TREES, PEOPLE AND THE BUILT ENVIRONMENT II

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Development and integration of a Vegetated Urban Canopy Model in a Meteorological Model

Richard Tavares, Isabelle Calmet, Sylvain Dupont

Contact : richard.tavares@ec-nantes.fr

Centrale Nantes iRSTV INRA cnrs

Outline

– Context and Objectives

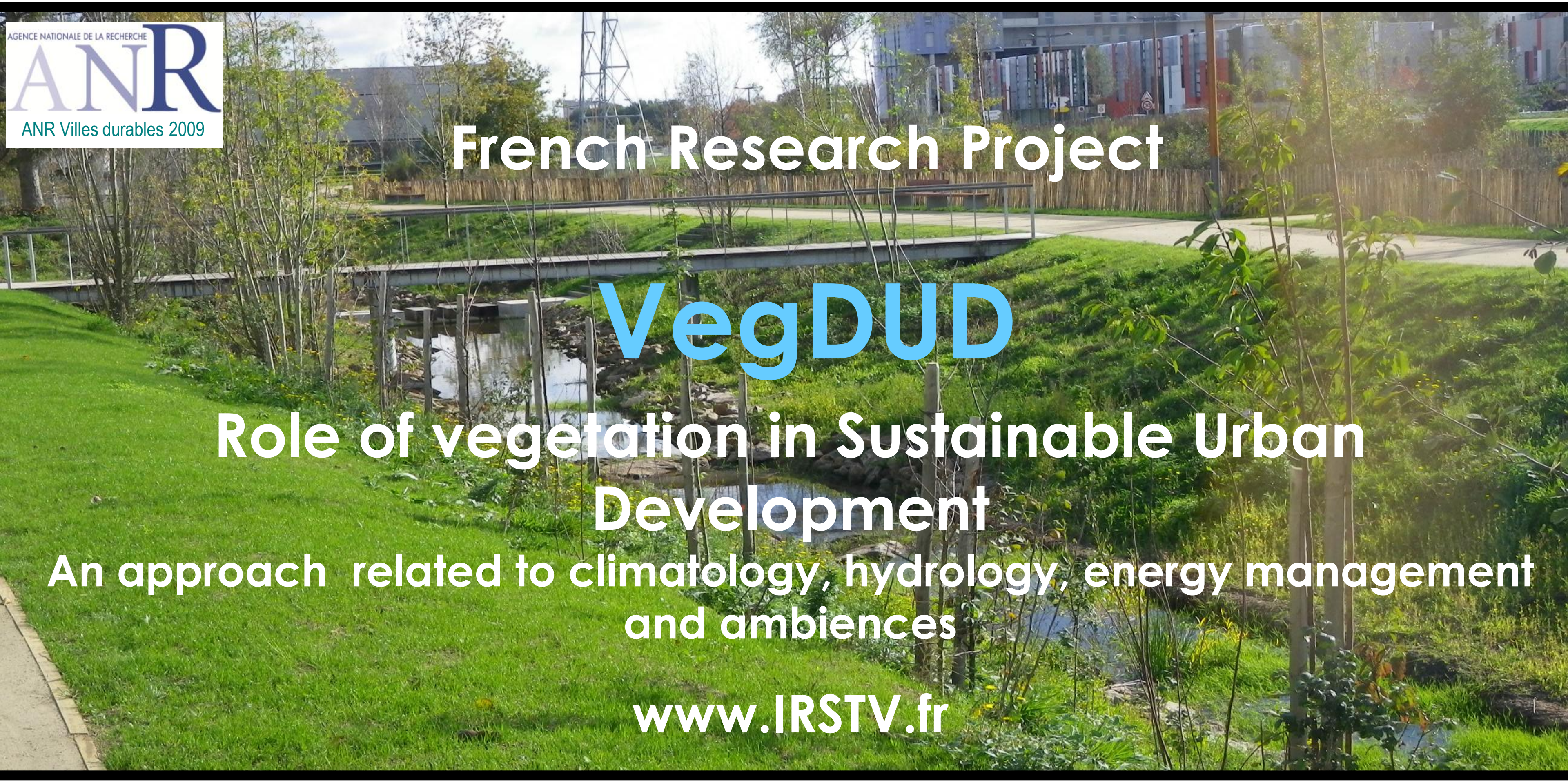
– Overview of the proposed modelling approach

– Application and performance analysis

– Final considerations and perspectives

Context
&
Objectives

Context



AGENCE NATIONALE DE LA RECHERCHE
ANR
ANR Villes durables 2009

French Research Project

VegDUD

Role of vegetation in Sustainable Urban Development

An approach related to climatology, hydrology, energy management and ambiences

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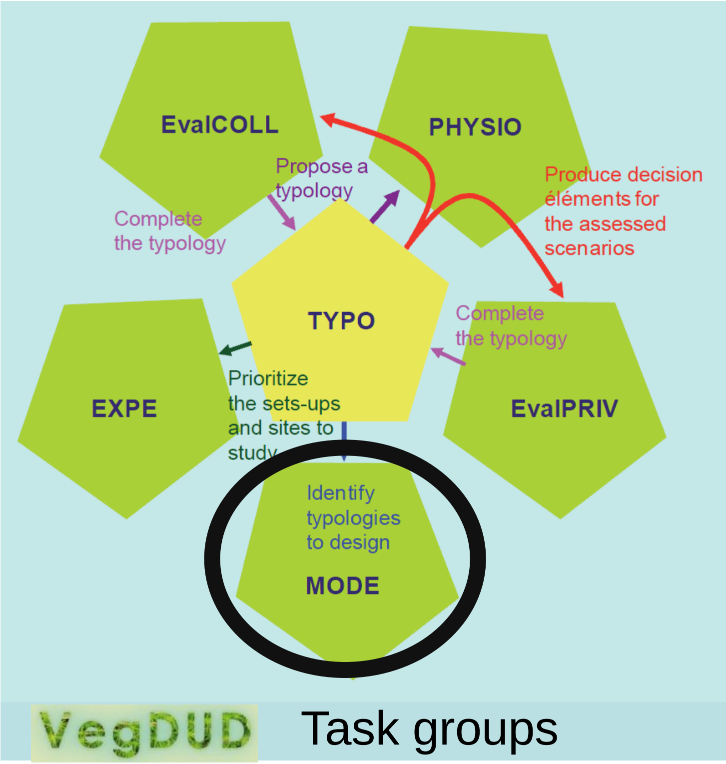
Context

MODE - MODELING task group

implement urban vegetation representations in different **models** for:

- **Climatology**
- Hydrology
- sound propagation
- building energy

Several **scales** are considered
- from the architectural up to the **city**.



