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# PARAMETERIZATION OF DRAG FORCES IN URBAN CANOPY MODELS USING MICROSCALE-CFD MODELS FOR DIFFERENT WIND DIRECTIONS

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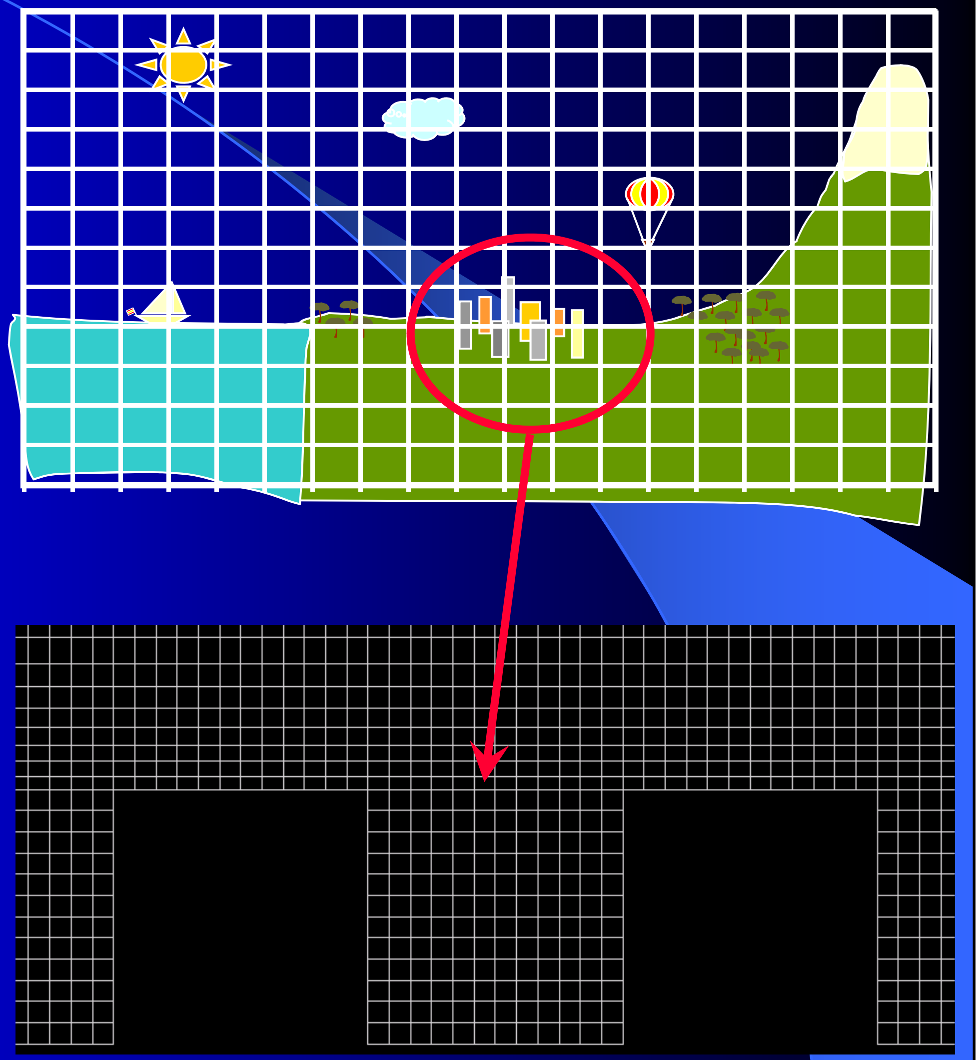
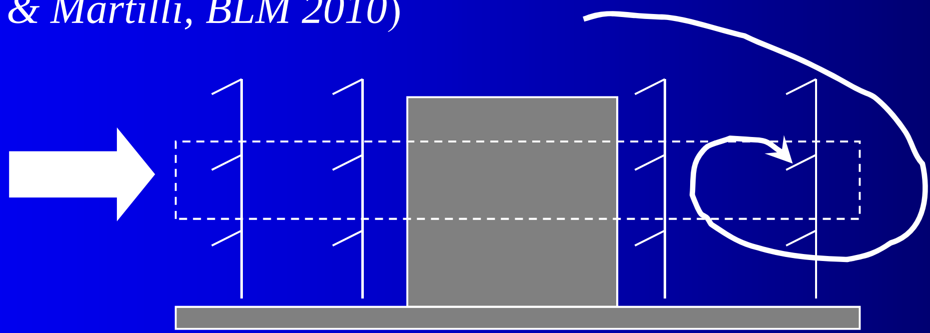
# INTRODUCTION



- Resolution:
  - Mesoscale ~ km ↔ Microscale ~ m
- Simplified Urban Canopy Models:
  - Buildings are not explicitly resolved.
  - Needs Urban Parameterizations (Compromise between simplicity and accuracy).
  - Parameterization of drag and turbulence.

# INTRODUCTION

- Improvement and assessment of UCP:
  - UCP → horizontally averaged variables over mesoscale cell (~ 1km).
  - Experimental measurements inside urban canopy → NO high resolution enough to obtain representative horizontal spatial average of physical properties.
- Our proposal:
  - Use CFD models (resolution ~ m) to obtain spatially averaged variables. (*Martilli & Santiago, BLM 2007; Santiago et al., BLM 2008 Santiago & Martilli, BLM 2010*)



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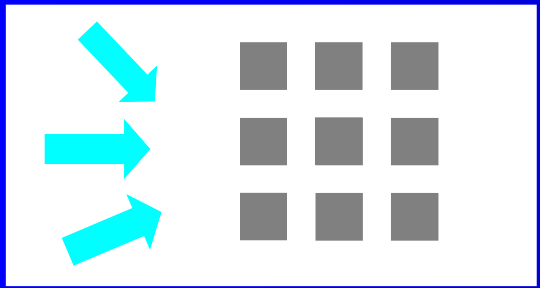
# OBJECTIVES OF THIS STUDY

- **Focused on the dynamical effects produced by buildings in cases with winds not orthogonal to building walls.**



Wind flow inside urban configuration (aligned array of cubes with $\lambda_p=\lambda_f=0.25$)

Periodic domain (study centre of array)

Different inlet wind direction

- Analysis of CFD (RANS & DNS) results (simple cases), flow around building explicitly solved.

