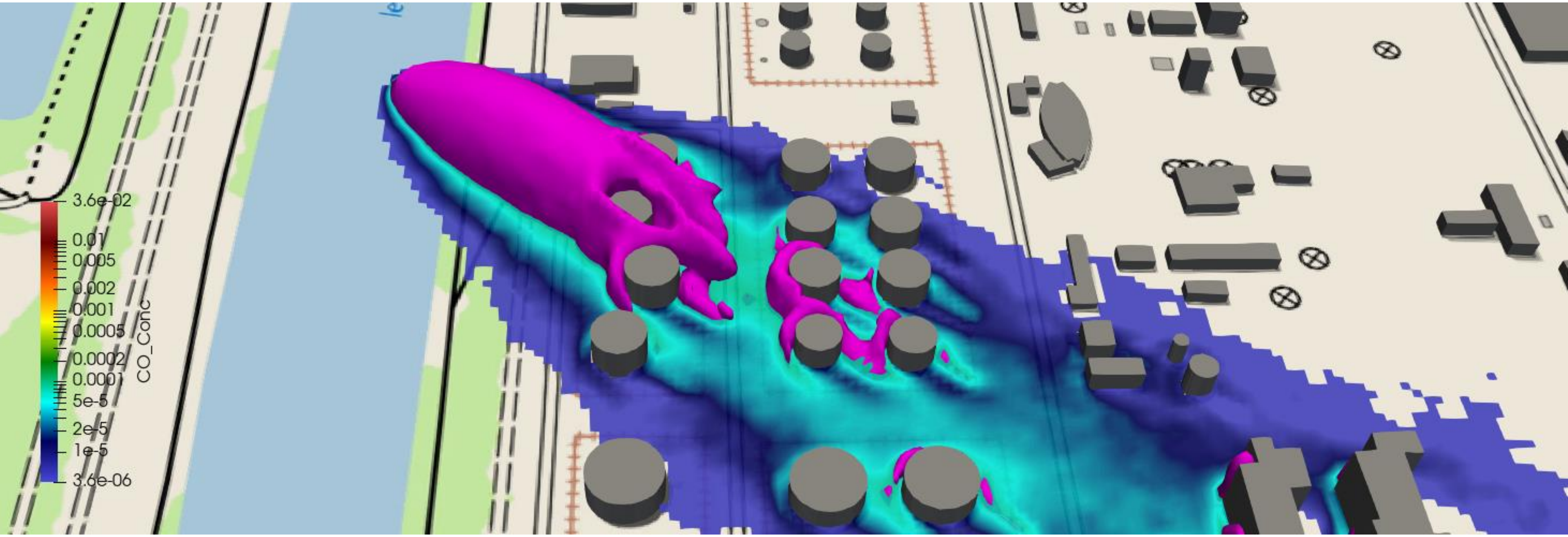
Laboratoire de mécanique des fluides et d'acoustique

Development of BUILD (Building Urban and Industrial Lagrangian Dispersion), a new operational dispersion model

Lionel Soulhac, Guillevic Lamaison, Perrine Charvolin, Mehdi Slimani, Patrick Armand, Luc Patryl



20th Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes Conference

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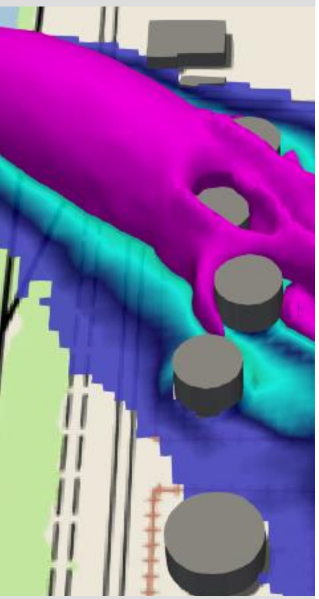


Outline

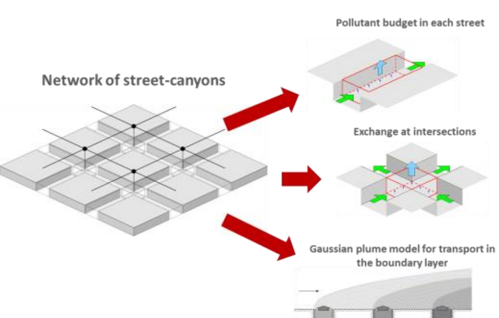
1. – Introduction

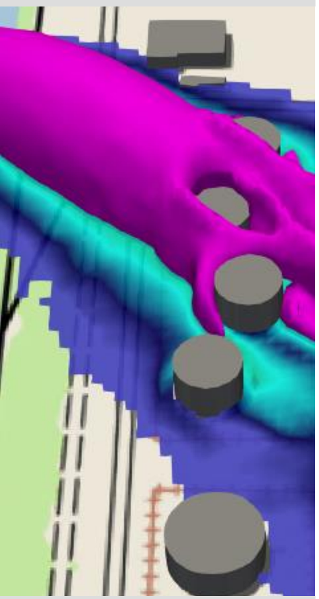
Atmospheric dispersion modelling for emergency response

- Accidental or deliberate releases of NRBC material
- In complex built-up areas like urban or industrial sites
- First responders and decision makers need fast and relatively precise estimates of the contaminated and dangerous area

Operational modelling approaches for built-up and urban areas

- Simple Gaussian plume or puff models (ALOA, PHAST, etc.)
- Diagnostic wind flow models coupled with Eulerian or Lagrangian dispersion models (PMSS, QUIC-URB, etc.)
- CFD based models (RANS or LES Navier-Stokes, Lattice-Boltzmann)
- **Network of streets models**
    - SIRANE : box canopy + Gaussian plume steady model (Soulhac et al., 2011, 2012)
    - SIRANERISK : box canopy + Gaussian puff unsteady model (Soulhac et al., 2016)





1. – Introduction

Advantages and limitations of the SIRANERISK approach

- Fast model, well adapted for regular network of streets urban configurations
- Limitation of the Gaussian approach to deal with non regular urban patterns, suburban or industrial geometry (group of obstacles)

Development of a new atmospheric dispersion model

- To overcome the previous limitations and extend the range of possible applications, keeping the constraint of a low computation time

➔ **BUILD – Building Urban and Industrial Lagrangian Dispersion model**

- Main characteristics of the model
  - Diagnostic parametrizations of the flow
    - Urban dense Canopy : “SIRANE-like” flow description with improvements for the flow and turbulence field inside streets
    - Obstacles : wake recirculation model
  - Particles stochastic Lagrangian dispersion model to allow a continuous description of the concentration field

2. – URBAN geometrical preprocessor

URBAN – Universal Recognition of Buildings Area and Network

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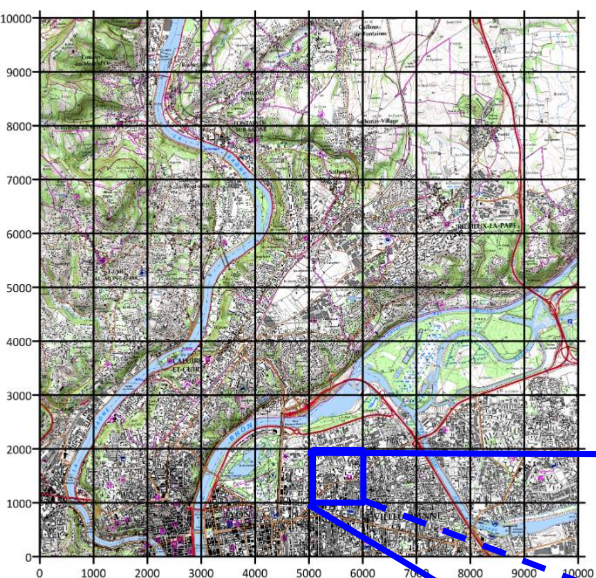
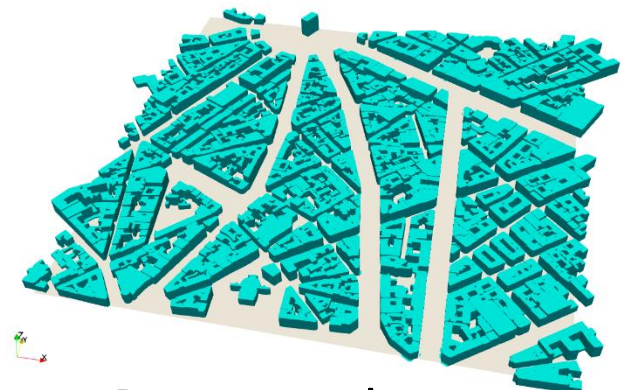
Gridding of the domain with 1km x 1km tiles, with 1m resolution

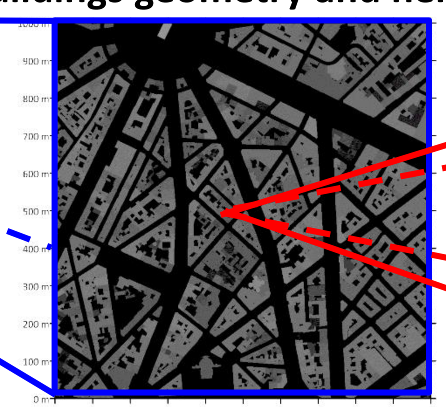
Grid of 1km x 1km tiles



Building geometry input data

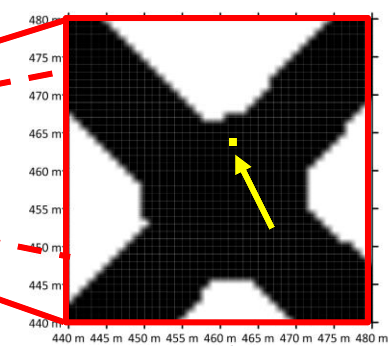


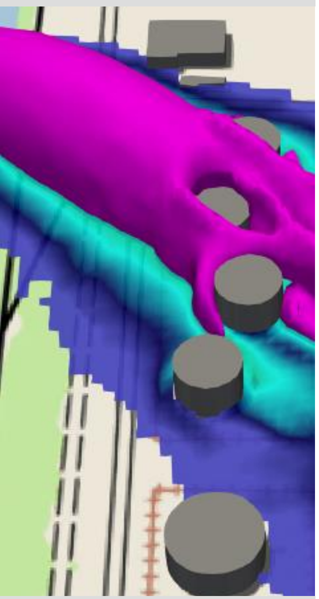
Raster grayscale representation of the buildings geometry and height



Typical pixel size of 1 meter:

- Good description of the details
- Efficient localization in the grid



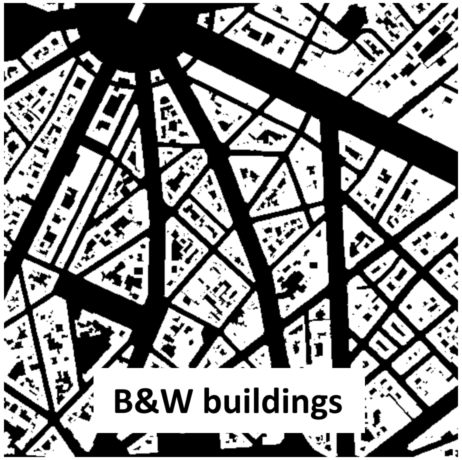


2. – URBAN geometrical preprocessor

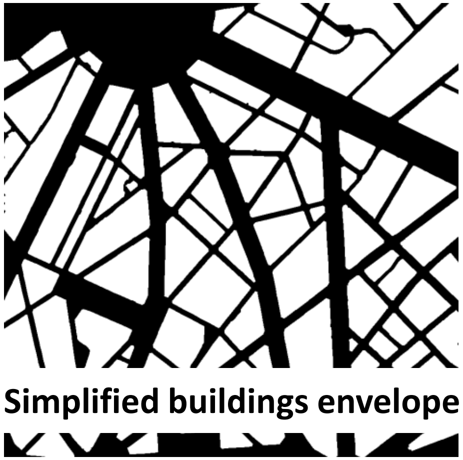
URBAN – Universal Recognition of Buildings Area and Network

