

Physical or/and Numerical modelling of applications embedded in the atmospheric boundary layer

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ERCOFTAC

European Research Community On
Flow, Turbulence And Combustion



**SCHOOL OF
MECHANICAL
ENGINEERING**
NATIONAL TECHNICAL
UNIVERSITY OF ATHENS



WIND TUNNEL

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

Interest

- Structural loads
- Wind comfort and protection
- Urban Microclimate
- Optimal siting in complex terrain



Applications

- Modelling the Atmospheric Boundary Layer
- Flows in complex terrain
- Flows past buildings and structures (PV, trees)
- Flows in urban areas (street canyon to city)



Methods and Applications

Example applications

Loads on structures

- Arrays of PVs
- Trees

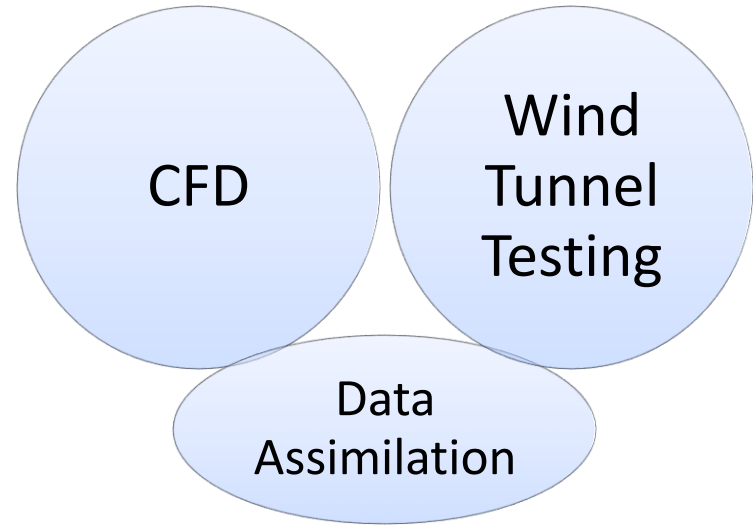
Wind Comfort

- Tall buildings
- Open areas

Urban Microclimate

- Street canyon or City scale w/wo thermal environment

- Numerical modelling
- Physical modelling
- Combining the two
(for improved accuracy ...etc)



The NTUA Wind Tunnel



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3 test sections



Long (“ABL”) test section
(w × h) = 3.5 m × 2.5 m, $U_{\max} = 15$ m/s



- Force balance
- Pressure scanners
- Hot wire anemometry
- Stereo, tomo – PIV

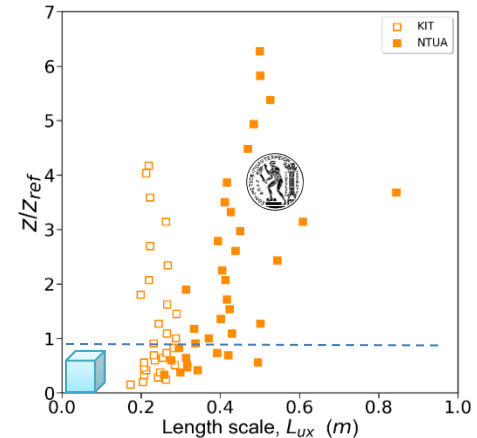
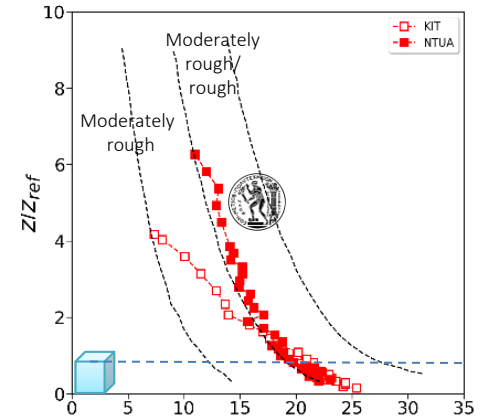
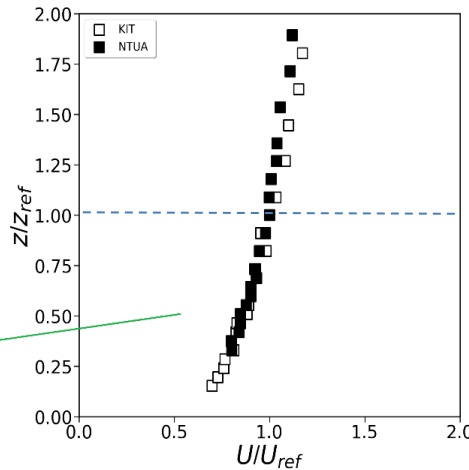
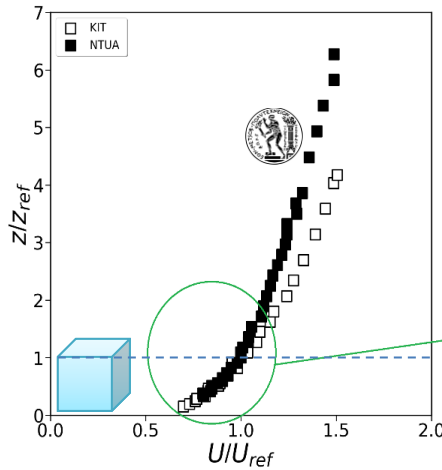
NTUA Wind Tunnel : ABL simulation

Profiles :