- Use these results to study drag parameterization in Urban Canopy Models (UCP). (Dynamical effects of building not explicitly solved by UCP)

# METHODOLOGY

**CFD simulations**

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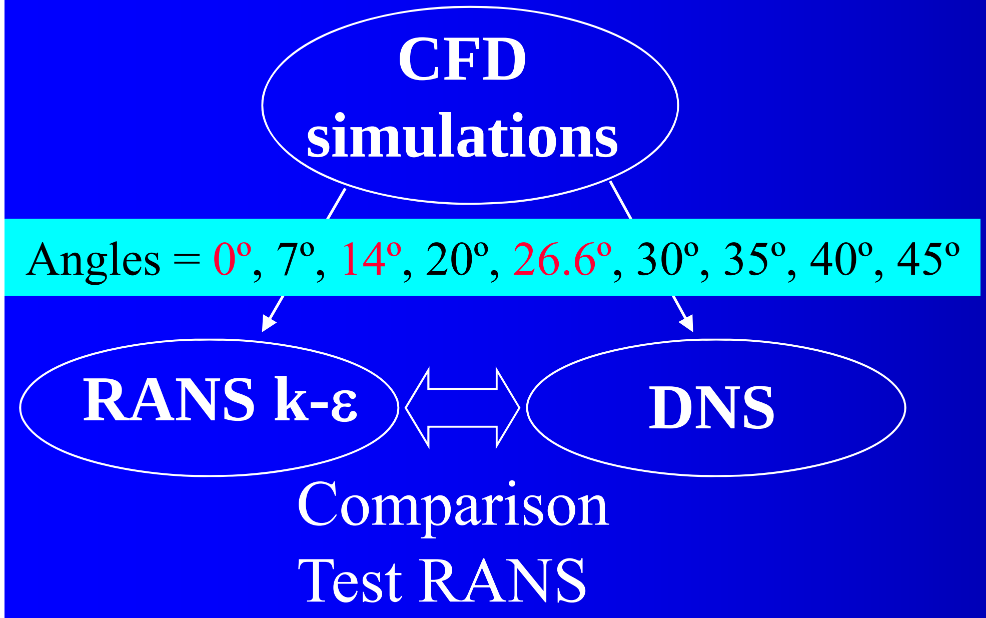
# *METHODOLOGY*

