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Multiscale Build-up Area Integration in Parallel SWIFT

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Content

Multiscale Build-up Area Integration in Parallel SWIFT

1. Introduction

Take into account the directional bulk effects of buildings for coarse grids

Parallel SWIFT (P-SWIFT) is the parallel version of SWIFT /Micro SWIFT.

SWIFT / Micro SWIFT is a mass consistent interpolator over complex terrain. Micro SWIFT contains Rockle type modeling to take into account buildings.

P-SWIFT is used in the AIRCITY project to model wind and turbulence at a few meters resolution over the whole Paris area.

To transition smoothly between the inner domain (Paris) where buildings are explicitly modeled to the outer domain, a directional canopy model has been studied.

Other applications could include runs for Paris on small size clusters where explicit building modeling is limited to a few kilometers domain.

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2. Canopy laws and directional canopy density

A canopy law is driven by its height and density, the later being responsible for the exponential shape

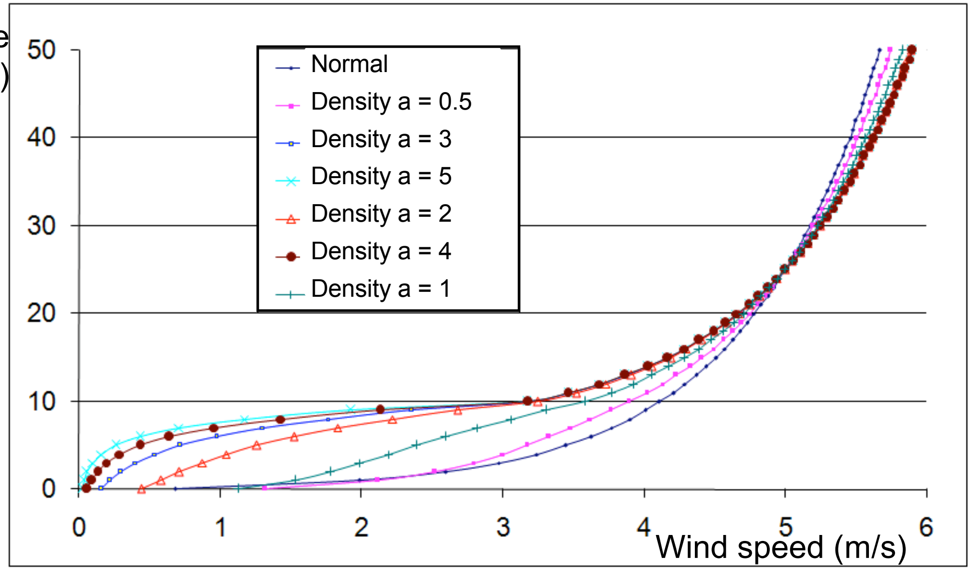
Canopy laws were originally developed for vegetative canopies .They have been extended to urban canopies (see for instance Macdonald, 2000)

Inside a canopy with height h_c and density a, an incoming wind U_i becomes:

$$U(z) \sim U_i(hc)\ [\ (1-F_c)\ U_i(z)\ /\ U_i(h_c) + F_c \exp(\ a\ (z/h_c\ -1)\ )\ \ ]$$

With F_c the canopy factor.

- F_c inside [0;1]
- F_c close to 1 if a is large



Influence of the canopy density parameter on a log wind profile shape with 5m/s at 25m (canopy height 10m, roughness 0.15m)

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To provide for the effects of buildings, a directional canopy approach was selected

Objective: take into account the influence of buildings on the flow through a canopy formulation.

Due to pattern of streets for city centers like Paris, we want to integrate a directional approach, hence a **directional canopy density**.

Definitions:

- **Macro** domain: domain with larger horizontal grid cells, building influence through canopy
- **Micro** domain: domain where buildings are explicitly modeled.

