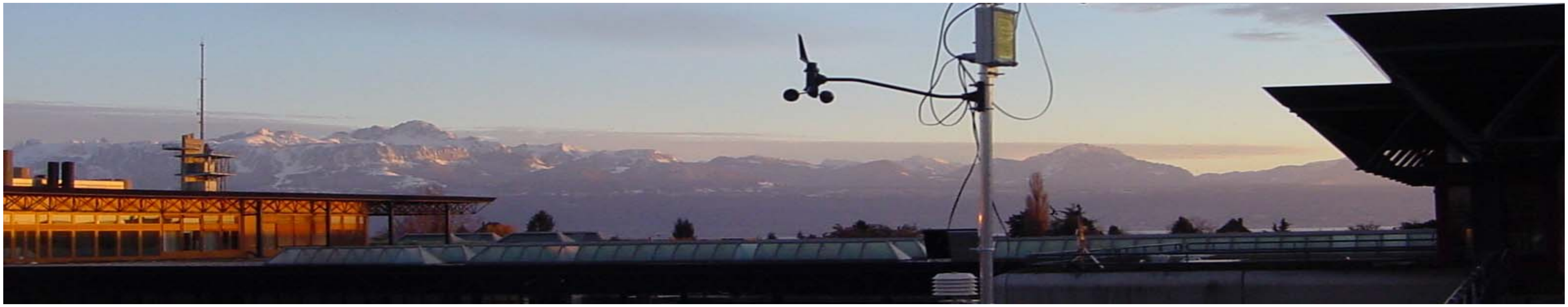
Determination of the Thermal Roughness Length for a Built Environment using High Resolution Weather Stations



Daniel Nadeau

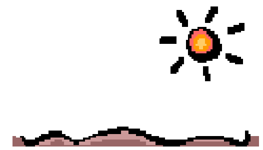
E. Bou-Zeid, M. B. Parlange, G. Barrenetxea, M. Vetterli

Stockholm, 11 June 2008

Motivations

Urban population is increasing

- now: 3.3 billion
- 2030 prediction: 5 billion (UN, 2008)



⇨ *Larger stress of built-up areas on the atmosphere*

Need to model land-atmosphere interactions in urban areas

- surface roughness z_0
- thermal roughness length z_{0h}

⇨ *Two methods to do so: morphometric or micrometeorological*

Motivations

Morphometric approaches

- use building geometry to calculate roughness parameters

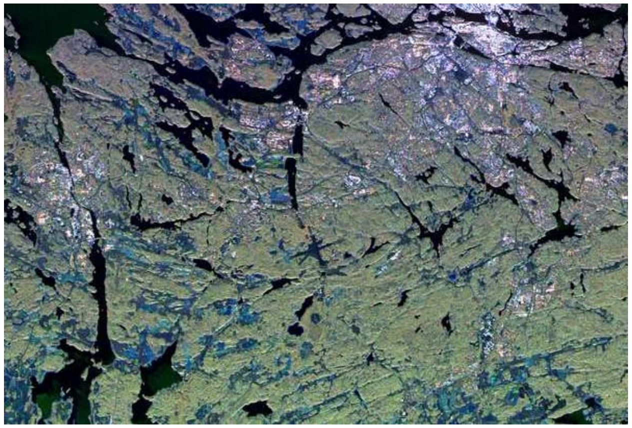
⇒ *different models often lead to widely varying estimates of roughness characteristics*

Micrometeorological approaches

- surface temperature typically inferred from satellite measurements
- MODIS:1-km spatial resolution for T_{sfc}

⇒ *Resolution too low to account for spatial heterogeneities*

Stockholm area as seen by Modis



Source: NASA, 2008

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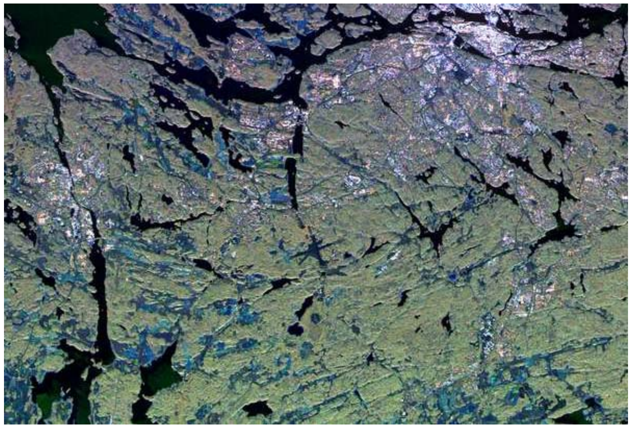


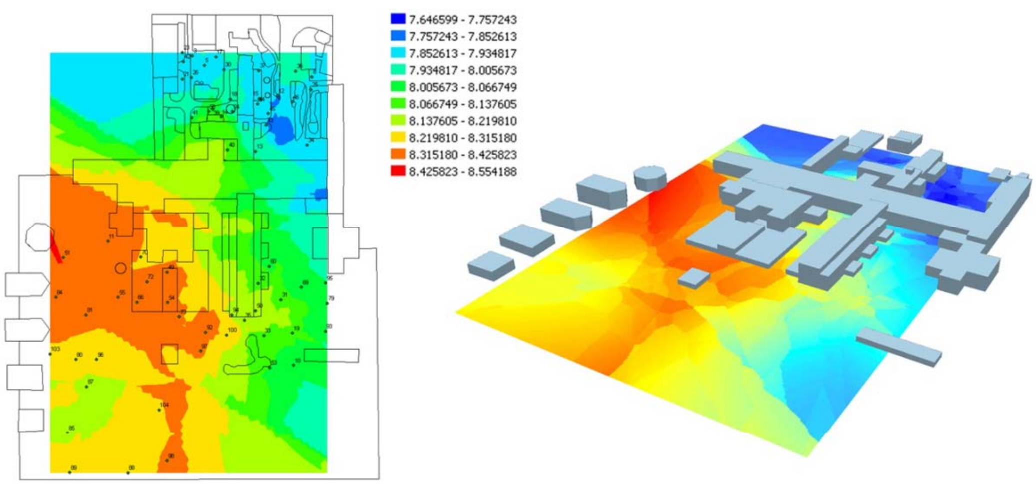
Source: NASA, 2008

Need for high resolution measurements of urban surfaces

Research Objectives

- better understand the impacts of spatial heterogeneities on land-atmosphere interactions over complex urban terrain

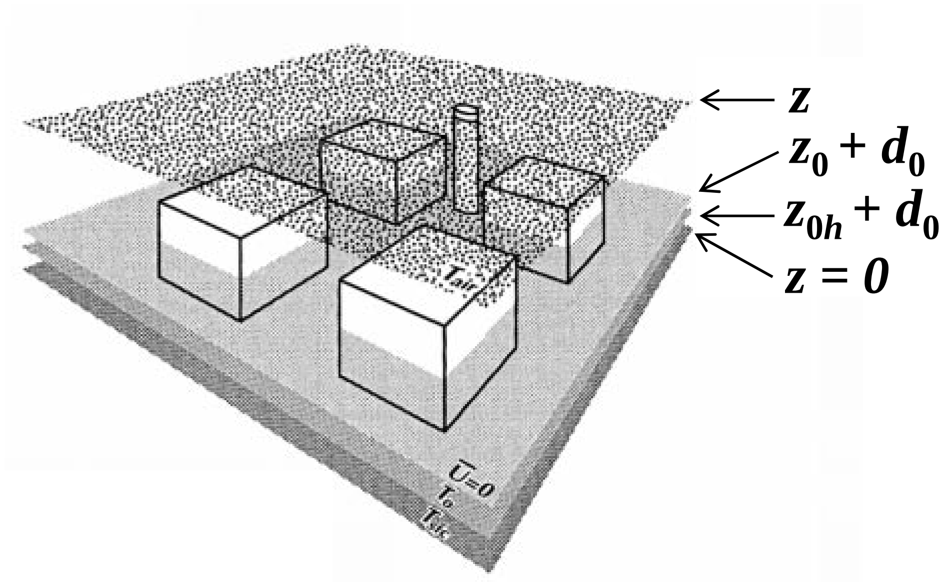
- calculate roughness lengths for momentum (z_0) and for heat (z_{0h}) using *in situ* measurements



