Ecole Centrale de Lyon
Laboratoire de Mécanique des Fluides et d'Acoustique

# *Pollutant dispersion through an obstacle array: numerical modelling and experimental investigation*

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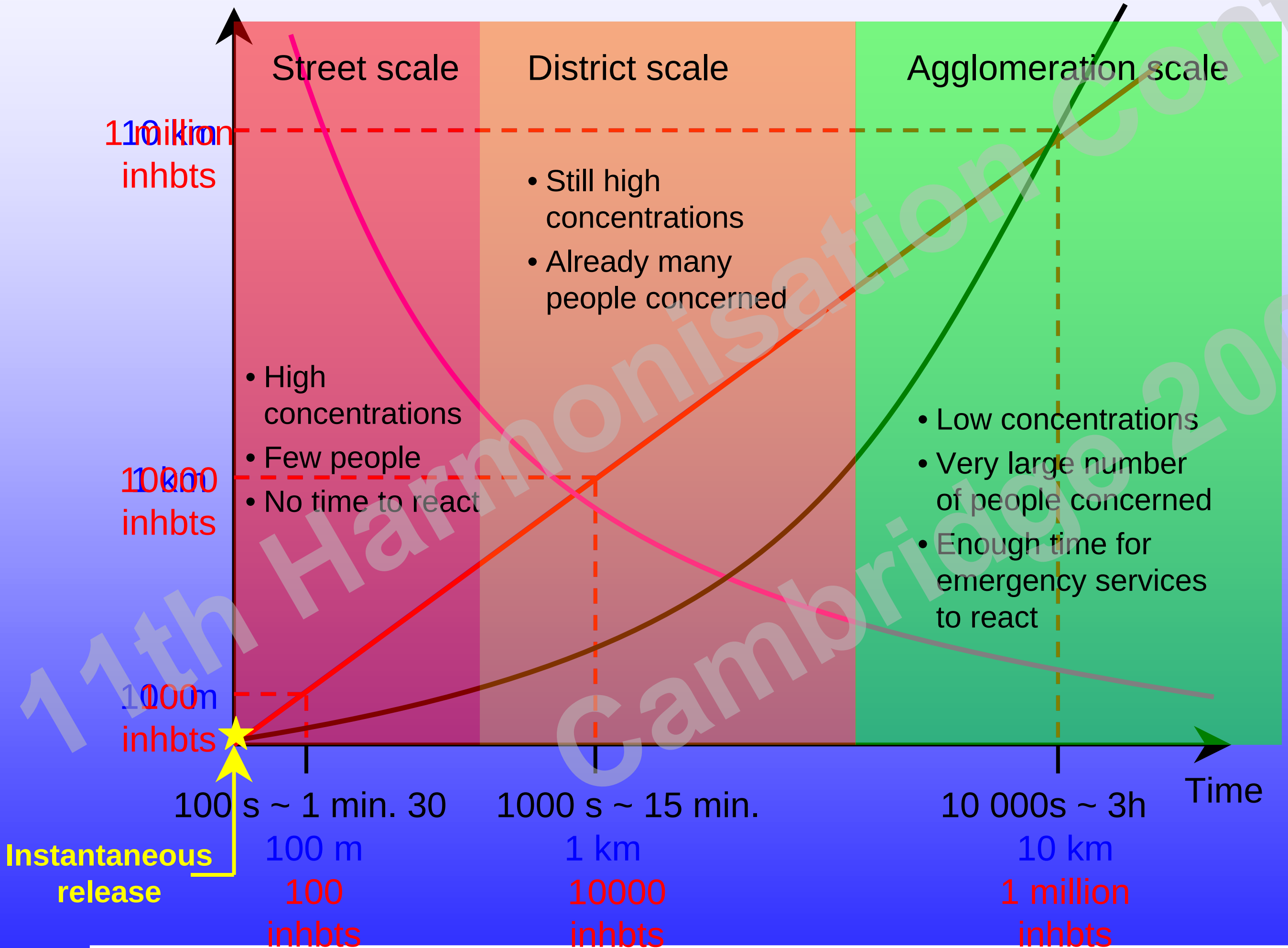
# 1. Introduction

## Dispersion of hazardous material in urban area

- Context of prevention from short accidental releases
  - Accidental releases due to urban industrial facilities
  - Transport of toxic materials
- Need of model tools in order to
  - Simulate different scenarios in preparation and training for an eventual release
  - Predict the dispersion for emergency response
  - Evaluate precisely the impact of a release in post-accident analysis

# 1. Introduction

## Some orders of magnitude




Concerned area (U ~ 1m/s)

Population affected (density ~ 10 000 inhbts/km²)

Concentration values

Capacity of reaction

**Focus on district scale**

# 1. Introduction

## Some modelling issues at district scale


- Which processes/parameters control dispersion at district scale?
- How to model a district of thousands street segments?
- How to predict one or two days of dispersion in a few minutes on a PC?

⇨ Find an alternative to CFD codes (Fluent, Mercure, …)

⇨ Need to develop simplified models for operational applications

⇨ Some approaches exist : MicroSwiftSpray, UDM, …

⇨ **We will develop an alternative approach for very fast emergency response**

# 1. Introduction

## Plan of the presentation

1. Introduction
2. Wind tunnel experiments on urban district
3. SIRANERISK dispersion model
4. Preliminary comparison SIRANERISK / measurements
5. Conclusions and perspectives

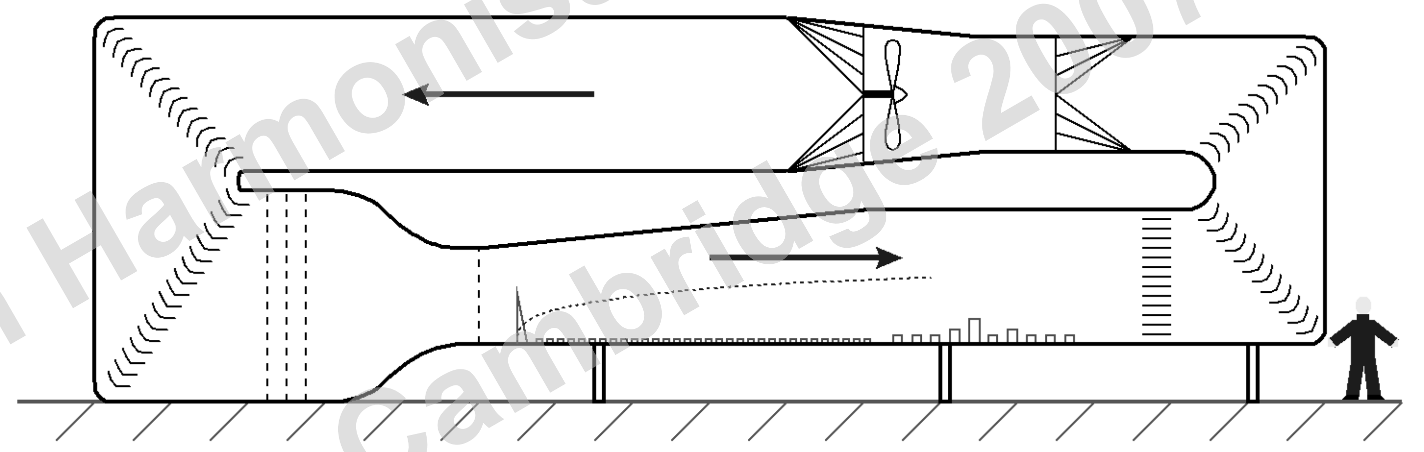
# 2. Wind tunnel experiments on urban district