**CFD simulations**

Angles = 0º, 7º, 14º, 20º, 26.6º, 30º, 35º, 40º, 45º

**RANS k-ε**

# *METHODOLOGY*



# *METHODOLOGY*

**CFD simulations**

Angles = 0º, 7º, 14º, 20º, 26.6º, 30º, 35º, 40º, 45º

**RANS k-ε** ⟺ **DNS**

Comparison

Test RANS

⇓

**Average Properties**

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Test RANS

⇓

**Average Properties**

⇒ **INPUT: Drag parameterizations**

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⇩

**Average Properties**

**INPUT: Drag parameterizations**

⇨ **UCP 1D configuration**

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# *METHODOLOGY*

**CFD simulations**

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Comparison

Test RANS

**Average Properties**

**INPUT:**
**Drag parameterizations**

**UCP 1D configuration**

**1D results for different cases**

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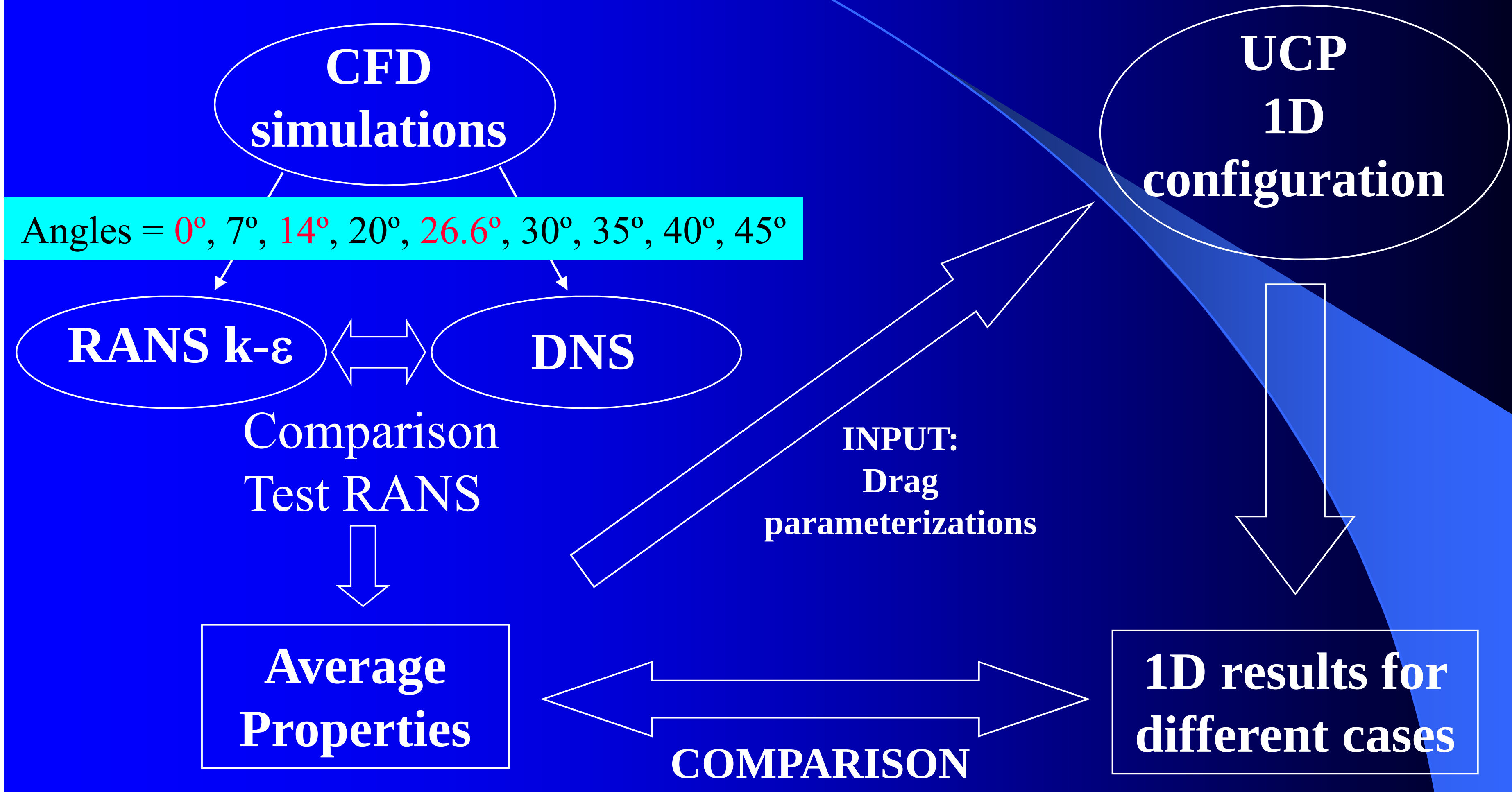
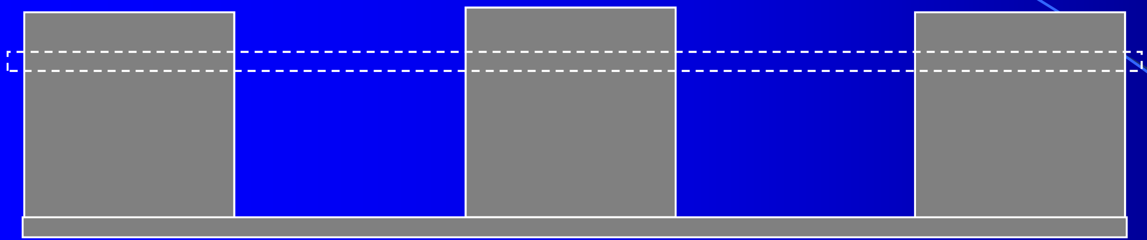
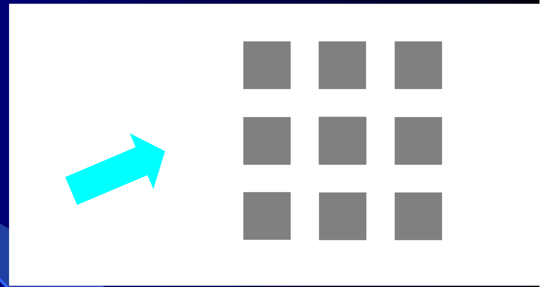
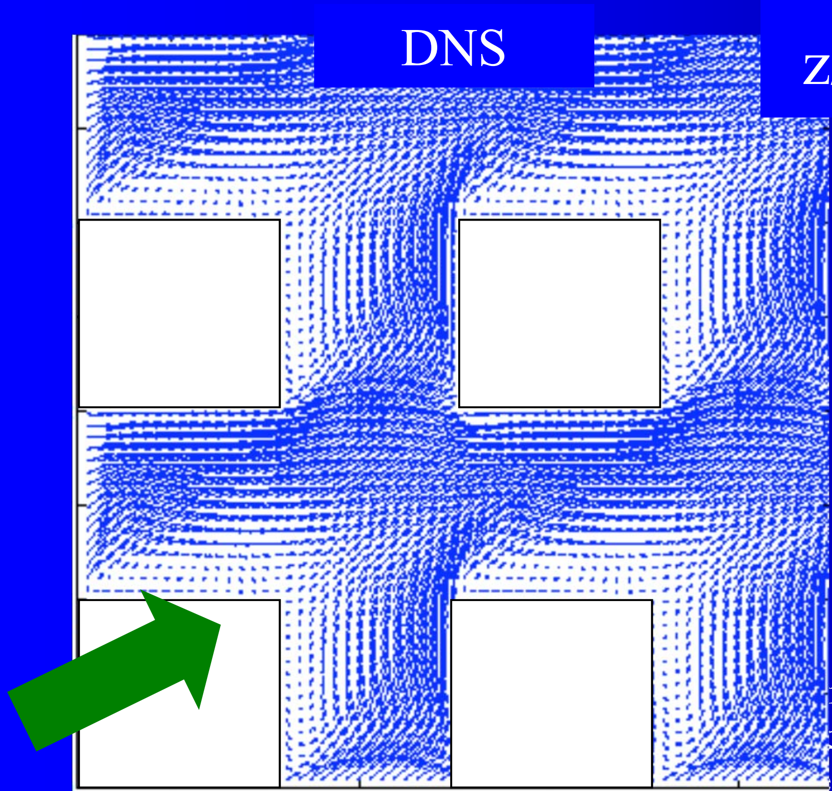
# *METHODOLOGY*