Source: S. Mortier, 2007

Background

Thermal roughness length z_{0h}

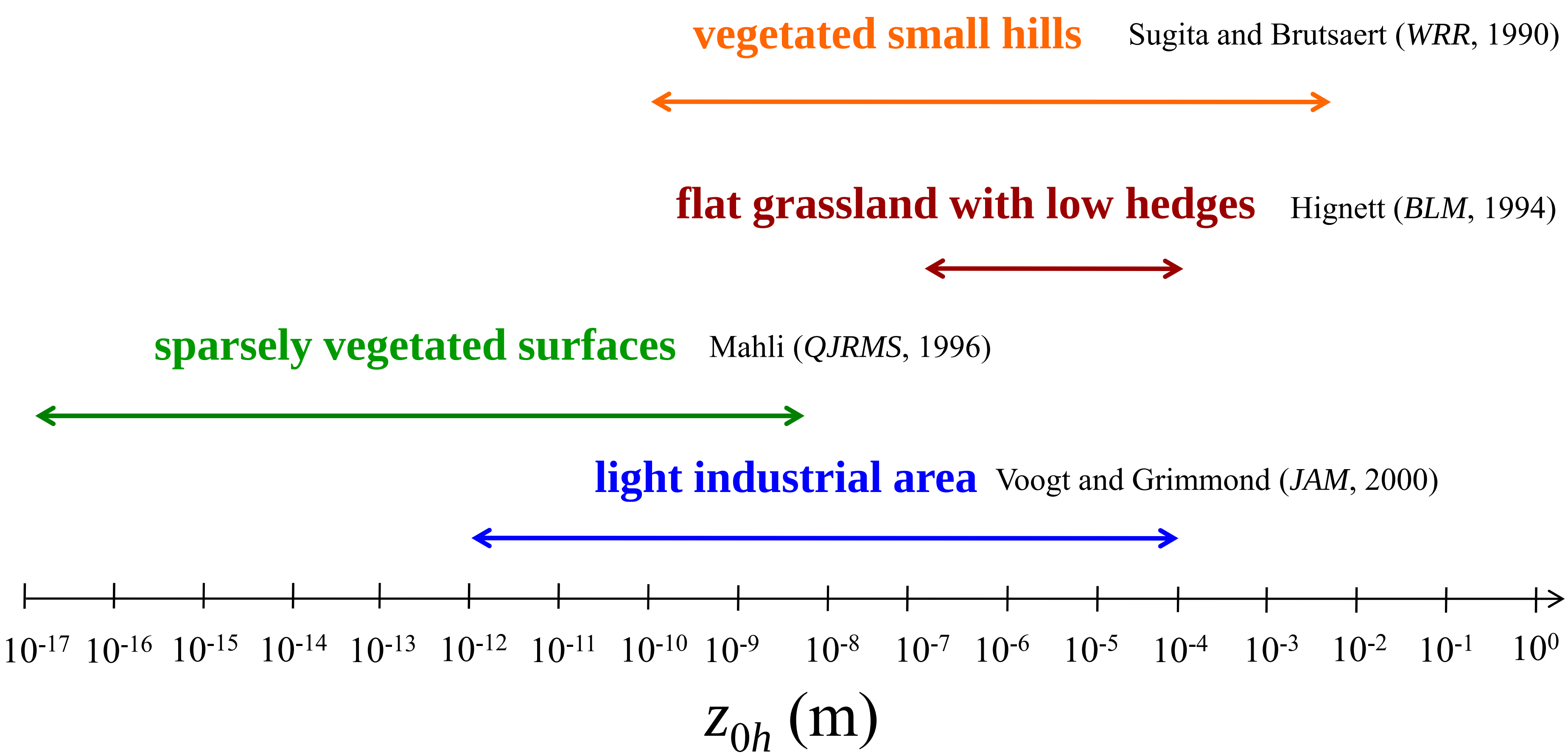


Source:Voogt and Grimmond, *JAM*, 2000

- also referred to as radiometric roughness length or scalar roughness for heat
- intercept of the logarithmic profile for potential temperature in the inertial sublayer

Background

Thermal roughness length z_{0h} over heterogeneous surfaces



Background

Monin-Obukhov Similarity Theory in the ABL

WIND SPEED

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

z_0: surface roughness (m)

AIR TEMPERATURE

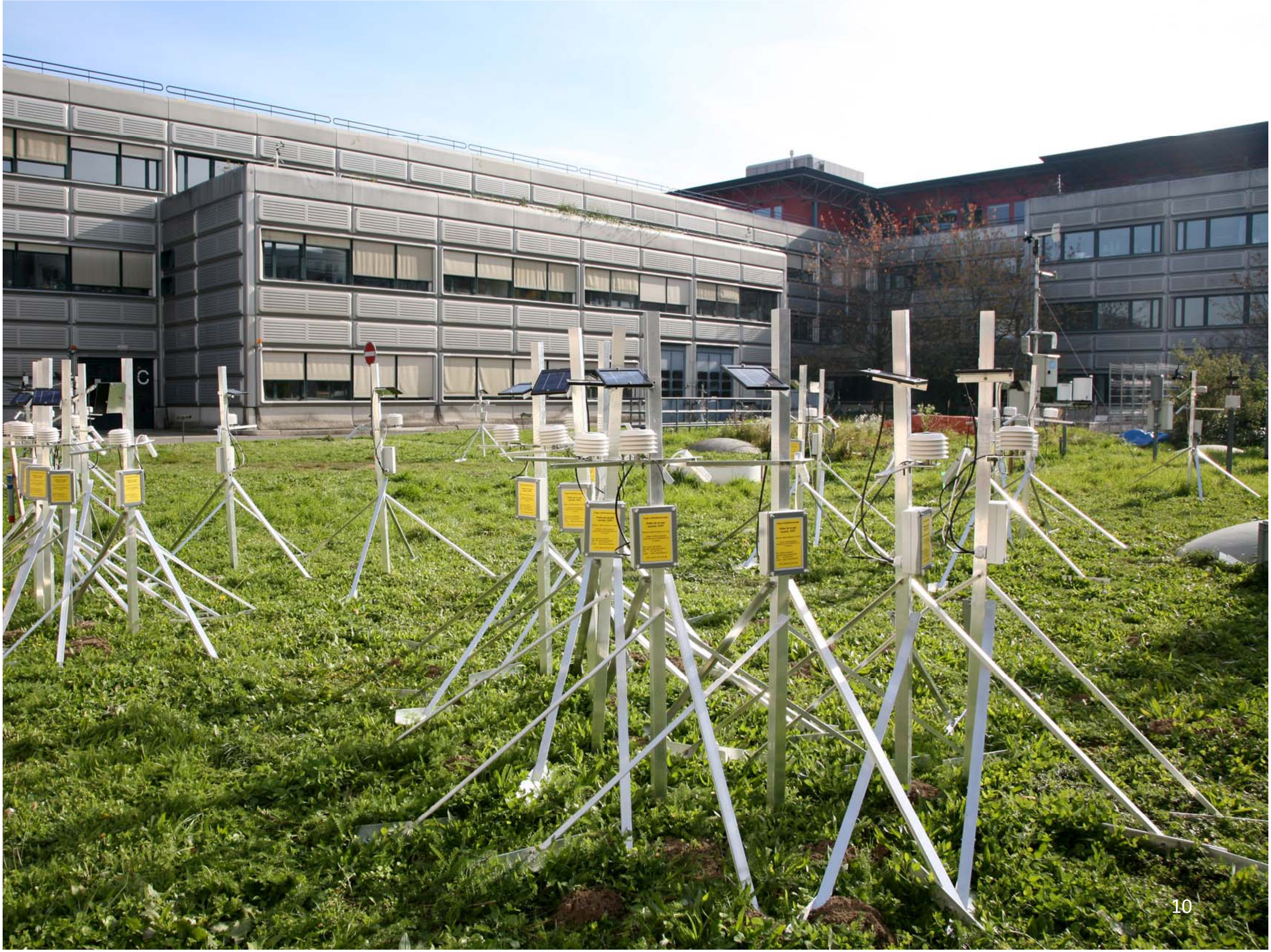
$$\theta_s - \theta = \frac{H}{\rho k u_* c_p}\left[\ln\left(\frac{z-d_0}{\boxed{z_{0h}}}\right) - \Psi_h\left(\frac{z-d_0}{L}\right) + \Psi_h\left(\frac{z_{0h}}{L}\right)\right]$$

z_{0h}: thermal roughness length (m)