## Experimental setting

**Study of turbulent dispersion from a continuous point source in an urban district**

**Influence of wind direction**

**Atmospheric wind tunnel of the Ecole Centrale de Lyon**

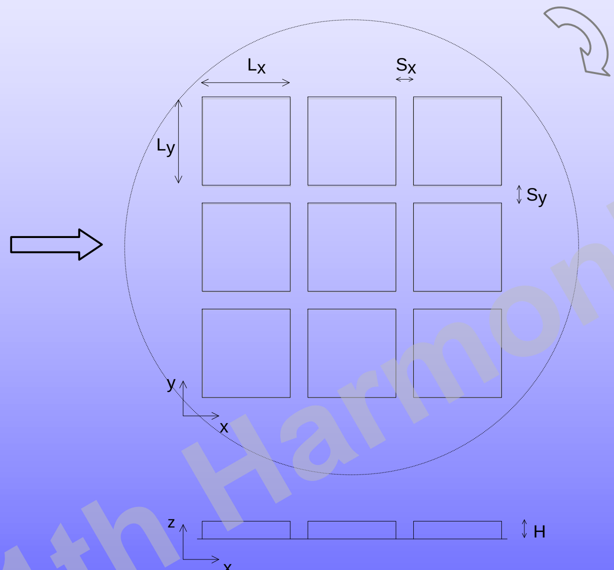


**Dimensions of the test section: 14m x 2.5 m x 3.7m**

# 2. Wind tunnel experiments on urban district

## Experimental setting

### Building geometry




**Model :**

$H = 50$ mm

$L_x = L_y = 5H$

$S_x = S_y = H$

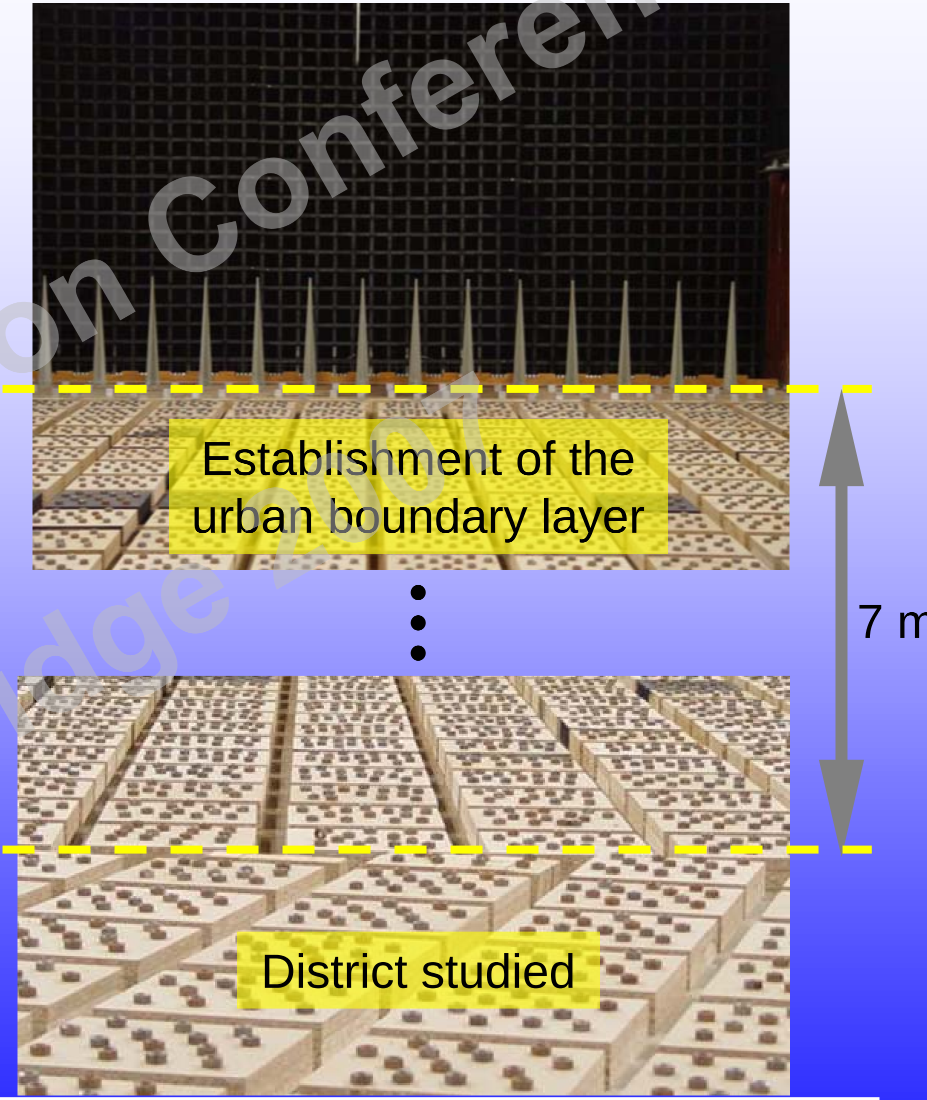
**Model scale 1:400**

**Reality :**

$H = 20$ m

$L_x = L_y = 100$ m

$S_x = S_y = 20$ m



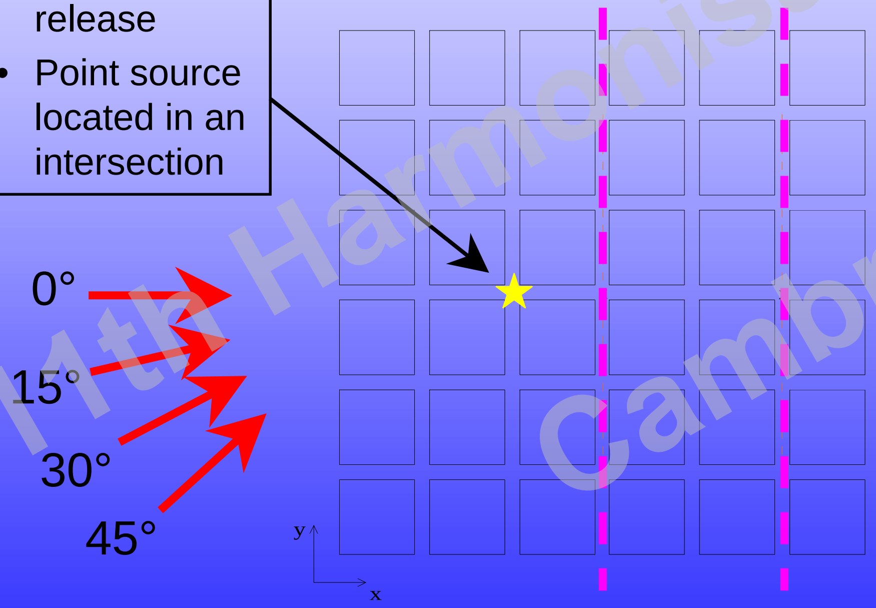
# 2. Wind tunnel experiments on urban district

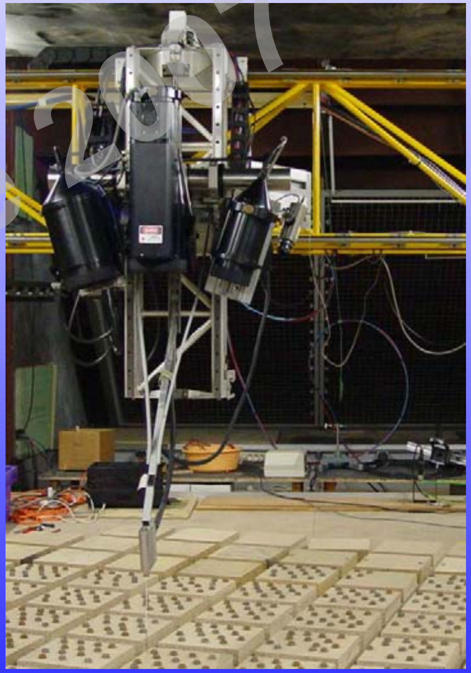
## Experimental setting

**Concentration measurements with Flame Ionisation Detector:**

- Lateral profiles (y-direction) at different distance from the source
- Variation of the wind direction