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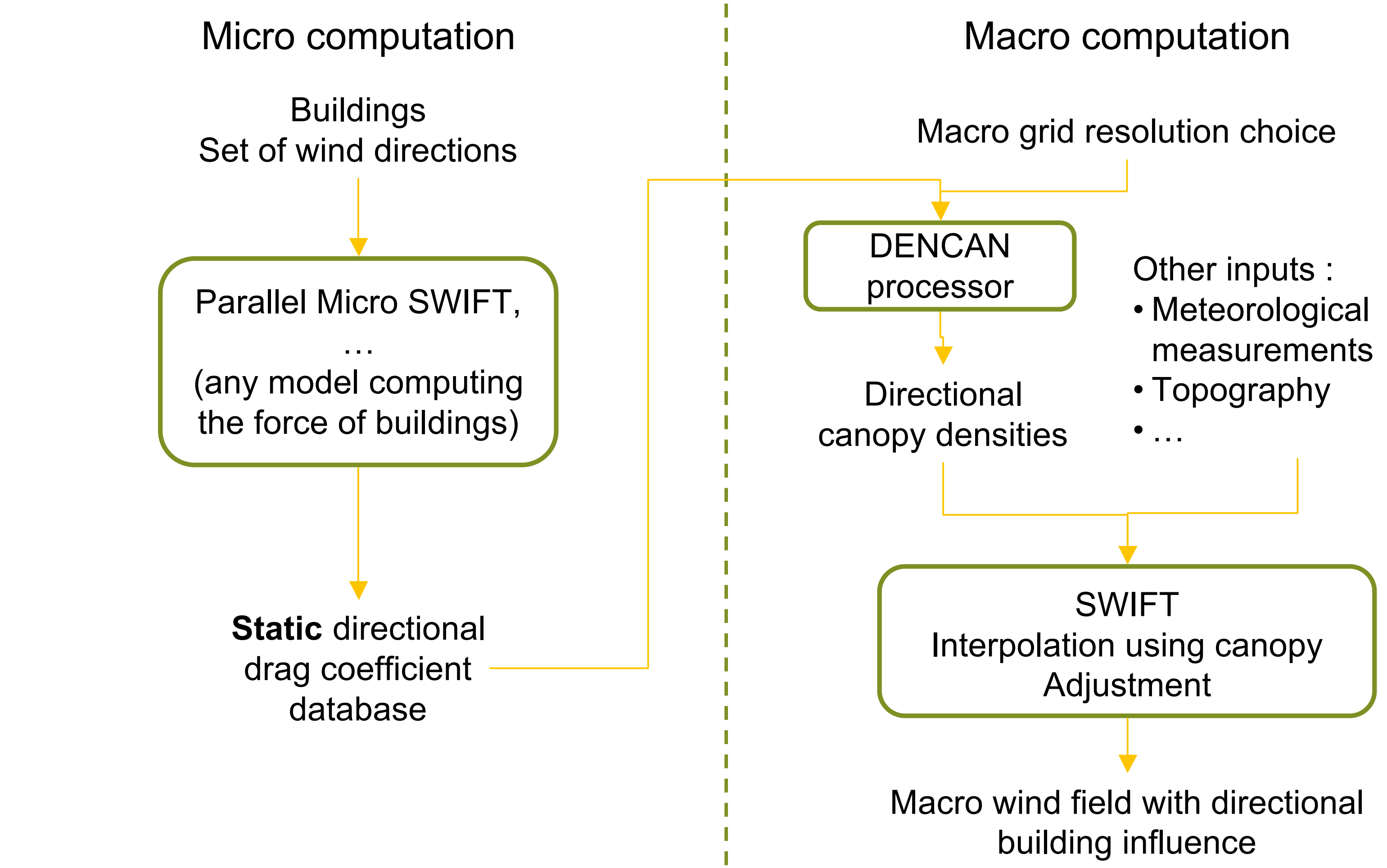
2. Directional canopy density: process overview

The directional drag coefficients database is then integrated at the wished resolution for macro computation



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Drag coefficients are computed using a local scale code, for instance Micro SWIFT, for a set of wind directions and stored in a static database

In the small scale domain, the flow around each buildings is explicitly resolved.

Micro SWIFT computes for each building and for a set of wind directions:

- The frontal area A_f,
- The drag coefficient C_d,

These data are stored in a static database.

The drag coefficient C_d is defined as:

$$C_d = F_u / (0.5 \rho u^2 A_f)$$

F_u is the force of the flow on the building, *within its surrounding*. In tests realized, it has been approximated using the pressure force.

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3. Derivation of canopy properties

3. Derivation of canopy density from static drag coefficient database

The canopy density is evaluated using equilibrium between Reynolds stress tensor and building drag force

The canopy exponential law derives from the equilibrium in the canopy between :

- Reynolds stress tensor,
- Building drag force.