Context – Urban microclimate

Urban microclimate

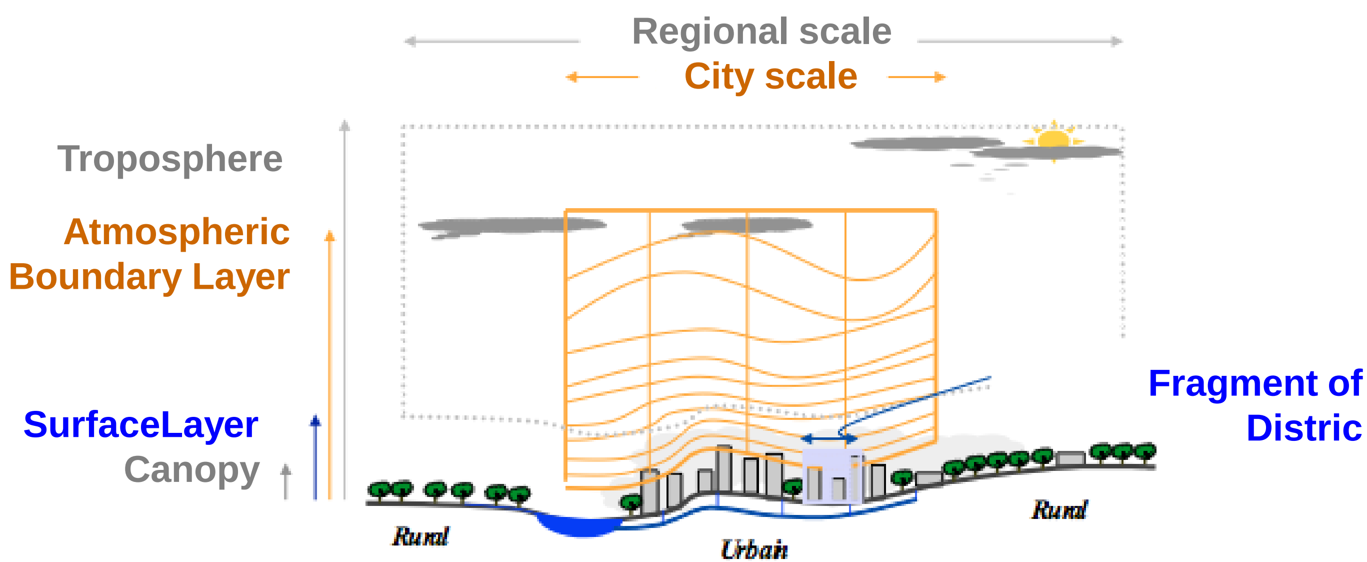
- Wind, air temperature and humidity
- Urban morphology and covering modes (vegetation) influence transfers between canopy and atmosphere
- Different types of districts which influence each other

Context – Modelling urban microclimate

Existing modelling methods

- At regional to **city scale** : Roughness approach in atmospheric boundary layer models
  → **no information inside the canopy**

- At **street scale** : Building resolving methods
  → **too expensive to study interaction between districts**



Objectives

Development and application of a **new modelling approach** that enables:

- To get information at different levels inside the urban canopy (**aerodynamic** and **energy budget**)

- To account for different **green devices** (vegetation on walls and roofs, trees, natural vs. artificial soils ...)

- To **evaluate the influence** of green devices on urban microclimate
  - Which vegetation devices influence more?
  - How green districts influence ‘non-green’ districts?
  - Which spatial distribution of green devices are the most efficient for mitigation purposes (particularly in densely built areas) ?
  - …

Overview of the Proposed modelling approach

Proposed modelling approach for urban climatology

- Consisted in the implementation of the **V**egetated **U**rban **C**anopy model in the large-eddy simulation atmospheric model **A**dvanced **R**egional **P**rediction **S**ystem (Xue et al. 2002)

ARPS – VUC

(A new *urbanized* version of ARPS meteorological code)

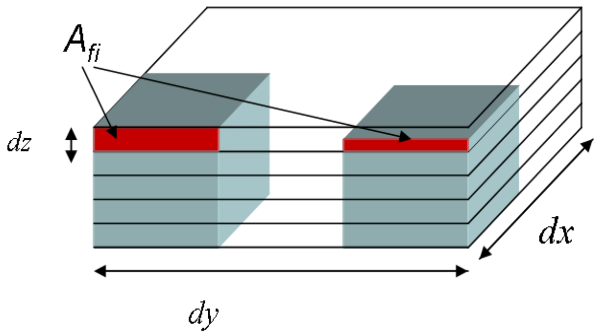
- Developed to account for:
  - **Aerodynamics influence of urban canopies**
  - **'Energy budget' – Thermo-radiative and hydric transfers between urban surfaces and atmosphere**

Aerodynamics modelling approach for urban canopy

- Use of a **Drag force modelling approach,** by adding **source or sink contributions from buildings and vegetation** in the conservation equations of ARPS model
- Based on previous developments for **forest canopies** (Dupont & Brunet, 2008), further adapted to **urban canopies** (Maché, 2012)