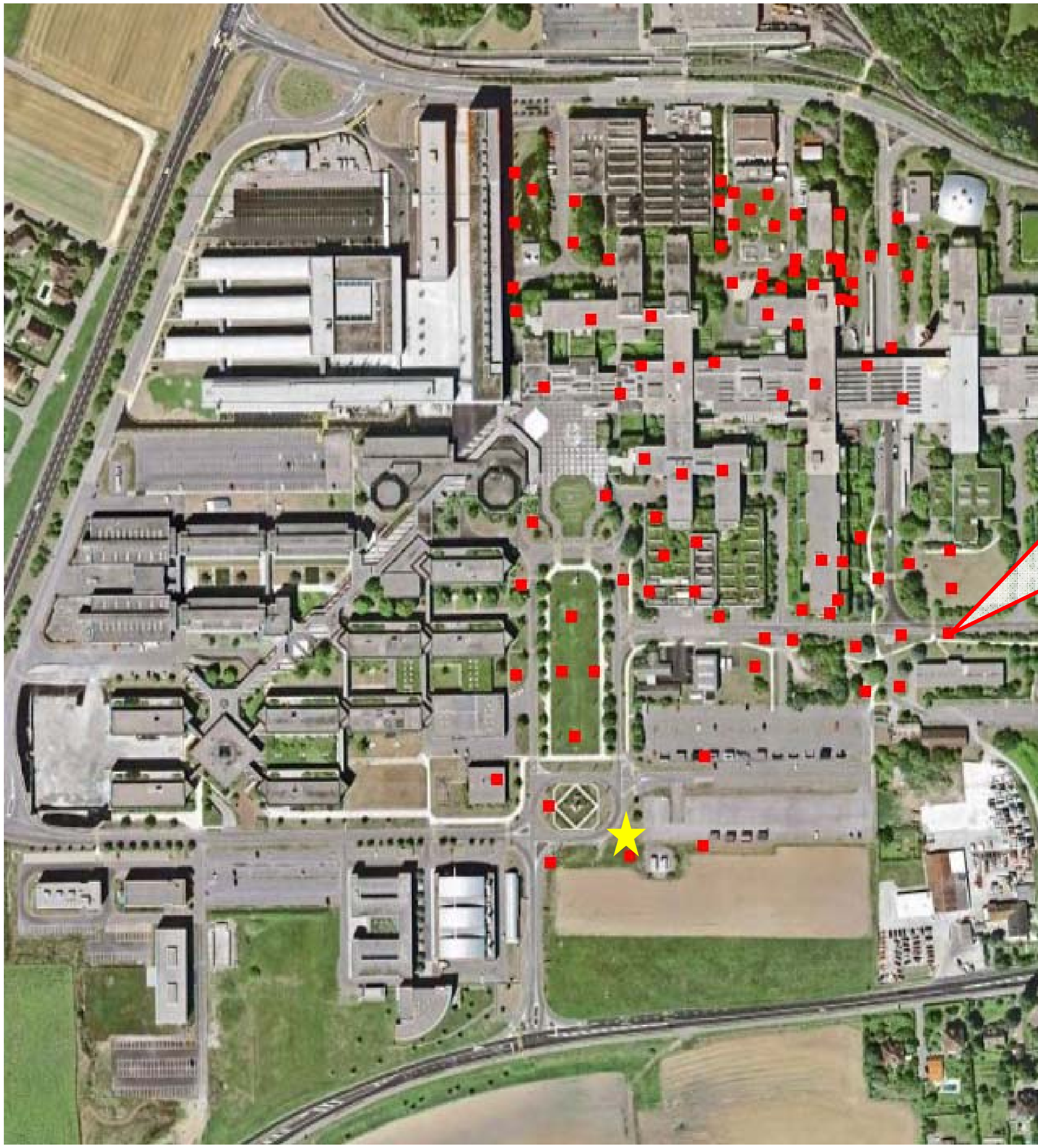
The EPFL Campus

a 750 x 500 m campus essentially consisting of buildings, vegetation, roads, and parking lots

Source: EPFL, 2008



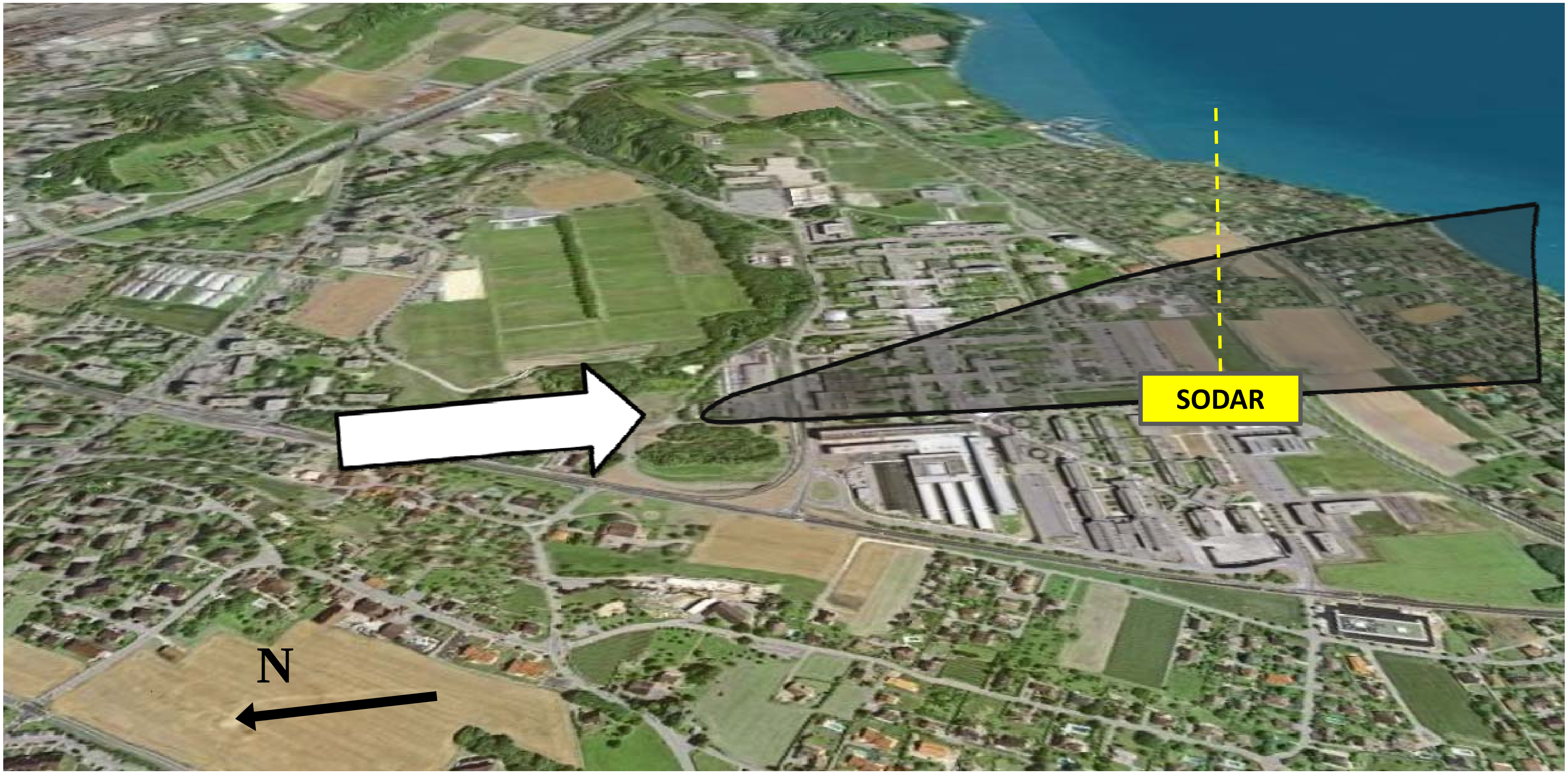
The Experimental Setup



Sensorscope stations

- •92 wireless weather stations
- •operating from Nov. 06 to May 07
- •sampling time of 2 min, but we use 30 min averages
- •parameters measured: skin temperature, air temperature, wind speed, relative humidity, etc.