Following Coceal (2004), we estimate the Reynolds stress tensor using a mixing length approach, which leads for the canopy density *a* to:

$$a^3 = h_c^3 \ \sigma_f / (2\, l^2)$$

With

- l: mixing length
- $\sigma_f = 0.5\ \Sigma(C_d\, A_f\,) / (\,A_t\, h_c\,)$, the sum being held on buildings in the grid cell
- A_t is the cell area of the macro domain

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Equilibrium between Reynolds stress tensor (modeled with mixing length approach) and drag forces of buildings:

$$d((l\, du/dz)^2) / dz = \Sigma\, 0.5\, C_d\, u^2\, A_f / (A_t\, h_c)$$

The mixing length is being defined as:

$$l = 0.5\, K\, (h_c - d)$$

With

K the von Karman constant

$d = h_c\, (1 - 4^{-\lambda p}\, (1 - \lambda_p))$

$\lambda_p = \Sigma\, A_p / A_t$ A_p being the building footprint

Sums are held over buildings in the grid cell

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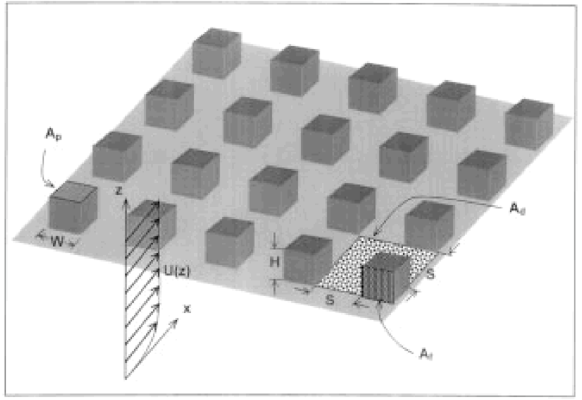
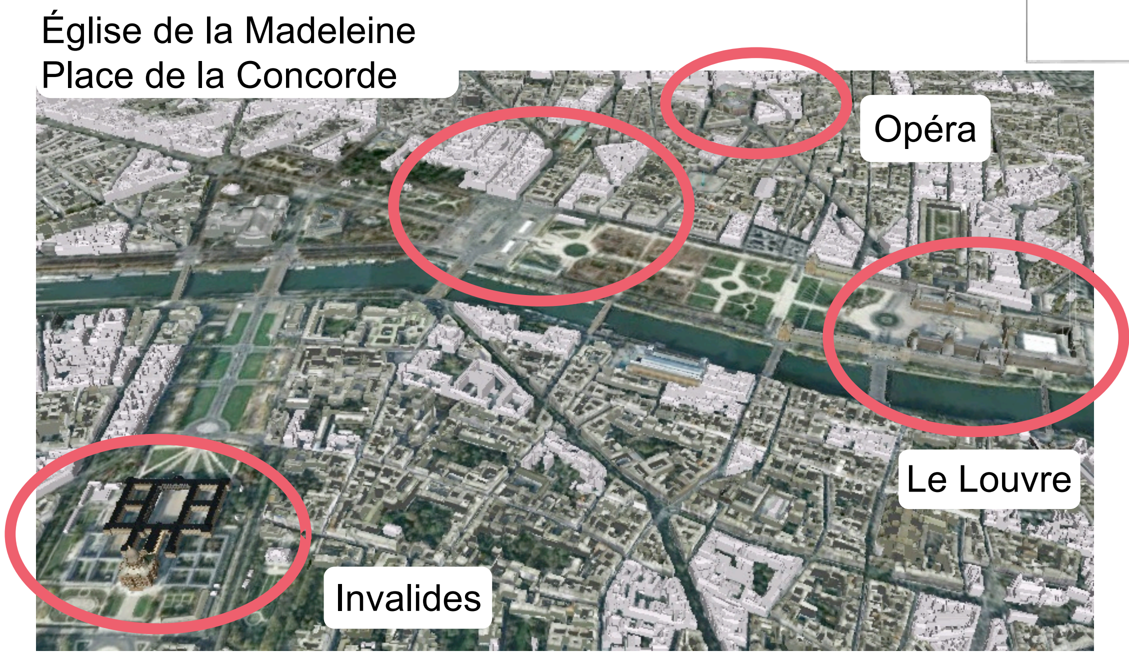
4. | Applications

Two test cases will be presented: a wind tunnel comparison and micro/macro computations over a part of Paris

- Wind tunnel data: regular array from Macdonald (2000)
- Limited area domain in the Aircity framework: hypercentre