Urban buildings image processing

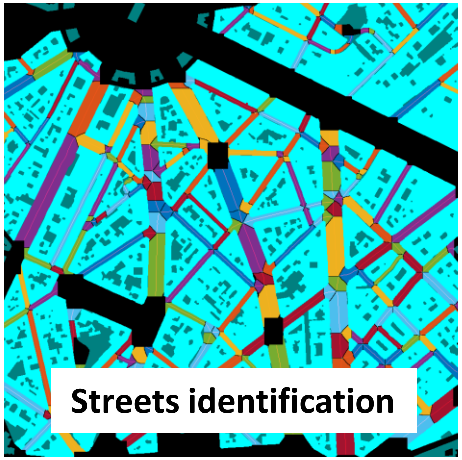
- Image processing toolbox to analyze the building height raster images



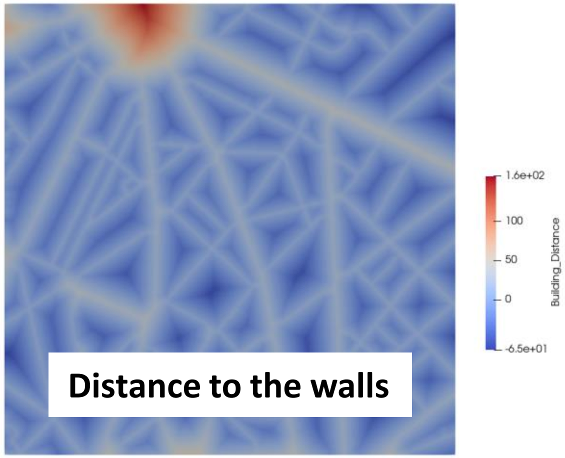
B&W buildings



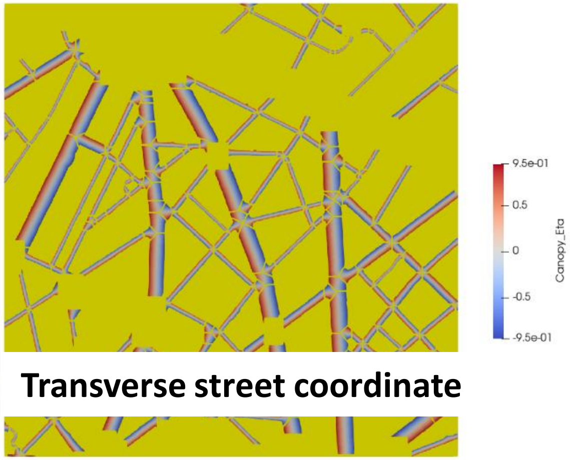
Simplified buildings envelope



Streets identification

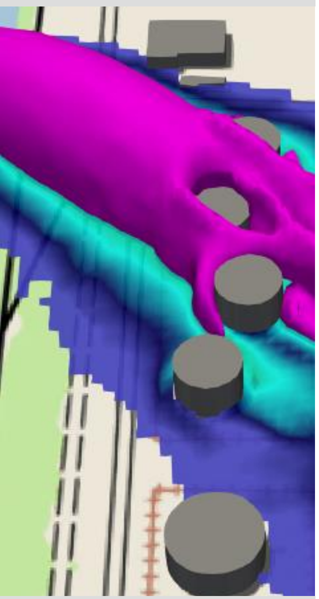


Distance to the walls



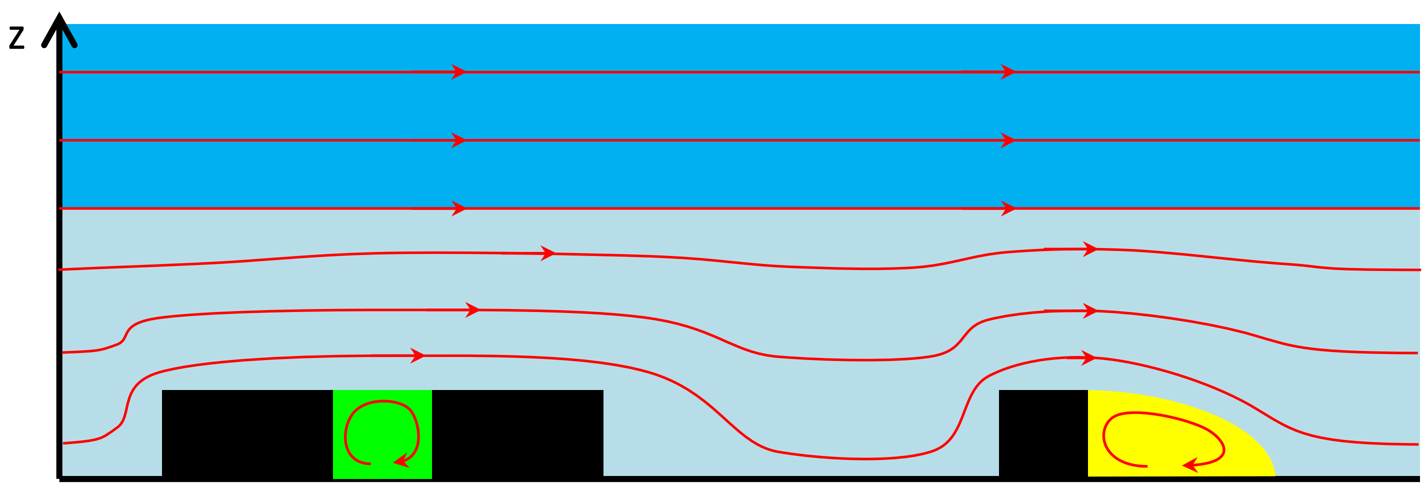
Transverse street coordinate

3. – Parameterized flow models



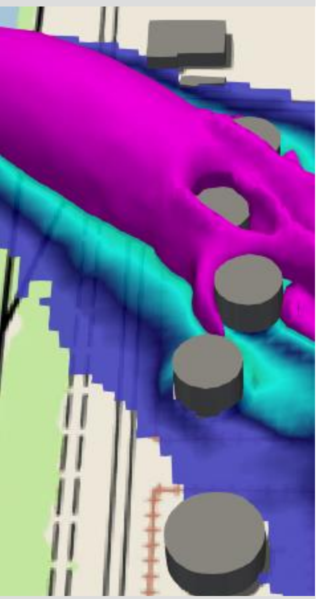
Zonal parameterizations of the wind and turbulence field

- Dense canopy and street-canyons
- Obstacles wake recirculations
- Roughness sublayer
- Atmospheric boundary layer



3. – Parameterized flow models

3.1. – Dense canopy and street-canyons

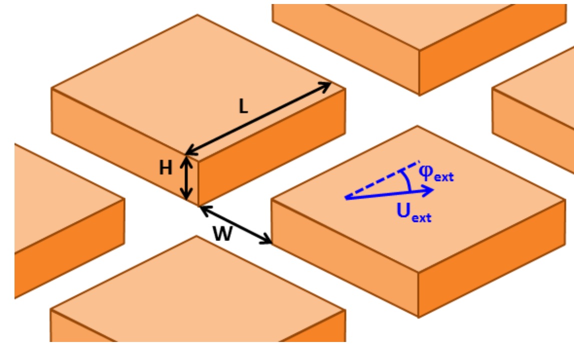


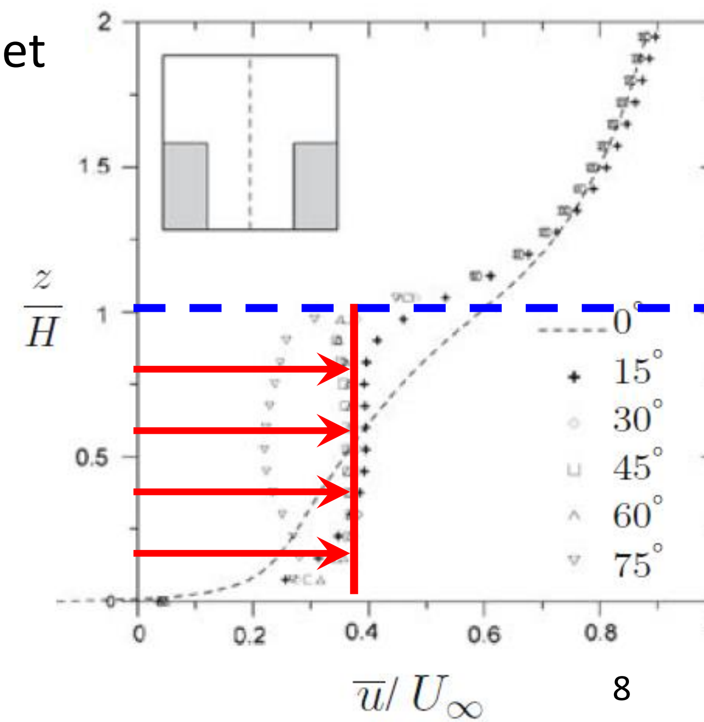
Uniform longitudinal mean velocity

- The longitudinal velocity is quite uniform in the street, only dependent on the component of the flow parallel to the street

$$\bar{u}(y,z) = u_{street} = K_m K_H u_* \cos(\varphi_{ext})$$

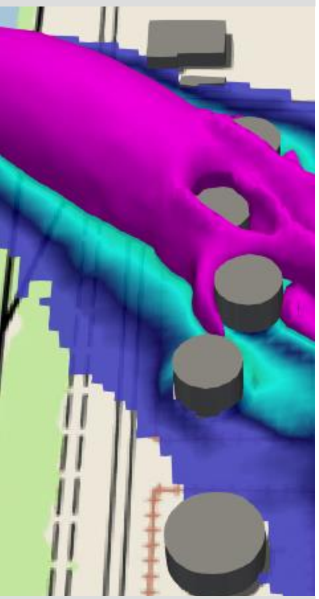
- K_m and K_H are parameterized according to the analytical model of Soulhac et al. (2008)