Influence of the buildings and high vegetation on the flow through a **drag force** in the momentum equations

$$F_{D_i}(z) = \frac{1}{2}\rho\, C_d(\lambda, z)\, a_f(z)\, \tilde{u}_i \sqrt{\tilde{u}_j \tilde{u}_j}$$



A **sectional drag coefficient** $C_d(\lambda, z)$ depends on **built density** λ and varies with **z** from the ground to the **canopy top H**

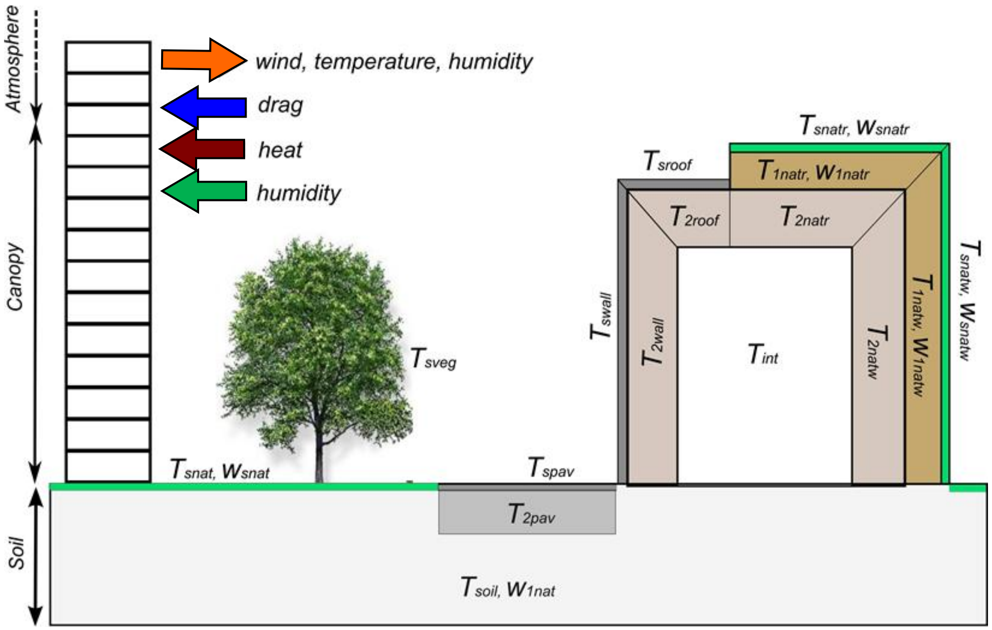
Frontal area density (m^2m^{-3})

$$a_f(z) = \frac{\sum A_{f_i}(z)}{dxdydz - \sum V_{bat_i}(z)}$$

Energy budget modelling approach for urban canopy

Thermo-radiative and hydric transfers within the canopy

- To compute **temperature** and **humidity** of the various surfaces
- To deduce **heat fluxes** which interact with the atmosphere



- Different kinds of surfaces described by their **thermal** and **radiative properties** and by their **area** in each cell
- **Heat conduction** in 2 or 3 layers
- **Short-wave radiation flux**
  - **Decay** toward the ground in function of **z**, **canopy density** and **day time**
  - Different for **vertical** and **horizontal** surfaces

Energy budget modelling approach for urban canopy

- **Net radiation flux**

$$R_n = (R_{sw}(1-\alpha) - \epsilon_s \sigma T_s^4 + \epsilon_{air}\sigma T_{air}^4)$$

- Radiation decay

- **Ground natural surfaces**

$$\frac{\partial T_{snat}}{\partial t} = C_{Tnat}\left(R_{nnat} - LE_{nat} - H_{snat}\right) - \frac{2\pi}{\tau}\left(T_{snat} - T_{soil}\right)$$

- Force-restore

- **Trees and building vegetation**

$$\frac{\partial T_{sveg}}{\partial t} = C_{Tveg}\left(R_{nveg} - LE_{veg} - H_{sveg}\right)$$

- **Artifical surfaces (pav, wall, roof)**

$$\frac{\partial T_{si}}{\partial t} = C_{Ti}\left(R_{ni} - H_{si} - Q_i\right)$$

- Conductive heat flux Q_i
- Modelled at 2 layers of material
- No latent heat

- **Heat fluxes**

$$H_{si} \propto \left(T_{si} - T_{air}\right) \qquad LE_{si} \propto \left(q_{si} - q_{air}\right)$$

Energy budget modelling approach for urban canopy

Momentum

$$\frac{\partial \tilde{u}_i}{\partial t} + \tilde{u}_j \frac{\partial \tilde{u}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \tilde{p}}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} - C_{d_{veg}} a_{f_{veg}} |\tilde{u}| \tilde{u}_i - C_{d_{bat}} a_{f_{bat}} |\tilde{u}| \tilde{u}_i$$

Sui

Drag - trees

Drag - buildings

Air Temperature

$$\bar{\rho}\frac{\partial \tilde{\theta}''}{\partial t} + \bar{\rho}\tilde{u}_j \frac{\partial \tilde{\theta}''}{\partial x_j} = -\bar{\rho}\tilde{u}_3 \frac{\partial \bar{\theta}_i}{\partial z} - \frac{\partial \tau_{\theta i}}{\partial x_i} + Hs_{roof} a_{roof} + Hs_{wall} a_{wall} + Hs_{veg} a_{veg}$$

$$+ Hs_{vegroof} a_{vegroof} + Hs_{vegwall} a_{vegwall}$$

Sθ

Sensible heat - buildings

Sensible heat - trees

Sensible heat – vegetation on buildings

Nat and pav surface fluxes at the 1st level

$$a_{surf} = \frac{S_{surf}}{V_{air}}$$

Air Humidity

$$\bar{\rho}\frac{\partial \tilde{q}}{\partial t} + \bar{\rho}\tilde{u}_j \frac{\partial \tilde{q}}{\partial x_j} = -\frac{\partial \tau_{qi}}{\partial x_i} + E_{veg} a_{veg} + E_{vegroof} a_{vegroof} + E_{vegwall} a_{vegwall}$$

