Characteristics of the flow over an urban to a vegetation terrain transition : a wind tunnel study

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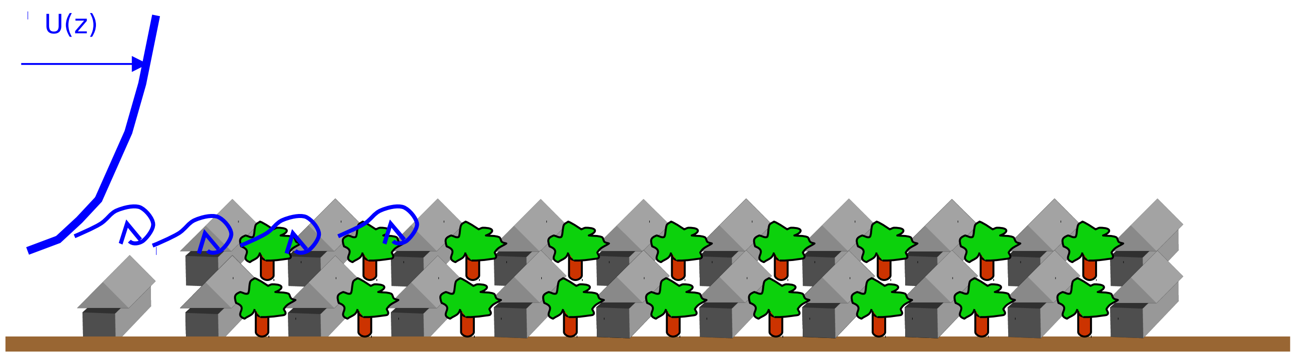
Motivation: VegDUD project

VegDUD - Role of vegetation in sustainable urban development. An approach related to climatology, hydrology, energy management and ambiances

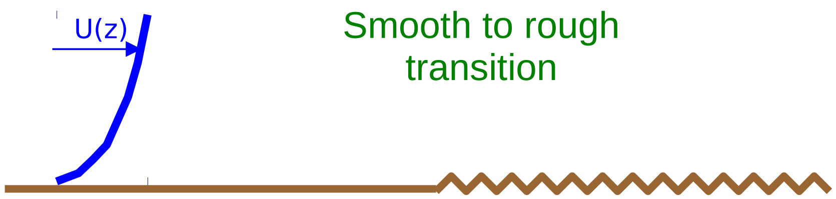


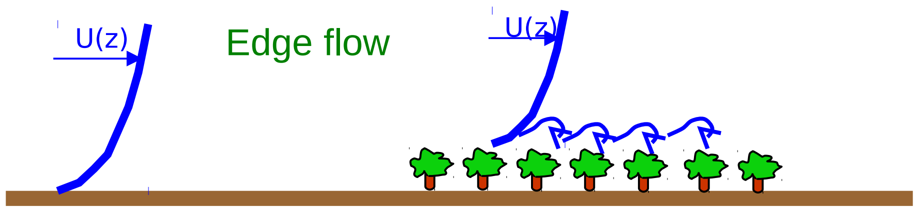
- Understand the physics of transport processes
- and the effect of transition between different terrains
- Provide test cases for developing and validating modeling methods and strategies

Context

From the literature:

- Flow over homogeneous canopies;
- Flow over changing terrain (Kaimal & Finningan, 1994; …);
- Edge flow (Belcher, Jerram & Hunt, 2003);
- Vegetation canopy edge flow (Dupont & Brunet, 2009);
- Vegetation embedded in street canyons (Gayev & Savory, 1999; Gromke & Ruck, 2008);





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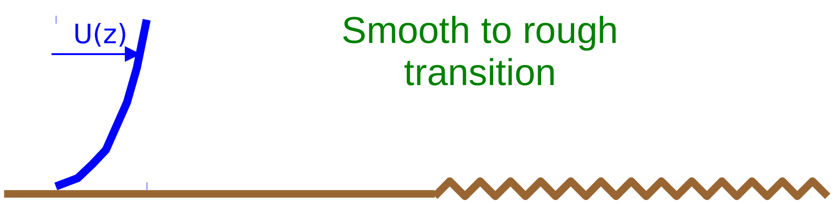
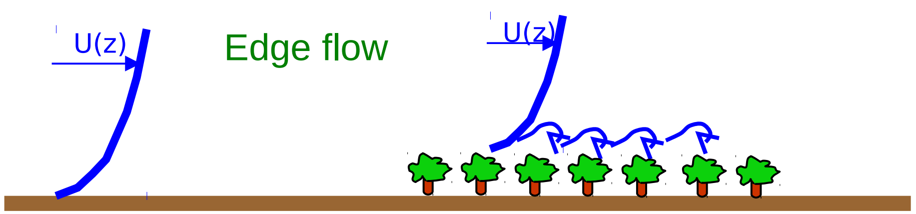




Transition between dense canopy flows ?
Obstacles of completely different geometry and scale ?

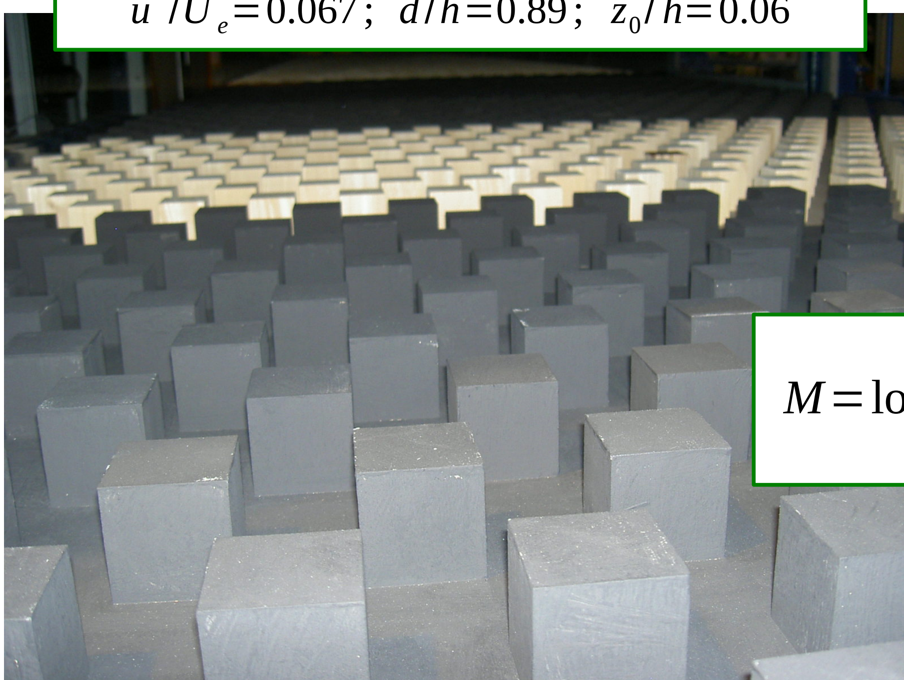
Wind tunnel study of idealized configurations