3. – Parameterized flow models

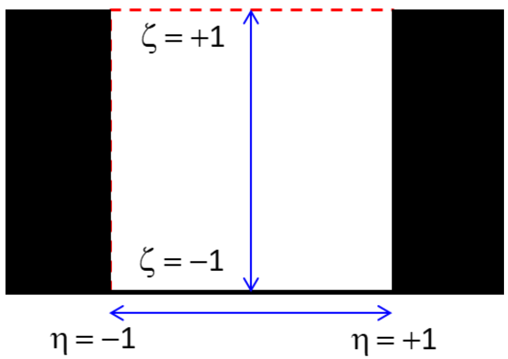
3.1. – Dense canopy and street-canyons

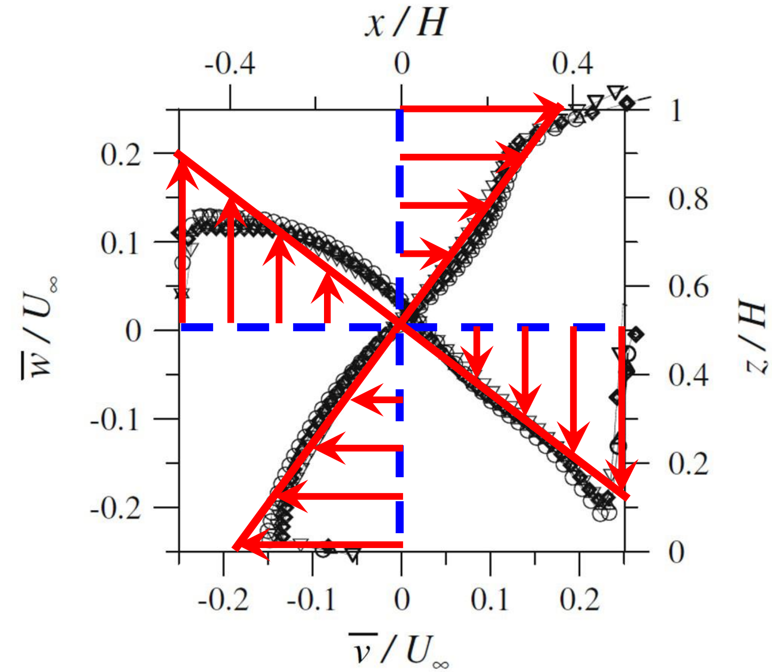


Transverse mean velocity field

- Linear model for the flow

- Street coordinates





Wind tunnel experiments of Salizzoni et al. (2011)

- Assumption of separated variables

$$\begin{cases} \overline{v}(y,z) = v_{street} f_v(\eta) g_v(\zeta) \\ \overline{w}(y,z) = -w_{street} f_w(\eta) g_w(\zeta) \end{cases}$$

with

$$\begin{cases} f_{v,lin}(\eta) = 1-\eta^2 \\ g_{v,lin}(\zeta) = \zeta \\ f_{w,lin}(\eta) = \eta \\ g_{w,lin}(\zeta) = 1-\zeta^2 \end{cases}$$

Velocity scale v_{street}

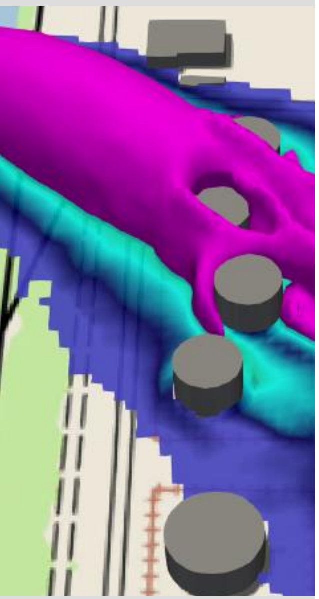
$$v_{street} = K_m K_H u_* \sin(\varphi_{ext})$$

Continuity equation

$$\frac{v_{street}}{W} = \frac{w_{street}}{H}$$

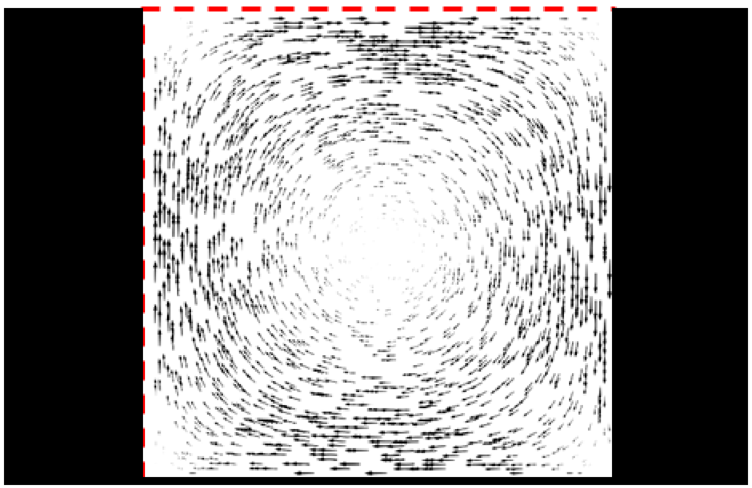
3. – Parameterized flow models

3.1. – Dense canopy and street-canyons

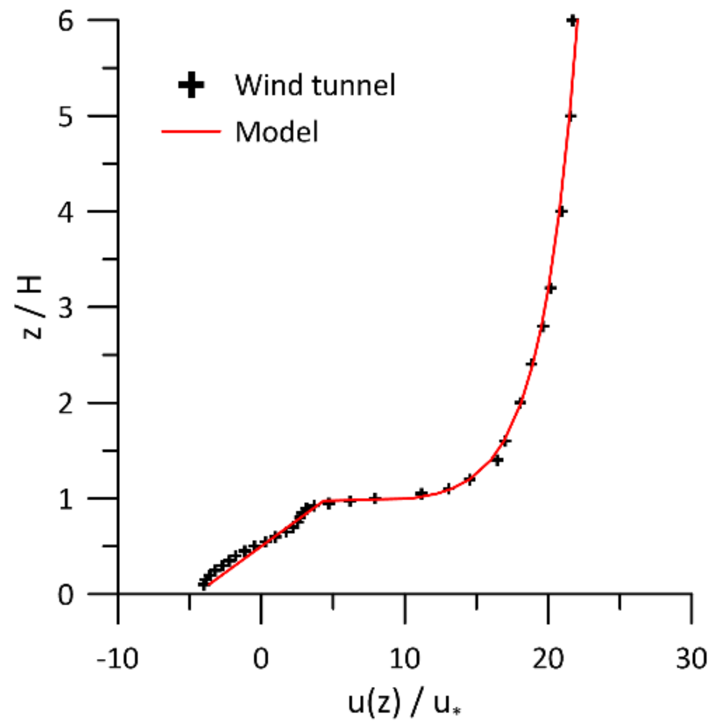


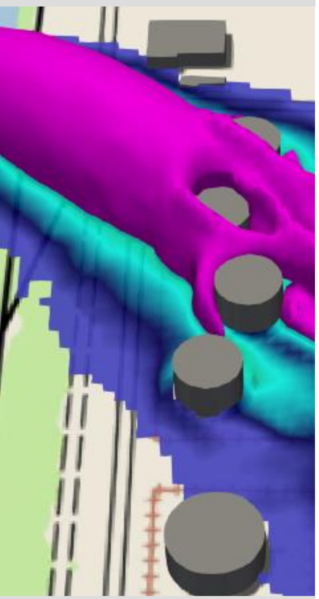
Transverse mean velocity field

- Vector field



- Validation against wind tunnel experiments





Parametrization of turbulence parameters

- Uniform values for k and ε, scaled on u_*
- For example, turbulent kinetic energy k is modelled with:

$$\frac{k_{street}}{u_*^2} \simeq 0.5$$

Wind tunnel experiments of Salizzoni et al. (2011)

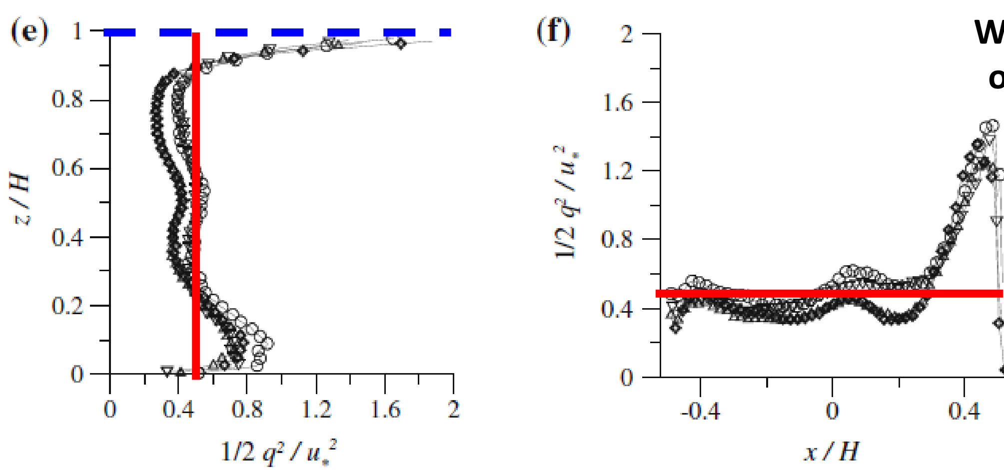
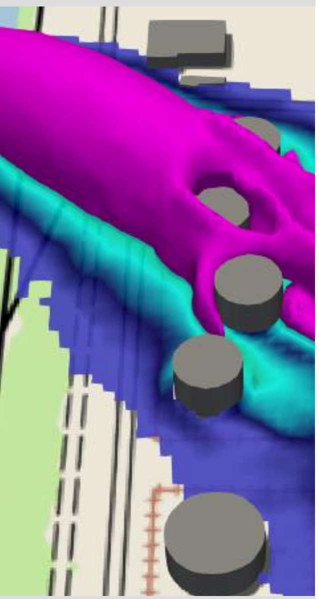
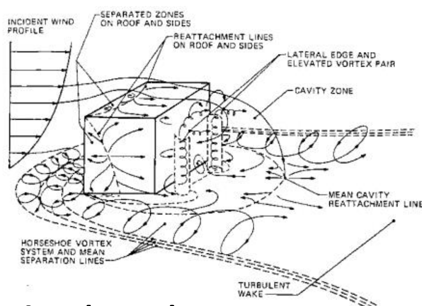


Fig. 11 Vertical and horizontal profiles of t.k.e. profiles within the cavity normalized with U_∞ (a and b), ΔU (c and d) and u_* (e and f). Same symbols as in Fig. 10

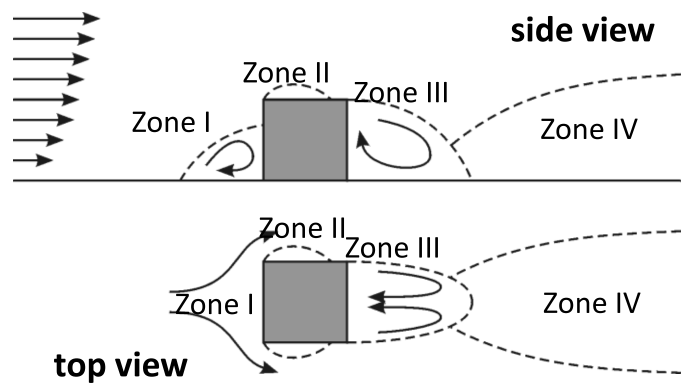


Recirculation in the wake of an isolated obstacle

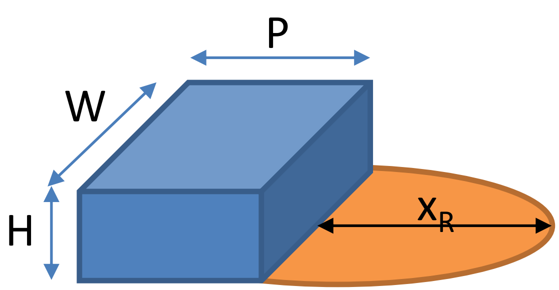
- Flow around an obstacle

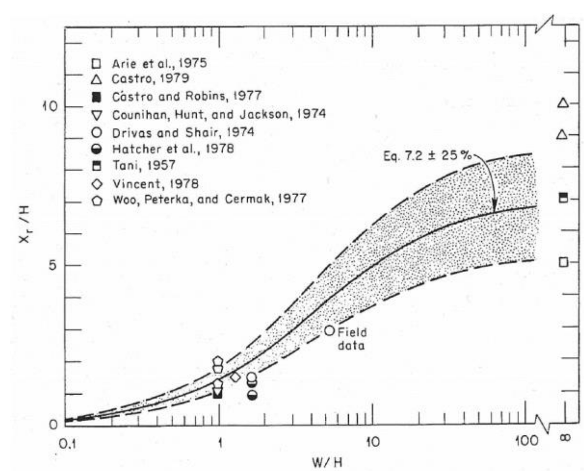


From Hosker (1985)