The Experimental Setup



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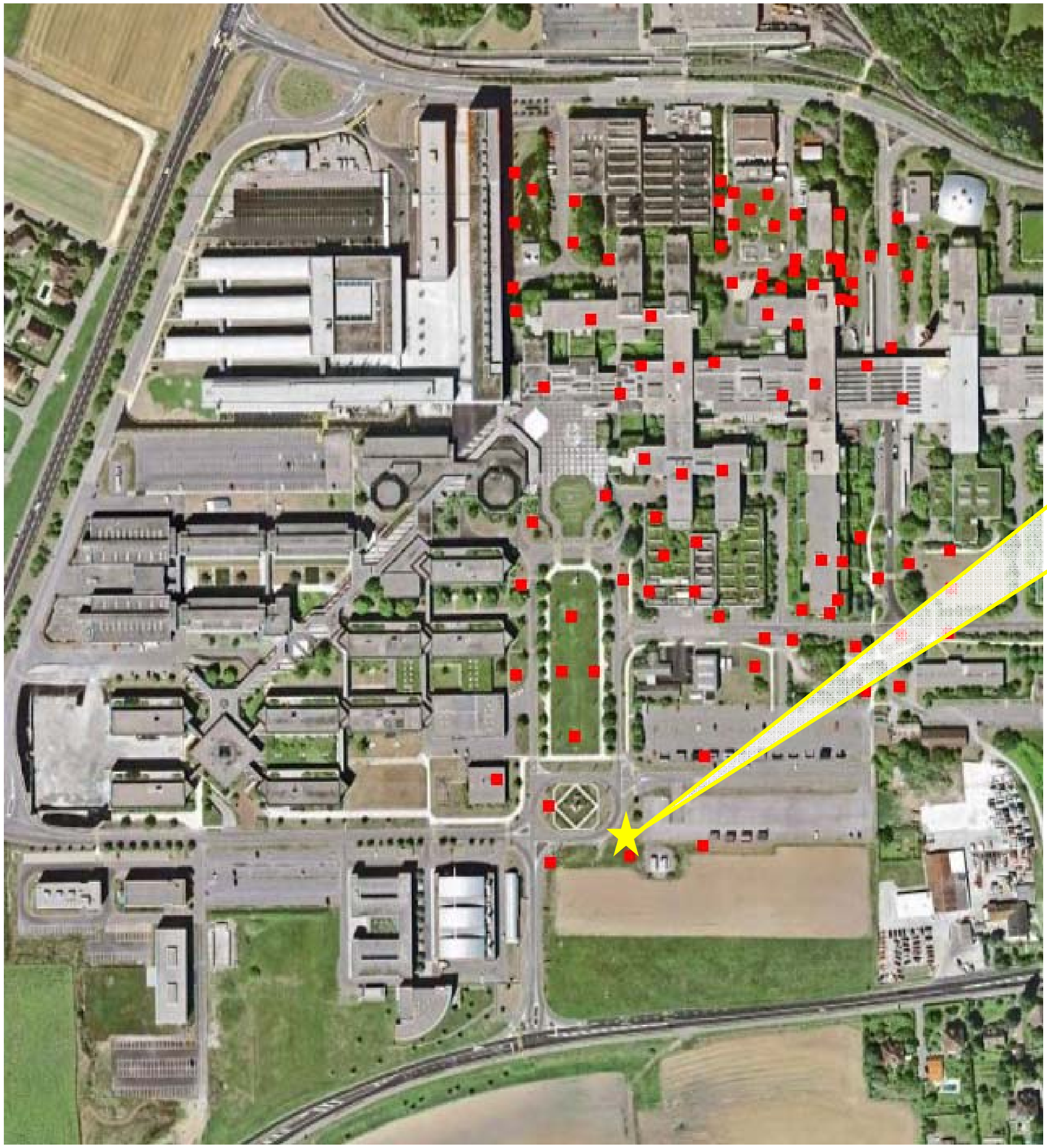


SODAR / RASS system

- operating from Jul. 06 to May 07
- wind and temperature profiles measured from 40 to 400 m
- averaging time of 30 min

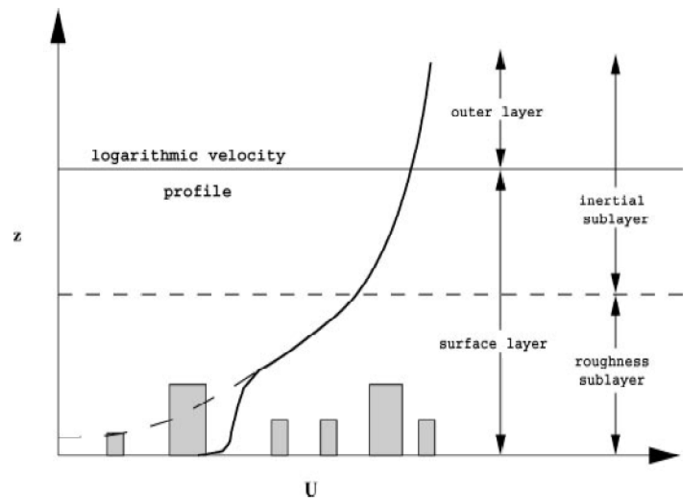
Finding Neutral Profiles

Range of interest

- Buildings range from 5 to 30 m
- Assume blending height ≈ 2 x h_0
- $z_{max}/z_{min} > 2$ (Bottema, *AE*, 1997)

$$\Rightarrow z = [z_{min} = 40, z_{max} = 100]\ \mathrm{m}$$

$$\Rightarrow d_0 = 20\ \mathrm{m}$$ (estimated)



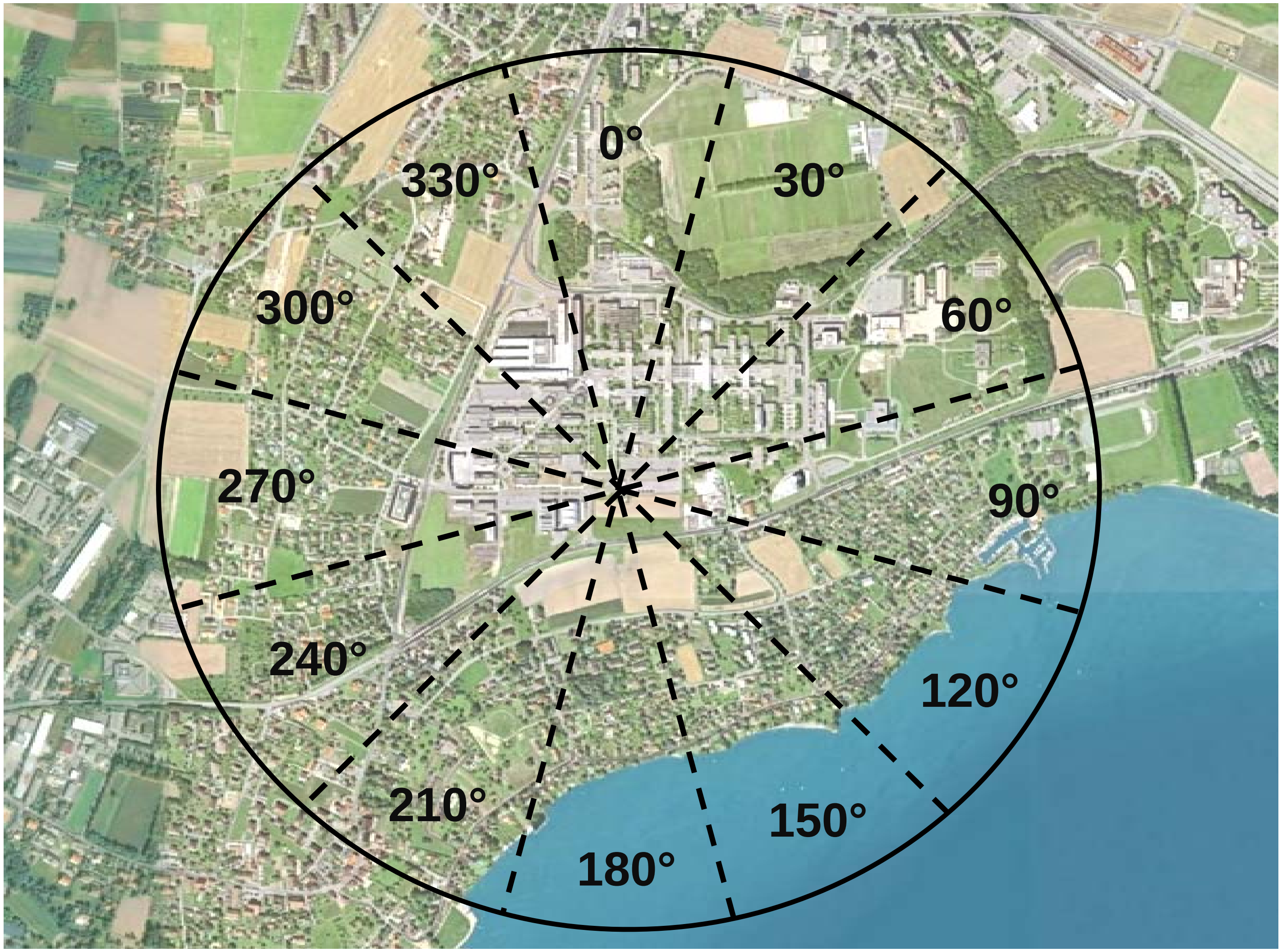
Adapted from Britter and Hanna, *ARFM*, 2003