Experimental setup: canopy modeling

Urban canopy model:

- Staggered cubes
- Cube height: h = 50mm
- Area density: 25%
- Fetch of cubes: 20m <=> ~ 400h
- U_e = 5.8m/s

$$u^*/U_e = 0.067;\quad d/h = 0.89;\quad z_0/h = 0.06$$

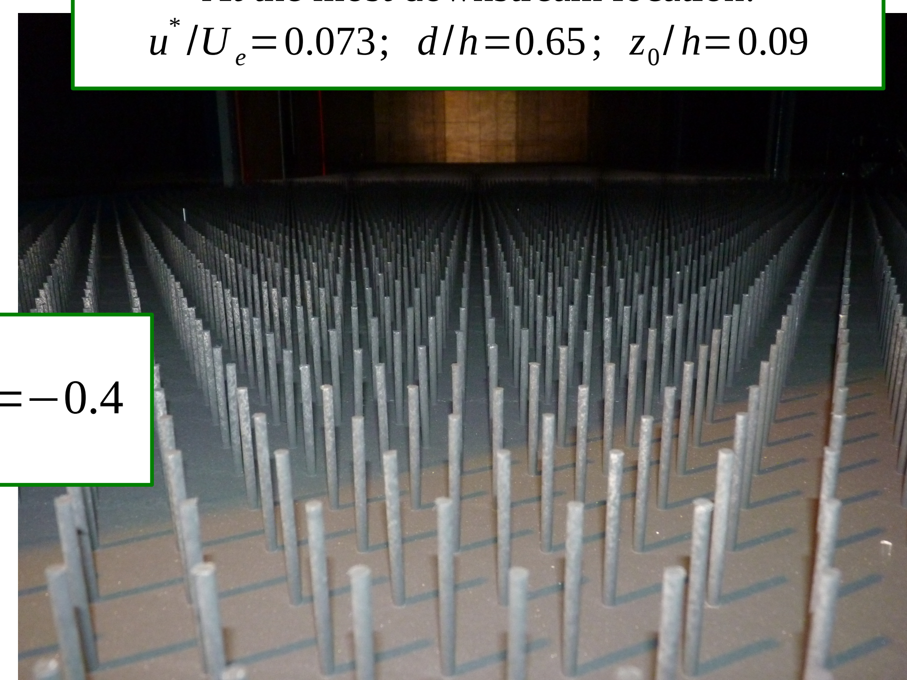


Vegetation canopy model:

- Staggered cylinders
- Cylinder height: h = 50mm
- Aspect ratio: 12.5
- Cylinder spacing within in a row: 32 mm
- Inter-row spacing: 16 mm
- Canopy density: n = 980 rods/m²
- Area density: a = n.d_r = 3.92 m^2m^{-3} (frontal area per unit volume)
- Frontal area index: λ = 0.39

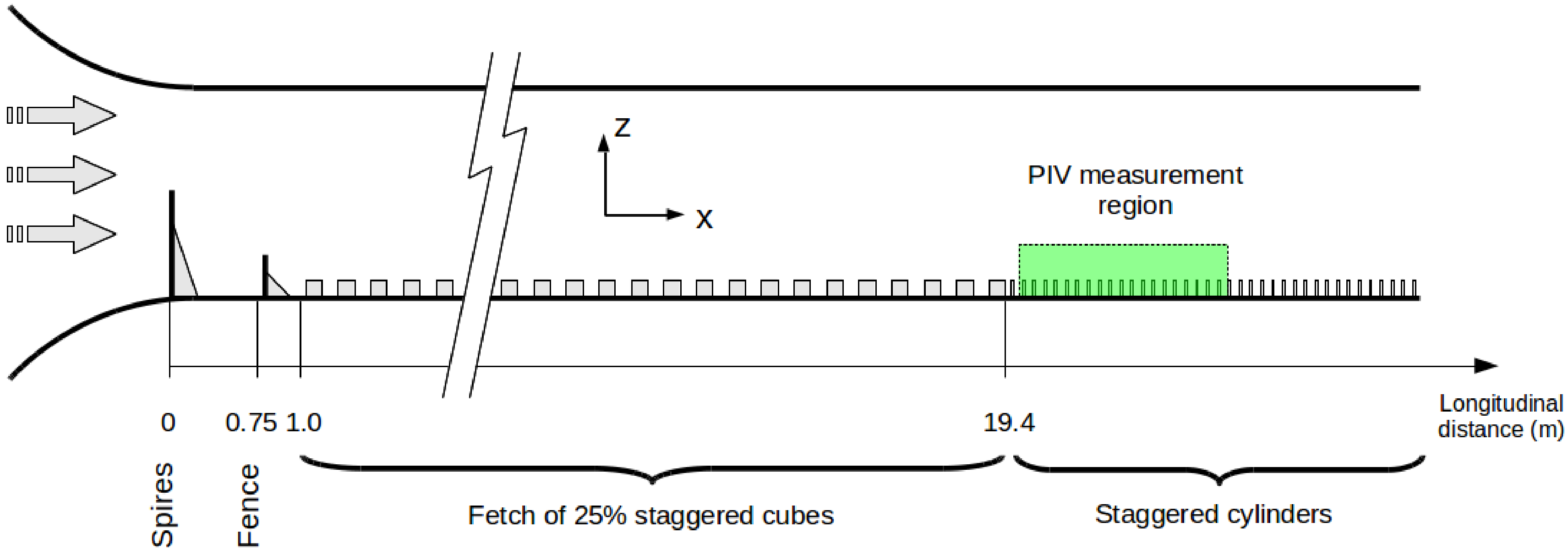
At the most downstream location:

$$u^*/U_e = 0.073;\quad d/h = 0.65;\quad z_0/h = 0.09$$



$$M = \log\left(\frac{z_{01}}{z_{02}}\right) = -0.4$$

Experimental details

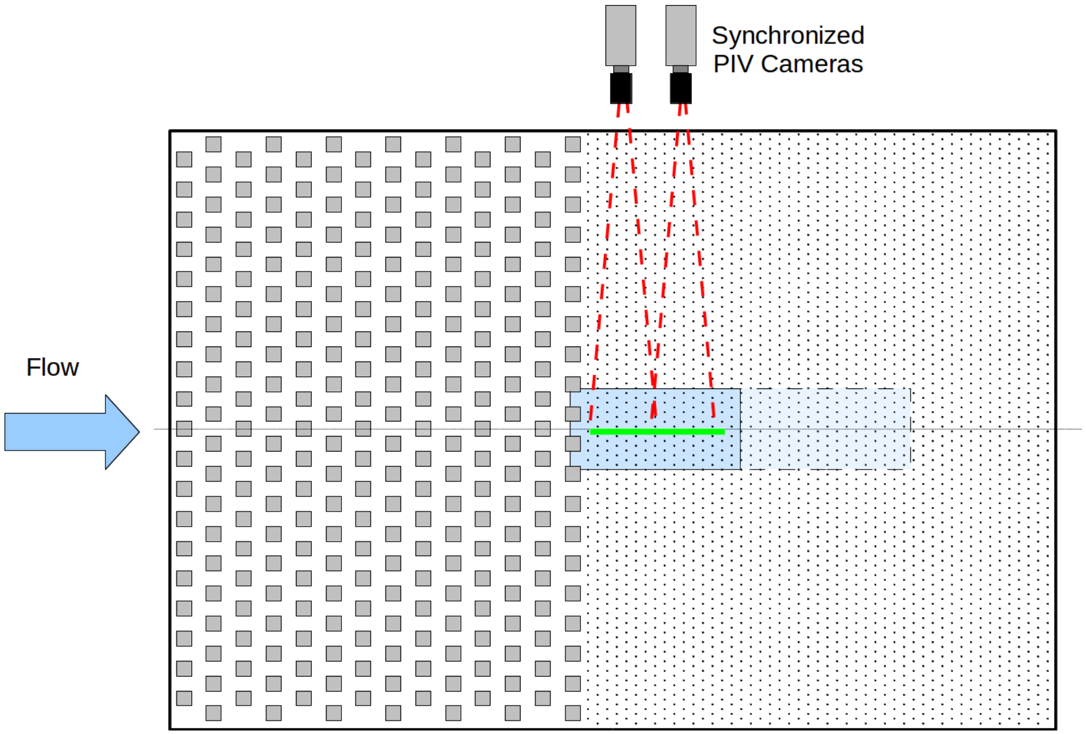


Wind tunnel:

- Open circuit, suck down wind tunnel
- Length: 24m
- Test-section: 2m x 2m
- Free-stream velocity: U_e = 5.8 m/s
- Turbulence generators
  - Five 800mm triangular spires
  - 200mm high fence

PIV system:

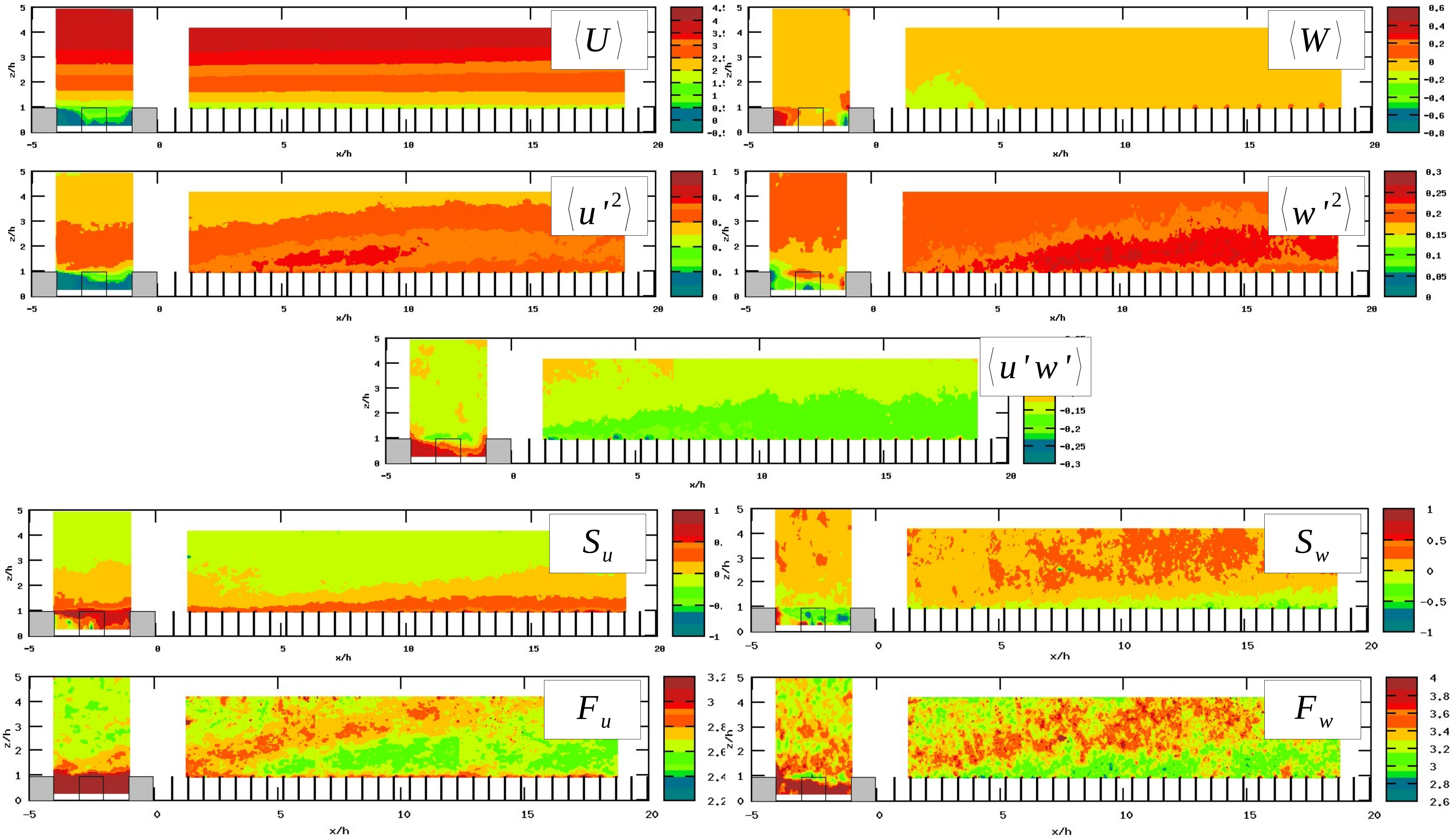
- 2 synchronized cameras
- 200mJ Nd-YAG laser
- 2-components
- Iterative cross-correlation analysis (32x32)