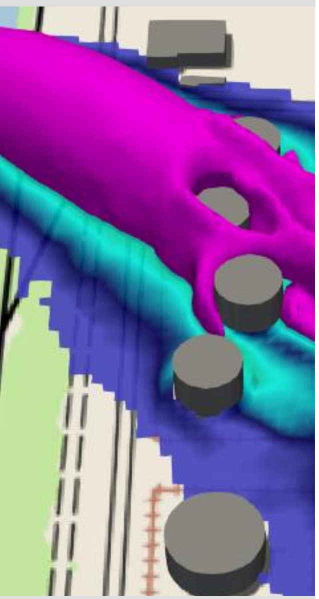


- Recirculation length





From Hosker (1985)



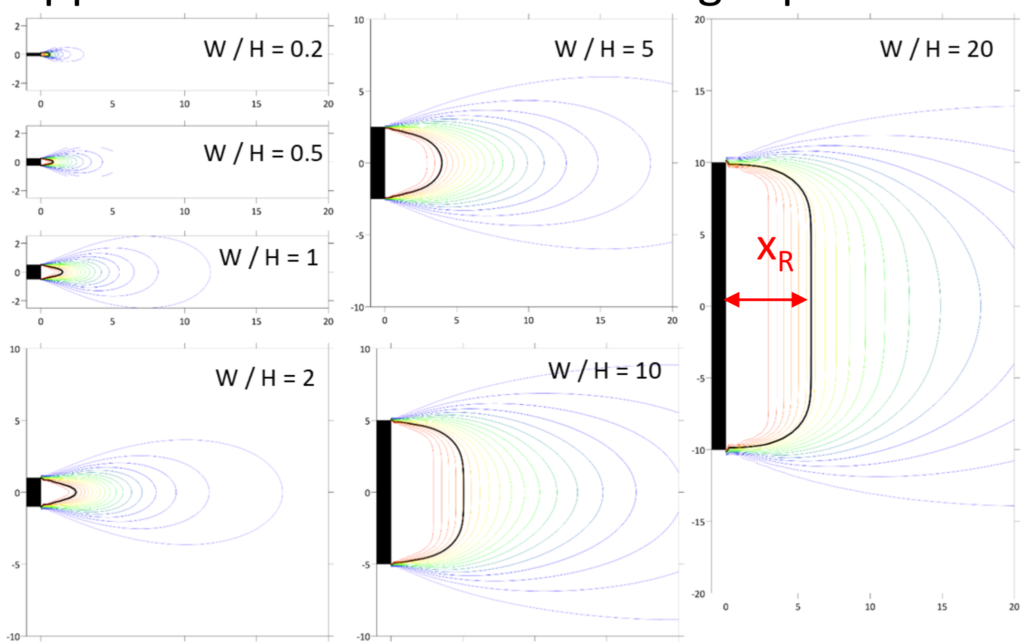
3. – Parameterized flow models

3.2. – Obstacles wake recirculations

Analytical model of advection-diffusion of the velocity defect in the wake of a rectangular building

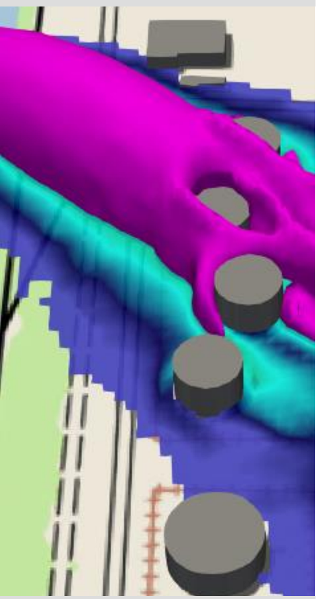
$$\frac{\Delta U}{U_0}=\frac{1}{4}\left[\operatorname{erf}\left(\frac{y+W/2}{\sqrt{2}\sigma_y}\right)-\operatorname{erf}\left(\frac{y-W/2}{\sqrt{2}\sigma_y}\right)\right]\left[\operatorname{erf}\left(\frac{z+H}{\sqrt{2}\sigma_z}\right)-\operatorname{erf}\left(\frac{z-H}{\sqrt{2}\sigma_z}\right)\right]$$

- Application for different building aspect ratios



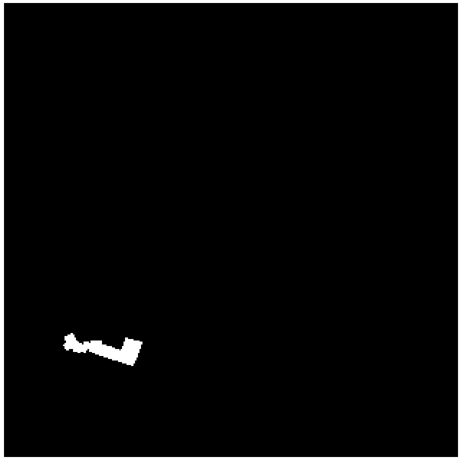
3. – Parameterized flow models

3.2. – Obstacles wake recirculations



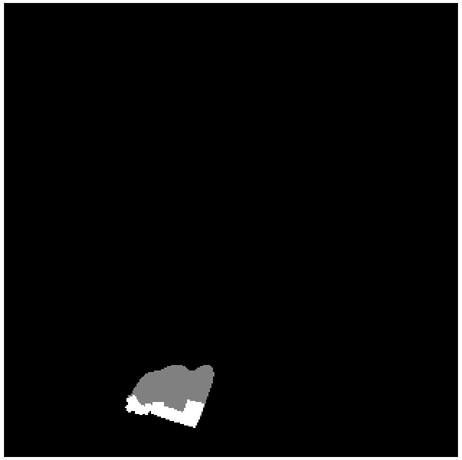
Generalization for a building of any shape

- Based on the image of the building, advection-diffusion process of the velocity defect is emulated by translation-blurring of the image
- The recirculation area is defined by thresholding the grayscale velocity defect field