Macdonald experimental setting



General view of *Hypercentre* domain in Paris

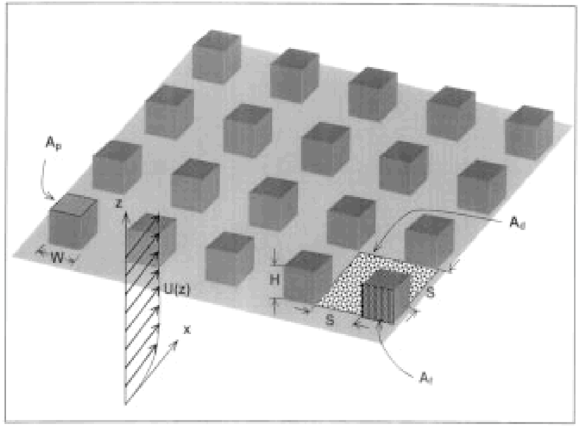
A set of building densities has been tested on Macdonald wind tunnel data

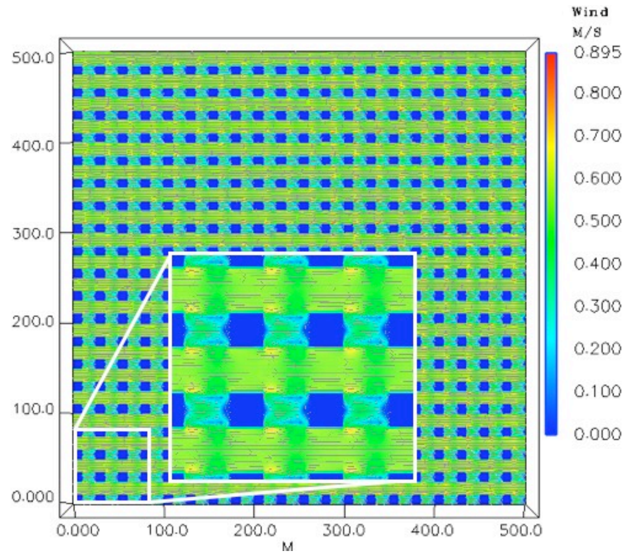
Wind tunnel data: regular array from Macdonald (2000)

- Cubes with characteristic dimension of 10m,
- Aligned or staggered,
- Various densities.

Micro domain: 1m resolution in a 500m large domair

Macro domain: 50m resolution, same domain





Micro domain calculation for west wind, wind field intensity and streamlines at a height of 5m

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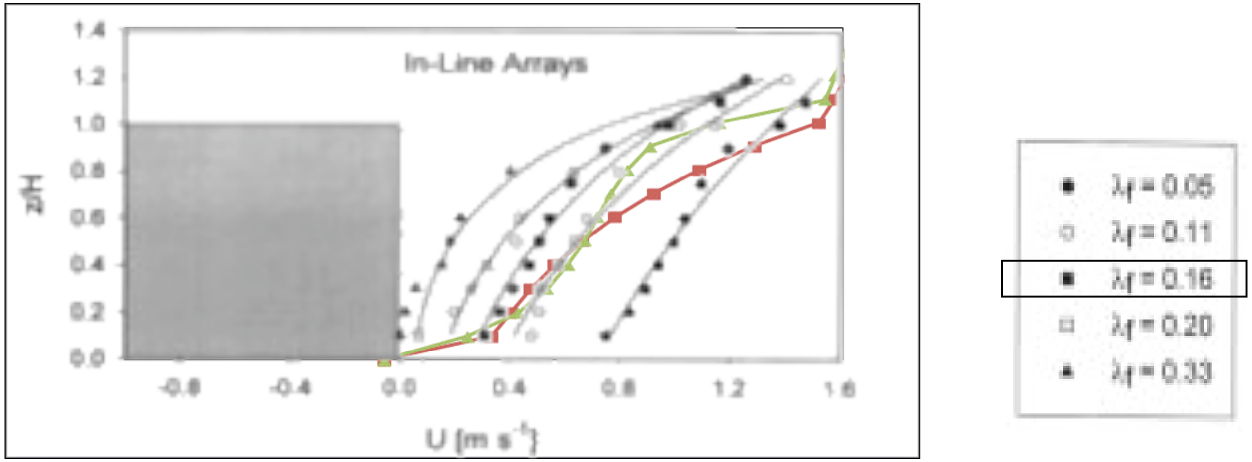
4. Test cases: Macdonald wind tunnel data against computations

General good agreement is observed

Results from micro and macro show good general agreement with experimental data

Experimental data show an average on a specific set of profile measurements, but in locations where the wind changes a lot,

Micro is a spatial average on the whole domain.