- Mean velocity
- Turbulence
- Length Scales



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Buildings

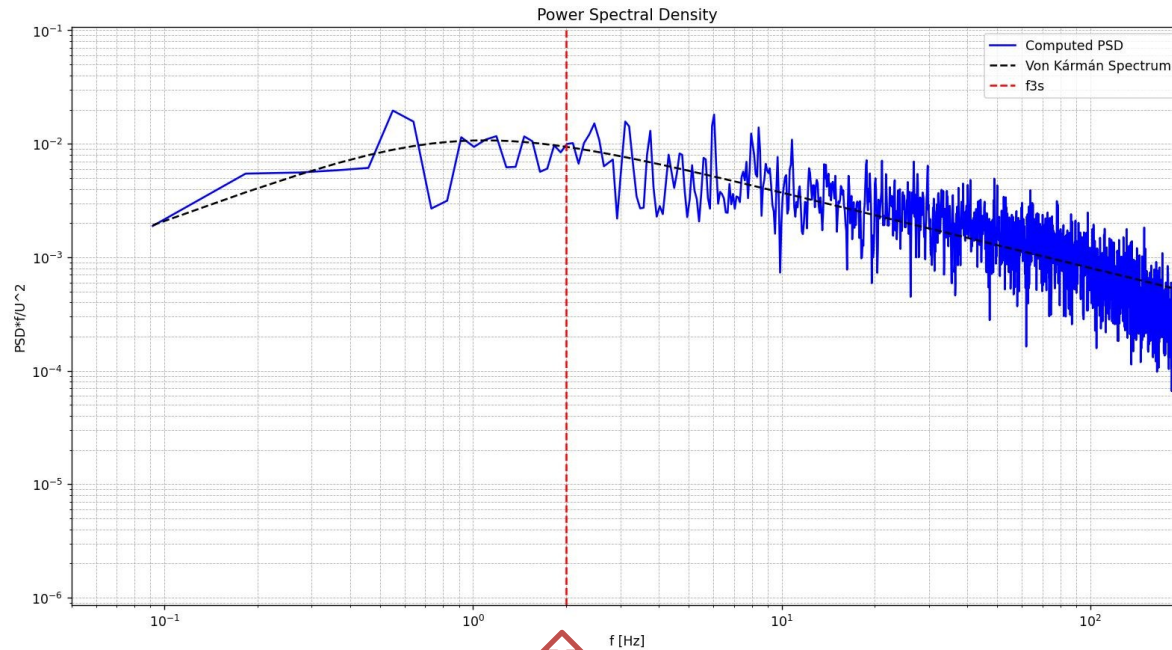
Scale 1:250-300

Eurocode: Category III

VDI: moderately rough - rough



Turbulence Spectrum



PV's
Time scale ratio $\sim 1/6$

3s full scale equivalent

Numerical Modelling : CFD

Numerical modelling
challenges for ABL
applications

Representative digital model of “topography” (natural or constructed)

Adequate spatial resolution

Flexibility in wind direction calculation

Application of appropriate ABL BCs
(preservation of inflow)

Turbulence modelling

Accounting for Atmospheric Stability Conditions

Modelling atmospheric dynamics
(solar & thermal radiation, buoyancy, humidity)

Representation of vegetation
aero- and thermo- dynamics.

Capturing unsteady phenomena.

Our CFD code

RANS, URANS, VLES on a cartesian collocated grid

Eddy viscosity turbulence modelling ($k-\epsilon$, RNG, $k-\omega$, SST, VLES)

Multi-local refinement

Import .obj files (QGIS, Rhino, Sketchup ...)

Variable inlet boundary (wind direction) on the same grid

Nudging to preserve inlet conditions in streamwise direction

Solar position tracking, shortwave, longwave radiation

Shading

Vegetation, evapo-transpiration

Conjugate heat transfer



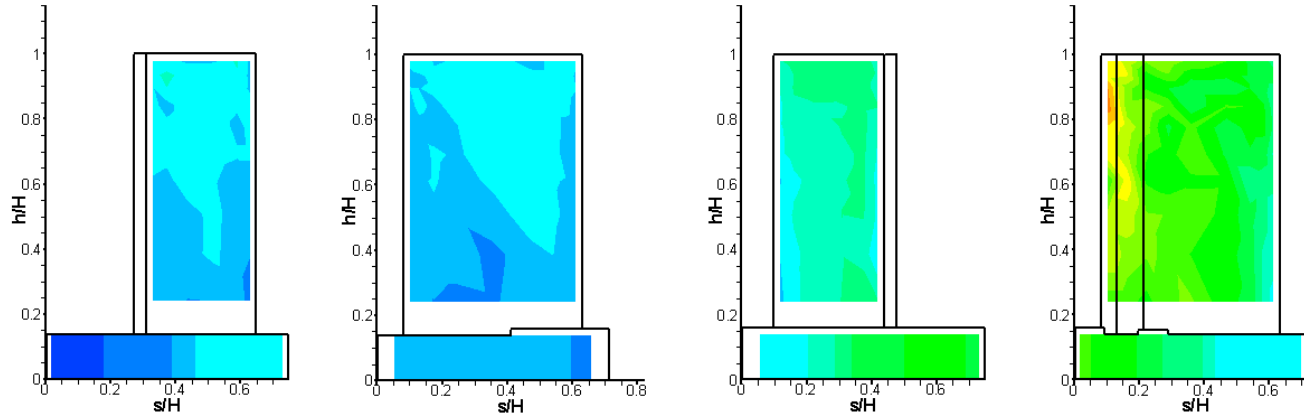
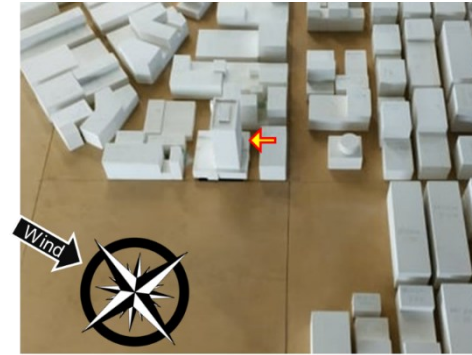
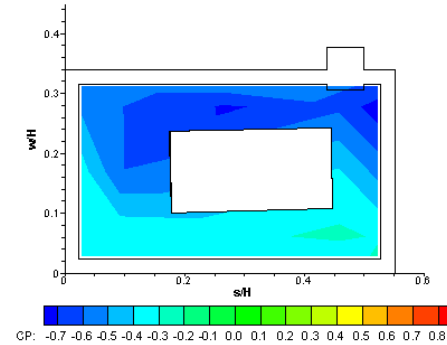
Selected Examples of Wind Tunnel Studies (Loads)