B&W image of a building

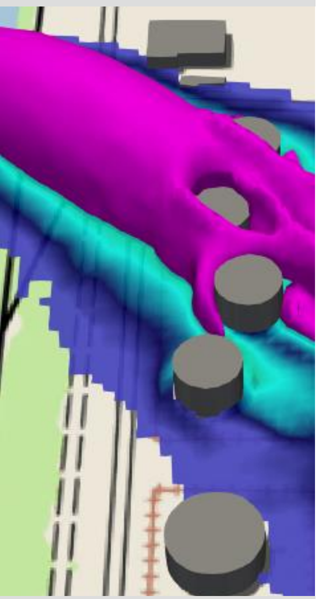
Grayscale velocity defect field



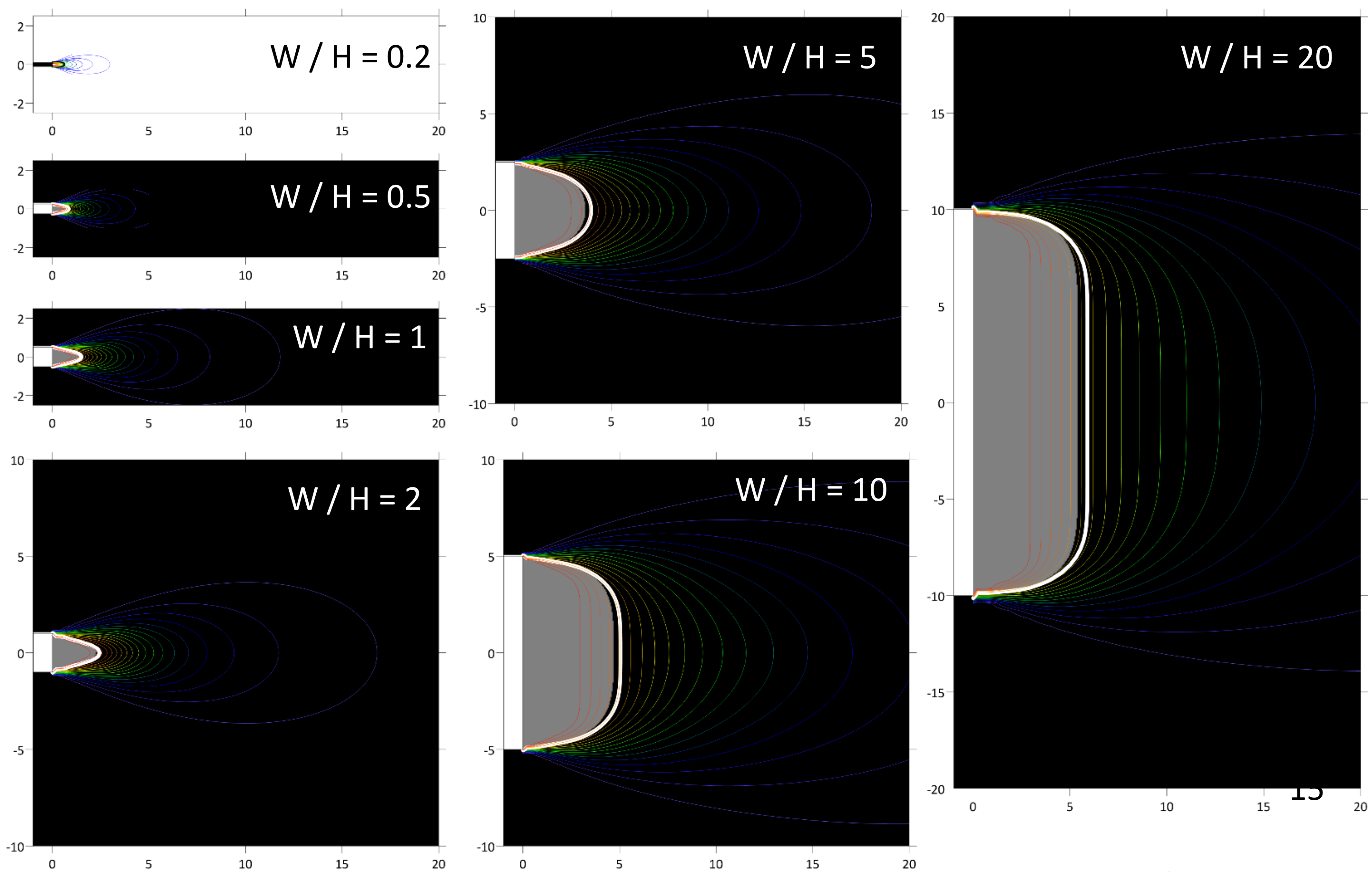
Recirculation area

3. – Parameterized flow models

3.2. – Obstacles wake recirculations

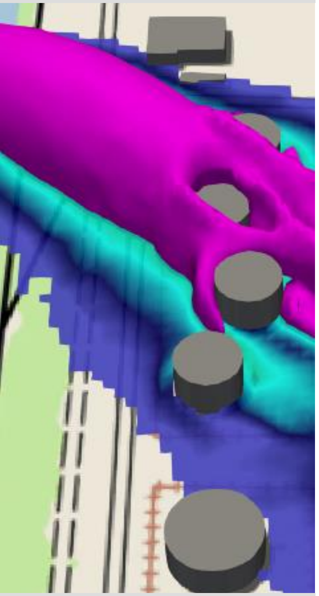


Validation against analytical solution for a rectangular building

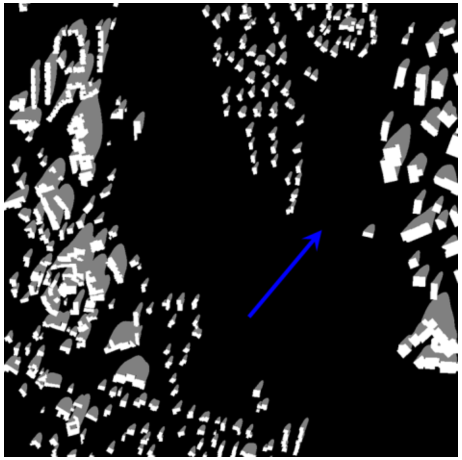


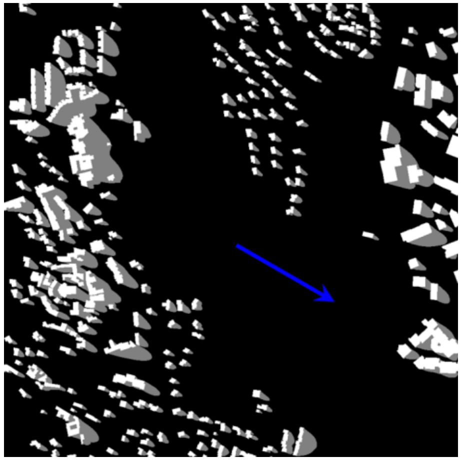
3. – Parameterized flow models

3.2. – Obstacles wake recirculations



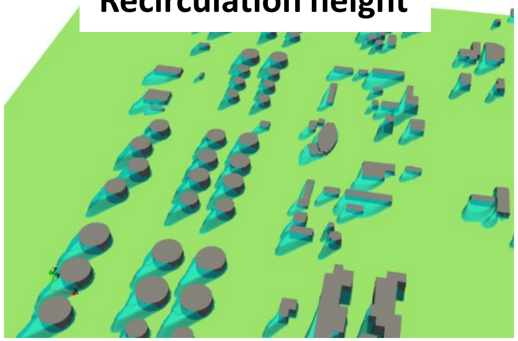
Application on a 1km x 1km tile for 2 wind directions



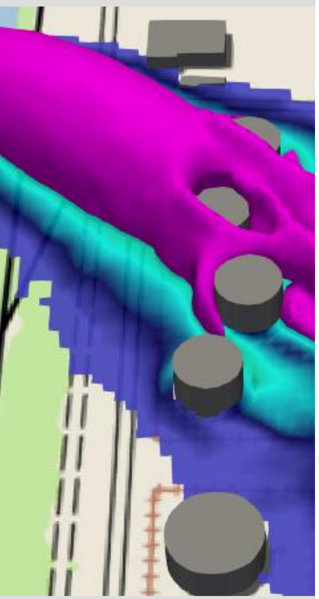


- From the same algorithm, we can also evaluate

Recirculation height



Coordinate η inside the recirculation

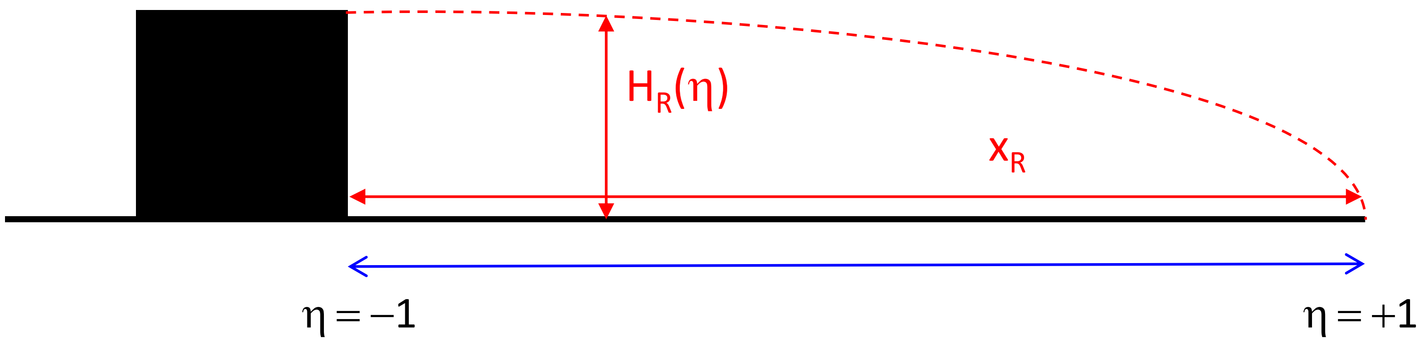


3. – Parameterized flow models

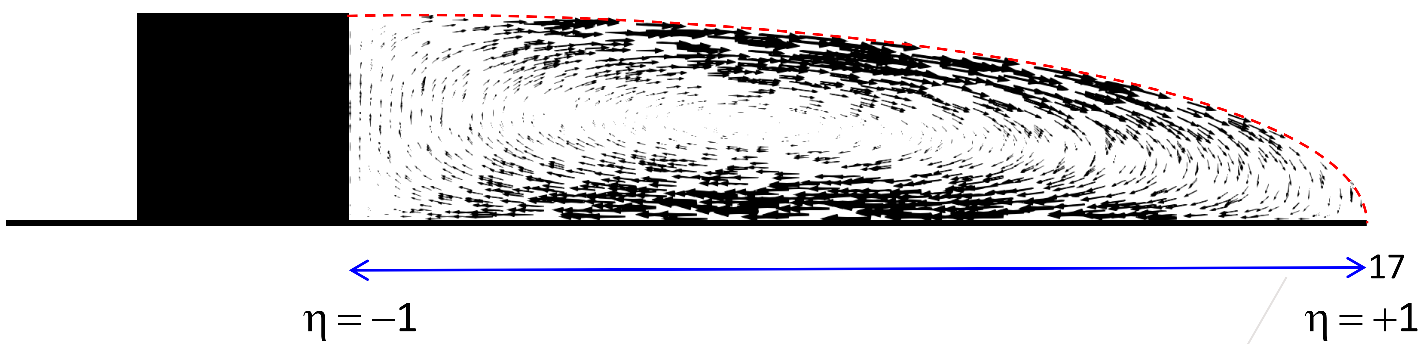
3.2. – Obstacles wake recirculations

Mean velocity field inside the recirculation zone

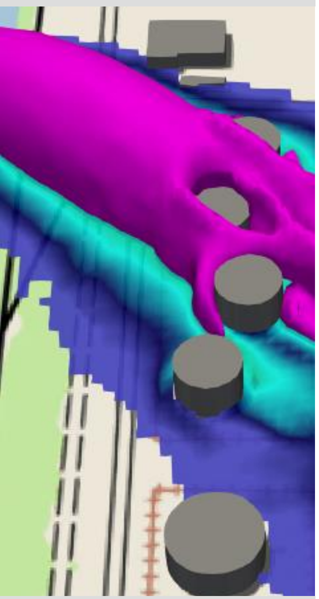
- Recirculation shape defined by length and local height



- By analogy with the linear recirculation flow model in street

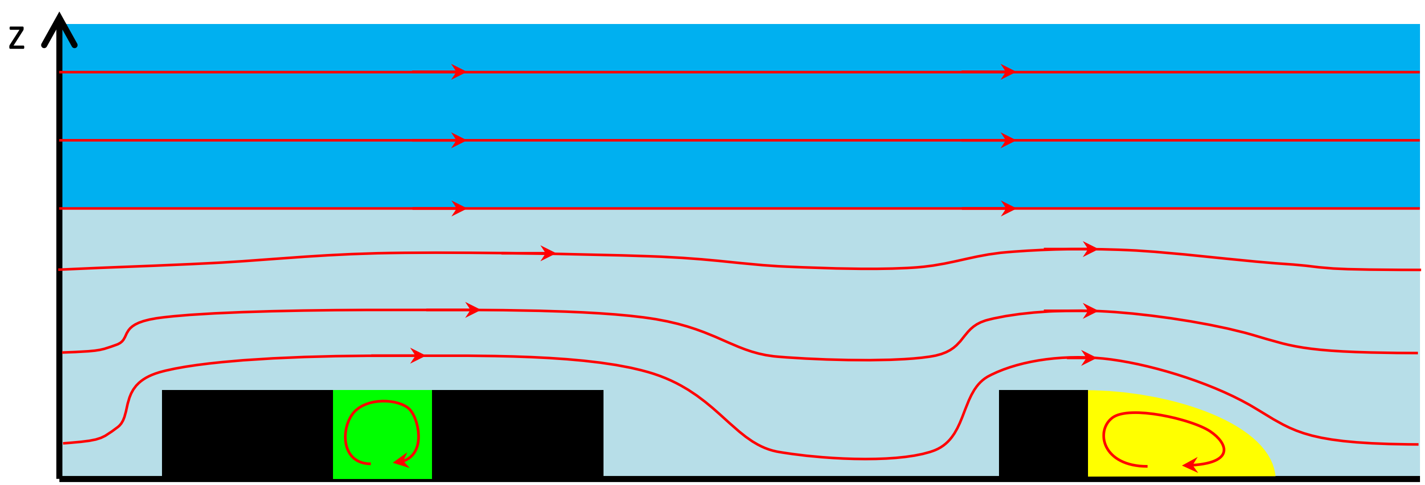


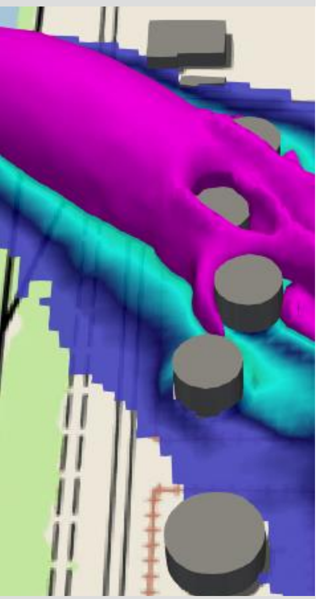
3. – Parameterized flow models



Zonal parameterizations of the wind and turbulence field

- Dense canopy and street-canyons
- Obstacles wake recirculations
- Roughness sublayer
- Atmospheric boundary layer