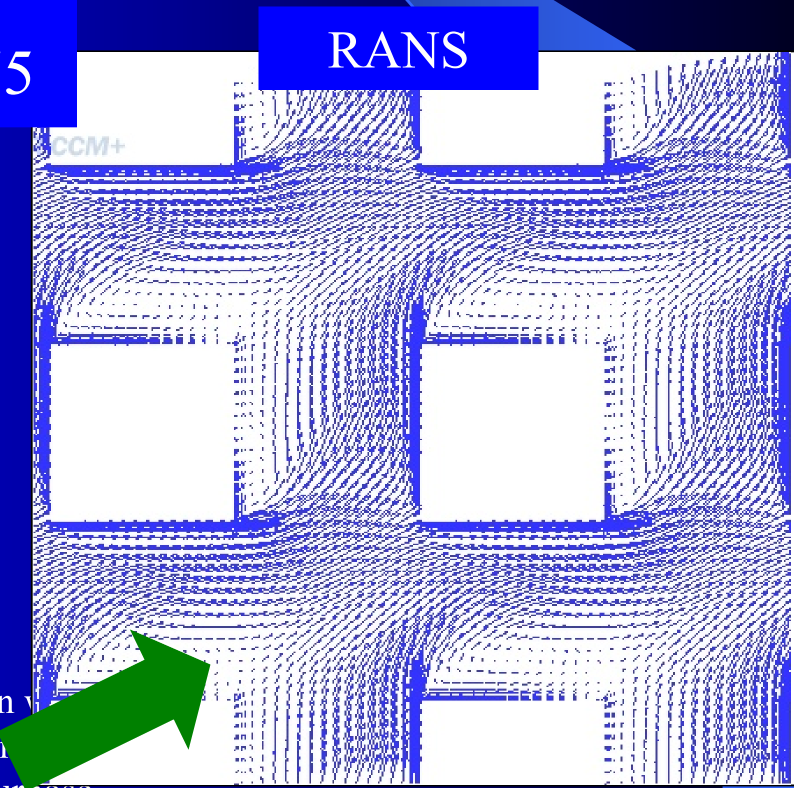
# CFD RESULTS: ANALYSIS OF FLOW FIELD






26º
z/h=0.75



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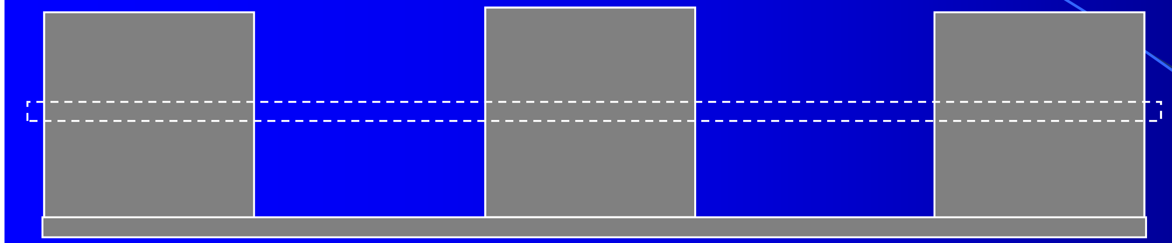
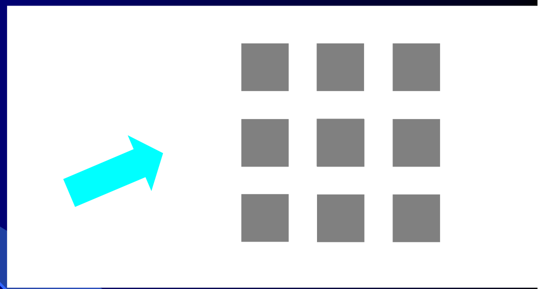
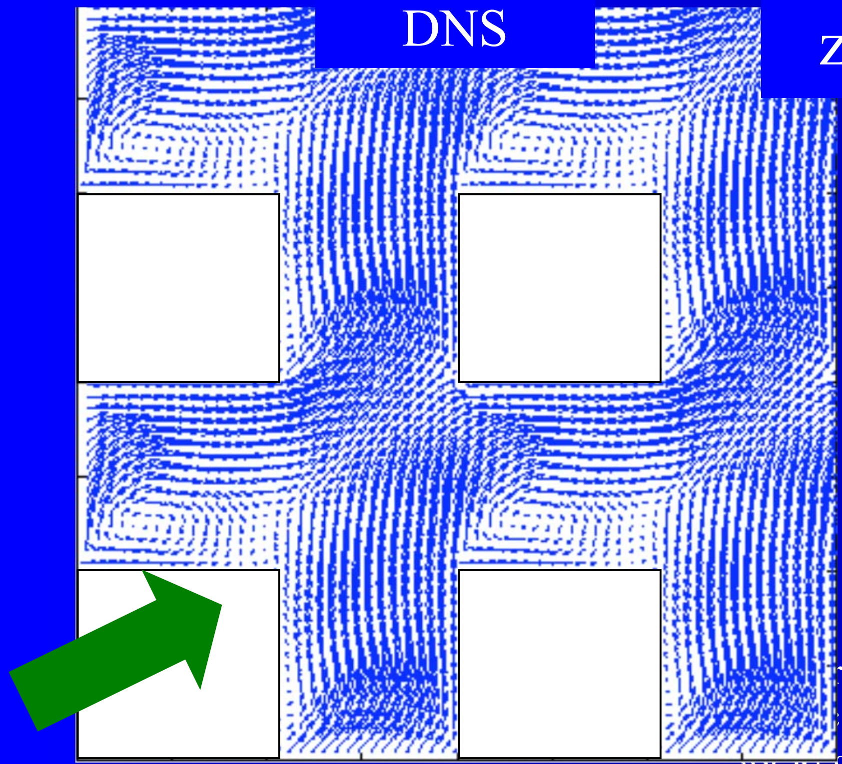
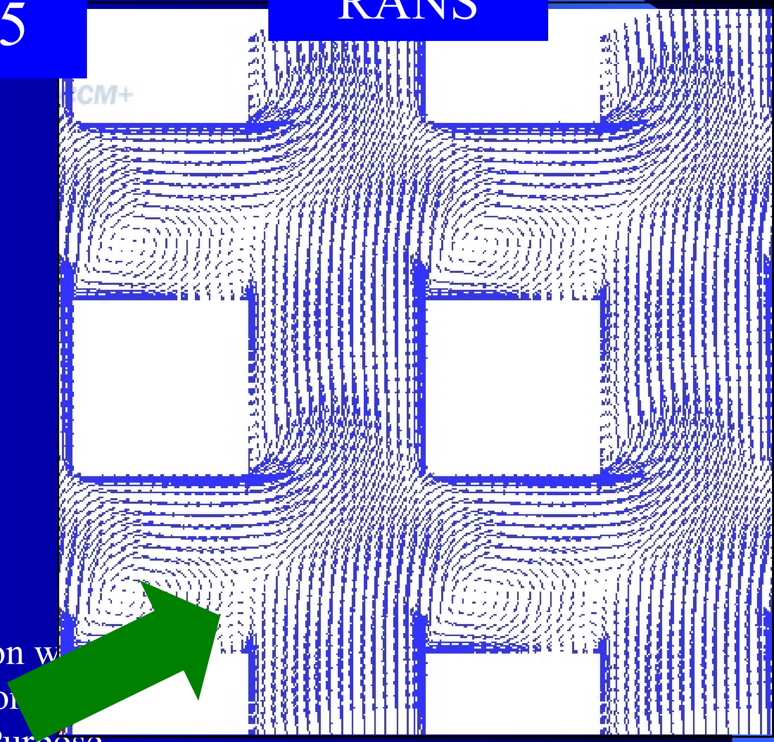