Selected Wind Tunnel studies : Loads

Cladding for Piraeus Tower



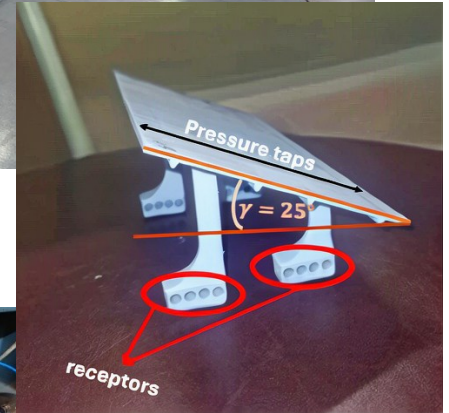
North NW



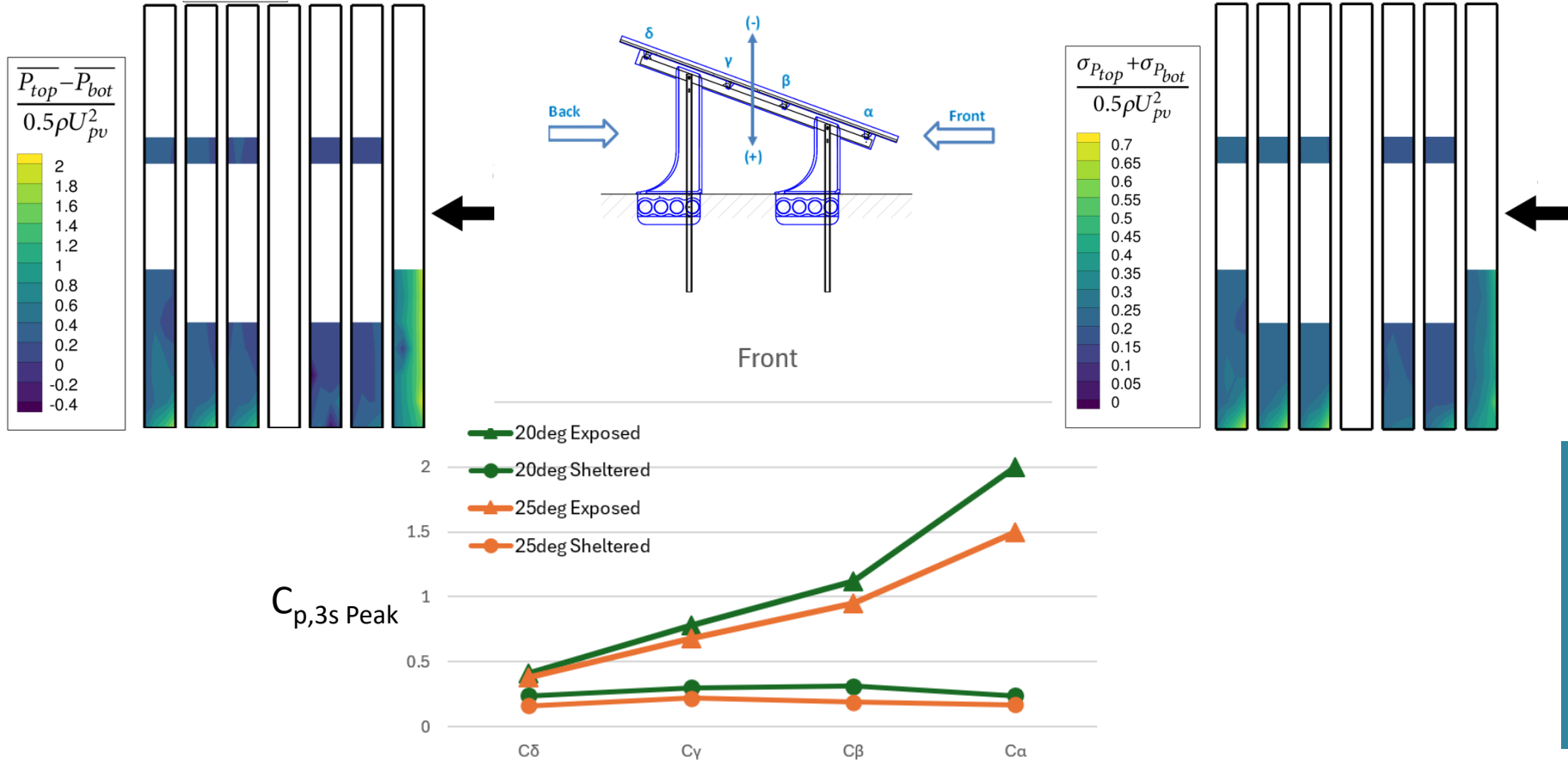
Piraeus Tower in the Wind Tunnel

Selected Wind Tunnel studies : Loads

Wind loads on PV arrays



PV panels – static loads

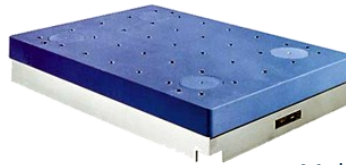


Selected Wind Tunnel studies : Loads

trees' aerodynamic parameters

Citrus sample trees