Sq

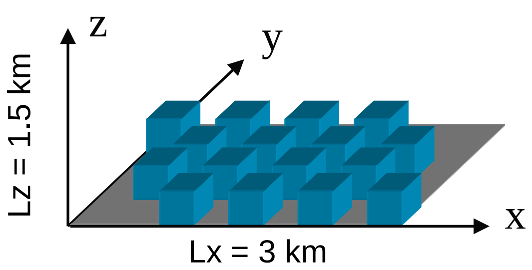
Humidity trees

Humidity – vegetation on buildings

Application and performance analysis

Aerodynamics simulations Performance Analysis

- Parameterization of the **drag coefficient** (homogeneous canopies)
  - LES simulations of the atmospheric mixing layer



→ Homogeneous canopy (cubes with height H = 10 m)

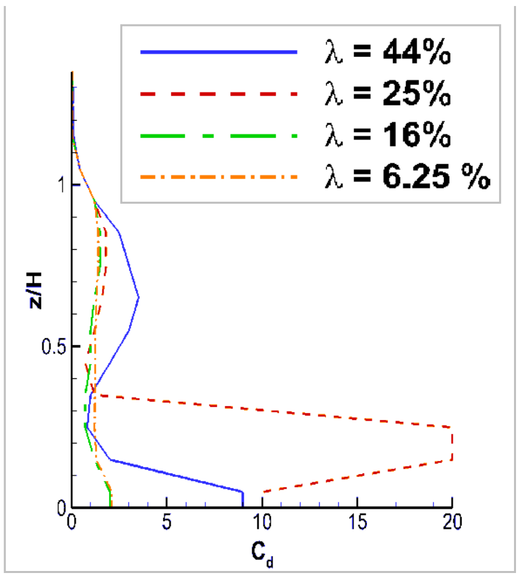
→ Grid : $\Delta x = \Delta y = 20$m

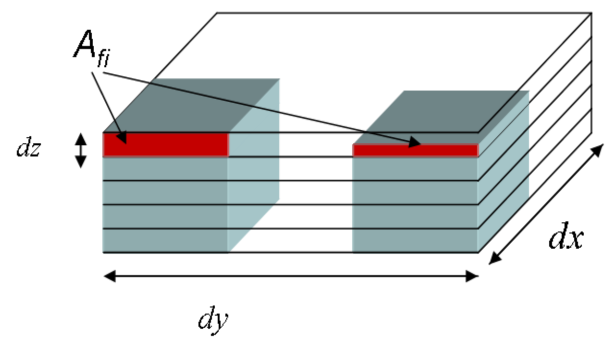
$\Delta z = 1$ m (untill $z \approx 25$m)

→ Periodic boundary conditions

→ Different surface built densities λ

$C_d(\lambda, z)$ vertical profiles





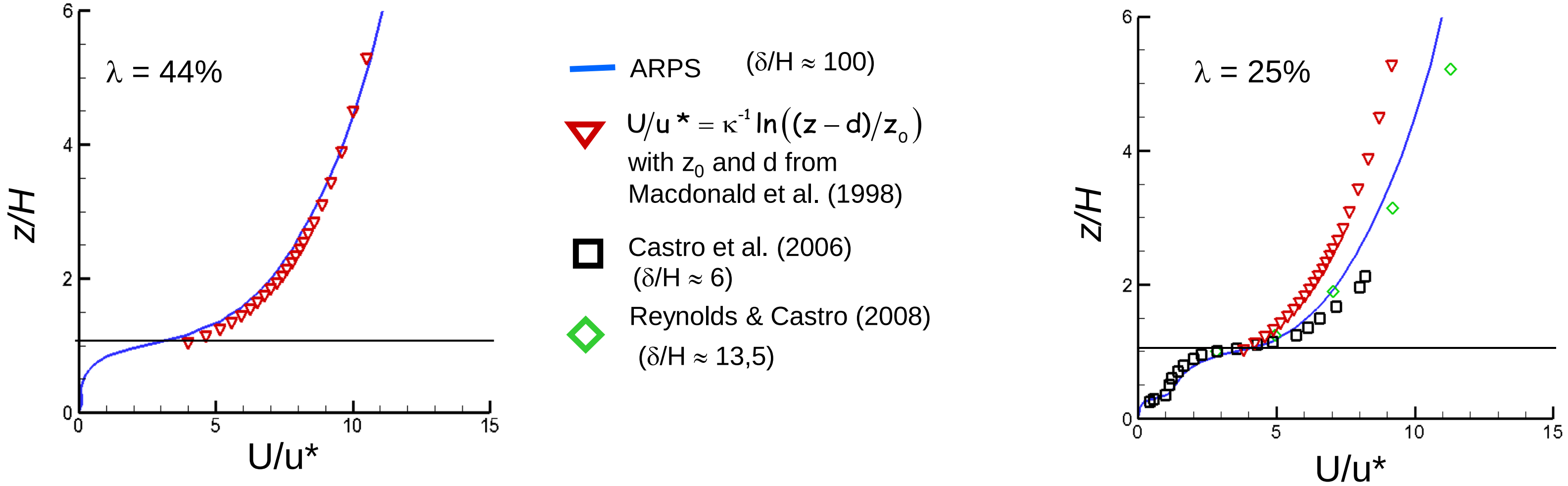
Frontal area density (m^2m^{-3})