Macdonald data for various building densities
Micro (green) and macro (red) computation for density 0.16

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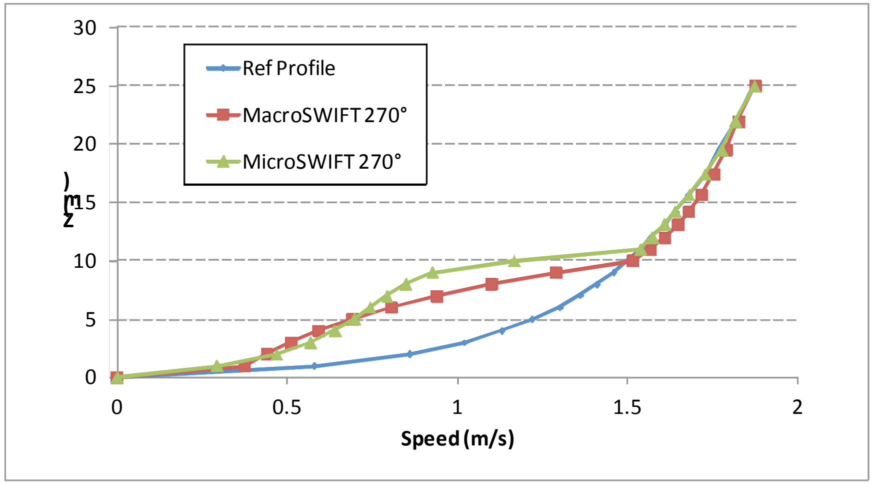
Macro and averaged micro computations show also good agreement

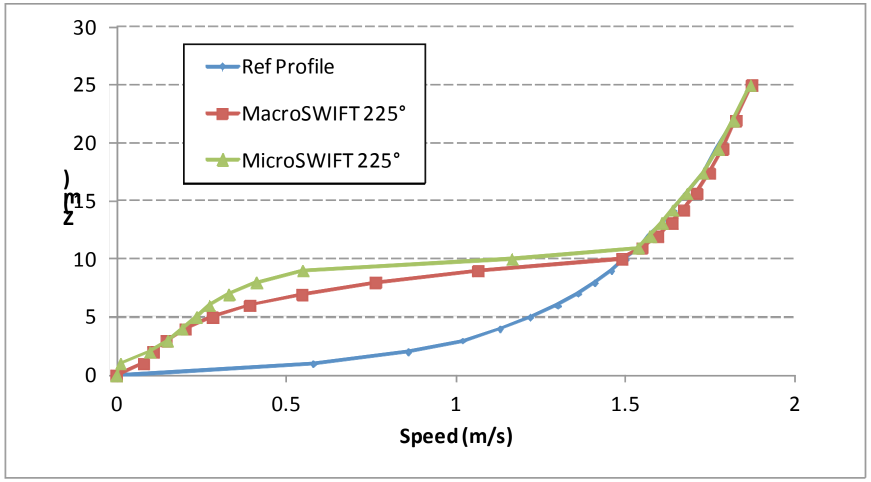
These charts present comparison between micro and macro computations on macdonald case, 0.16 density.

- Reference profile in blue
- Macro case in red
- Micro case in green
- Top picture: wind aligned with buildings
- Bottom one: 45° off angle for the wind



Results show:

- Good agreement between macro and averaged micro computation
- Strong change in wind speed with wind direction



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Hypercentre domain is located in a mix of densely built areas and open spaces around the Seine river

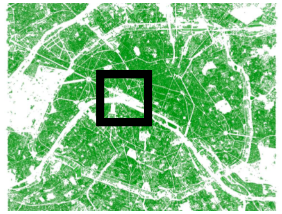
The domain taken to test directional canopy within Paris is called Hypercentre :

- Situated near the bottom of the Champs Élysées,
- Contains Grand Palais, Place de la Concorde, Église de la Madeleine, Opéra, and part of the Seine River (plus part of Louvre and Invalides too),
- Almost a square, 2.3km side length.