Tested 3 tree specimens of different heights (1.3m, 1.5m, 1.8m), species and orientations

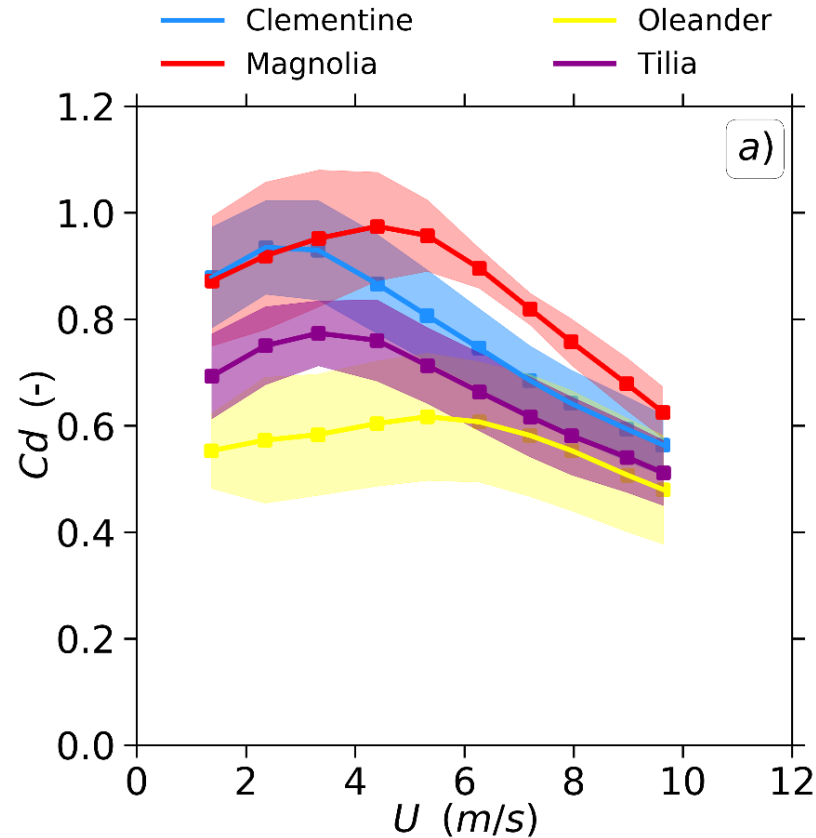


Multicomponent Force



vegetation

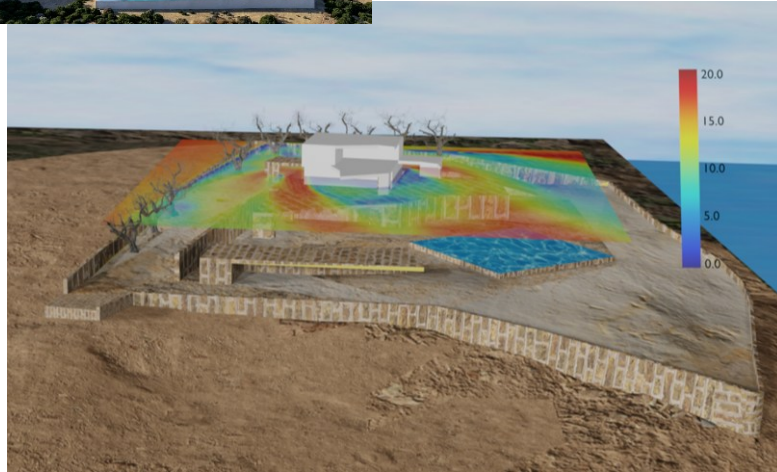
- Mean drag coefficient
- Variation includes specimens and orientation
- Trees reconfigure at high wind speed and reduce drag



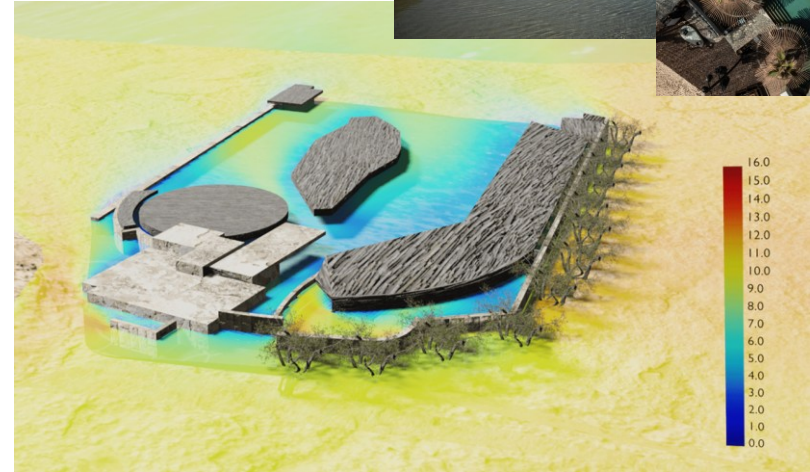


Selected Examples of CFD Studies (Wind Comfort and Urban Microclimate)