Results: one-point statistics

Longitudinal component

Vertical component

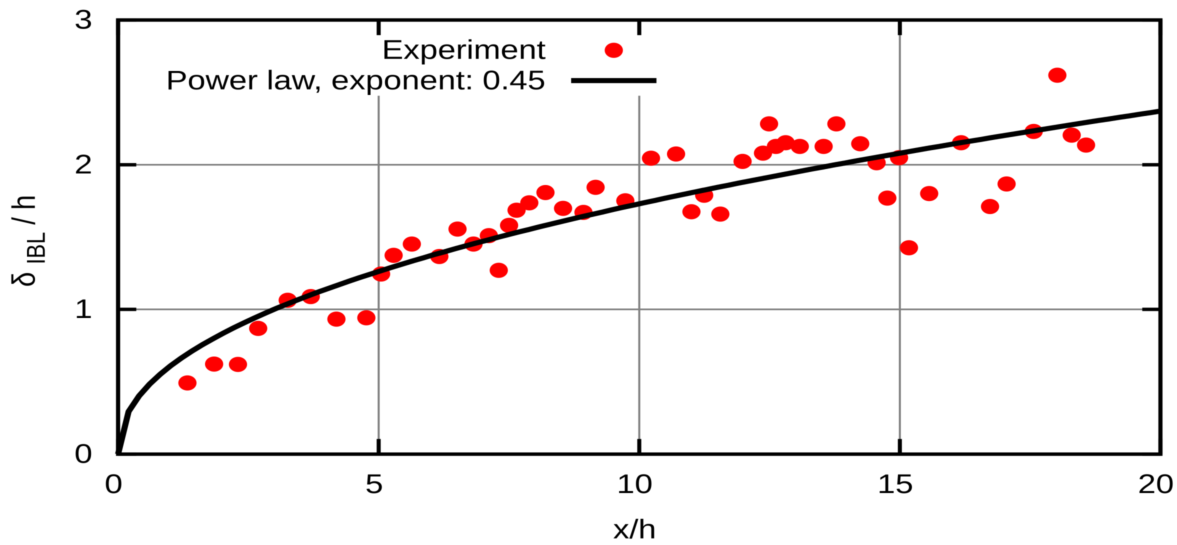


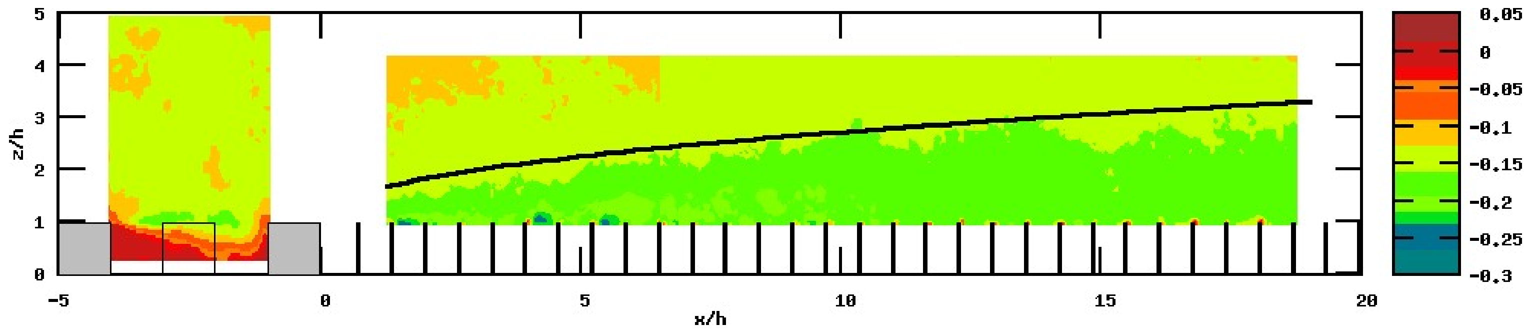
Clear influence of the transition on the flow statistics

Results: one-point statistics

Shear-stress internal boundary layer:

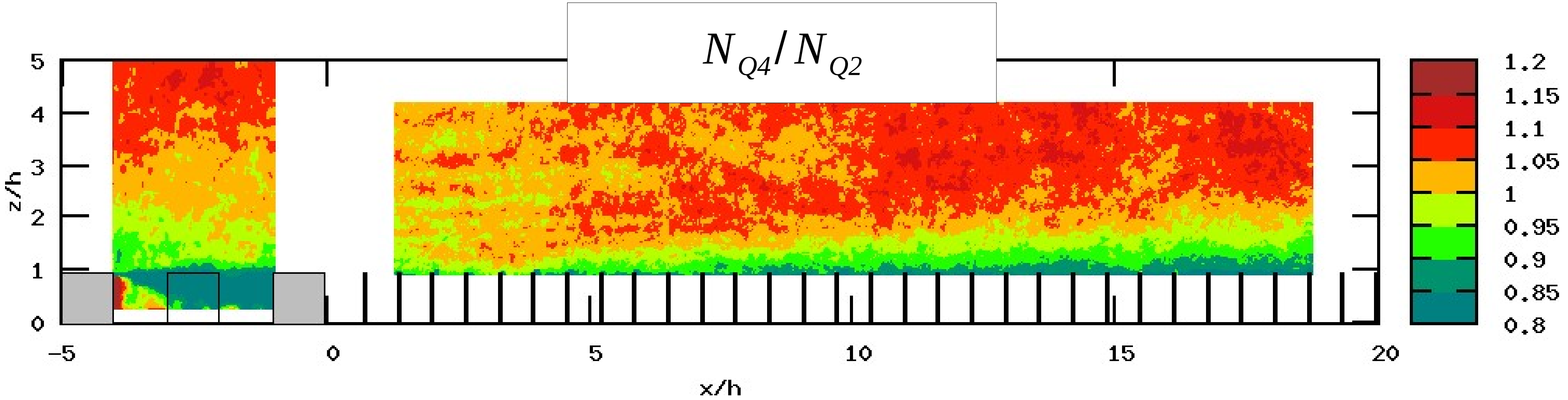
$$\delta_{IBL}(x) = \text{height where } \langle u'w' \rangle (x,z) = \alpha \langle\langle u'w' \rangle\rangle_{cubes}(z)$$

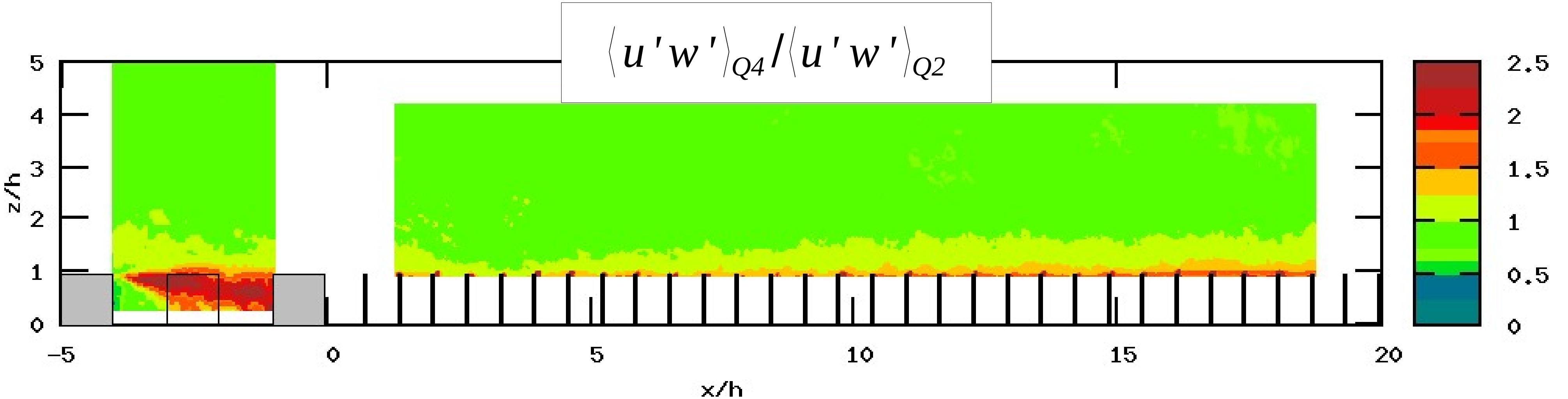




Sweep and ejection contribution to shear stress

Quadrant analysis: sweeps (Q4), ejections (Q2)