Criteria for near-neutral conditions

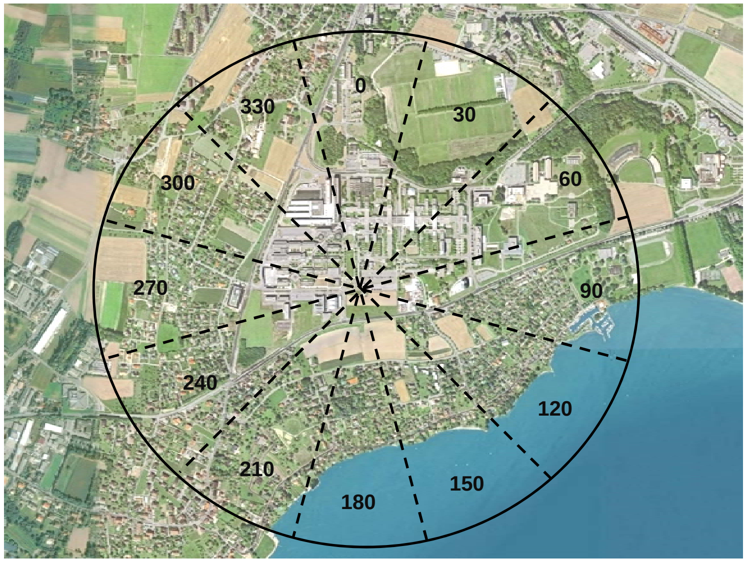
1) consistent wind direction with height
2) $u > 5$ m/s
3) Least-square fitting between u and $\ln(z - d_0)$ yields $R^2 \geq 0.5$
4) $|Ri_g| \leq 0.1$

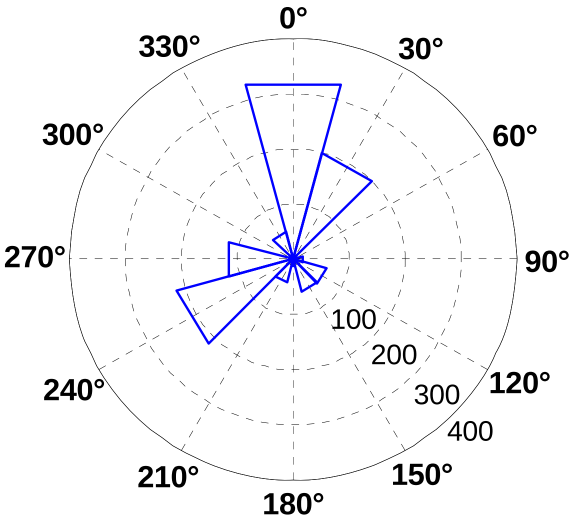
$$Ri_g = \frac{\dfrac{g}{\overline{\theta}_v}\dfrac{\partial \overline{\theta}_v}{\partial z}}{\left[\left(\dfrac{\partial \overline{U}}{\partial z}\right)^2 + \left(\dfrac{\partial \overline{V}}{\partial z}\right)^2\right]}$$

Wind Sectors



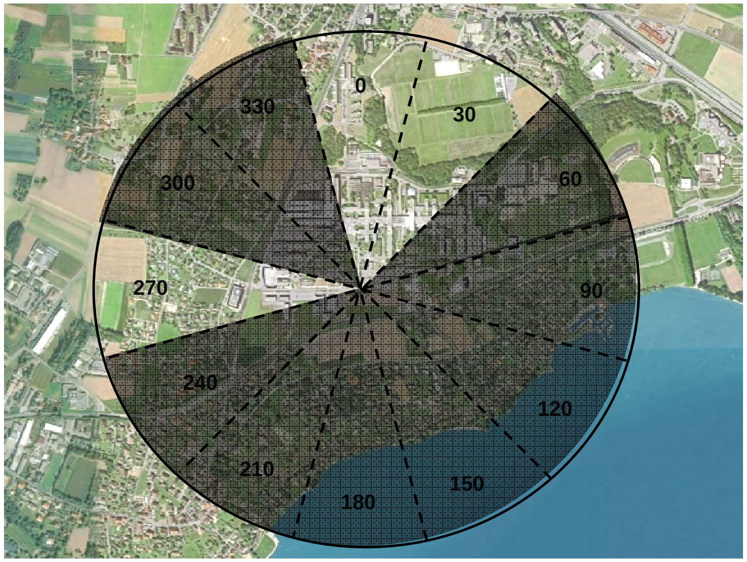
Finding Neutral Profiles



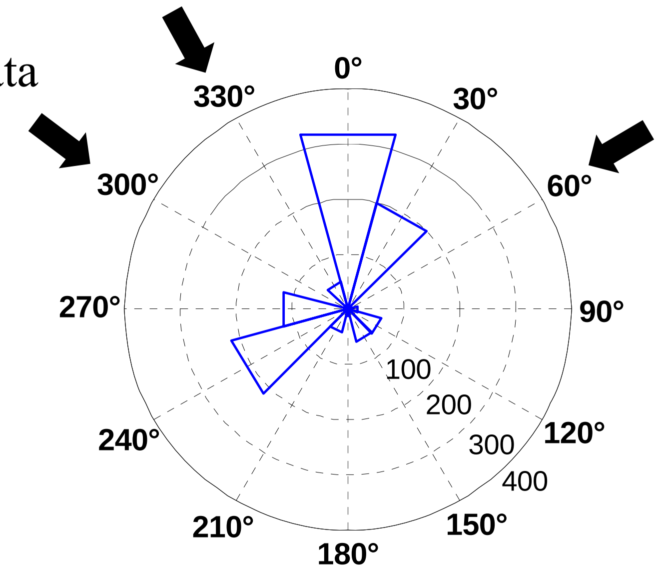


Number of cases of wind speed exceeding 5 m/s. Measurements at 50 m from July 06 to May 07.

Momentum Surface Roughness



no data



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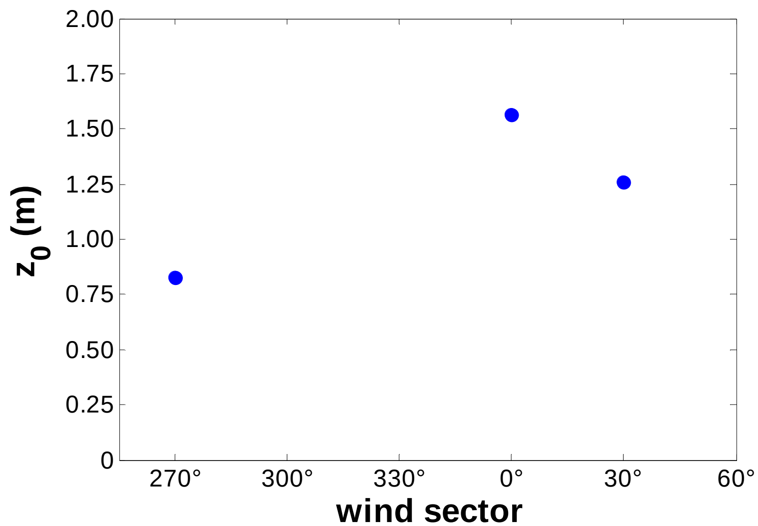


Median of surface roughness distribution for wind sectors with sufficient data.