Selected CFD studies : wind comfort



Antiparos

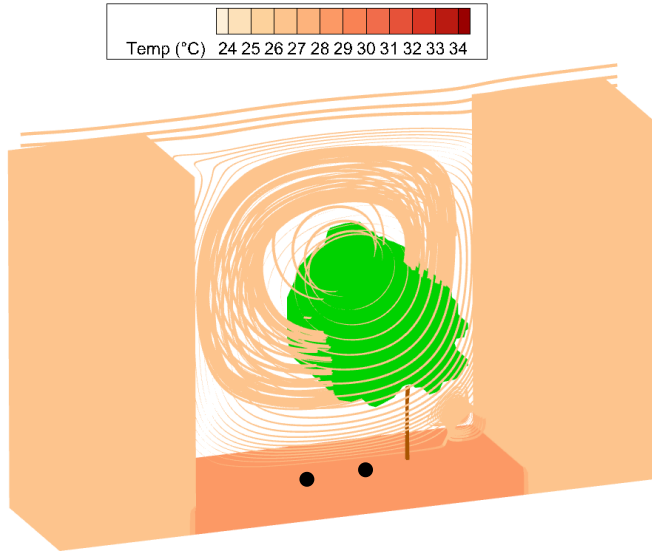


Mykonos

- Occupant comfort
- Viability of business

Street canyon- Diurnal Aero-thermos dynamics, vegetation effects

12 AM



$Re = 41,096$

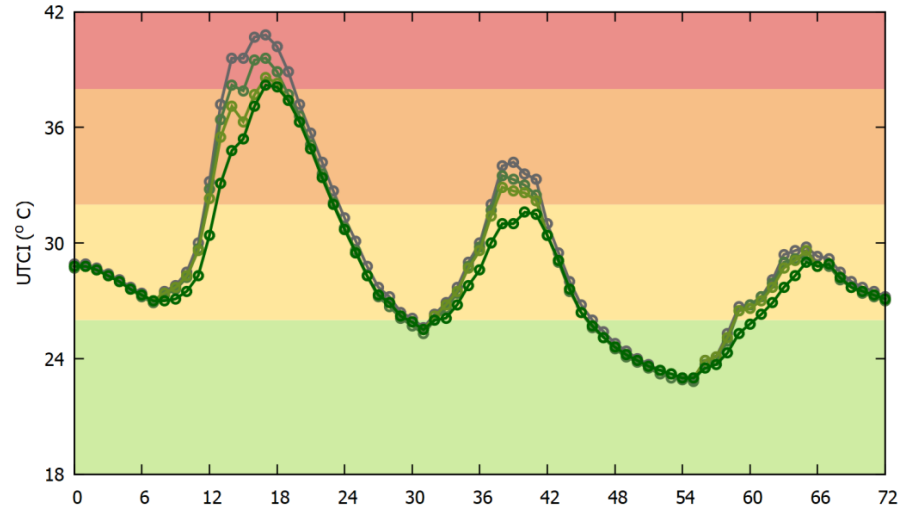
RNG k- ϵ

$Ri_b = 1.57$

$\Delta t = 20s$

$dx_{min} = 1.5 \text{ mm}$

$$UTCI = f(T_{air}, RH, U_{wind}, T_{rad})$$



No vegetation -A

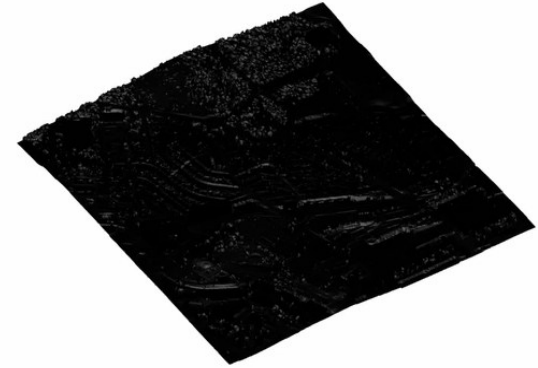
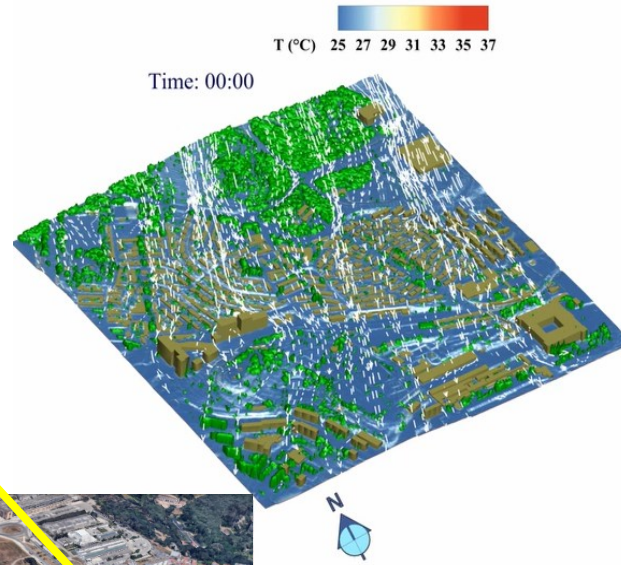
Vegetation (Drag + Transp.) -A