$$a_f(z) = \frac{\sum A_{f_i}(z)}{dxdydz - \sum V_{bat_i}(z)}$$

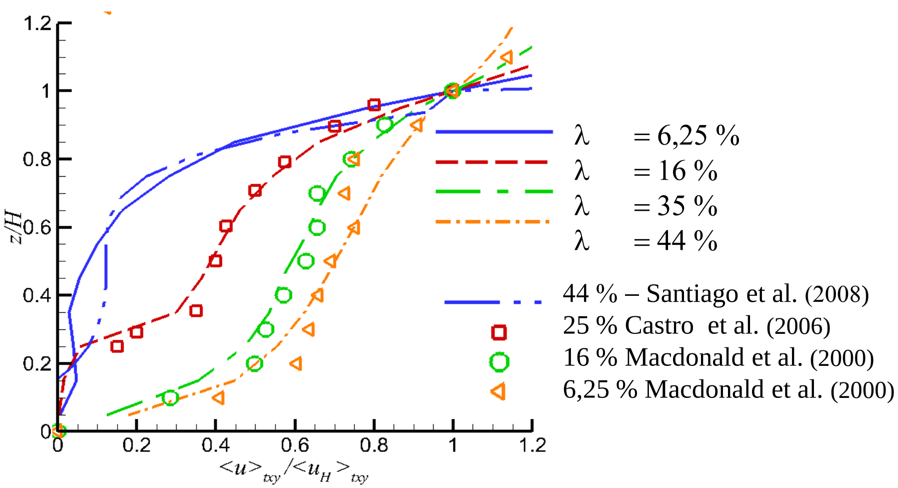
Aerodynamics simulations Performance Analysis

- Canopy-atmosphere dynamic interactions (**homogeneous configuration**)

U/u* mean wind speed in and above the canopy



U/U$_H$ mean wind speed in the canopy



Good agreement of simulated flow with the literature for a homogeneous boundary layer

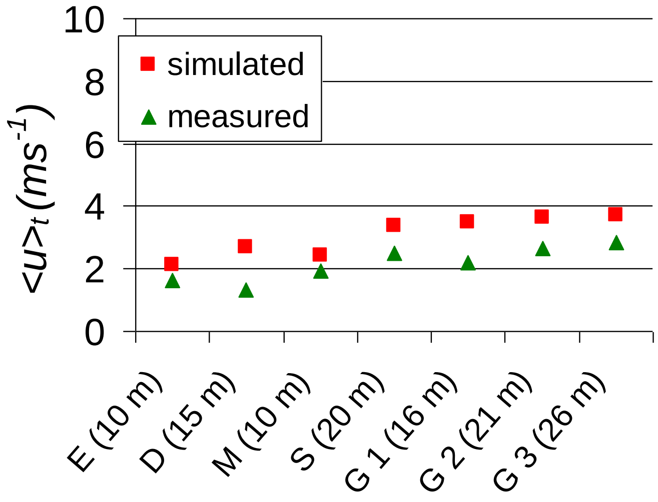
This approach is suitable to be used for an intermediate scale between micro- and meso-scales

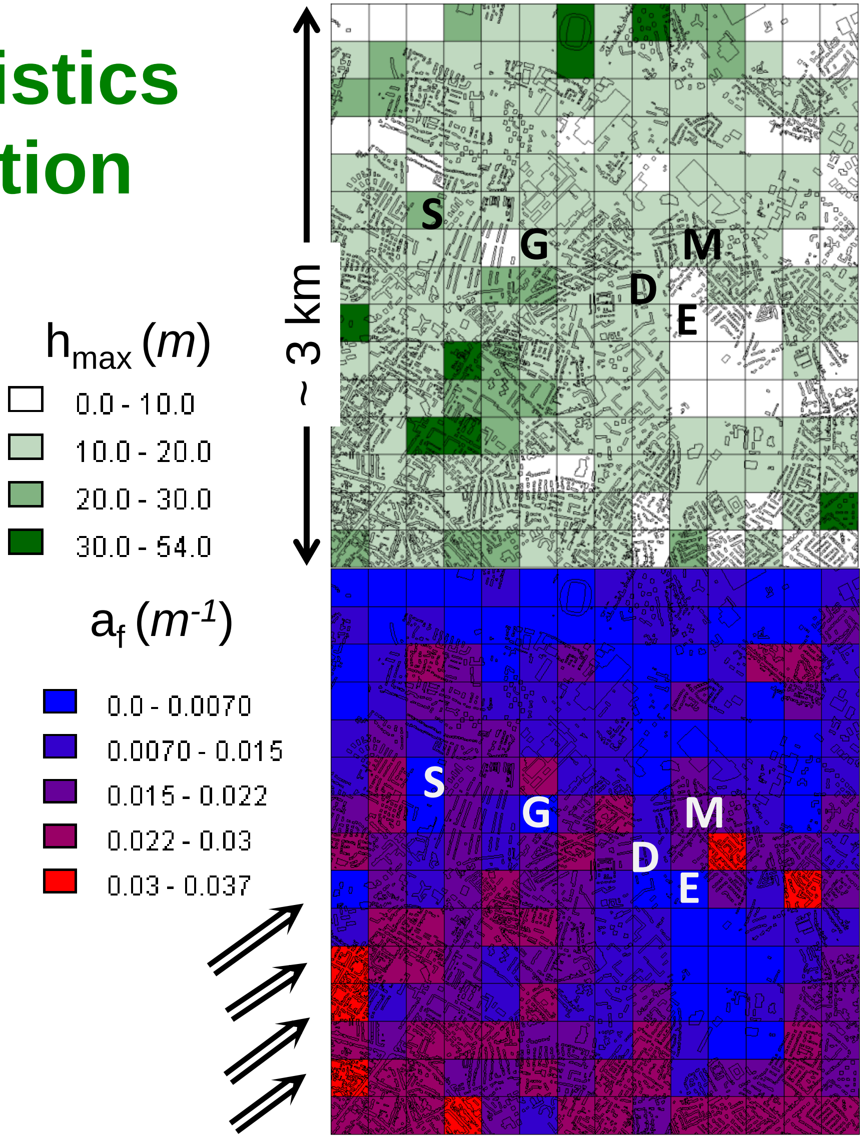
→ based on morphological parameters (*λ* and a_f) instead of aerodynamics parameters (z_0 and *d*)