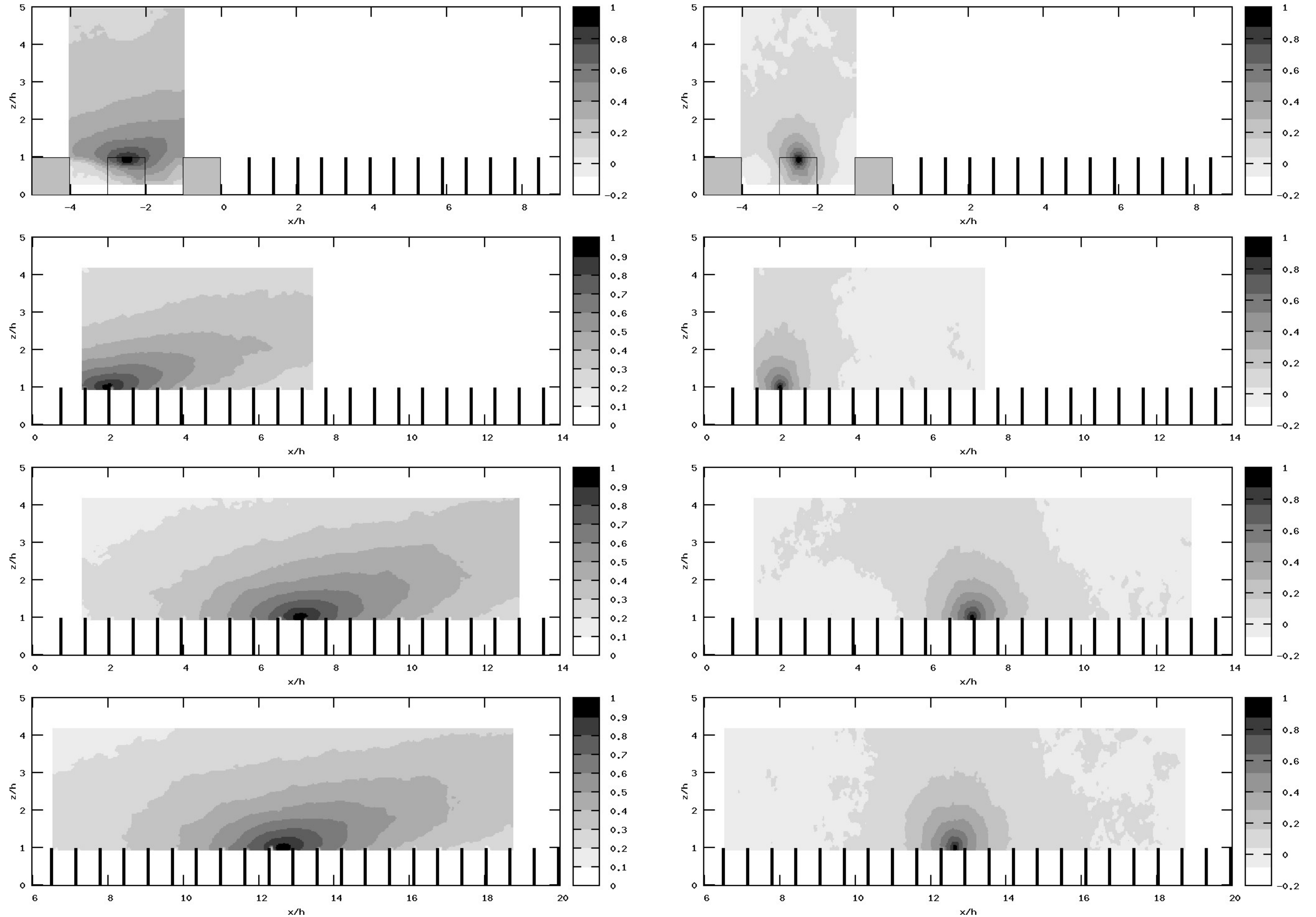
Results: two-point statistics

$R_{uu}(x_{0}, z_0 = h, x, z)$ $\quad$ $R_{ww}(x_{0}, z_0 = h, x, z)$

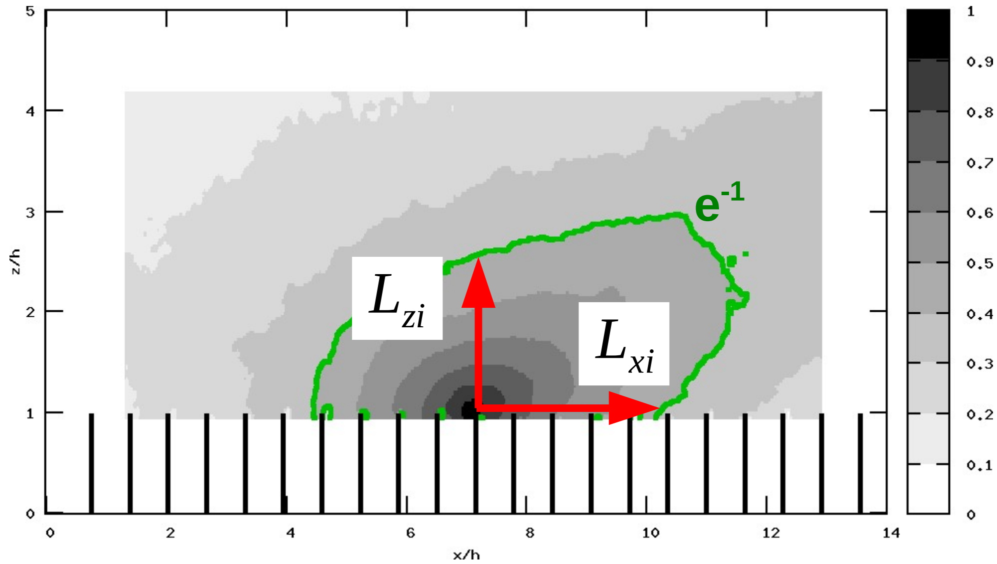
$x_0 = 2\ h$

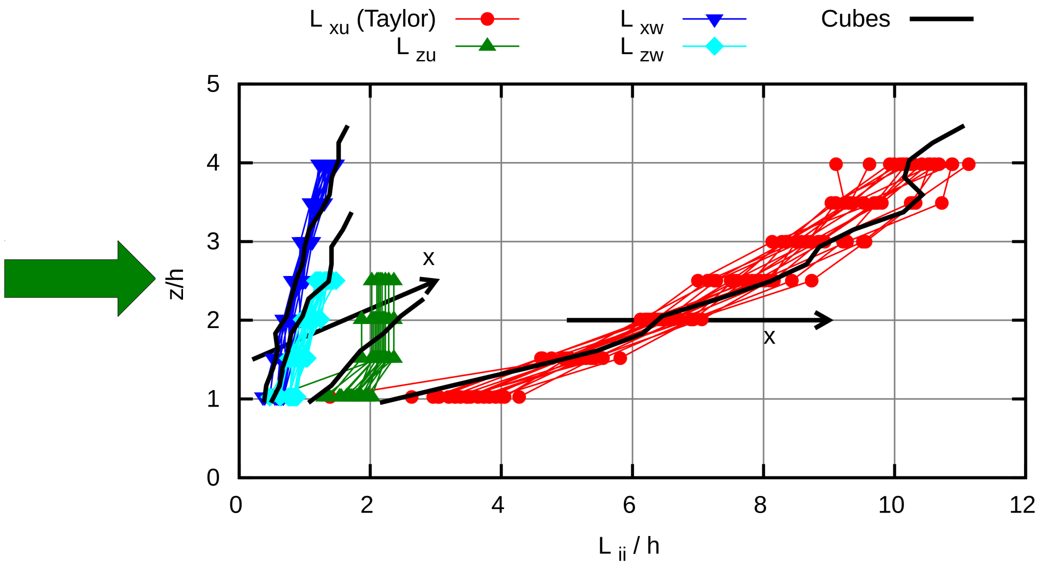
$x_0 = 7.1\ h$

$x_0 = 12.5\ h$



Integral length scales