- Continuous release
- Point source located in an intersection



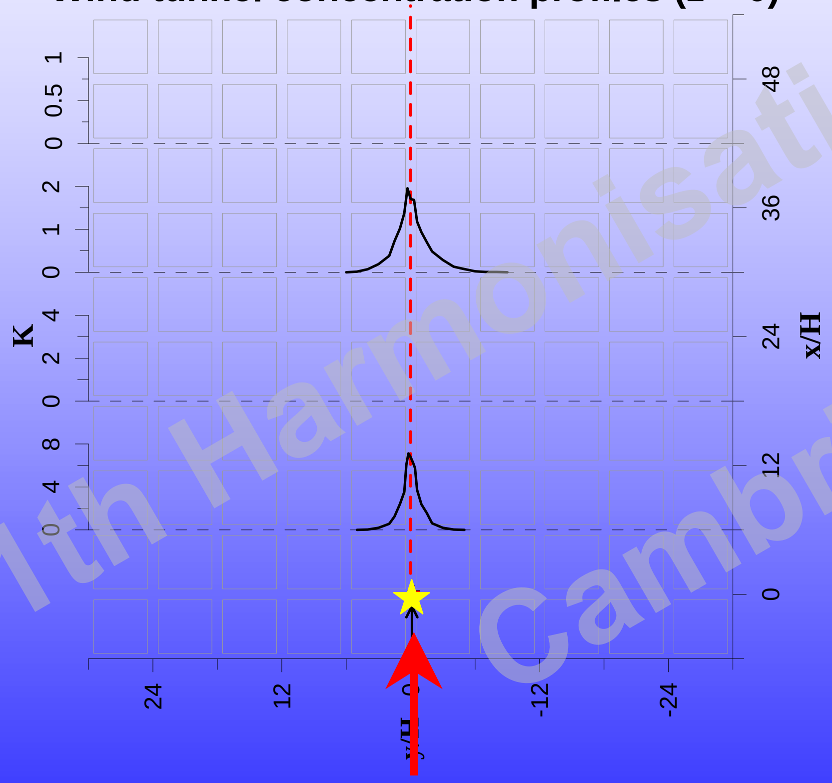



# 2. Wind tunnel experiments on urban district

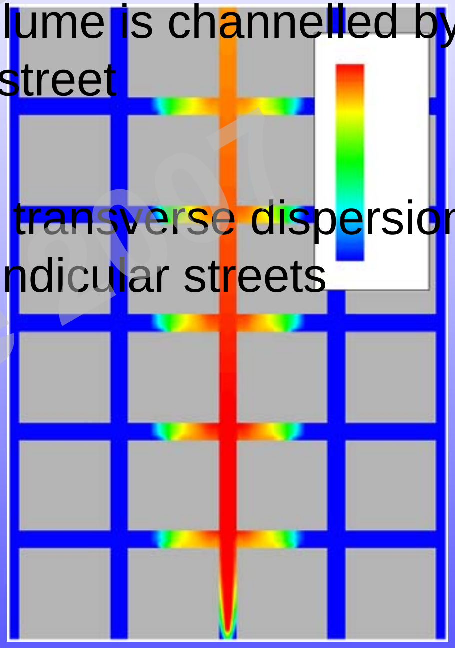
## Experimental results

### *Wind direction = 0°*

**Wind tunnel concentration profiles (z = 0)**




**RANS CFD calculations**



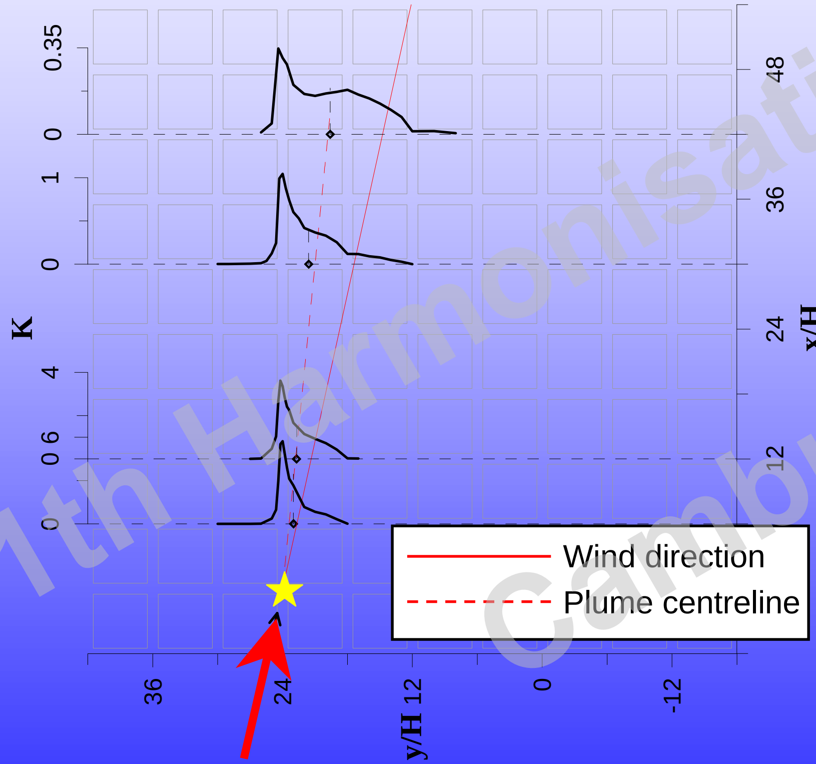
- The plume is channelled by the main street
- Small transverse dispersion in perpendicular streets

# 2. Wind tunnel experiments on urban district

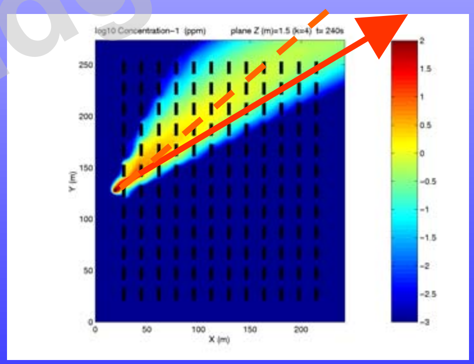
## Experimental results

***Wind direction = 15°***

**Wind tunnel concentration profiles (z = 0)**




- The plume spreads more rapidly than in the 0° case
- The plume centreline is shifted due to a channelling mechanism