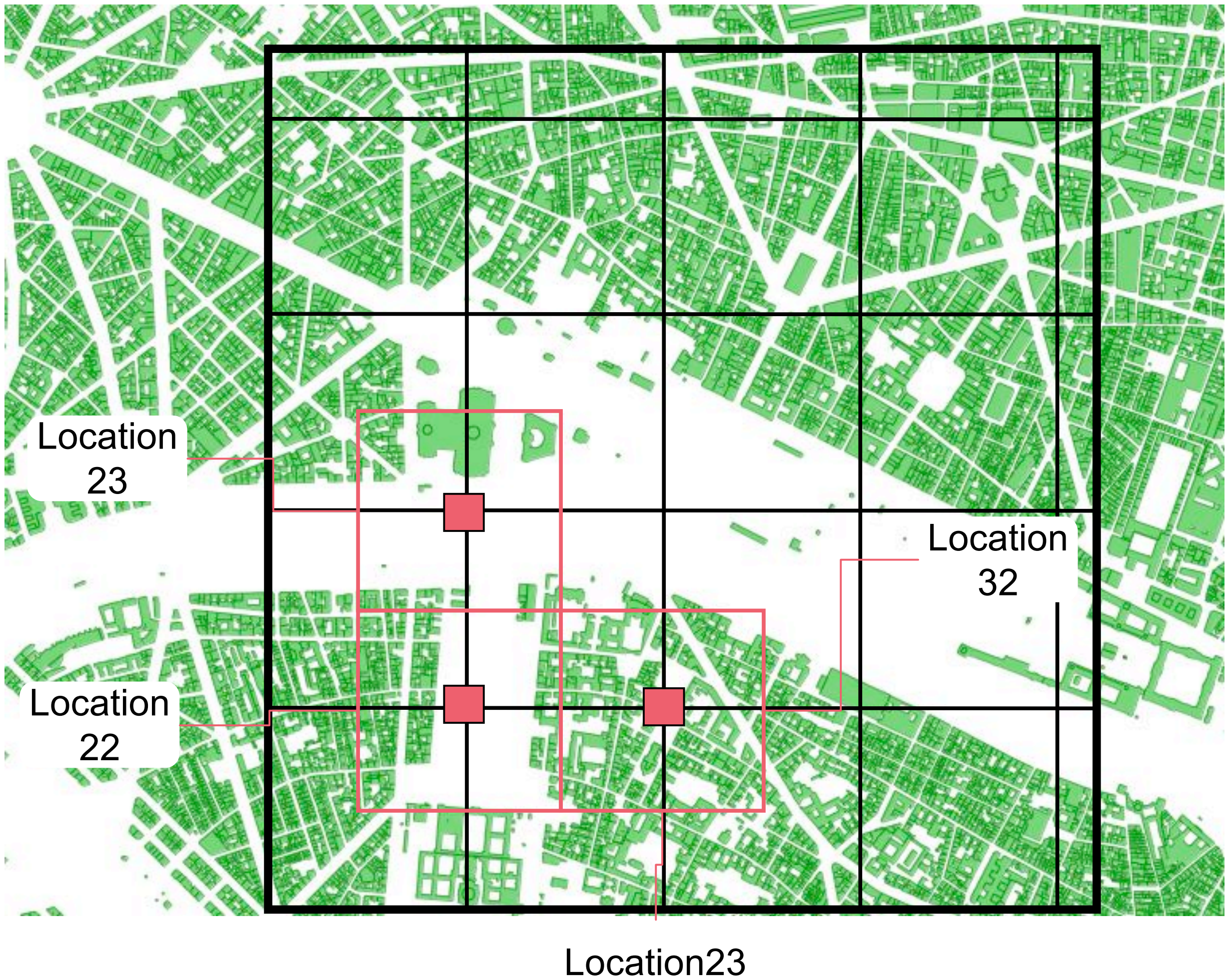
Test Cases :

- Micro: 3m horizontal resolution (around 760 points both in x and y, 35 vertical levels), explicit modeling of buildings (around 6000 polygons),
- Macro: 500m horizontal resolution (5 by 5 points in horizontal), directional canopy derived from Micro case.

Three extraction are presented



- 500m Macro grid
- Red dot are grid values displayed in following slides
- Red squares show the area of significance (staggered from the grid)



4. Test cases: Aircity Hypercentre layout in Paris

Locations are ranging from narrow streets with Haussmann type buildings to open space around monuments or near the Seine river