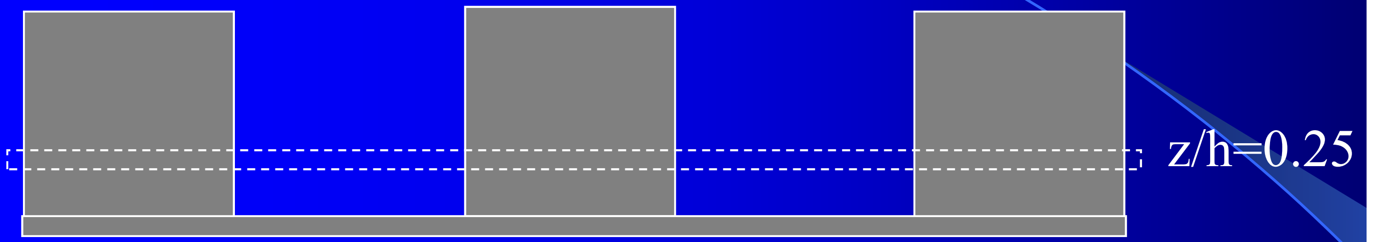



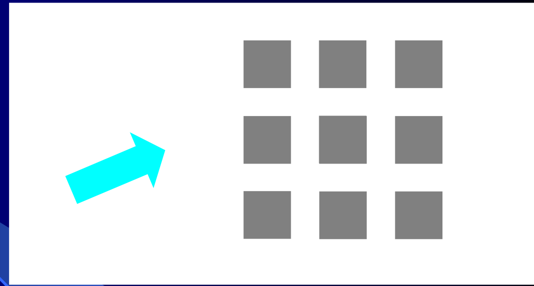



26º
z/h=0.5

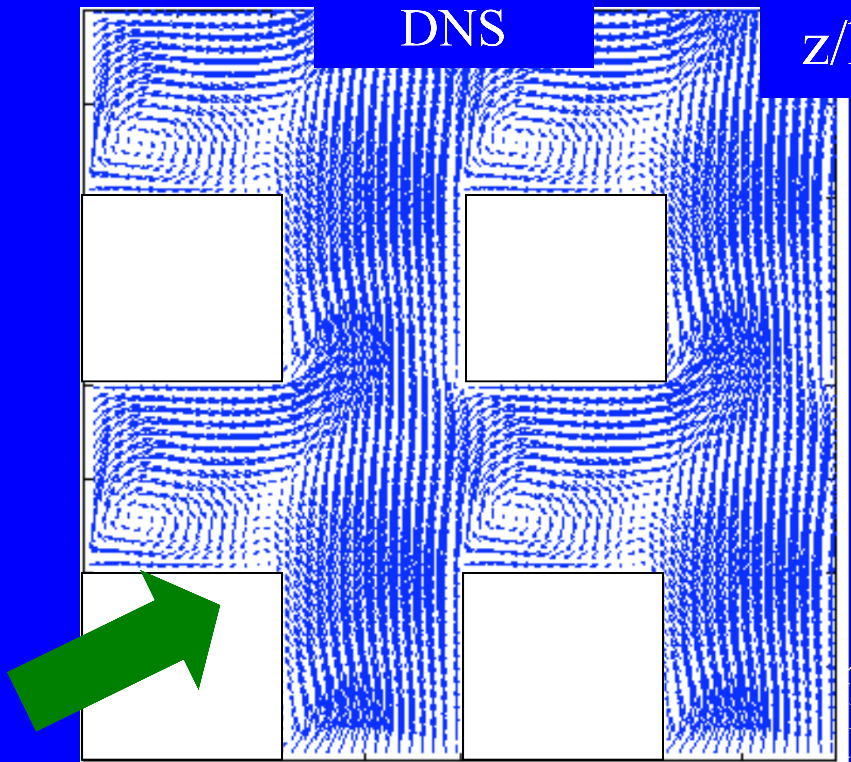


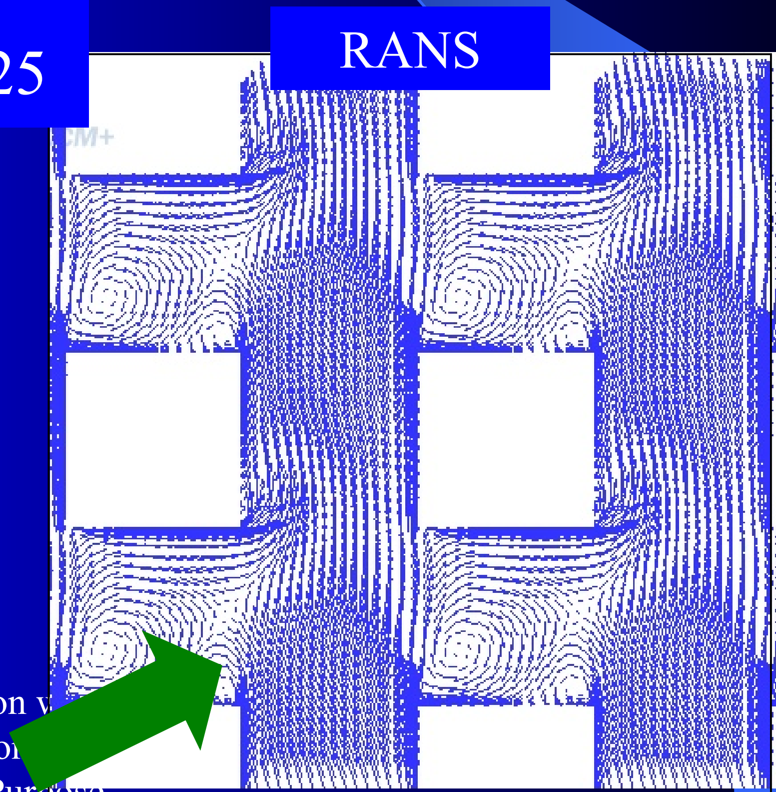
# CFD RESULTS: ANALYSIS OF FLOW FIELD



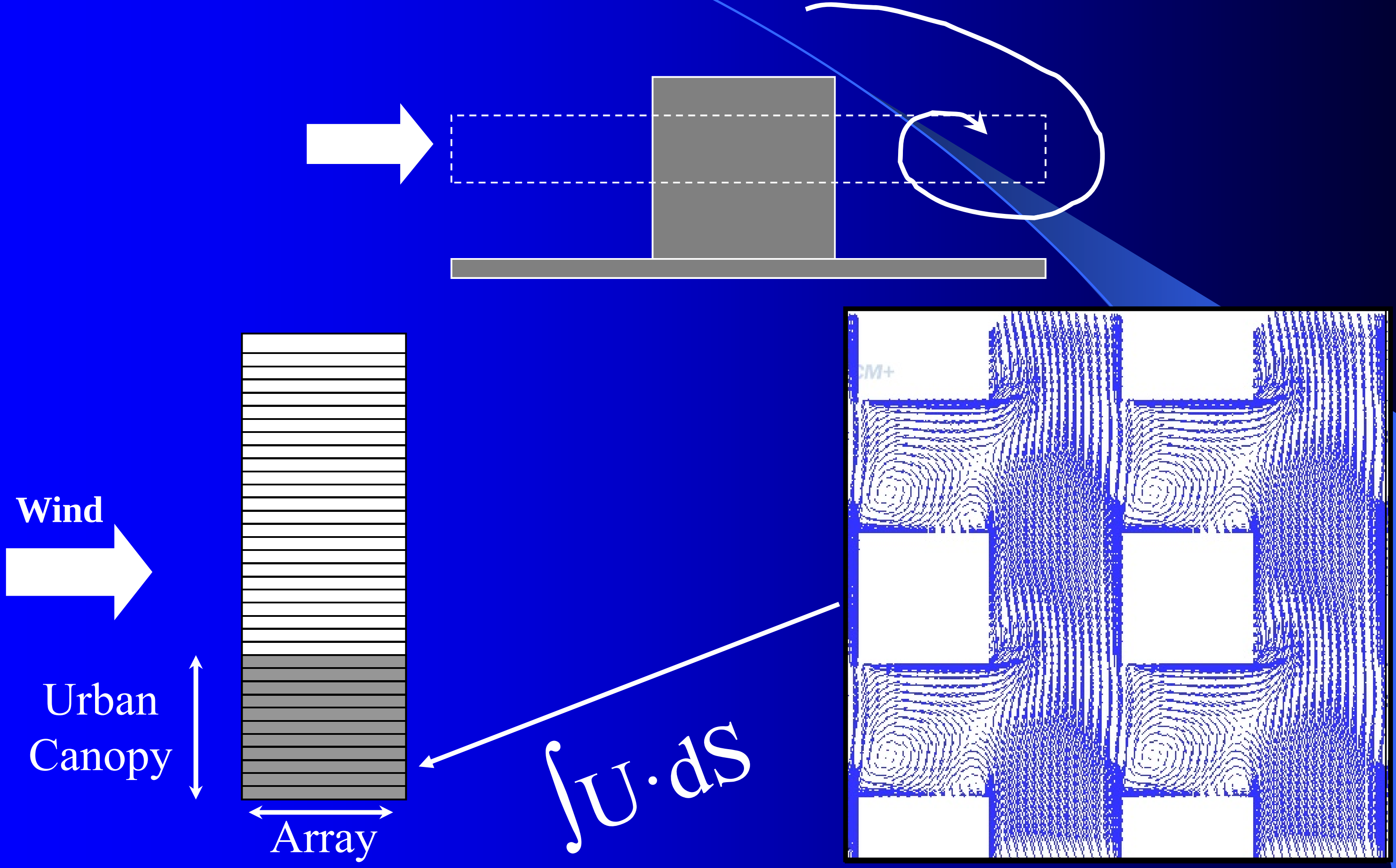