Aerodynamics simulations Performance Analysis

Mean dynamical characteristics for a real scenarios simulation

Good agreement with local velocity measurements
(experimental site FluxSAP)

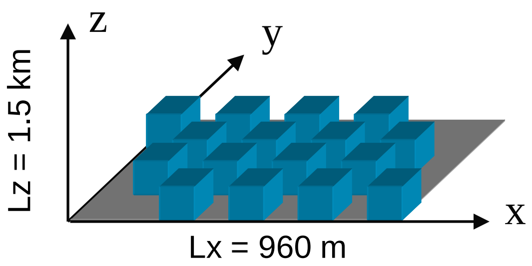




Thermodynamics simulations Performance Analysis

- Canopy-atmosphere thermodynamic interactions
- Temperatures considering **homogeneous configurations**

Case Study	Scenario	Configuration
Case study 1 (natural environment)	Scen 0	Natural ground low vegetation
	Scen 1	Natural ground low & high vegetation
Case study 2 (built environment)	Scen 0	Buildings (λ=25%)
	Scen 1	Buildings (λ=25%) & high vegetation between
	Scen 2	Buildings (λ=25%) with 50% green roofs & high vegetation between

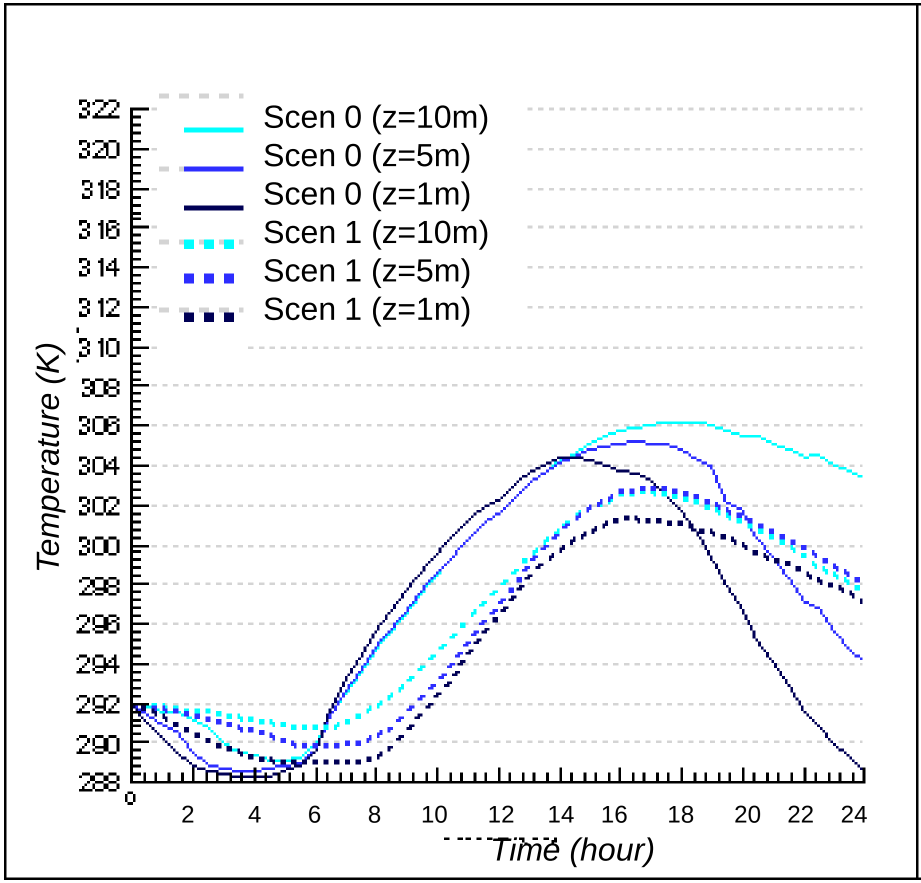


→ Homogeneous canopy (height H = 10 m)
→ Grid : $\Delta x = \Delta y$ = 20m
Δz = 1 m (untill z ≈ 25m)
→ Periodic boundary conditions
→ Cd values - same as previously used (same grid resolution)
→ A_f of high vegetation varies in z