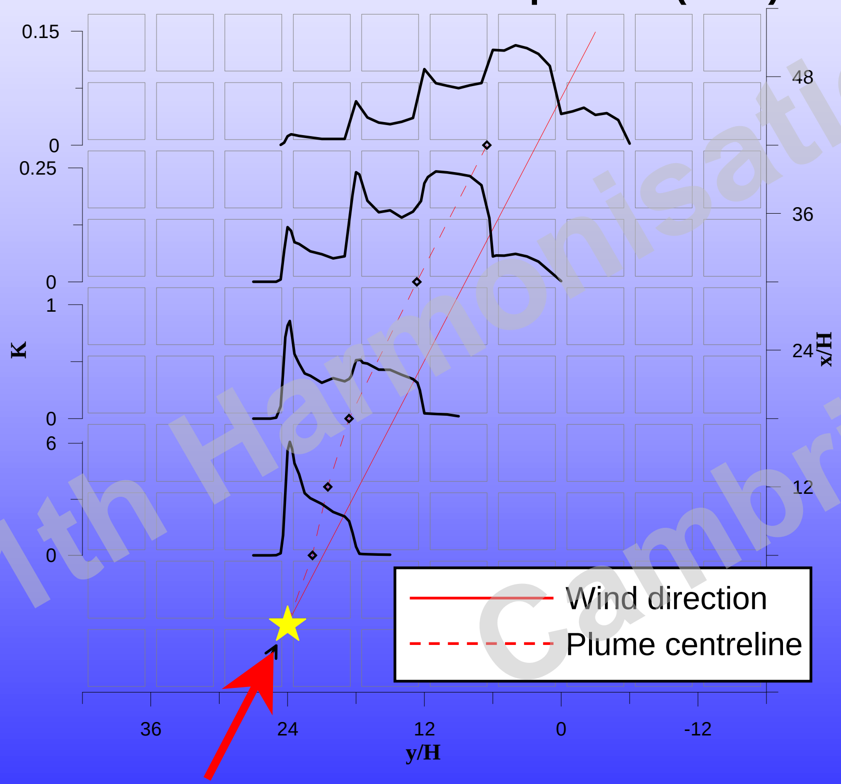
Analogy with plume behaviour in this CFD simulation of the MUST experiment (Carissimo, 2001)

# 2. Wind tunnel experiments on urban district

## Experimental results

***Wind direction = 30°***

**Wind tunnel concentration profiles (z = 0)**



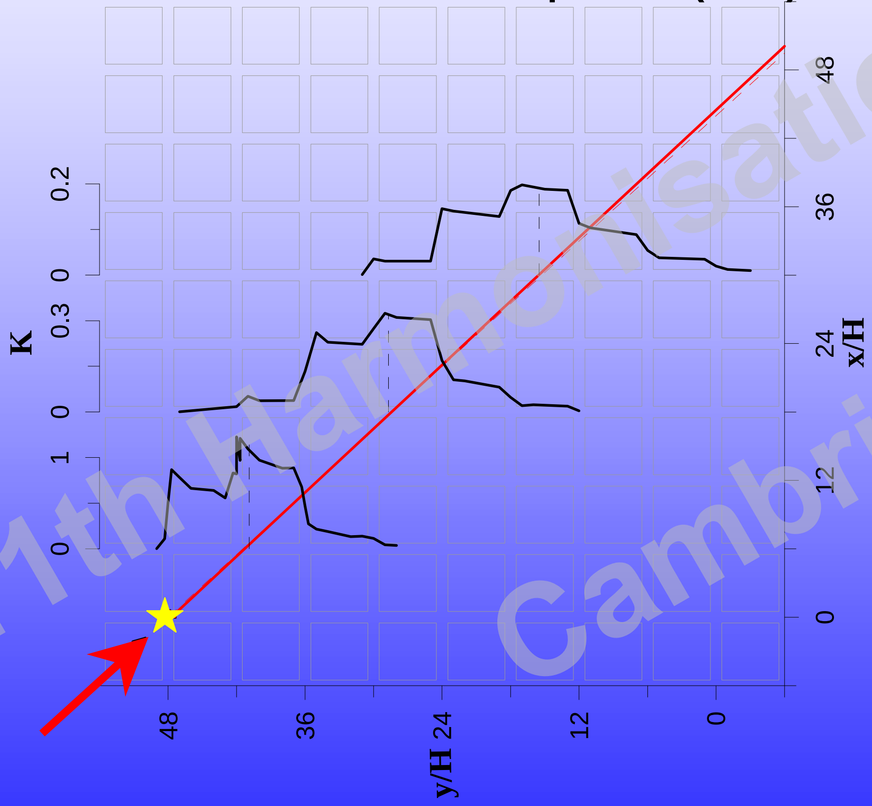

- The plume spreads even more rapidly
- The steps in the concentration profiles correspond to the presence of the streets
- The concentration is almost homogeneous in each street

# 2. Wind tunnel experiments on urban district

## Experimental results

***Wind direction = 45°***

**Wind tunnel concentration profiles (z = 0)**



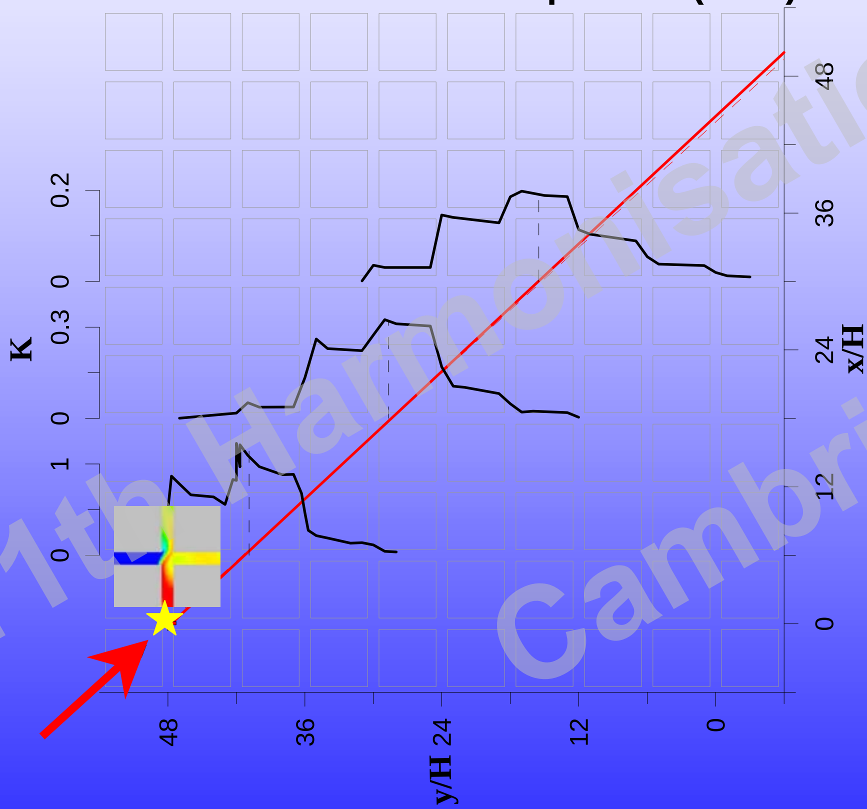

- The plume centreline deflection disappears in the symmetric case
- The concentration is almost constant in each street but varies from one street to the other