26º
z/h=0.25



# CFD RESULTS: SPATIAL AVERAGE FLOW



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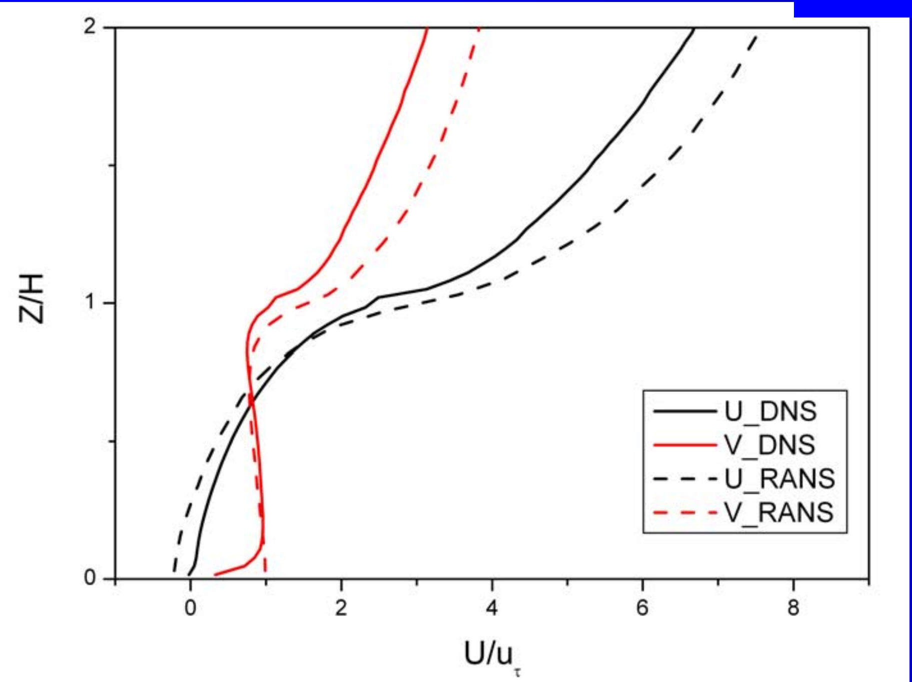
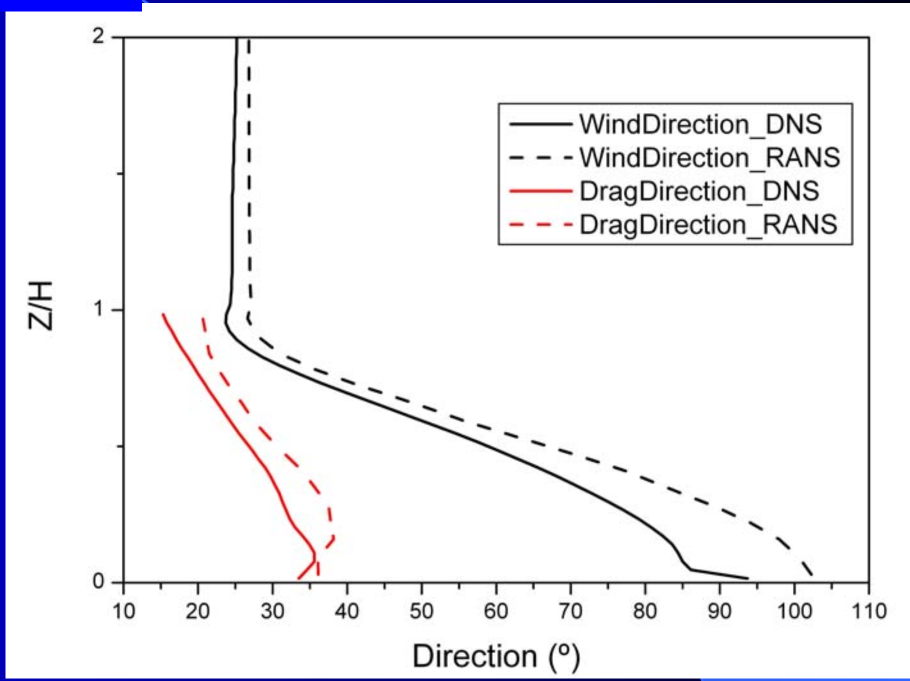
# CFD RESULTS: SPATIAL AVERAGE FLOW