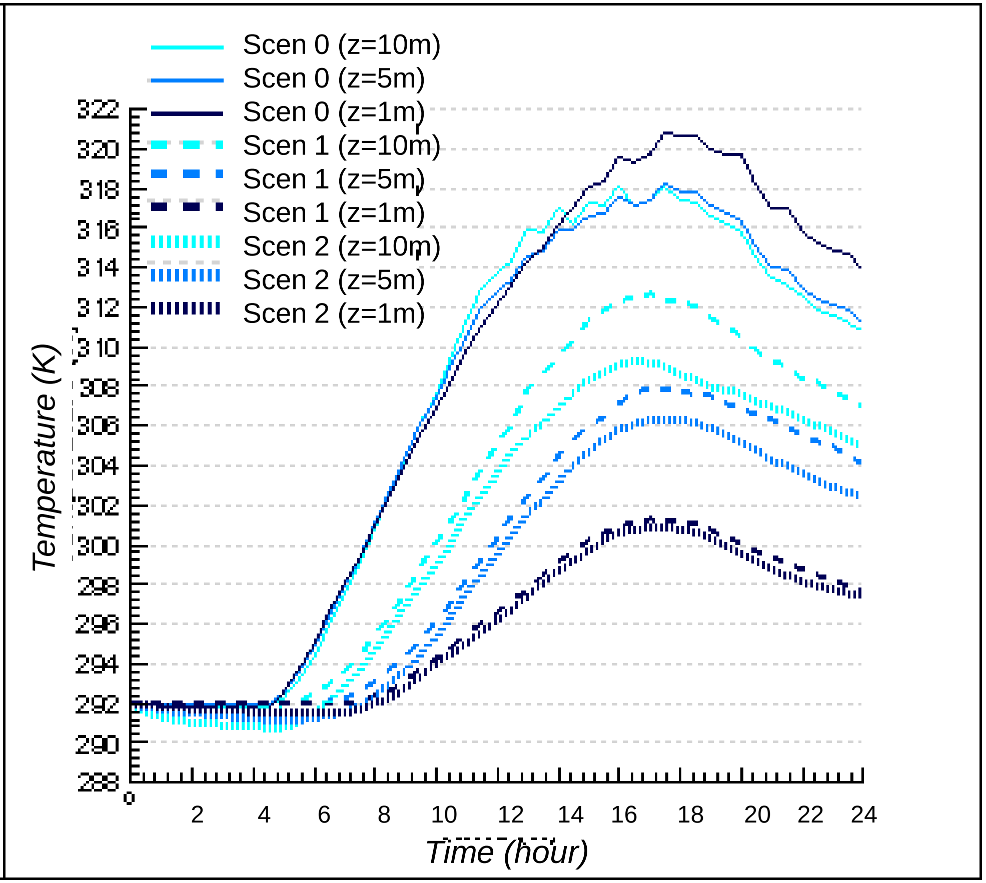
Thermodynamics simulations Performance Analysis