# 2. Wind tunnel experiments on urban district

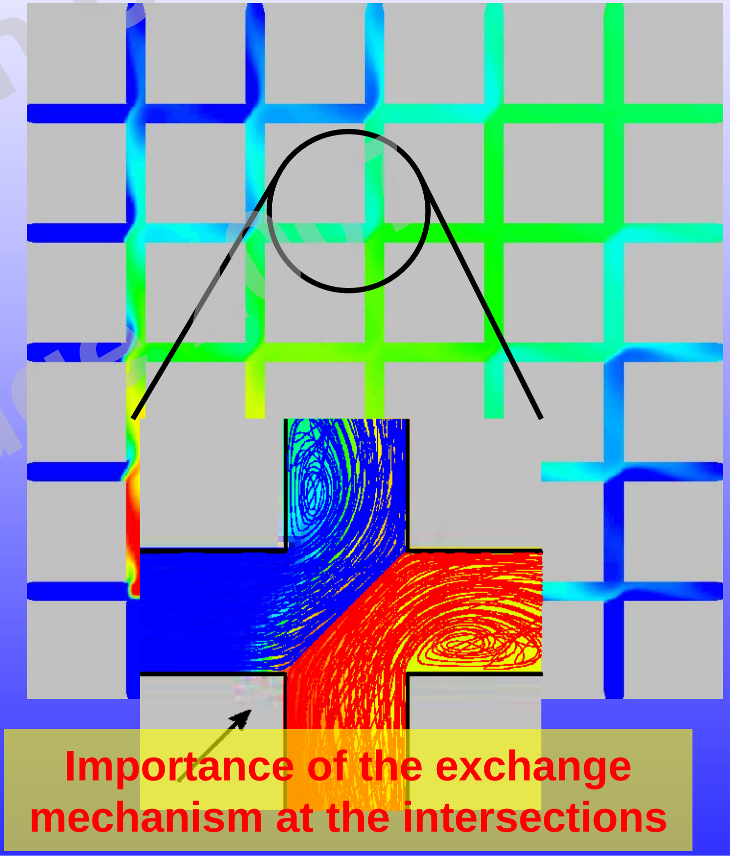
## Experimental results

***Wind direction = 45°***

**Wind tunnel concentration profiles (z = 0)**



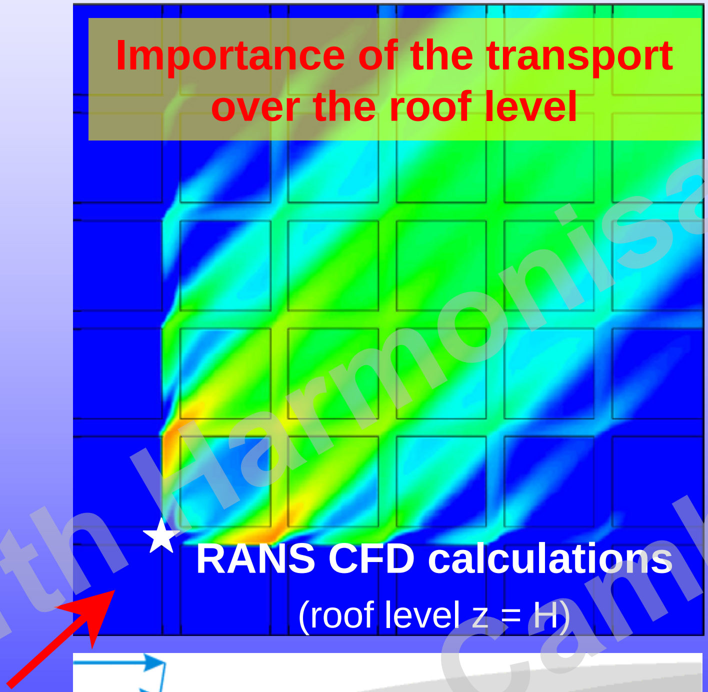

**RANS CFD calculations**

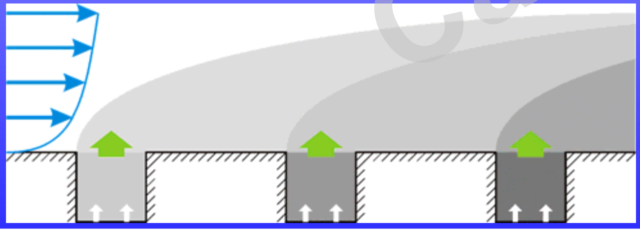


# 2. Wind tunnel experiments on urban district

## Experimental results

***Wind direction = 45°***



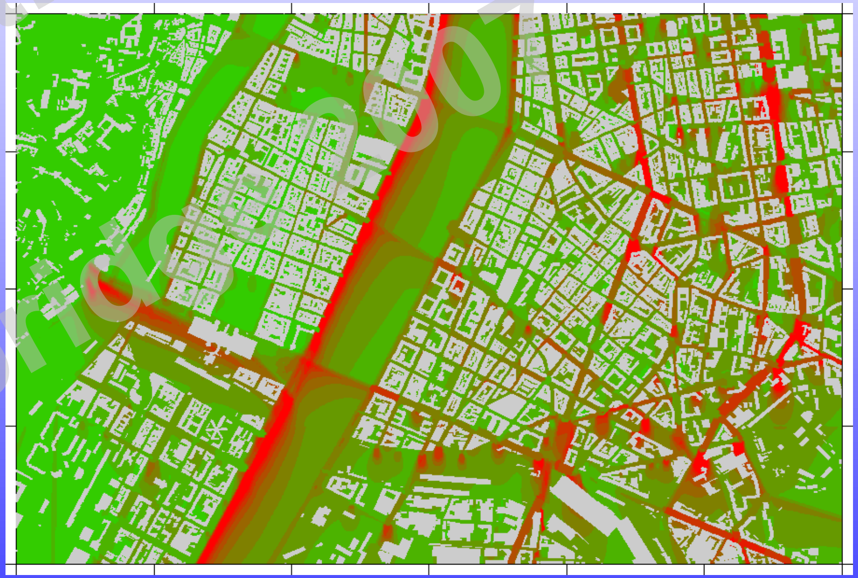
⇨ **Two mechanisms control the dispersion in a district :**

1. Exchanges at each intersection
2. Exchange with the external flow and dispersion over the roof level

# 3. SIRANERISK dispersion model

## Introduction

- SIRANERISK is an evolution of the SIRANE model, used for air quality modelling in urban area (application on Lyon, Paris, Grenoble, Torino, Milano, …)
- SIRANE is a steady state model ➔ SIRANERISK is an unsteady model



