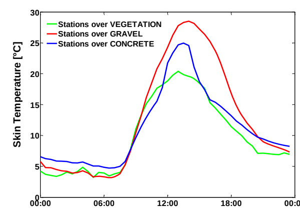

Figure 5: Daily evolution of skin temperature on 14 Mar. 2007 (sunny day).

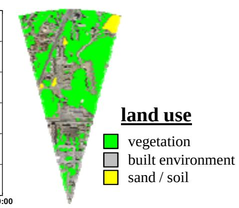

Figure 6: Land use for the 0° wind sector (see Fig. 3).

One approach to get more accurate values of skin temperature is to compute a weighted average based on a land use analysis (see Fig. 6):

$$\langle \theta_s \rangle = a\theta_{s,\text{vegetation}} + b\theta_{s,\text{sand/soil}} + c\theta_{s,\text{built environment}} \quad \text{(Eqn 3)}$$

Exposure to solar radiation

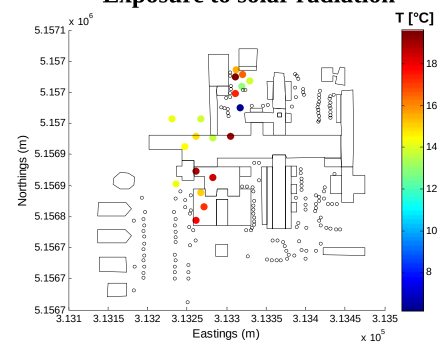

Figure 7: Distribution of skin temperature for the 0° wind sector on 14 Mar. 2007 at 10:00 (clear sky).

The modelling of shadow effects is under development.

6 – Calculation of Thermal Roughness Length

The determination of the thermal roughness length involves iterative calculations based on vertical profiles measured by the SODAR/RASS setup. Below is a sample calculation for 14 Mar. 2007 at 10:00.

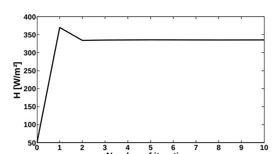

Figure 8: Convergence of H for 14 Mar. 2007 at 10:00.

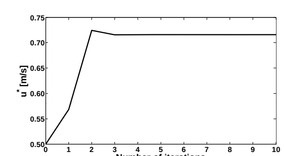

Figure 9: Convergence of u_* for 14 Mar. 2007 at 10:00.

Output

$z_{0h} = 1.786$ m

7 – Conclusions

- High spatial resolution network of sensors provides more accurate values of θ_s and z_{0h}
- Outputs from iterative calculations are sensitive to irregularities in the temperature and wind profiles