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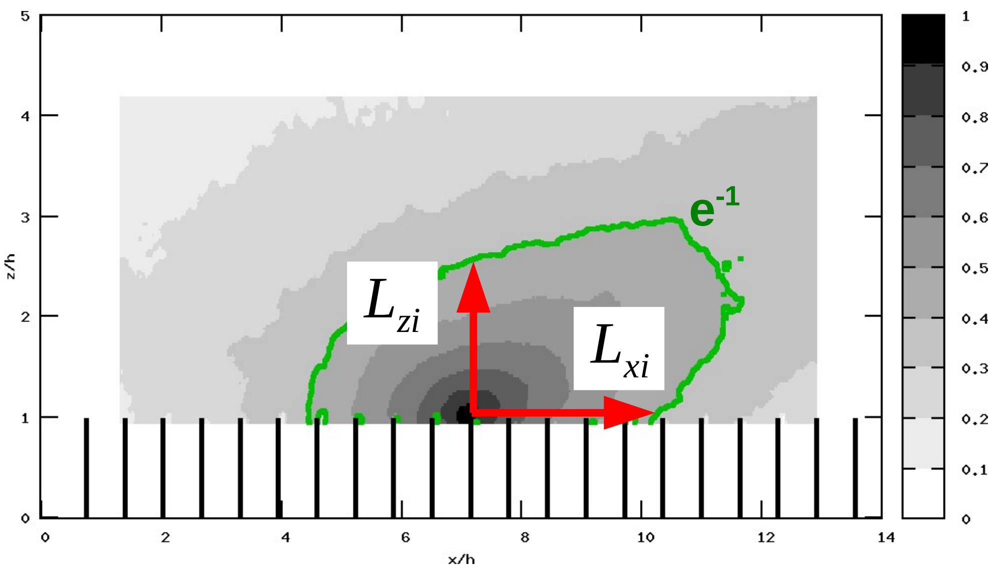
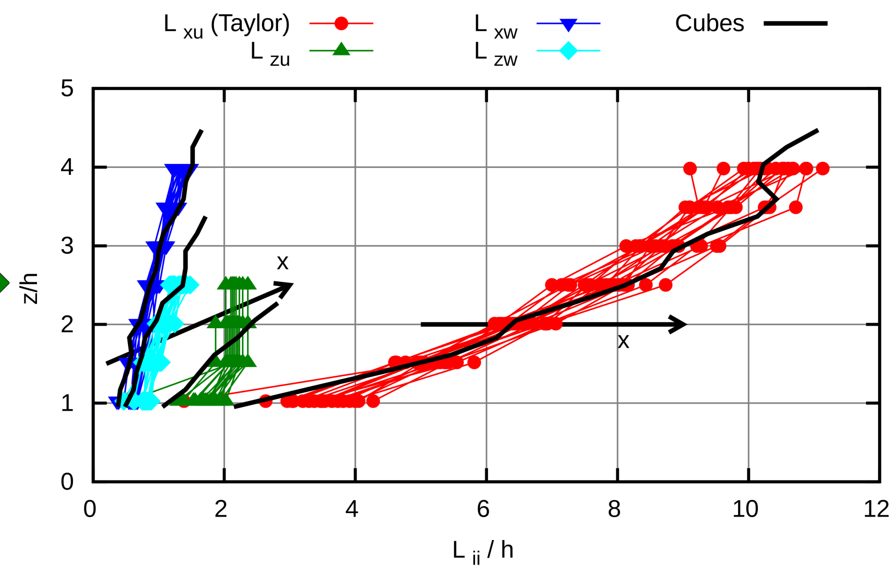
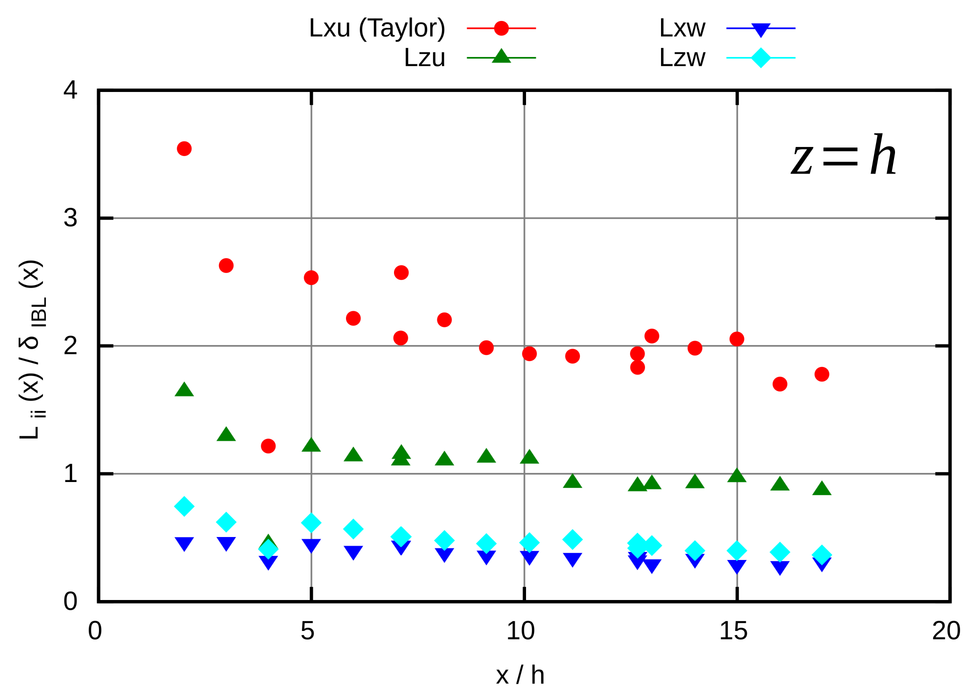






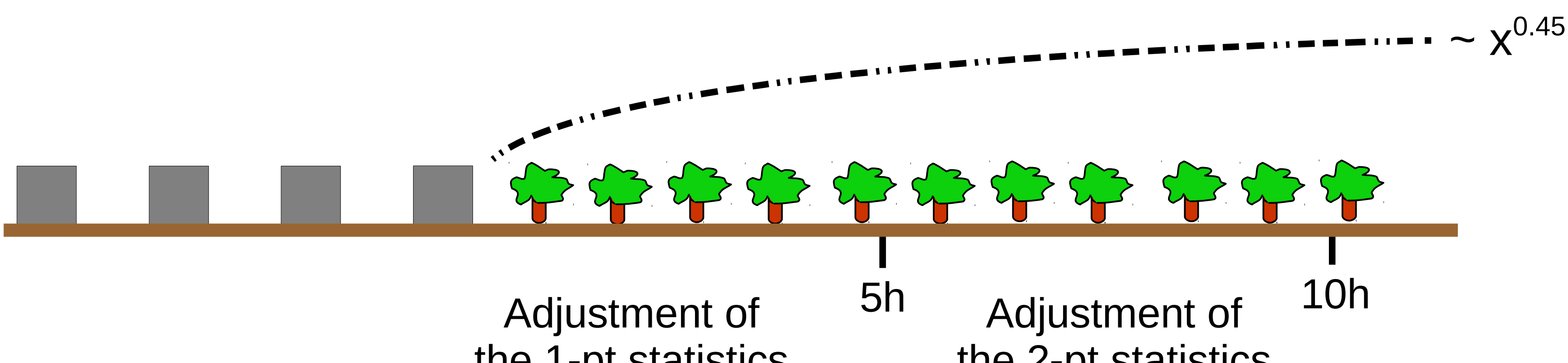
Local integral length scale at *canopy top* as a function of the internal BL depth