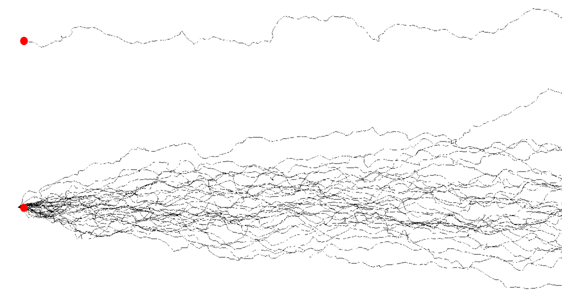




4. – Lagrangian dispersion model

Particles stochastic Lagrangian dispersion model

- Advection of particles



$$X_i(t+dt) = X_i(t) + \boxed{U_i(t)}\,dt$$

$$U_i(t) = \bar{U}_i(t) + \boxed{U_i'(t)}$$

$$U_i'(t+dt) = U_i'(t) + dU_i'$$

- Stochastic differential equation

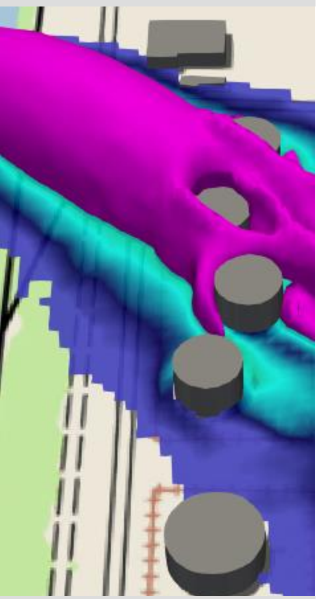
$$dU_i' = a_i(\vec{X},\vec{U}',t) + \sum_j b_i(\vec{X},\vec{U}',t)\,d\xi_j$$

with

$$\begin{cases} a_i = -\dfrac{U_i'}{T_L i} + \dfrac{1}{2}\dfrac{\partial \sigma_{ui}^2}{\partial x_i} + \dfrac{U_i'}{2\sigma_{ui}^2}\left(\bar{U}_j \dfrac{\partial \sigma_{ui}^2}{\partial x_j}\right) \\ b_{ij} = \delta_{ij}\sqrt{C_0 \varepsilon} \end{cases} \qquad T_{Li} = \frac{2\sigma_{ui}^2}{C_0 \varepsilon}$$

C_0 is the Kolmogorov constant

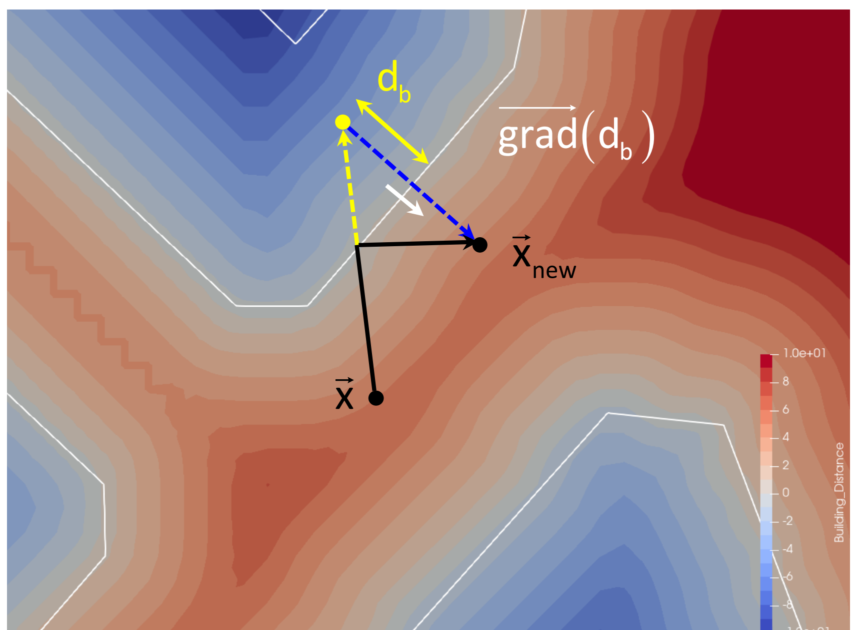
4. – Lagrangian dispersion model



Wall treatment

- Elastic reflection on solid walls
- Calculation of the reflection on vertical walls using the gradient of the building distance field:

$$\vec{x}_{new} = \vec{x} + 2\left|d_b\right|\overrightarrow{grad}\left(d_b\right)$$



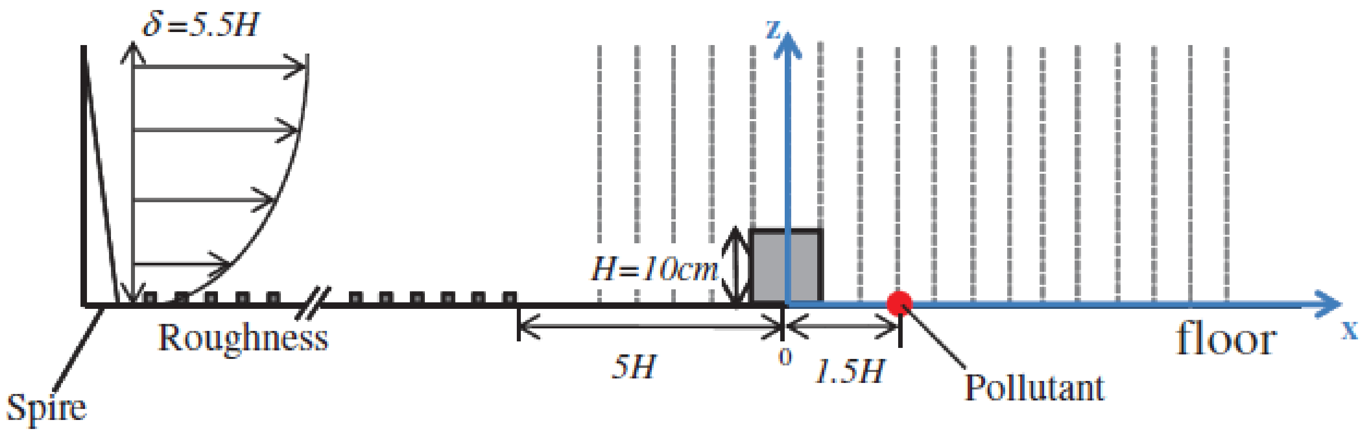
5. – First validations and applications

5.1. – Isolated 2D obstacle

See the more detailed presentation of Slimani et al. (H20-012)

Experimental set-up

- Wind tunnel experiment of Gamel PhD thesis (2015)



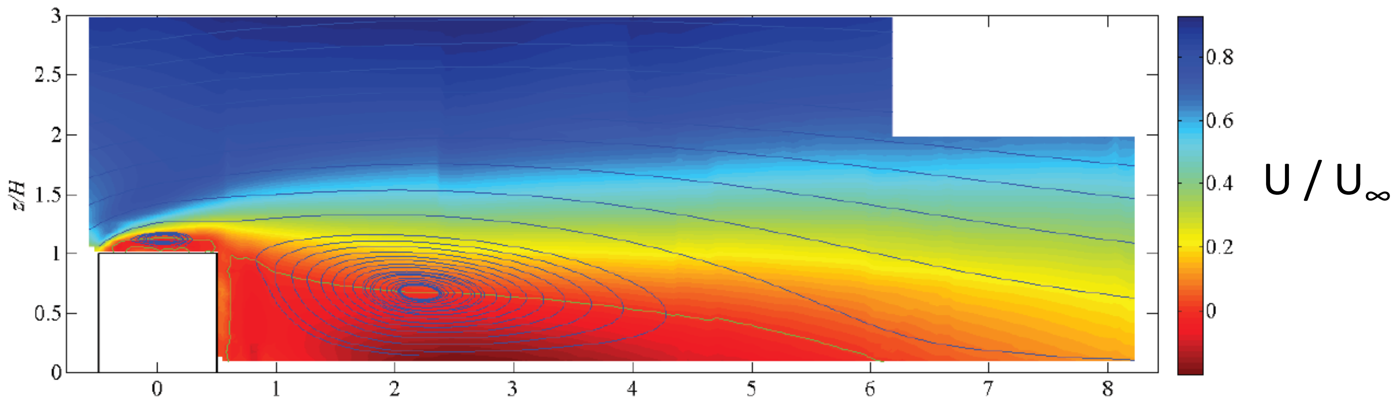
- 2D surface mounted obstacle, perp. to the wind
- Boundary layer flow over a rough wall
- Line source at 1,5H downstream of the obstacle

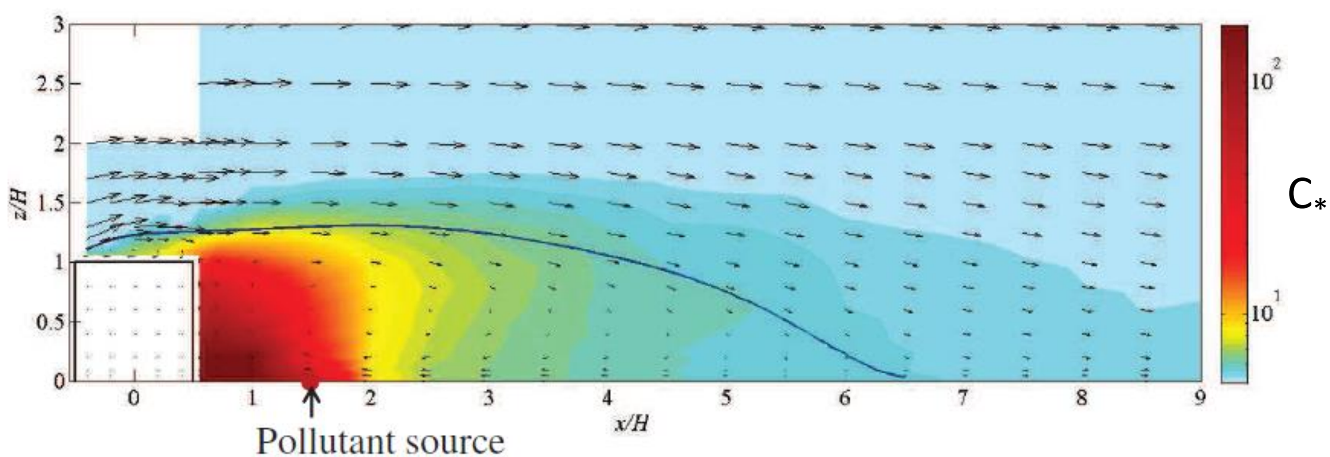
5. – First validations and applications

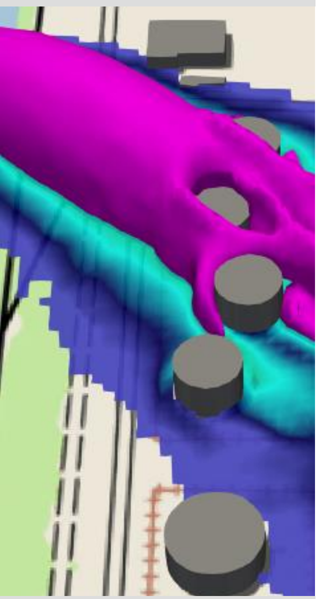
5.1. – Isolated 2D obstacle

Experimental data

- Wind tunnel experiment of Gamel PhD thesis (2015)





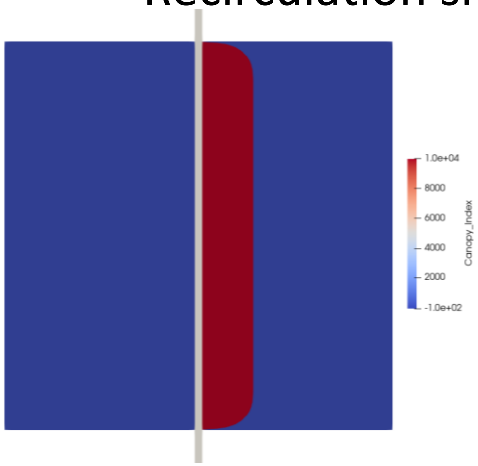


Application of the URBAN geometrical preprocessor

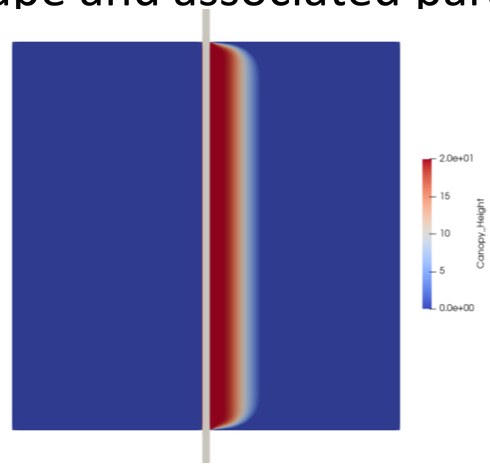
- Computational time for 1 direction = 1.5 sec