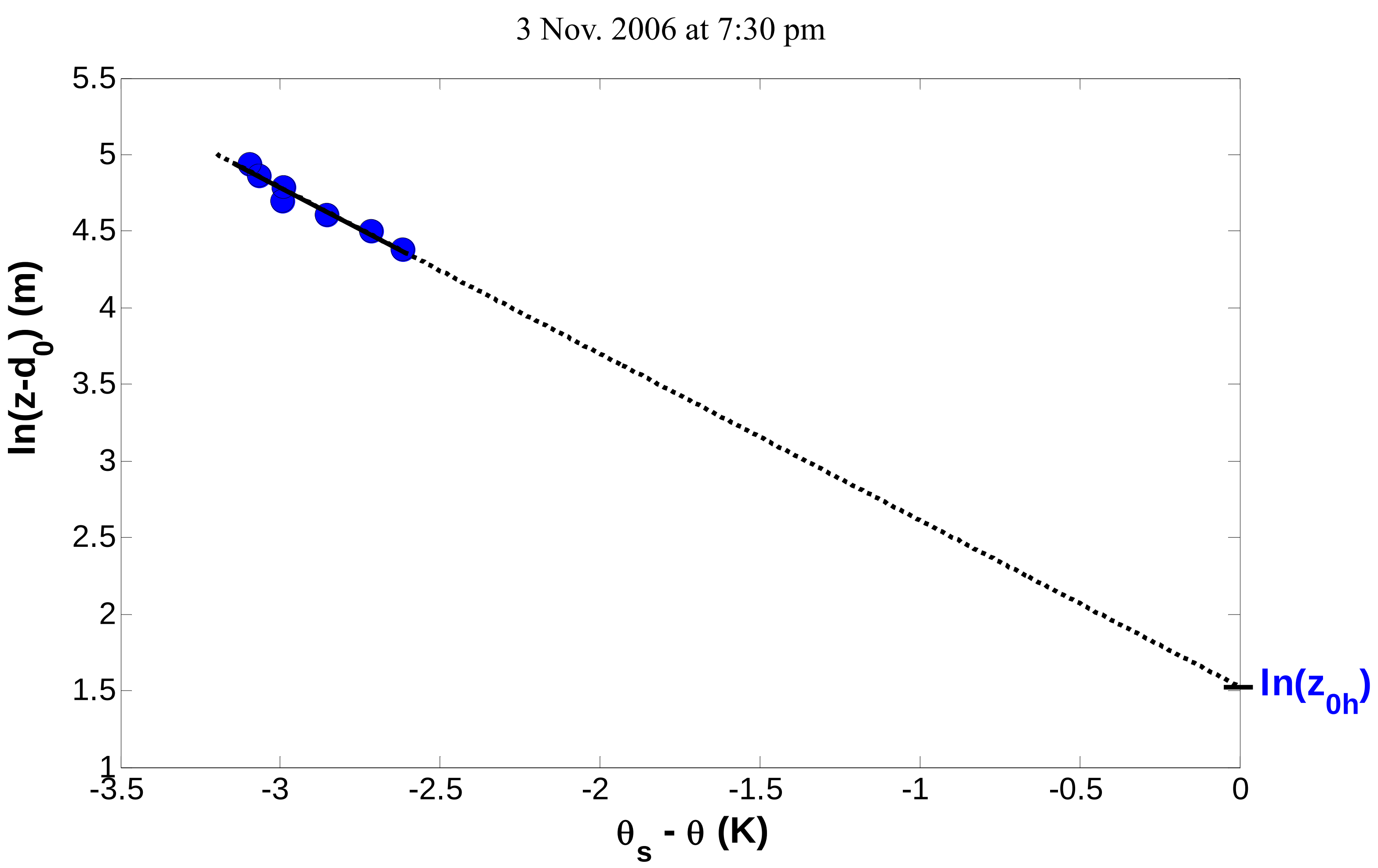
Center of large towns and cities (Stull, 1988)

Total number of profiles: 16 128

Near-neutral profiles: **108** (0.7 %)

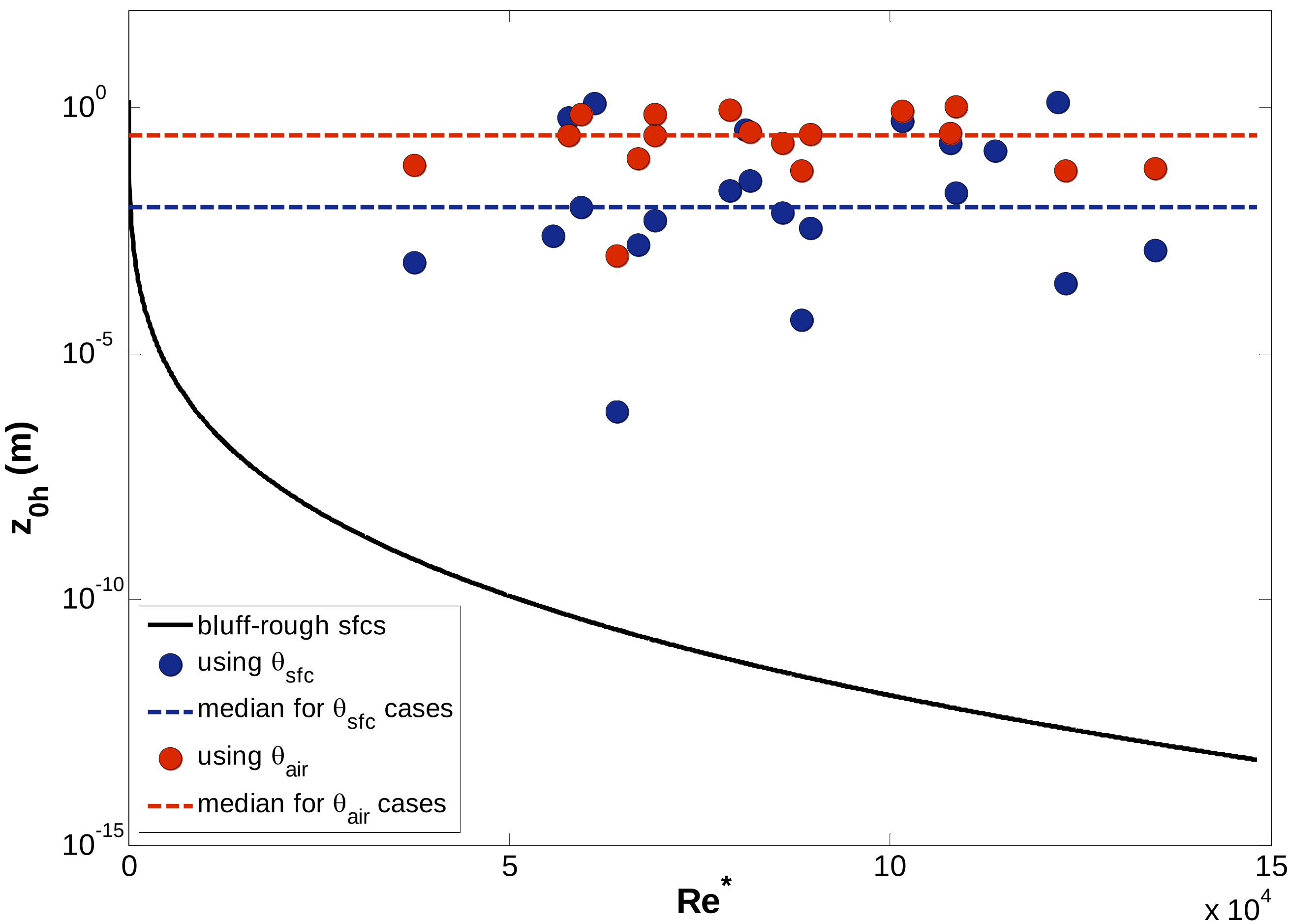
Thermal Roughness Length

Regression for near-neutral potential temperature profiles



Thermal Roughness Length

Preliminary results for z_{0h}



For bluff-rough surfaces

$$z_{0h} = z_0 \exp\left[\left(-k\right)\left(4.31\,\mathrm{Re}_*^{0.247} - 5\right)\right]$$