Temperatures of air at z = 10, 5 and 1 m

Case study 1



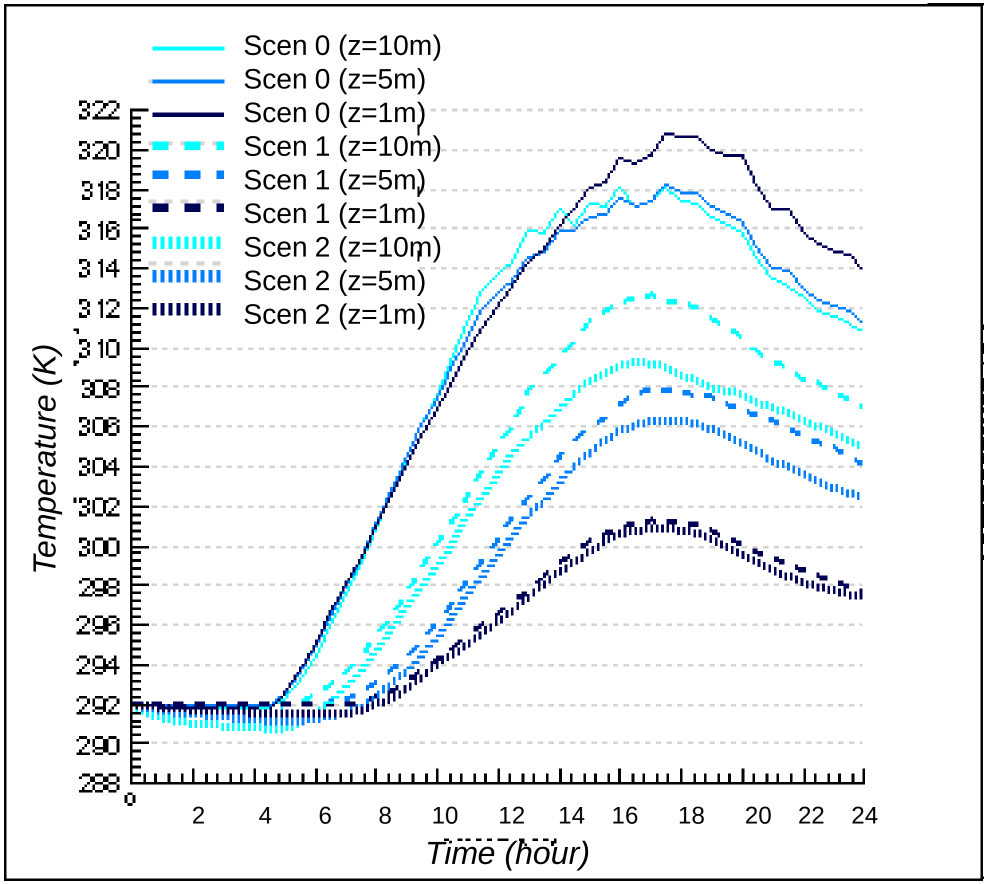
Case study 2



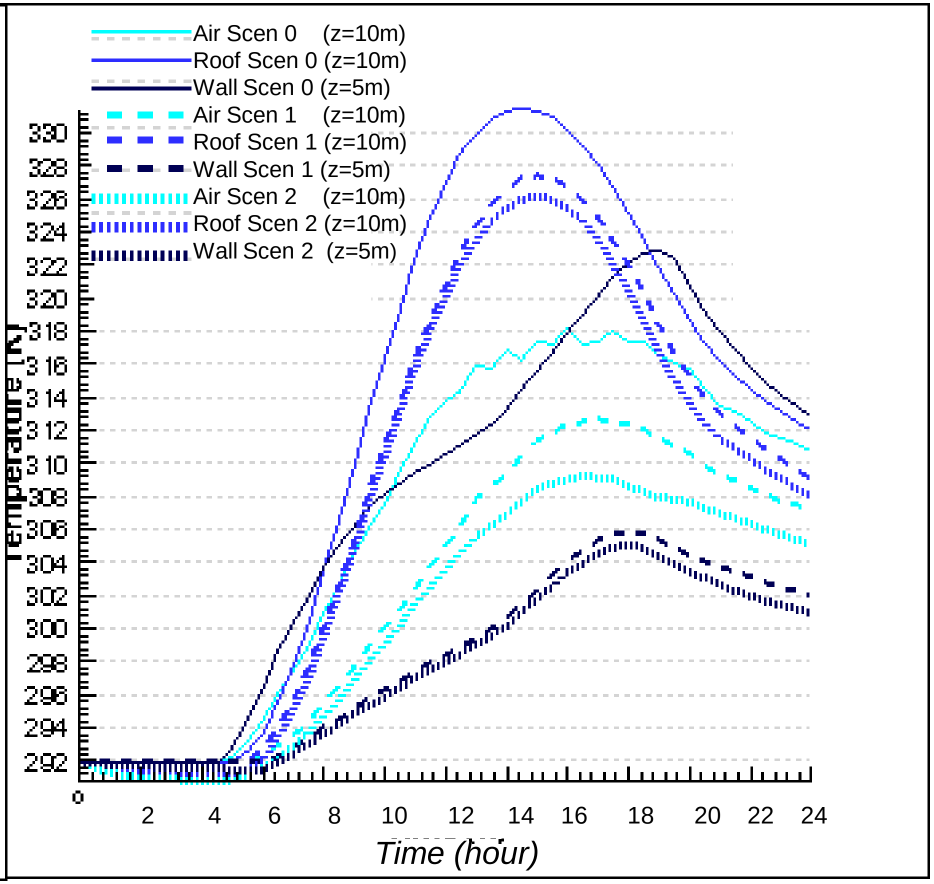
Thermodynamics simulations Performance Analysis

Temperatures at z = 10, 5 and 1 m

Air



Buildings surfaces



Final considerations
&
Perspectives

Final considerations and perspectives

- Well established that vegetation is an instrument of planning strategies to reduce & control local heat island and improve human comfort in urban areas,

- Yet, there is still a lack of the overall understanding of the implications on urban meteorology at neighbourhood (district) scale,

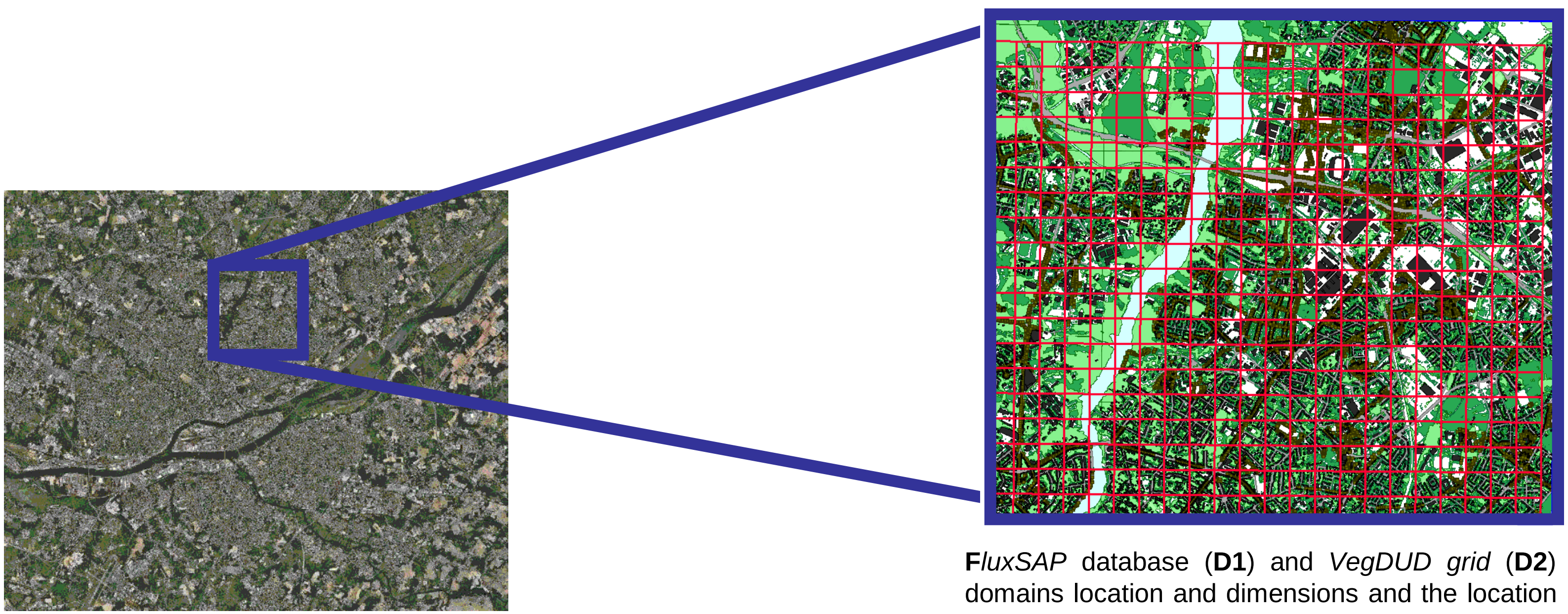
- Numerical models can be a powerful tool to support such studies in a less expensive way than traditional ‘experimental measurements’ ,

- Demonstrated the relevance of integrating the Vegetated Urban Canopy Modelling approach in tis meteorological model to describe in a ‘more realistic way’ the influence of buildings and vegetation canopies at neighbourhood (district) and city scales,

- Drag-force approach enables modelling the canopy, accounting built and vegetation elements, based on morphological characteristics instead of aerodynamic characteristics,

Final considerations and perspectives

- On-going application to test cases (homogeneous and heterogeneous canopies)
- Simulation of Vegetated Urban Canopies (homegeneous canopies)
- Simulation of rela heterogeneous canopy scenarios – Nantes:
    - Present urban configuration with and without vegetation
    - Future variations of green devices



F*luxSAP* database (**D1**) and *VegDUD grid* (**D2**) domains location and dimensions and the location of the *reference monitoring point* (**P1**) (OrbisGIS V4.0 generated image).

Thank for your attention !

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