Vegetation (Drag + Transp. + Shading) -A

Vegetation (Drag + Transp. + Shading) -B

Selected CFD studies : urban microclimate

Diurnal Lisbon
real geometry



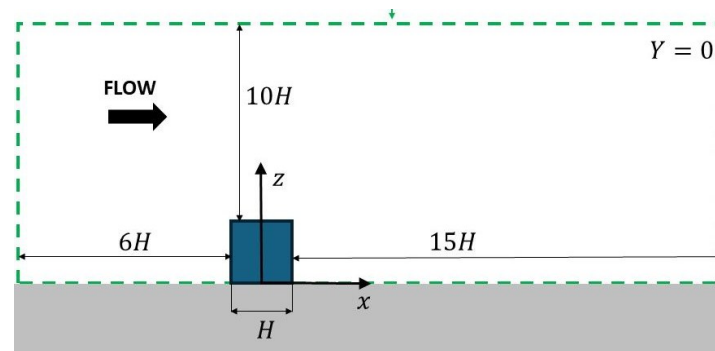
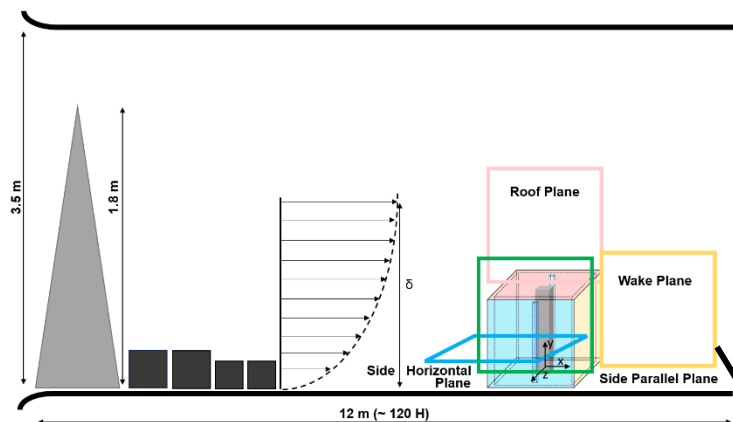
Time: 00:00



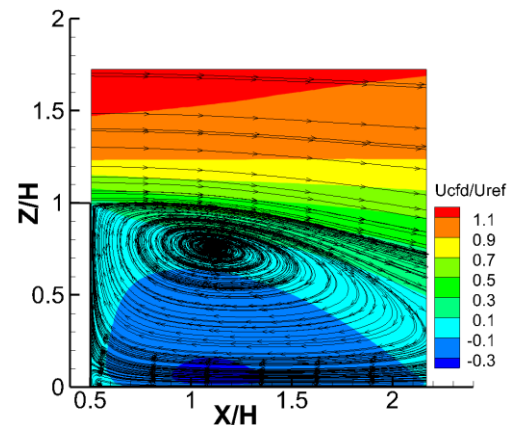
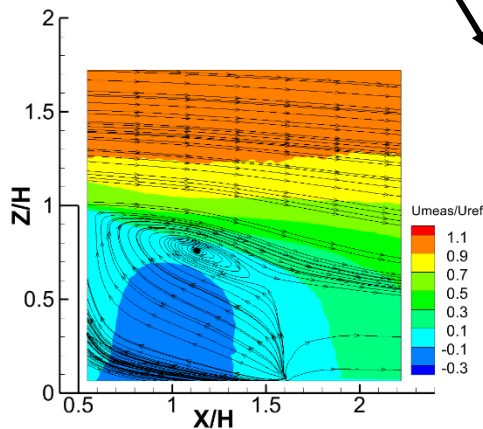


Assimilation of Wind Tunnel Measurements to CFD simulations

Assimilation of PIV Data to CFD



Stereo PIV
 $Re = 1.6 \cdot 10^4$
Suburban ABL

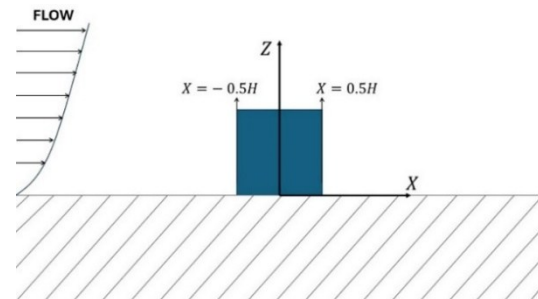


3D OpenFoam
RNG k- ϵ
Grid : 3.3 M
WT inflow

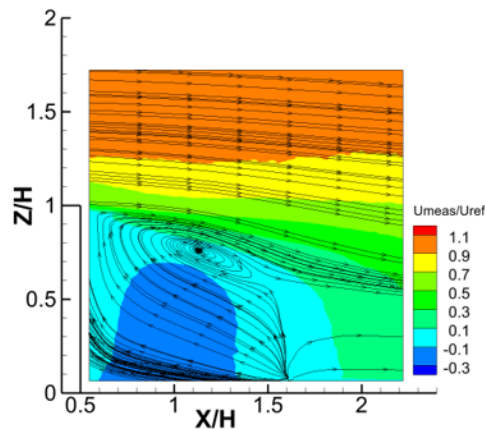
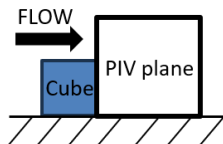
Data Assimilation for ABL flow past a cube