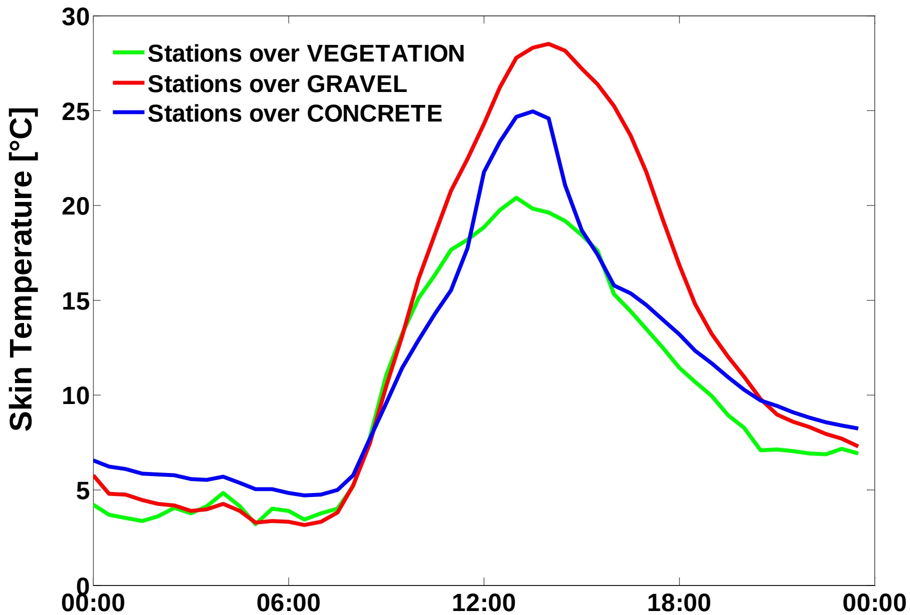
(Cahill et al., *WRR*, 1997)

$$\mathrm{Re}_* = \frac{u_* z_0}{\nu}$$

Thermal Roughness Length

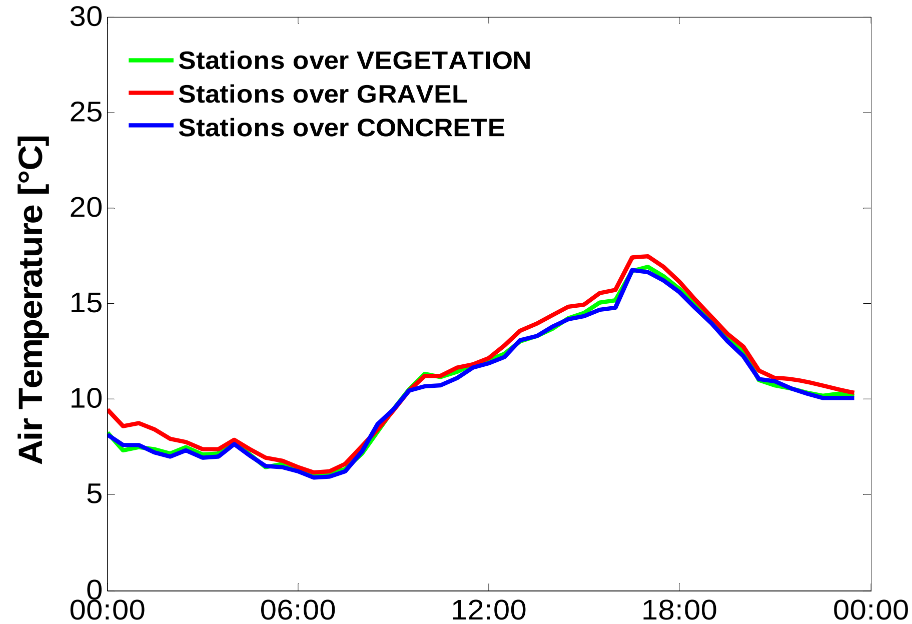
Considering surface type

SKIN TEMPERATURE



14 Mar 2007

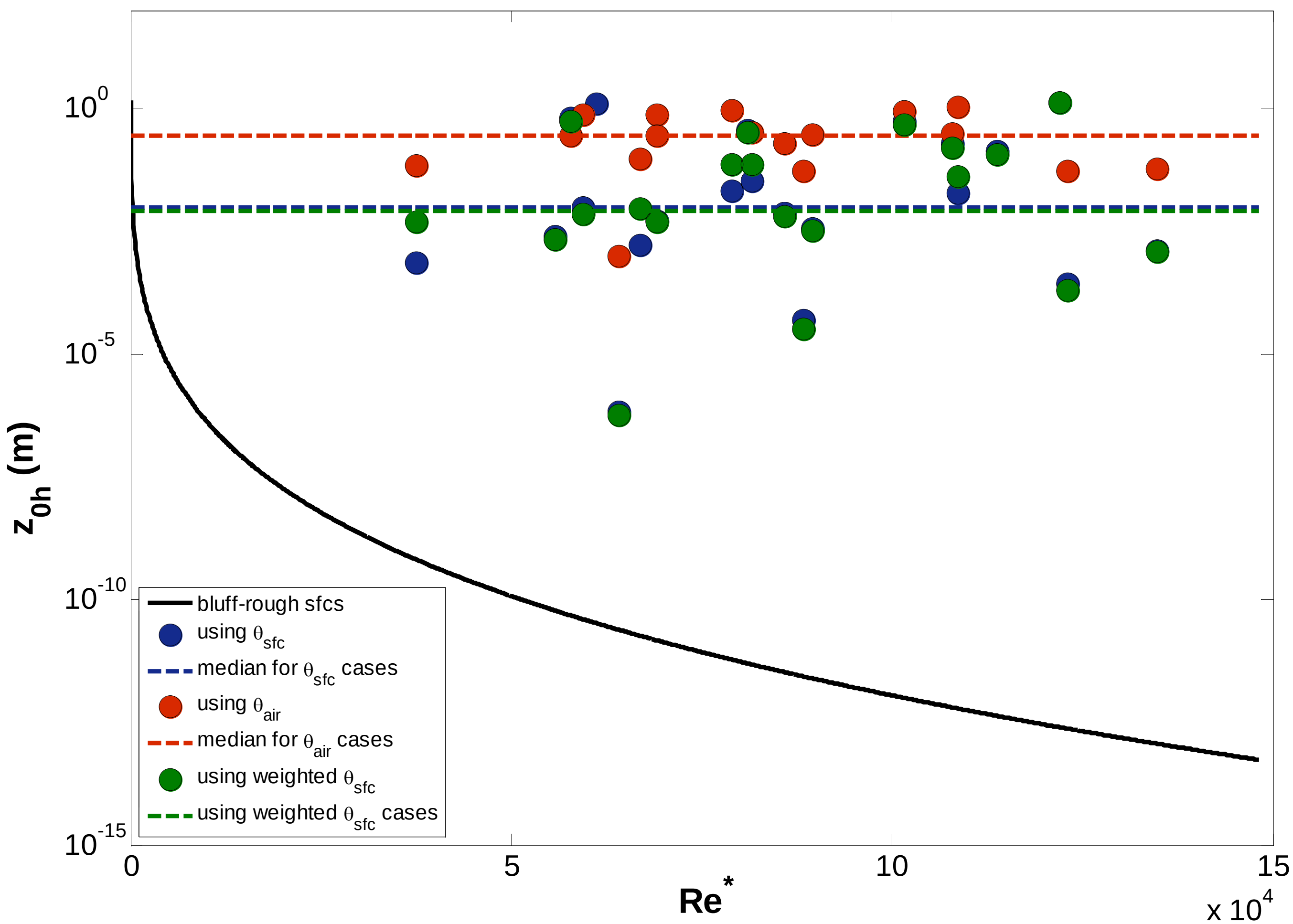
AIR TEMPERATURE



14 Mar 2007

Thermal Roughness Length

Using a weighted average: $\langle \theta_s \rangle = a\theta_{s,\text{vegetation}} + b\theta_{s,\text{urban}}$