**SIRANE model – Agglomeration of Lyon – 2003**

Example of hourly $NO_X$ concentrations

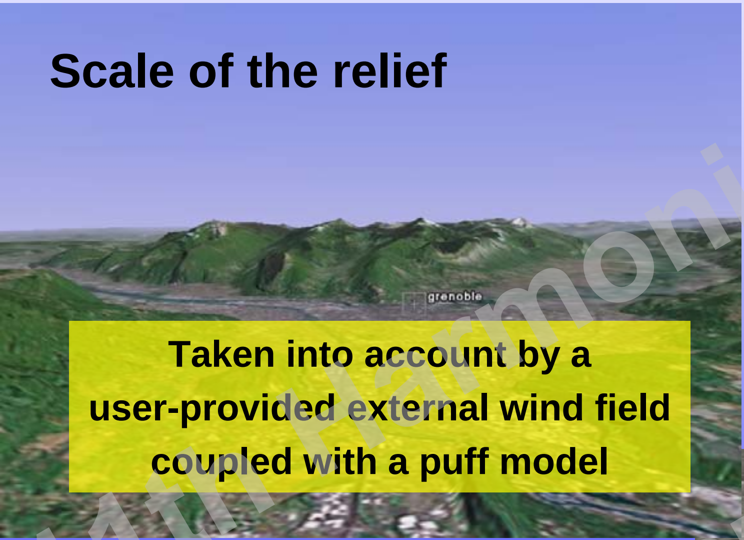
# 3. SIRANERISK dispersion model

## Geometrical description of a district

Urban geometry is complex at different scales

→ need to simplify in an operational model

**Scale of the relief**



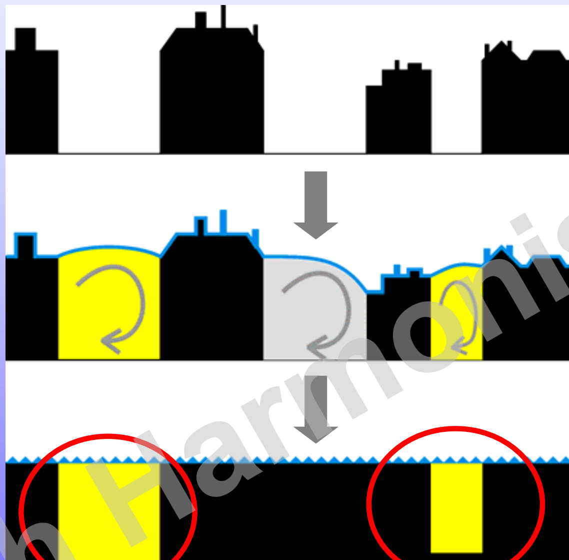

**Scale of the detail on buildings**

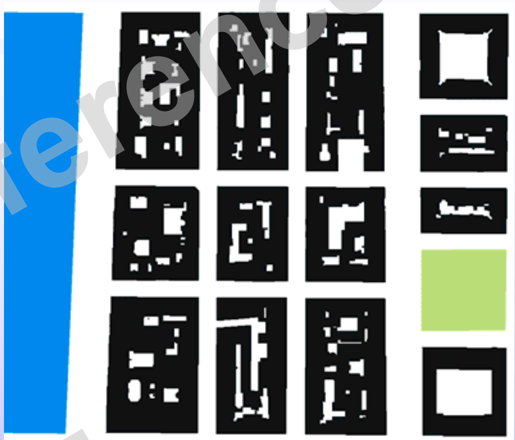

**Scale of buildings**

# 3. SIRANERISK dispersion model

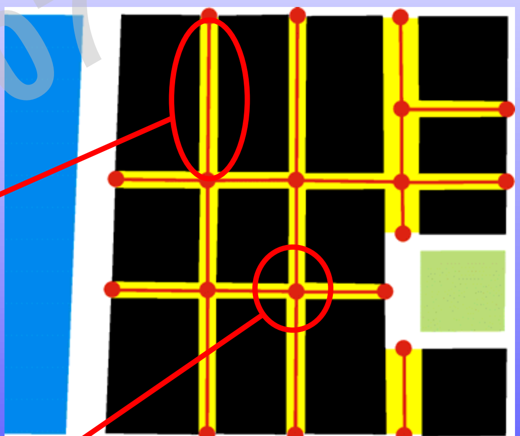
## Geometrical description of a district

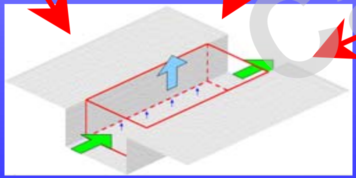
**Representation of urban canopy**



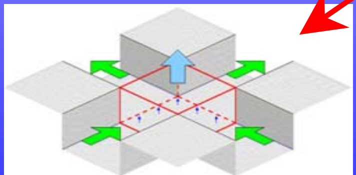


**Simplification of building geometry**





**Pollutant budget in each street**



**Exchange at intersections**

# 3. SIRANERISK dispersion model

## Concentration model in each street

- Analytical model for the average velocity in each street
  (Soulhac et al., 2007, submitted to Boundary Layer Meteorology)

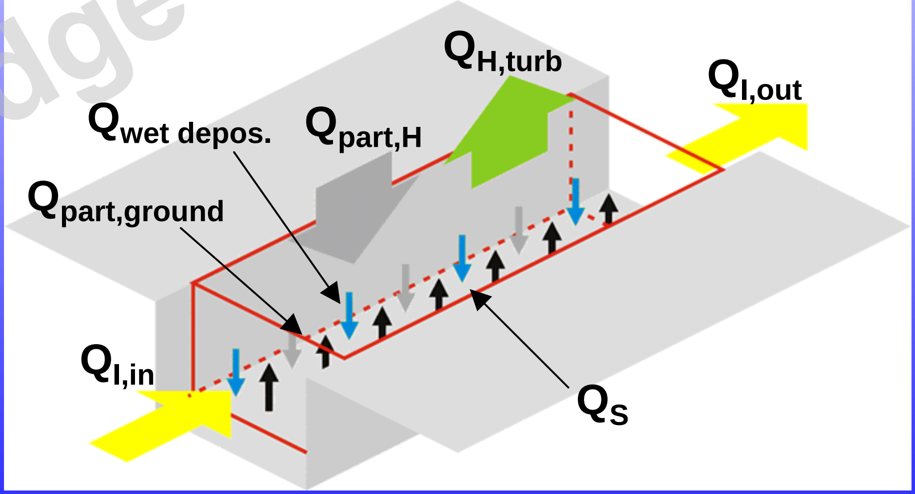
- Budget of pollutant mass in the street

$$\frac{d\left(HWL.C_{street}\right)}{dt} = \underbrace{Q_S + Q_{I,in} + Q_{part,H}}_{\text{In fluxes}} - \underbrace{Q_{H,turb} + Q_{I,out} + Q_{part,ground} + Q_{wet\ depos.}}_{\text{Out fluxes}}$$

- Turbulent exchange at the interface

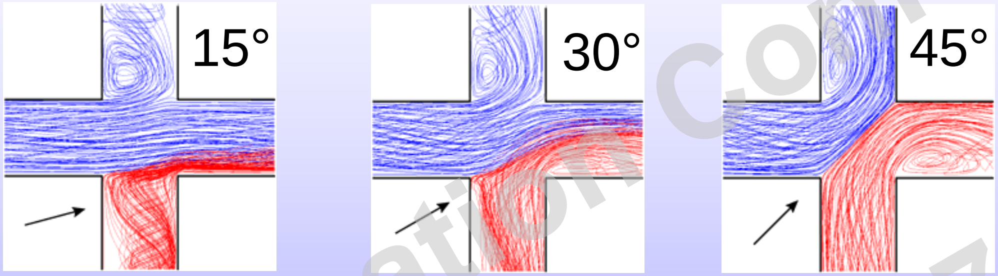
$$Q_{H,turb} = \frac{\sigma_w WL}{\sqrt{2\pi}}\left(C_{street} - C_{street,ext}\right)$$

Emission of a new rectangular puff over the street

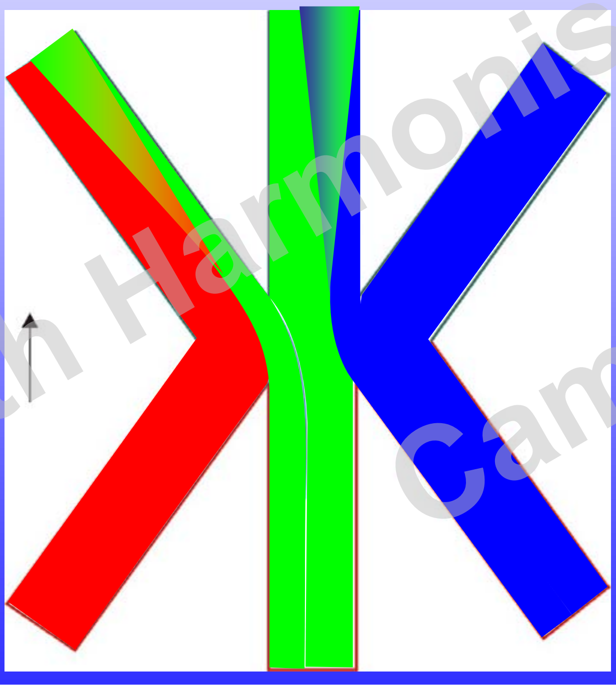


# 3. SIRANERISK dispersion model

## Exchange model for an intersection




**RANS CFD calculations**



Calculation of exchange fluxes as a function of wind direction :

$$P_{i,j}(\theta)$$

Averaging fluxes over wind direction fluctuations :