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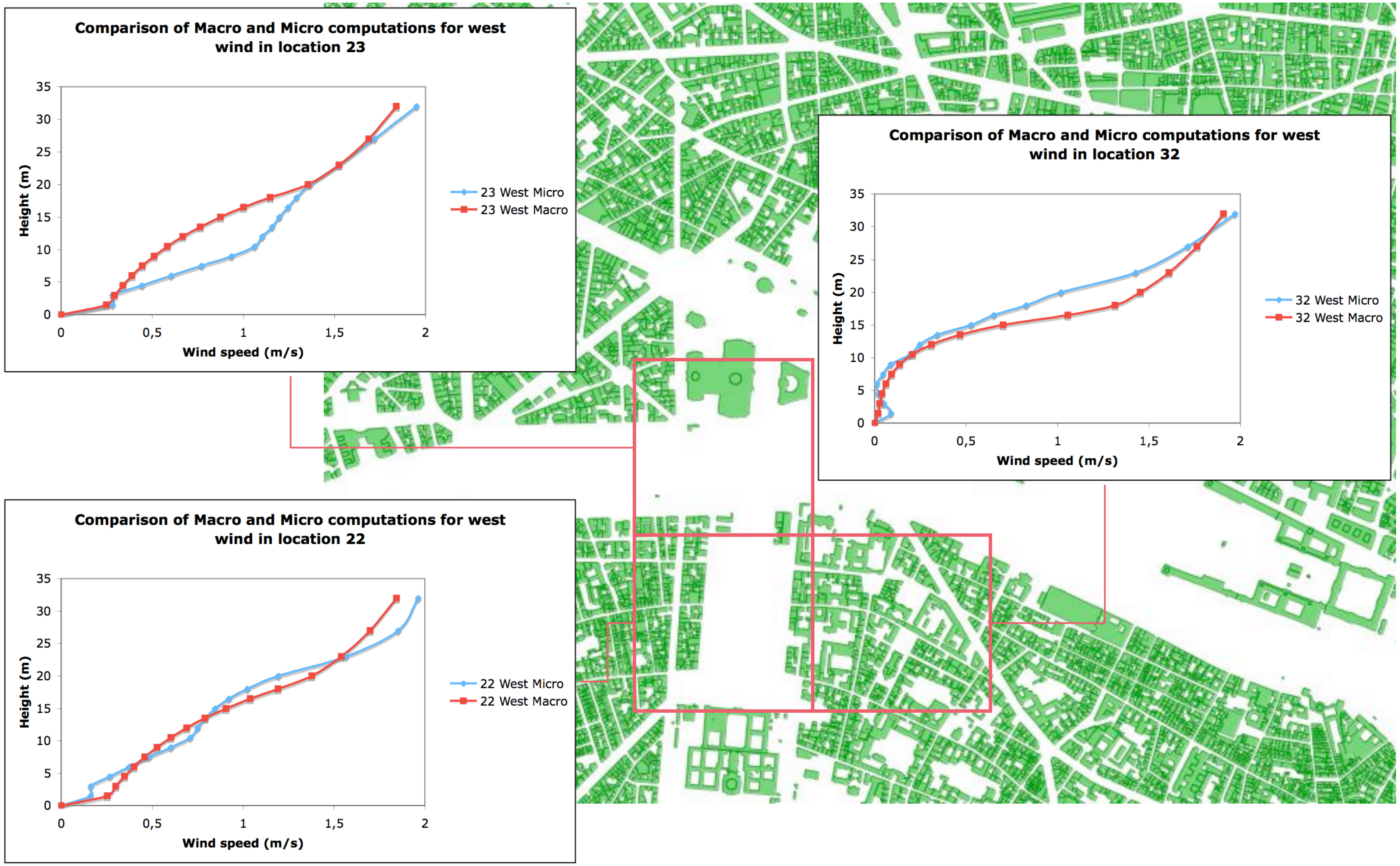
Macro computations display very similar behavior with averaged Micro SWIFT computation



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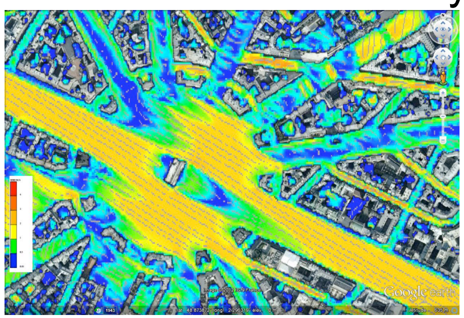
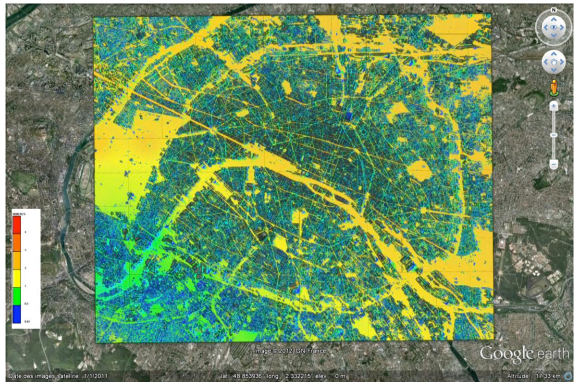
5. Conclusions

- A methodology has been implemented to take into account the directional influence of the bulk effects of buildings in an urban coarse grid (few hundred meters) situation,
- The methodology display comparable behaviors for Macro and averaged Micro computations on testes cases presented,
- Parallel SWIFT is able to compute a directional database of drag coefficients over large cities. This database is then projected at the wished resolution, provided the resolution is licit for the statistic nature of the canopy laws,
- More testing will be performed in the wake of Aircity project for usage on small clusters.