For a 10 km fetch

a: estimated fractional cover of vegetation

b: estimated fractional cover of built-up areas

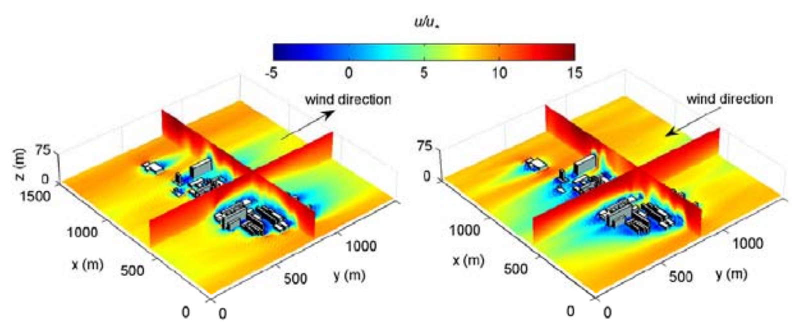
Conclusions and Future Work

Conclusions

- momentum surface roughness obtained by regressing near-neutral profiles
- large values of z_{0h} found (compared to literature): from 10^{-6} to 1 m
- z_{0h} very far from approximation for bluff-rough surfaces

Future work

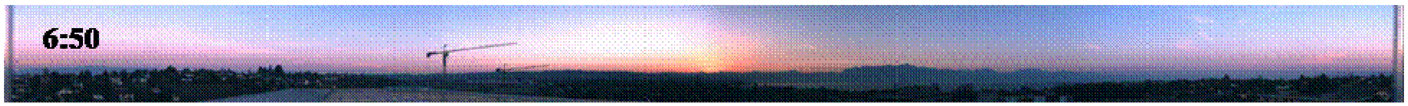
- study convective cases for z_{0h}
- footprint analysis
- compare with morphometric models
- perform LES simulations

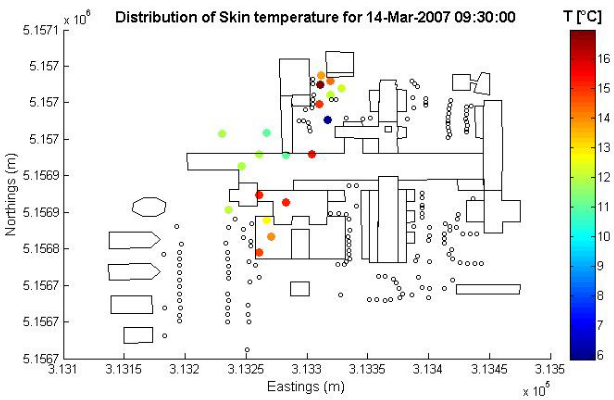


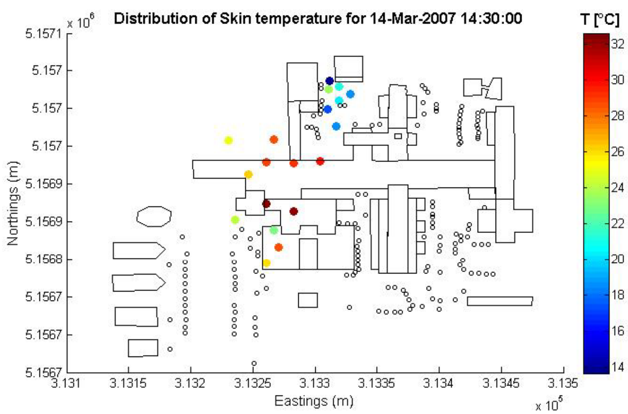
Source: E. Ouyang, E. Bou-Zeid, 2007

Future Work

Modeling shaded areas





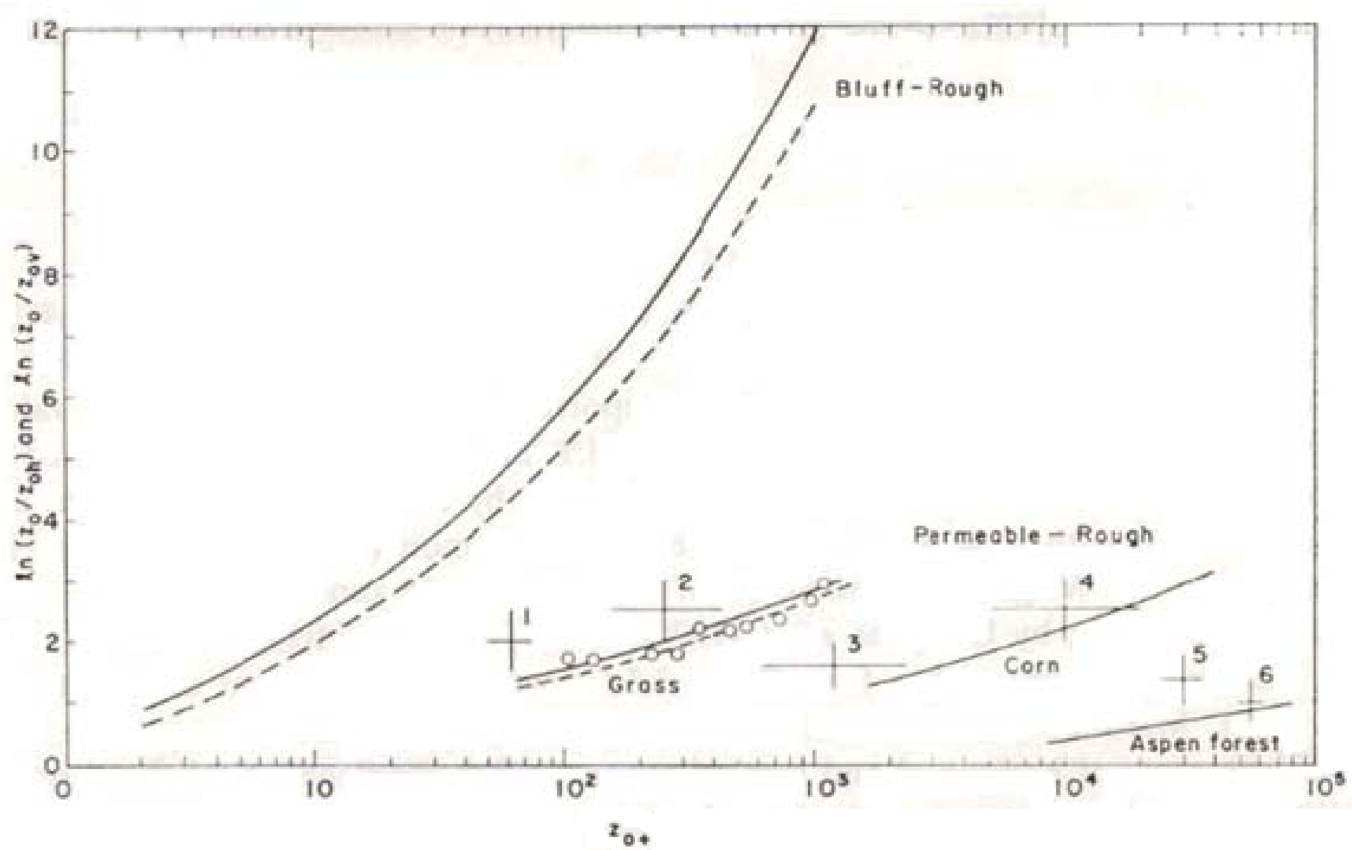


- shaded areas can greatly influence skin temperature and in turn the spatially averaged heat flux (Sun and Mahrt, *BLM*, 1995)
- dependance of z_{0h} on the sun angle (Kustas et al., *AFM*, 1989)
- heat flux dominated by sunlit areas (Voogt and Grimmond, *JAM*, 2000)

Thank you !

Thermal Roughness Length

Dependance of z_0/z_{0h} on the flow



Source: Brutsaert, *Evaporation into the Atmosphere*, 1982

Instruments

SODAR/RASS accuracy

u horizontal: 0.1 - 0.3 m/s
u vertical: 0.03 - 0.1 m/s
wind direction: 2 - 3°
thickness of vertical layers: 5 – 100 m
range: 200 – 500 m
temperature: 0.2 °C

Sensorscope accuracy

surface temperature: 0.6°C
air temperature: 0.3°C

Scintec Flat Array SFAS

Sensorscope station