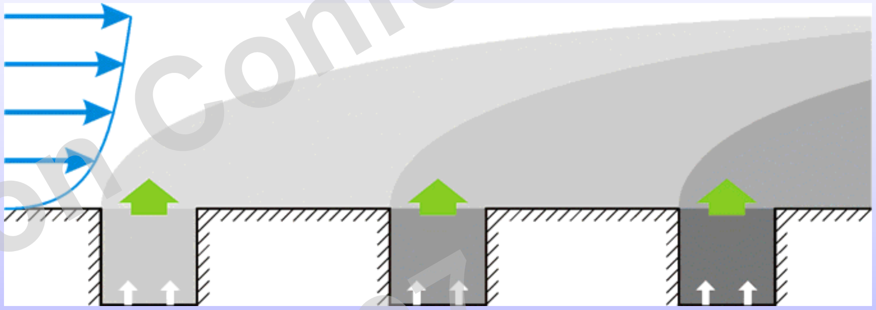
$$\bar{P}_{i,j}(\theta_0) = \int f(\theta - \theta_0) P_{i,j}(\theta) d\theta$$

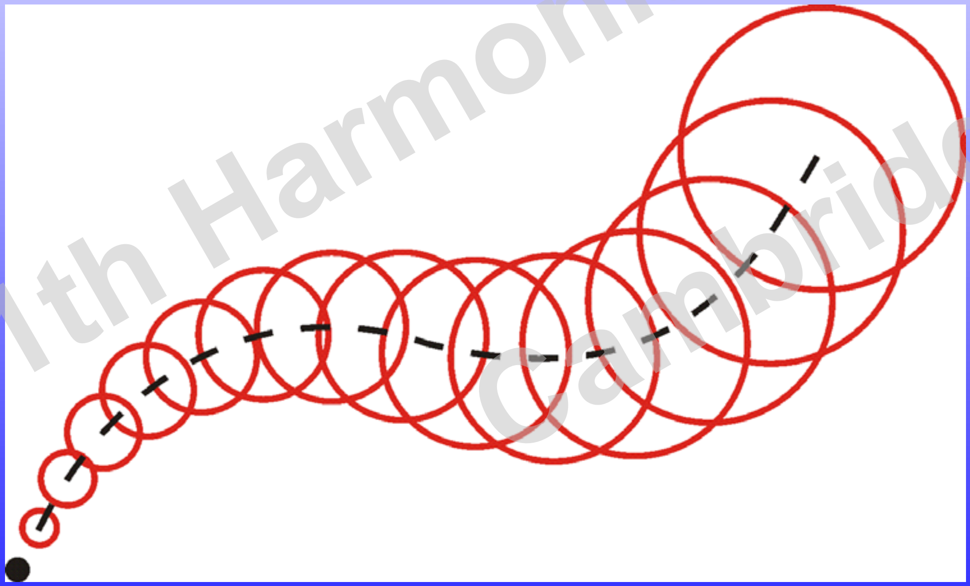
$$\text{with } f(\theta - \theta_0) = \frac{1}{\sigma_\theta \sqrt{2\pi}} \exp\left[ -\frac{1}{2} \left( \frac{\theta - \theta_0}{\sigma_\theta} \right)^2 \right]$$

# 3. SIRANERISK dispersion model

## Puff dispersion model over the roof level

Each vertical flux of pollutant is modelled by a source of puffs

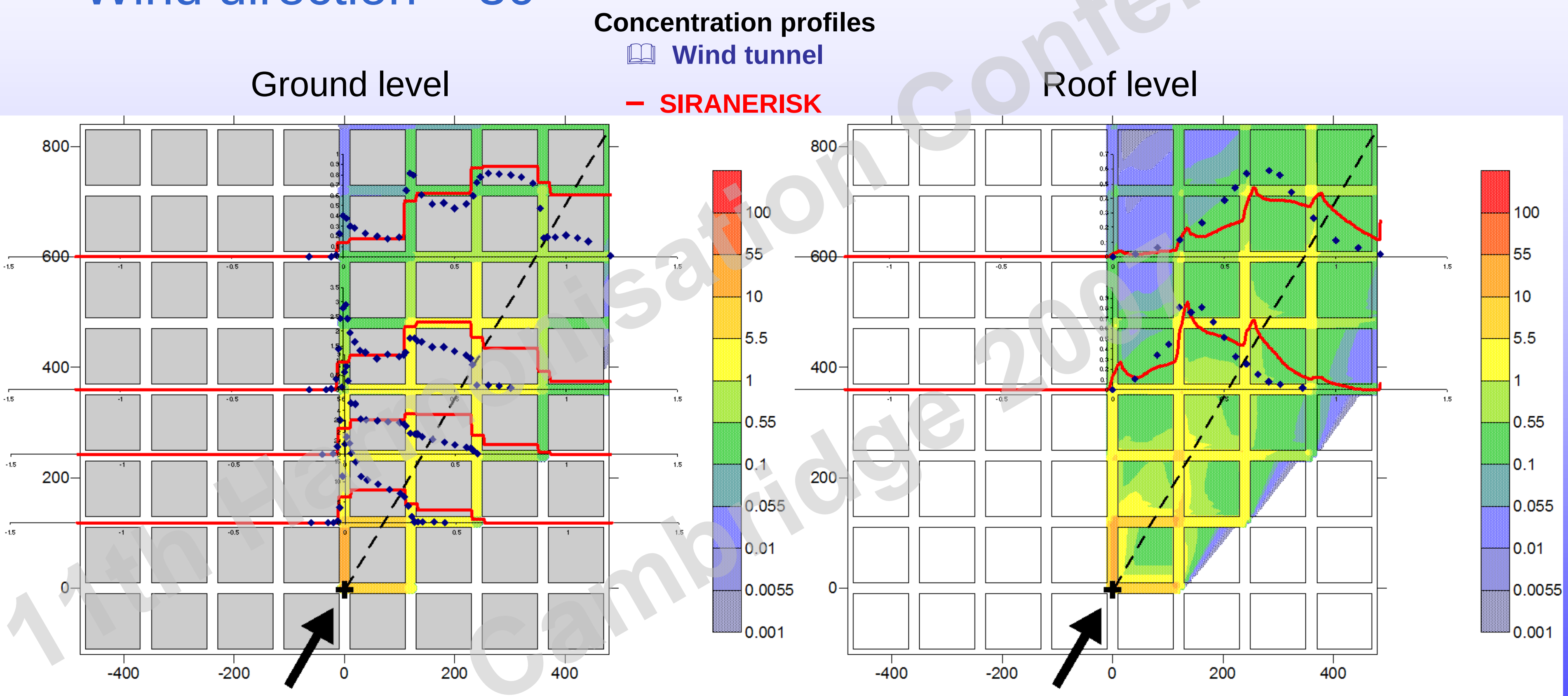




- Each puff is advected by the wind field
- Each puff spreads to model turbulent dispersion