26º




- Mean wind direction changes with height inside the canopy.

Drag Force Angle(z) ≠ Wind angle(z)

# CONCLUSIONS OF CFD RESULTS

- DNS and RANS provide similar flow structures inside the canopy.
- Mean wind direction changes with height inside the canopy.
- Drag is usually parameterised as,

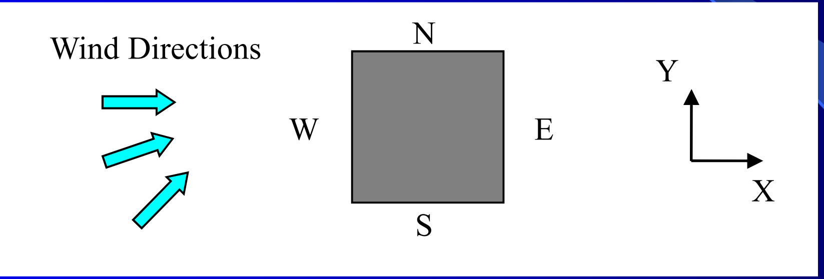
$$Drag(z) = \rho S(z) C_d \left| U^{ORT} \right| U^{ORT}$$

- Results obtained:

Drag Force Angle(z) ≠ Wind angle(z) ≠ Angle $(U^2/V^2)(z)$

# URBAN CANOPY PARAMETERIZATION (PARAMETERIZATION OF DRAG FORCE)

- Different behaviour of walls ORT and walls PAR.




- Our proposal:

$$\vec{D}rag(z) = \vec{D}rag(z)^{ORT} + \vec{D}rag(z)^{PAR} =$$
$$= \rho S^{ORT}(z) C_d^{ORT}(z) \left| U^{ORT} \right| \vec{U}^{ORT} + \rho S^{PAR}(z) C_d^{PAR}(z) \left| U^{PAR} \right| \vec{U}^{PAR}$$

- $U^{PAR}$ is U orthogonal to wall PAR.

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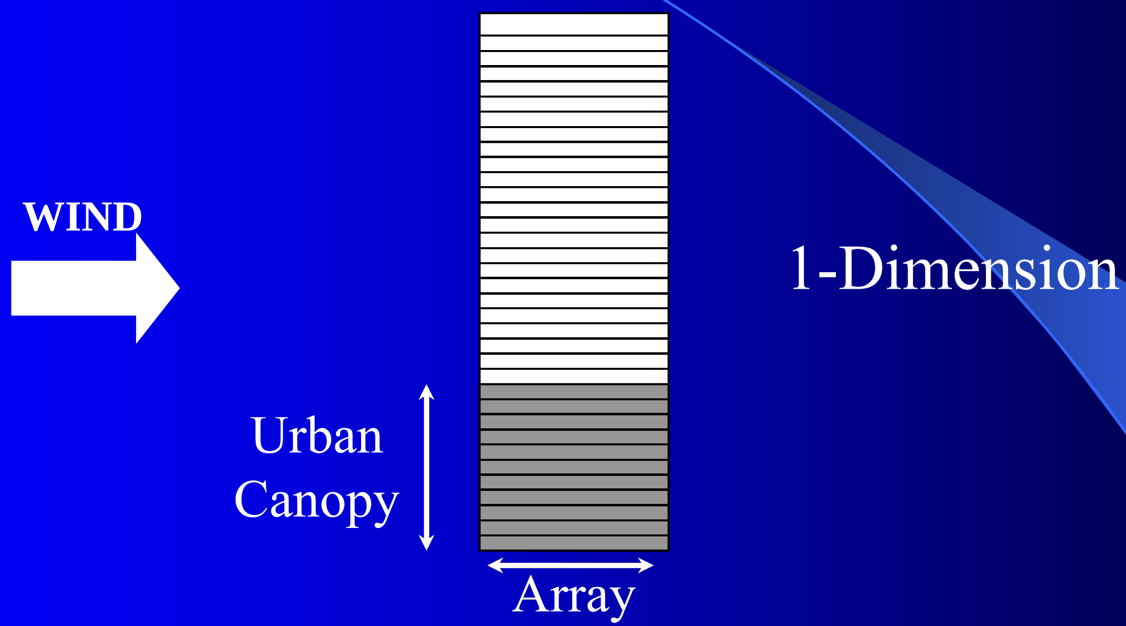
# *UCP (1-D SIMULATIONS)*




- The simulations are tested in 1-Dimension (one column of cells).
- In horizontal only one cell represents the array of cubes (All horizontal gradients are considered 0 except a pressure gradient which is imposed).