Ensemble Kalman filtering

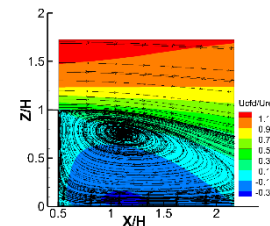
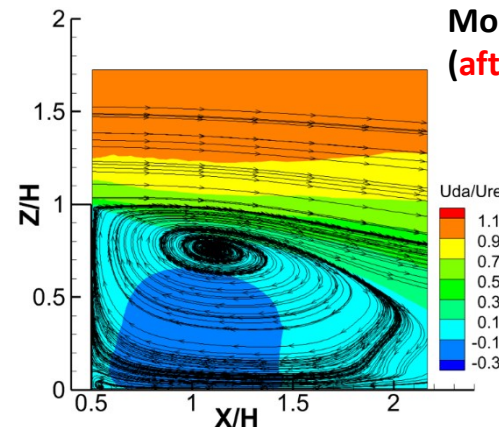
- Reynolds independent flow
- δu^* equivalent to δRe for log law
- Measured $u^* \sim N\left(\overline{u^*} = 0.22, 0.114^2 \overline{u^*}^2\right)$
- 50 ensemble members from scaling of single CFD run
- Measurement uncertainty is min. resolved vel. (5% U_{ref})



PIV data



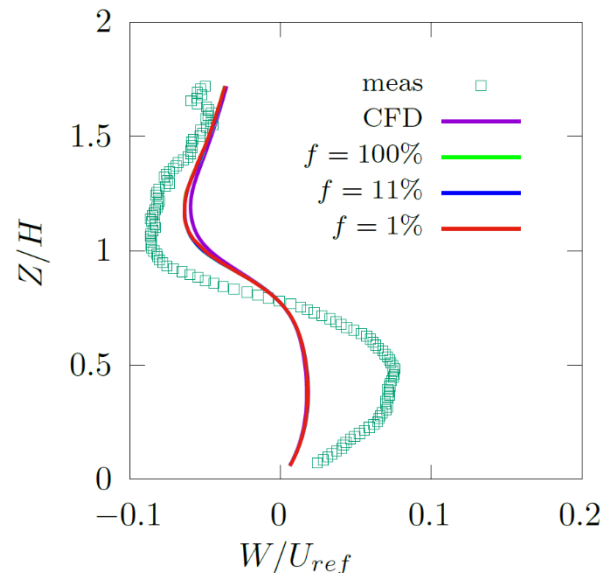
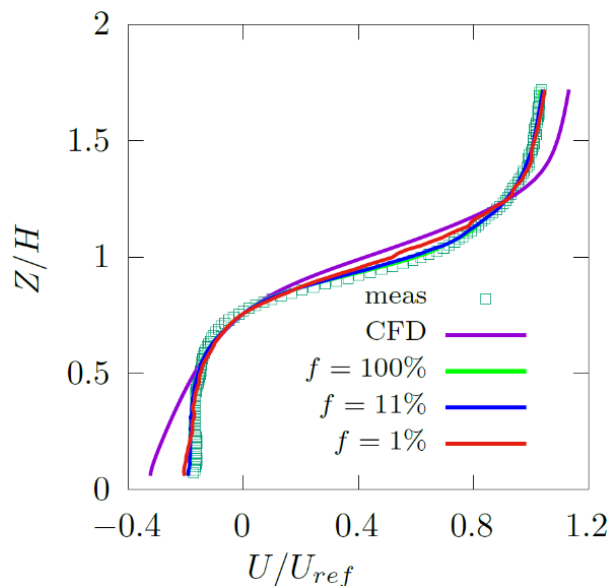
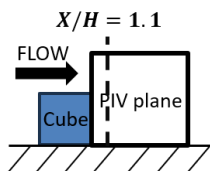
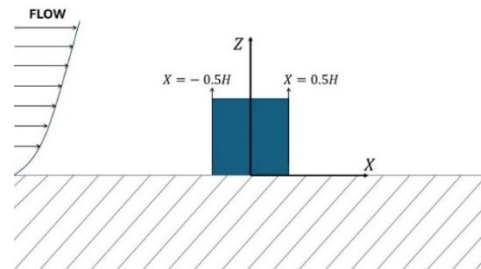
Model solution
(after DA)



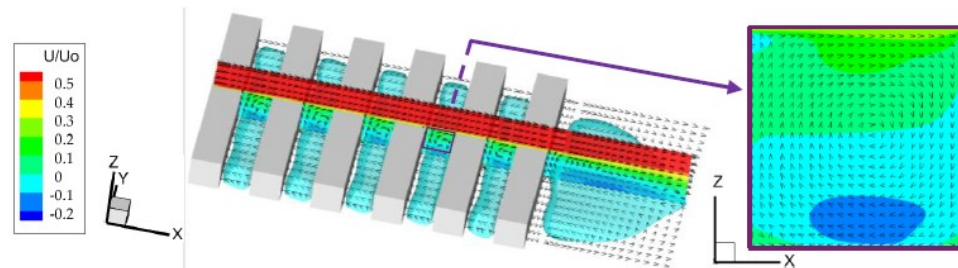
Data Assimilation for ABL flow past a cube