$$L_{ii}(x)/\delta_{IBL}(x)\ @\ z=h$$

Summary

Wind tunnel study of the flow over a urban-vegetation transition

- Engulfment of the flow into the canopy for $0 < x < 5h$
- Development of an IBL but not clearly for <U>
- Shear stress IBL grows as $\sim x^{0.45}$
- Contribution of sweep and ejection to shear stress influenced for $0 < x < 5h$
- Shape of the correlation function R_{uu} and R_{ww} affected by the transition
- Close to canopy top: integral length scales affected for $0 < x < 10h$
- For $10h < x$, integral length scales grow as IBL



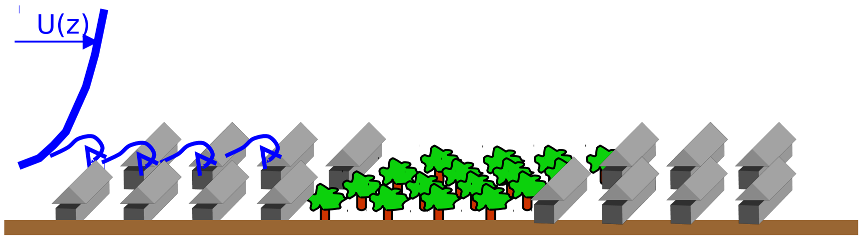
Future plans

Using the present PIV database:

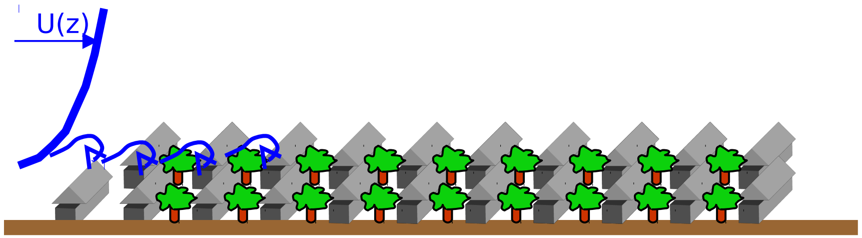
- Fine investigation of the coherent structures and their organization;
- Study of the development of the shear layer at the top of the canopy;
- Turbulent kinetic energy budget downstream of the terrain change;

Future configurations:

vegetation *canyon* within an urban canopy



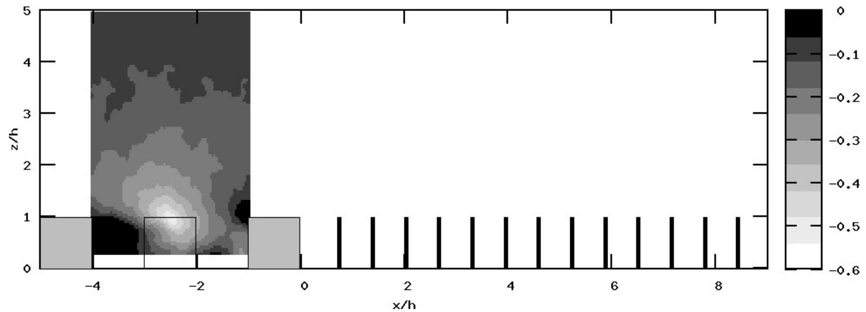
vegetation *mixed* within an urban canopy



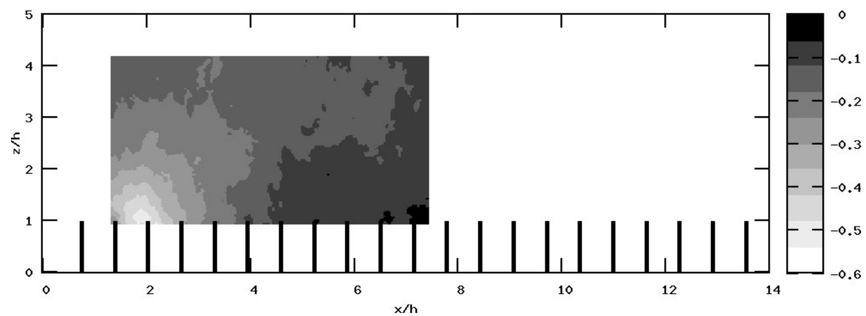
Thank you for your attention

Results: two-point statistics

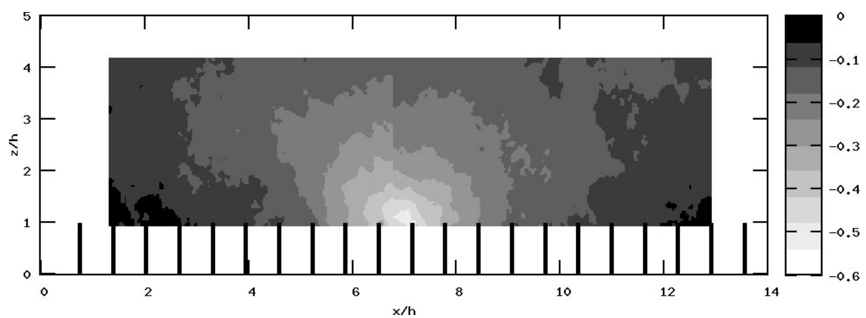
$$R_{uw}(x_{0,} z_0 = h, x, z)$$



$x_0 = 2\ h$



$x_0 = 7.1\ h$



$x_0 = 12.5\ h$