Detailed and general views of wind field computed over Paris by PMSS





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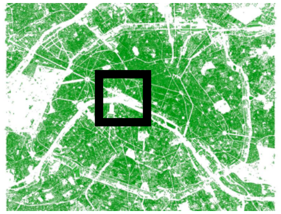
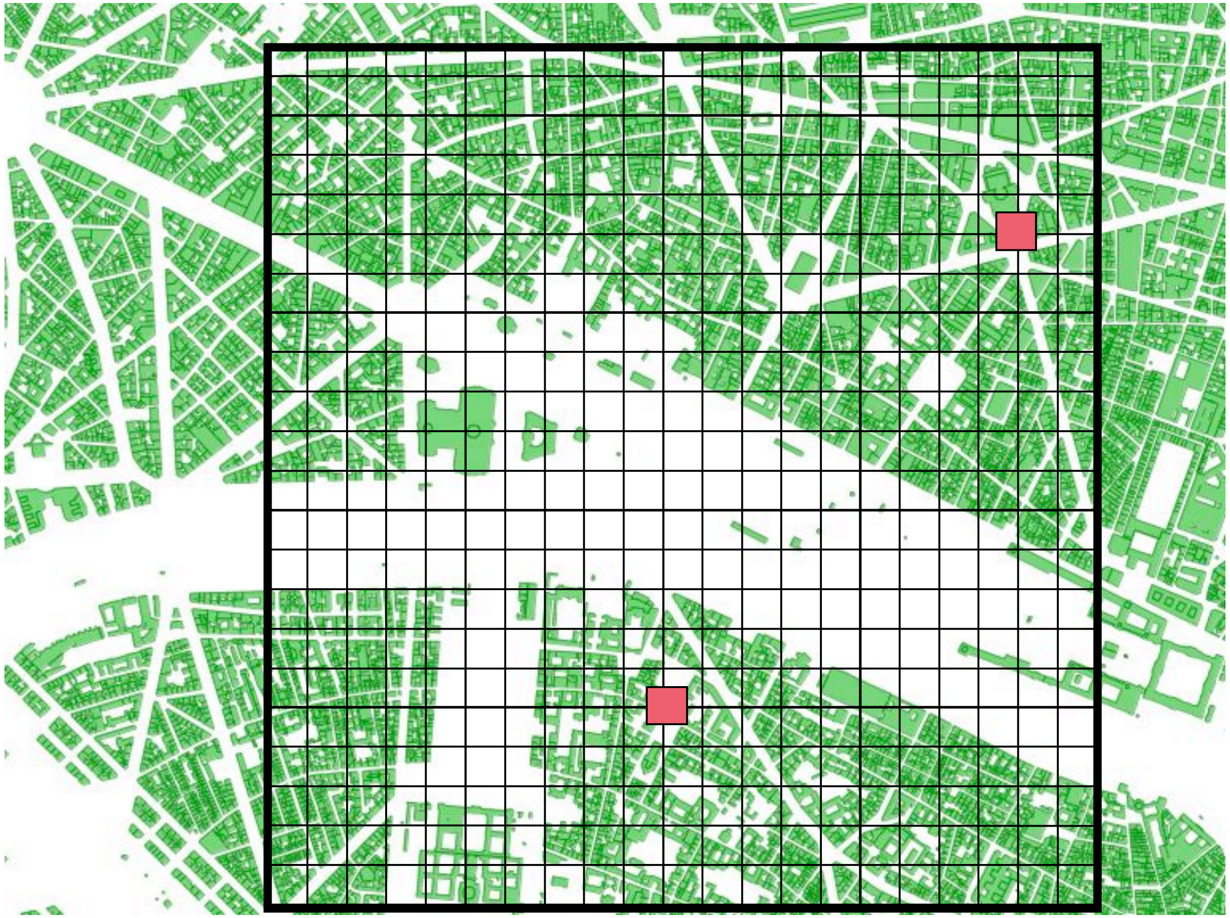
Backup !



Grid 100m



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