# TESTS OF PARAMETERIZATION OF DRAG FORCE

- **TEST 1:** Drag coefficients are computed directly from RANS simulations.

$$C_d^{ORT}(z,angle) = \frac{\Delta P^{ORT}(z,angle)}{\rho (U^{ORT}(z,angle))^2} \qquad C_d^{PAR}(z,angle) = \frac{\Delta P^{PAR}(z,angle)}{\rho (U^{PAR}(z,angle))^2}$$

- **TEST 2:** The z dependency is removed but keeping the drag force integrated in the whole canopy equals to that computed by RANS simulations.

$$C_{deq}^{ORT}(angle) = \frac{\int_0^h \Delta P^{ORT}(z,angle)\, dz}{\rho \int_0^h \left(U^{ORT}(z,angle)\right)^2 dz} \qquad C_{deq}^{PAR}(angle) = \frac{\int_0^h \Delta P^{PAR}(z,angle)\, dz}{\rho \int_0^h \left(U^{PAR}(z,angle)\right)^2 dz}$$

- **TEST 3:** Same value of Cd for the two orientations. Computed from RANS results.

$$C_{deq}^{ORT}(angle) = C_{deq}^{PAR}(angle) = \frac{\int_0^h \left(\left(\Delta P^{ORT}(z,angle)\right)^2 + \left(\Delta P^{PAR}(z,angle)\right)^2\right)^{0.5} dz}{\rho \int_0^h \left(\left(U^{ORT}(z,angle)\right)^2 + \left(U^{PAR}(z,angle)\right)^2\right) dz}$$

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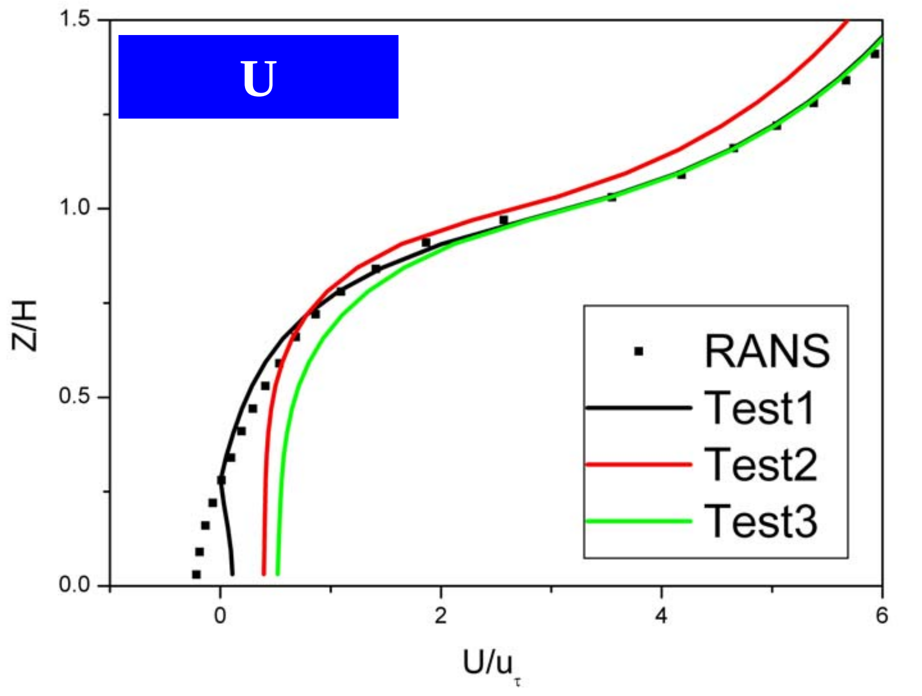
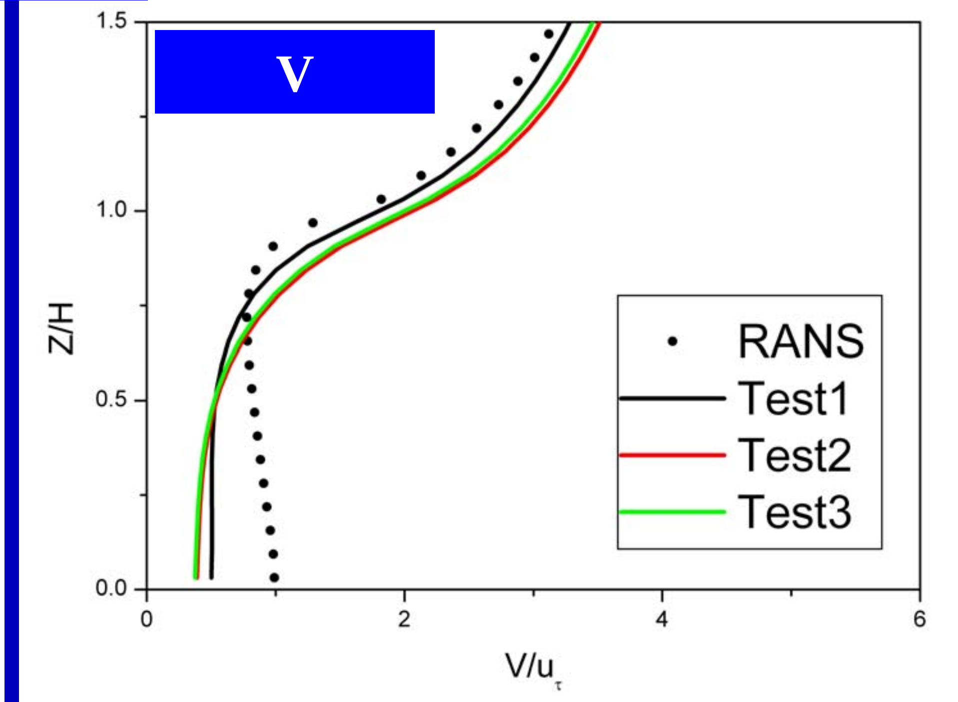
# UCP 1-D RESULTS

## 26º




- In general for Test 2 and Test 3, close to ground U is overestimated, especially for small angles where Cd at this height is very high. And U is always greater than V inside the canopy producing a wrong wind direction.
- UCP with drag coefficients removing z dependency does not reproduce the changes of wind direction inside canopy.
- At least for these cases, it seems to be necessary to take into account the height-dependency of the drag coefficient.

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# CONCLUSIONS

- The flow within the array, when the inlet wind is not orthogonal to the buildings, is very complex and sometimes unintuitive (including effects such as channelling in the streets in preferential directions and changes of mean wind direction with height within the canopy)
- The importance of a good parameterization of drag to reproduce the effects mentioned above. In particular, a height-dependent drag coefficient seems to be necessary.
- UCP reproduces spatially-averaged flow similar to those computed from CFD when a suitable parameterisation of drag forces is used.
- Future studies are necessary to improve the drag parameterisation and to generalise it to other layouts.

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# *Thank you for your attention*