  (Dell Precision Mobile 7530)

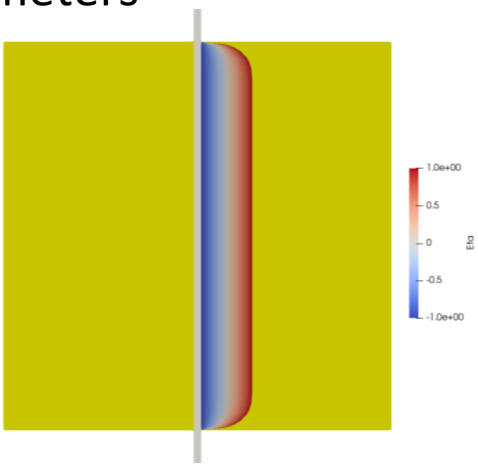
- Recirculation shape and associated parameters



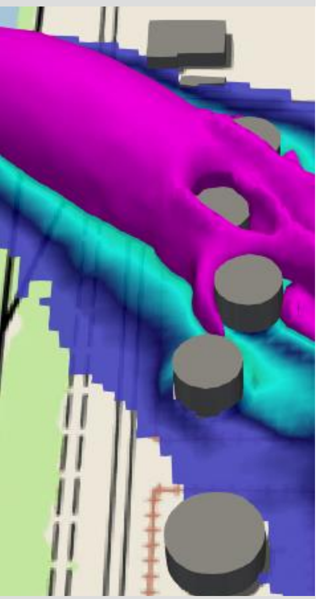
Recirculation index



Recirculation height



η coordinate

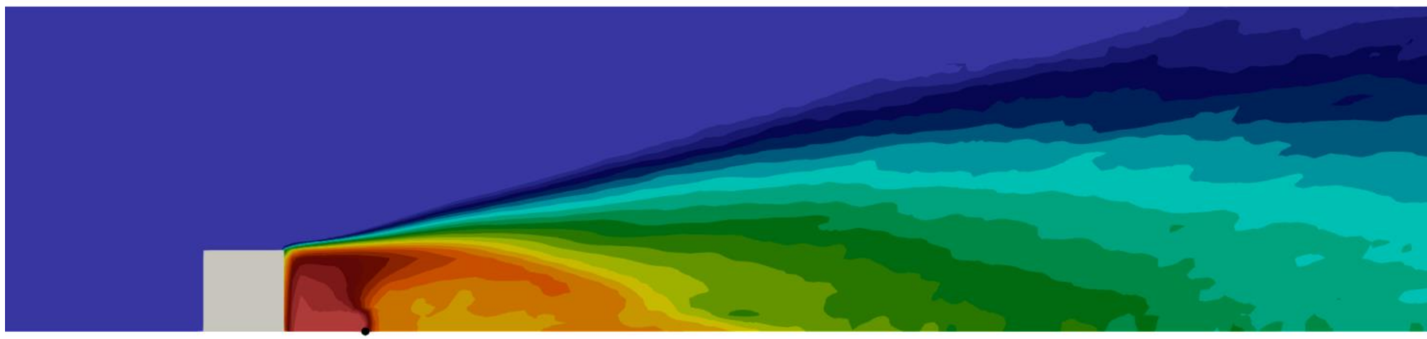


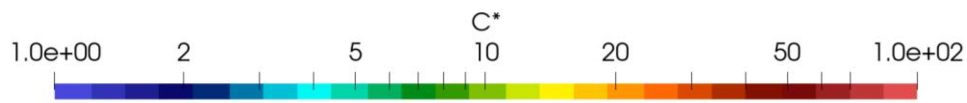
5. – First validations and applications

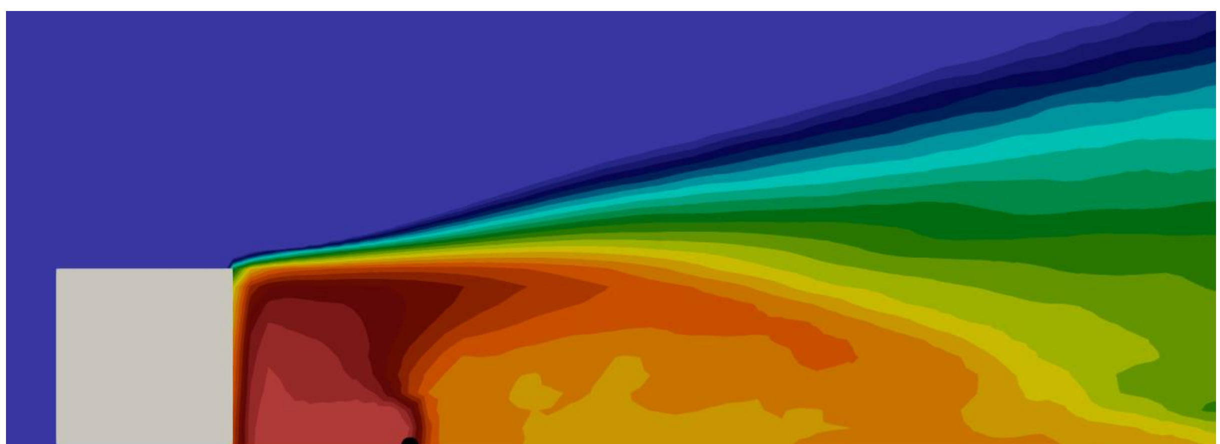
5.1. – Isolated 2D obstacle

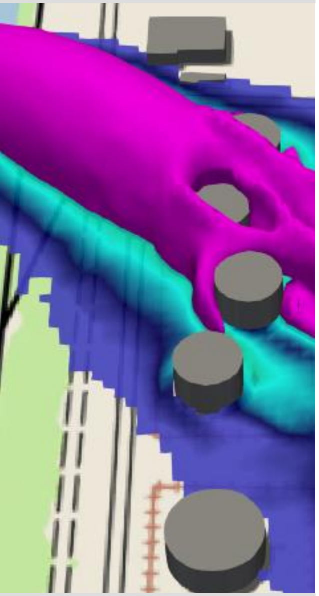
BUILD concentration field

- Computational time = 11.1 sec



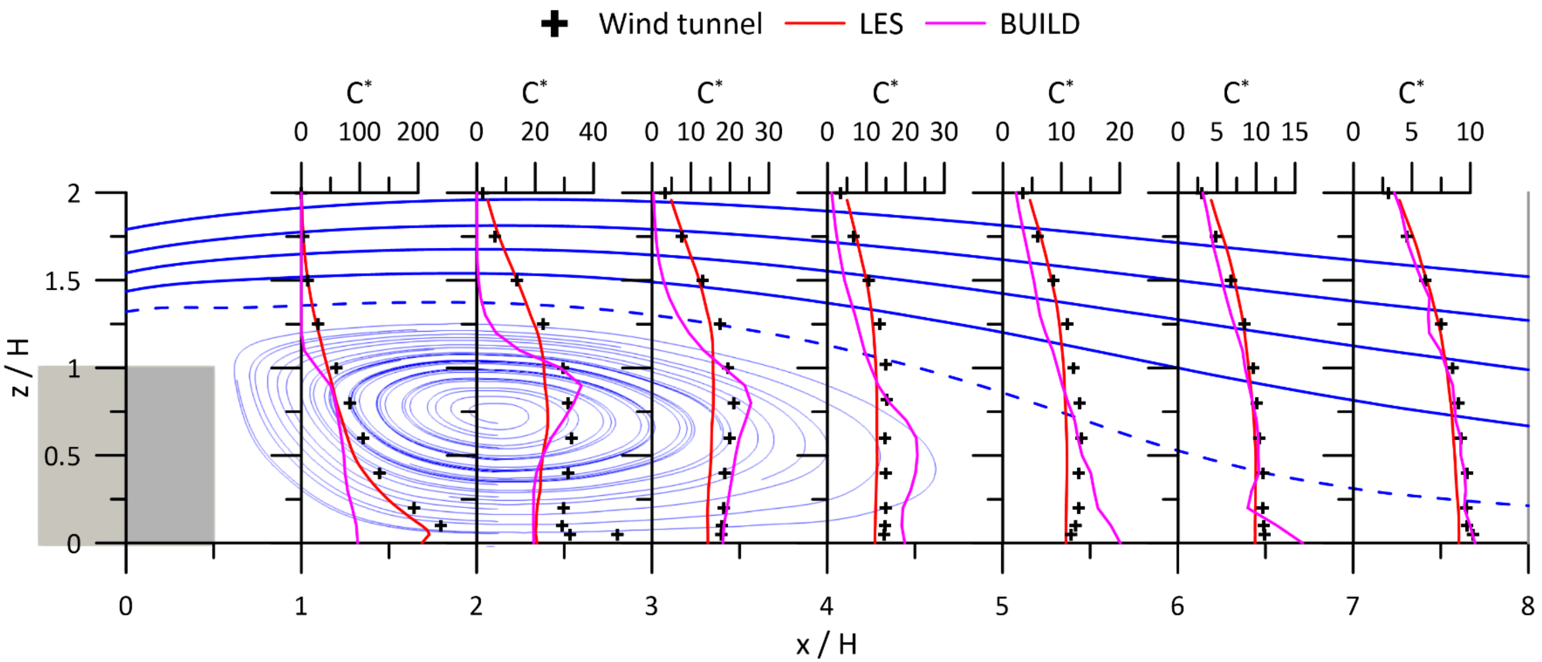


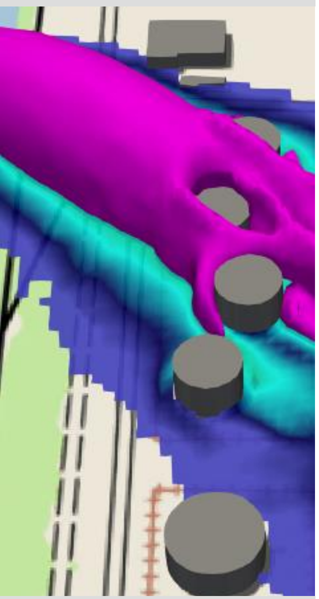




Comparison with wind tunnel and LES data

- Dimensionless concentration field



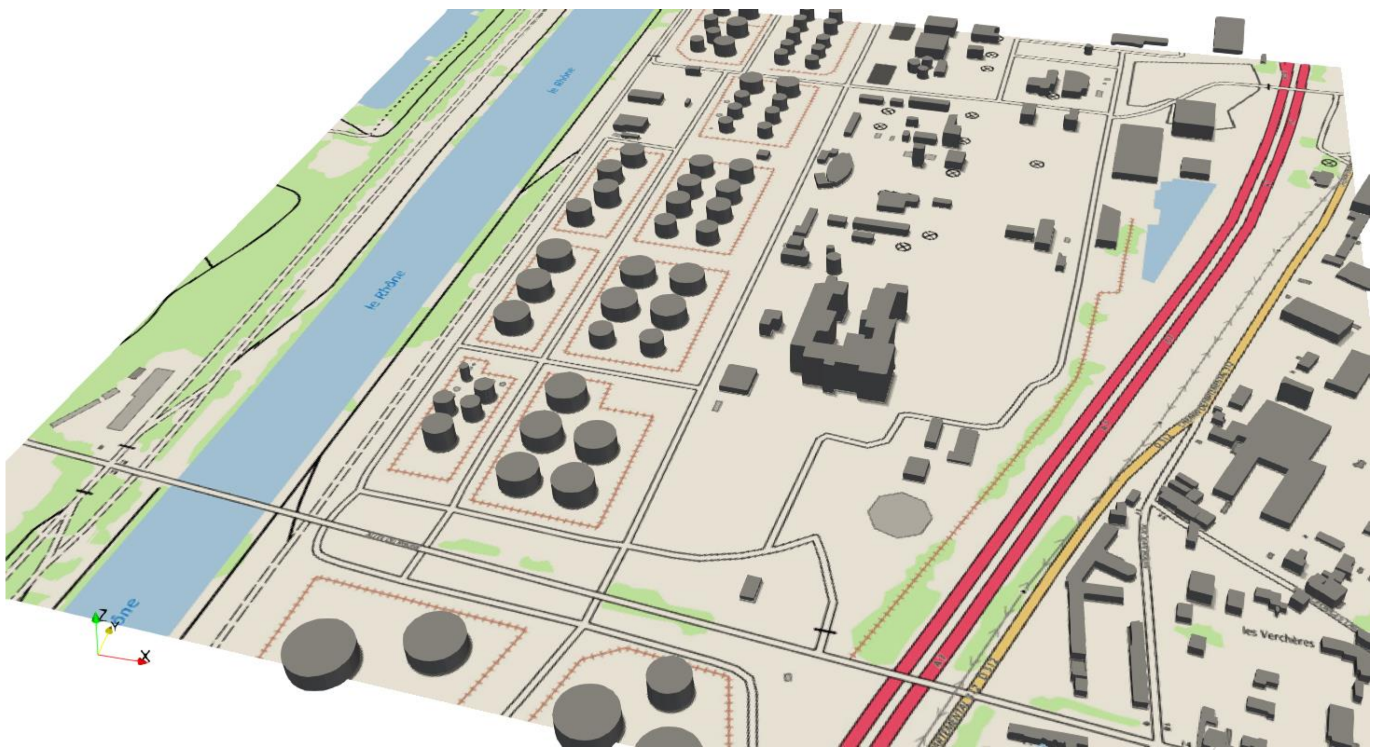


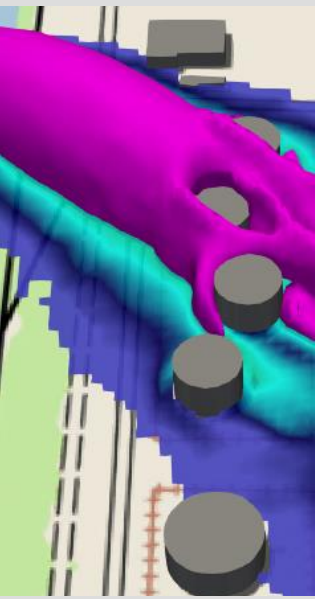
5. – First validations and applications

5.2. – Release on an industrial area

Real industrial site with 215 obstacles in the domain

- Feyzin refinery
- Canopy with intermediate density of buildings





5. – First validations and applications

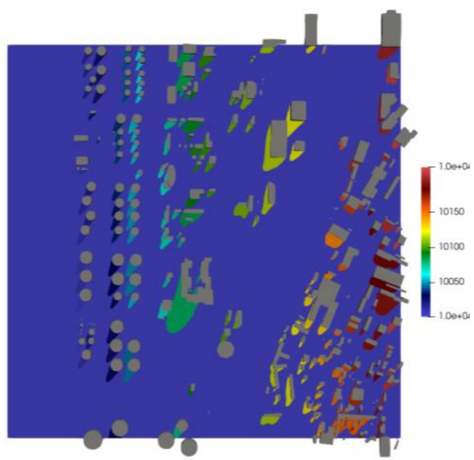
5.2. – Release on an industrial area