# 4. Preliminary comparison SIRANERISK / measur.

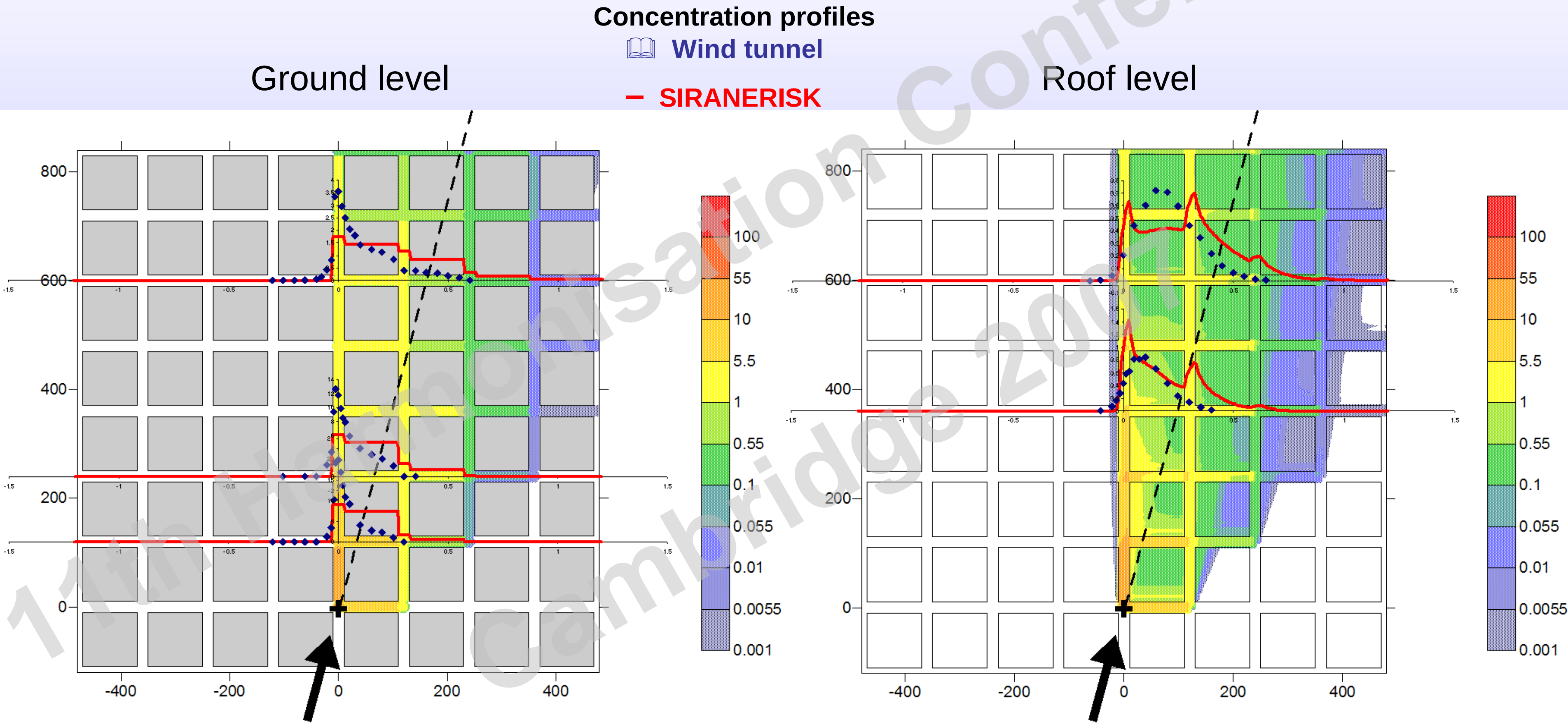
## Wind direction = 30°




- The model seams to represent the main features of the concentration field
- Need to parameterize the different exchange coefficients to compare more precisely

# 4. Preliminary comparison SIRANERISK / measur.

## Wind direction = 15°



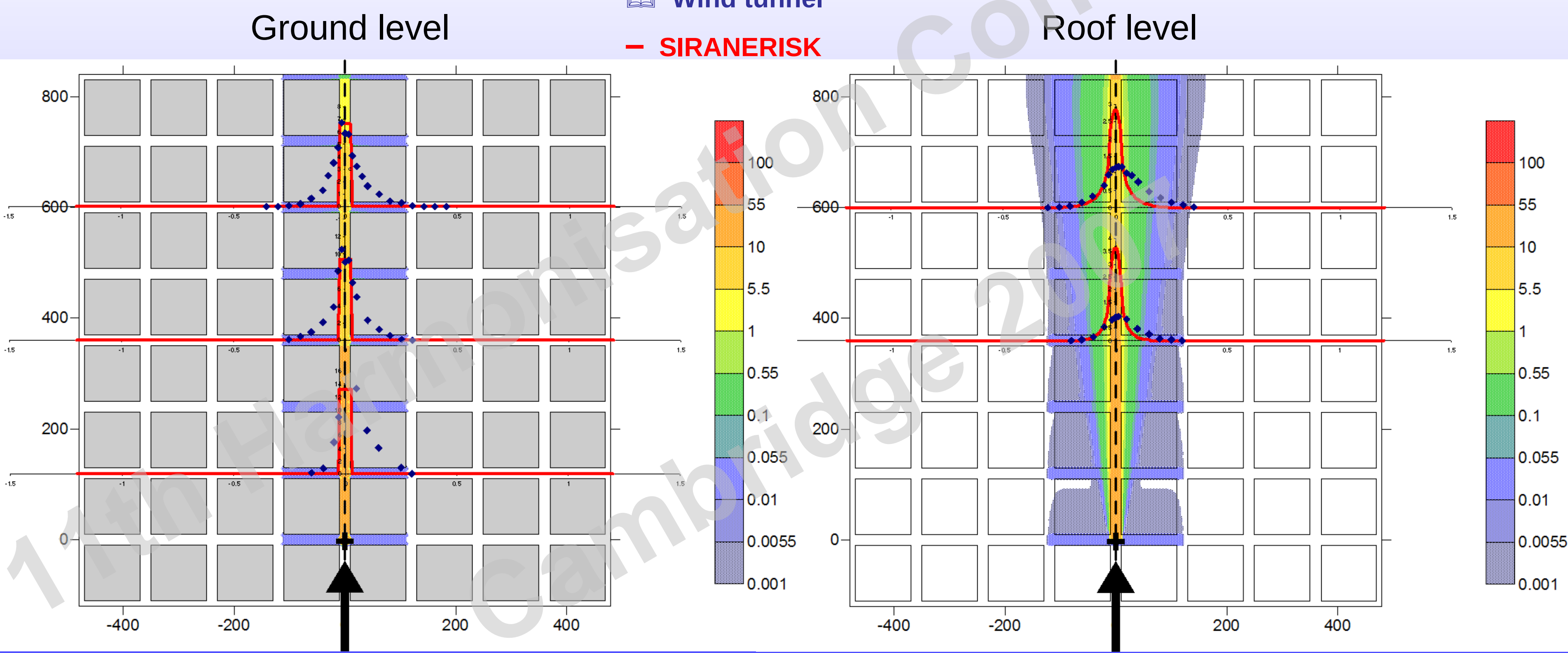
# 4. Preliminary comparison SIRANERISK / measur.

## Wind direction = 0°

Concentration profiles

Wind tunnel

SIRANERISK




- Difficulty to describe the lateral diffusion in this case → Pietro Salizzoni's presentation

# 5. Conclusions and perspectives

- Wind tunnel experimental study

  ➔ **Identification of main dispersion mechanisms**

- Development of an unsteady puff-canopy dispersion model, SIRANERISK, for operational purposes

  ➔ **Need to validate SIRANERISK model**

- A preliminary comparison between model and experiments shows that

  ➔ **SIRANERISK describes the main characteristics of the plume**

- Perspectives

  ➔ **Need to parameterize the different exchange coefficients**

  ➔ **Validation on unsteady dispersion cases**