Ensemble Kalman filtering

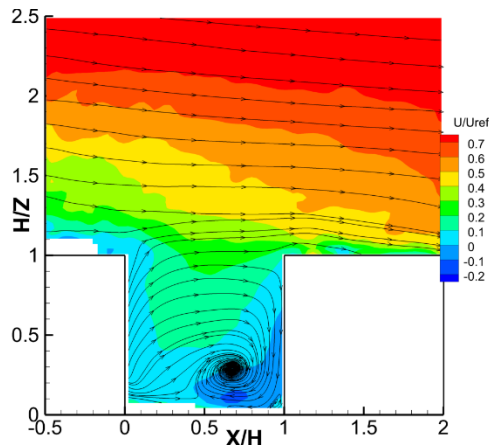
- PIV points = 5 x (CFD grid)
- Reduction to only 1% of the PIV data (~100 points) does not significantly affect results
- Vertical velocity unaffected as values are close to measurement uncertainty



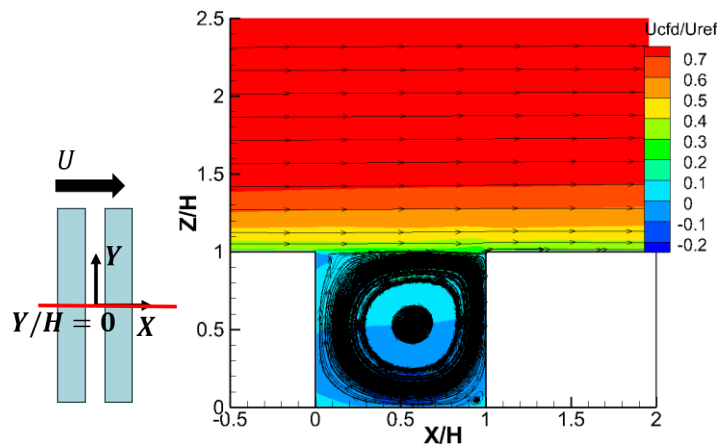
Urban street canyon



PTV (TU Delft)



CFD

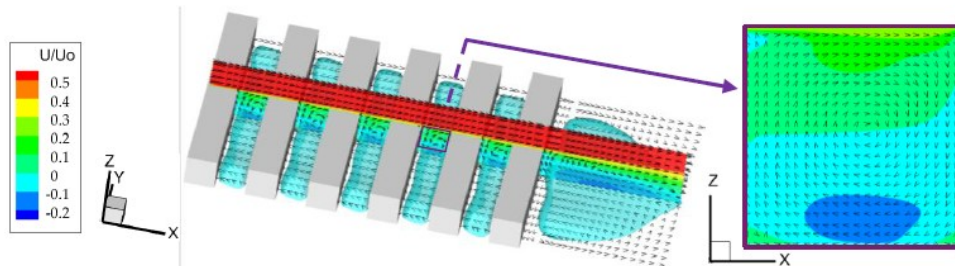


3D, RNG k- ϵ
Grid: 6.7 M,
100x100 4th canyon
WT inflow

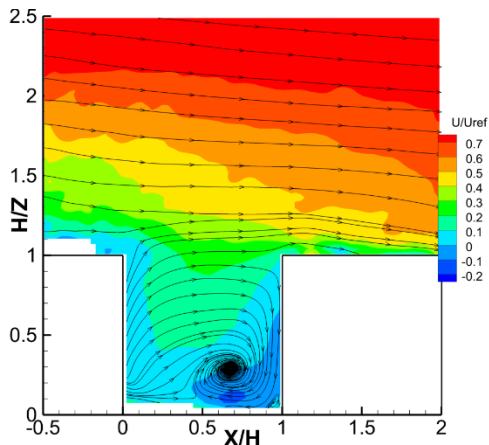
Pallas N-P, Dsouza B., Gromke C., Sciacchitano A., Bouris D. (2026) Wind tunnel measurements of scale effects on 3D turbulent flow in an urban street canyon configuration. Experiments in Fluids (2026) 67:149

Data Assimilation for flow in an urban street canyon

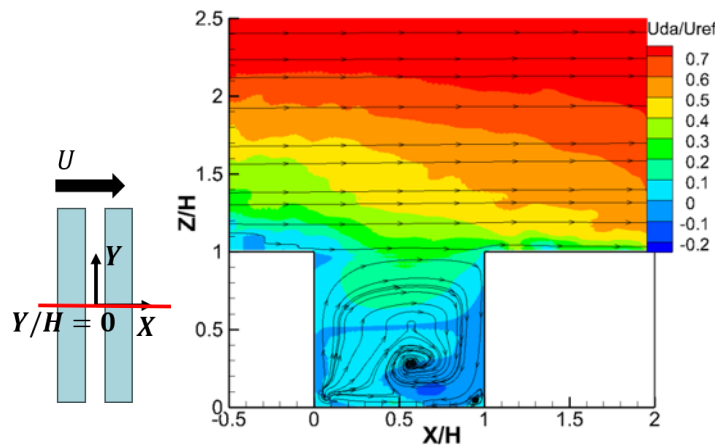
Can we do it with
Full Scale Measurements ?



PTV (TU Delft)



DA



Ensemble
Kalman filtering
(4% PTV data)

Many thanks to all who contributed :

Dr. Vasiliki Pappa

Mr. Nikolaos-Petros Pallas

Ms. Maria Kotsiopoulou

Mr. Alexandros Giannakakos

... and many more



Thank you !