Application of the URBAN geometrical preprocessor

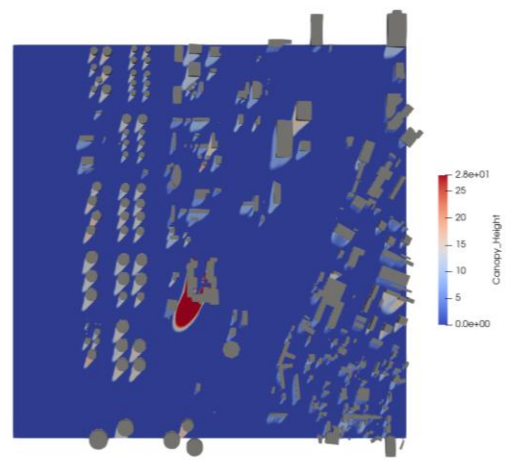
- Computational time for 1 direction = 31 sec

  (Dell Precision Mobile 7530)

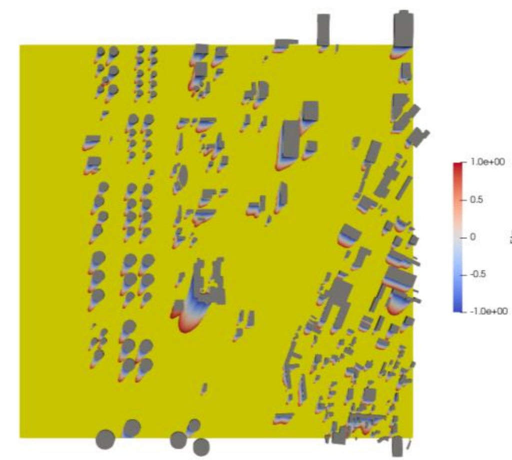
- Recirculations shapes and associated parameters



Recirculation index



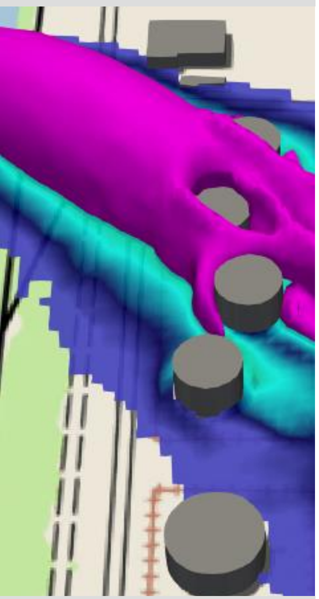
Recirculation height



η coordinate

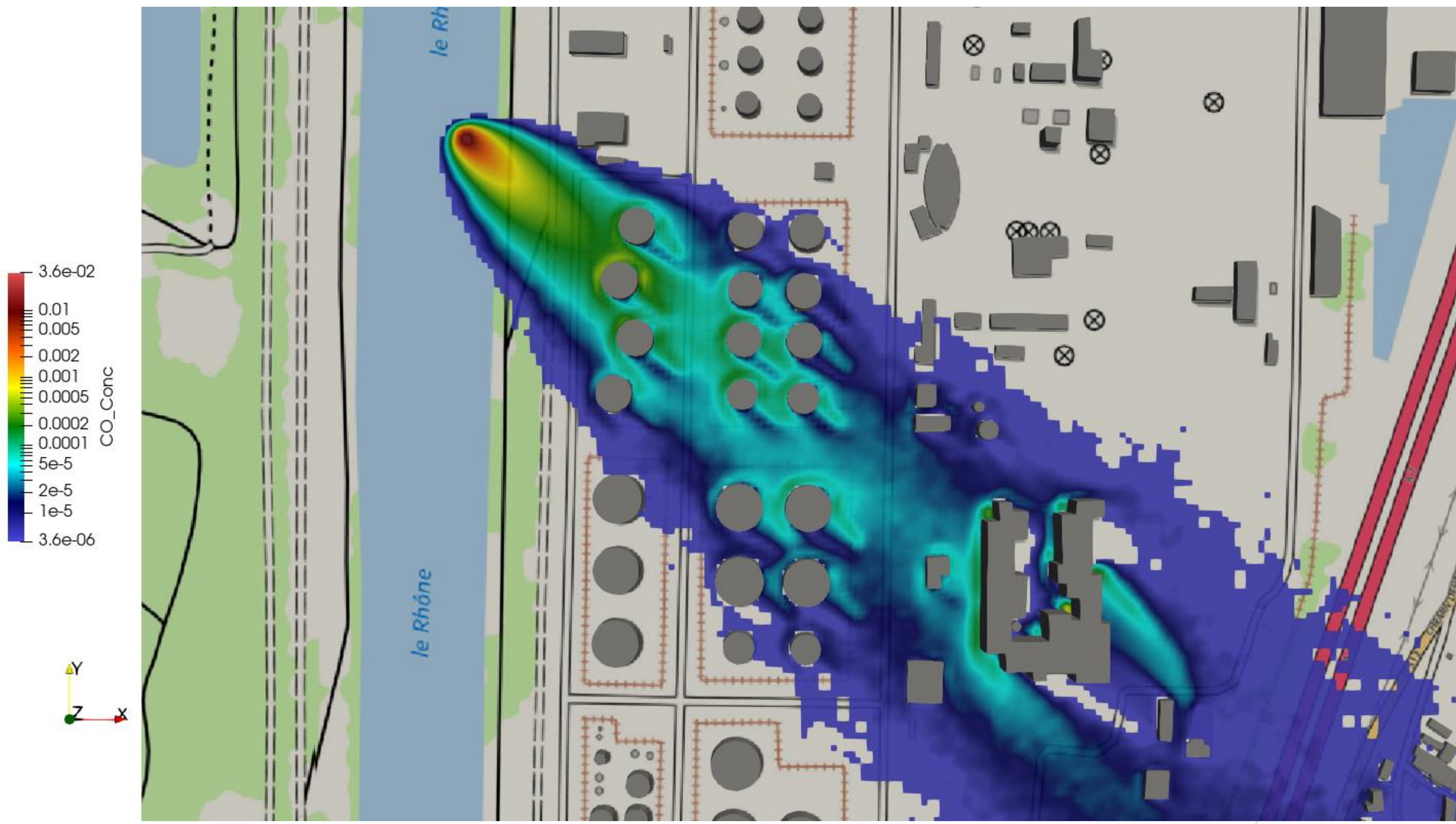
5. – First validations and applications

5.2. – Release on an industrial area



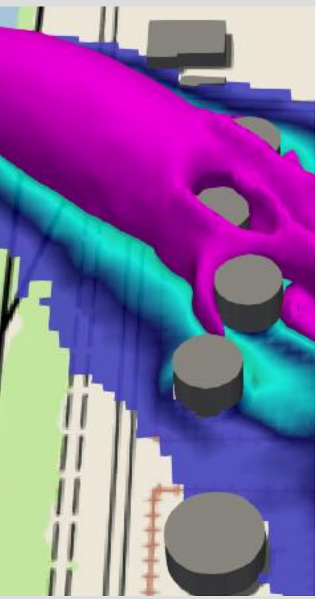
BUILD concentration field

- Computational time = 19.52 sec (100 000 particles)



Building, Urban and Industrial
BUILD
Lagrangian Dispersion model

6. – Conclusions



- A new operational model is developed for atmospheric dispersion of accidental or deliberate releases in built-up areas
- Based on
  - Enhanced network of streets parameterization of the flow in dense canopy
  - New building wake recirculation model
  - Roughness and surface boundary layer model
- First validations and applications have shown encouraging results and numerical performances
- Work in progress…