Measurements and CFD simulations of flow and dispersion in urban geometries

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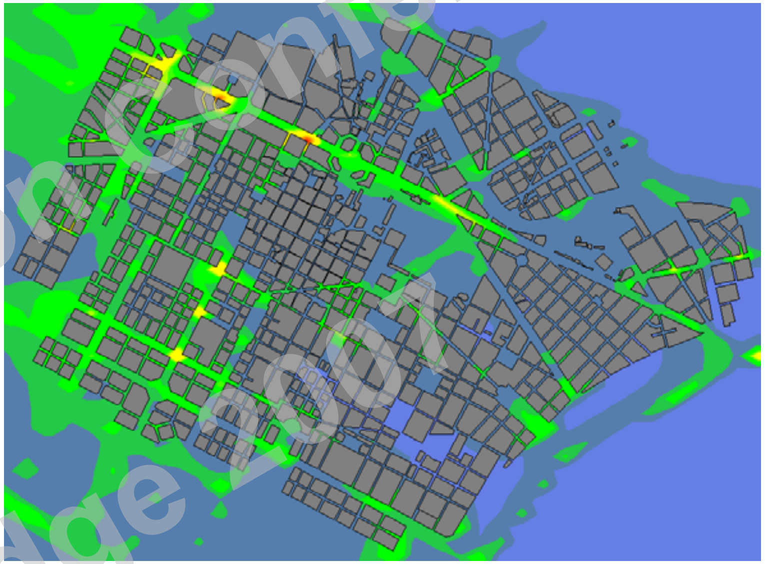
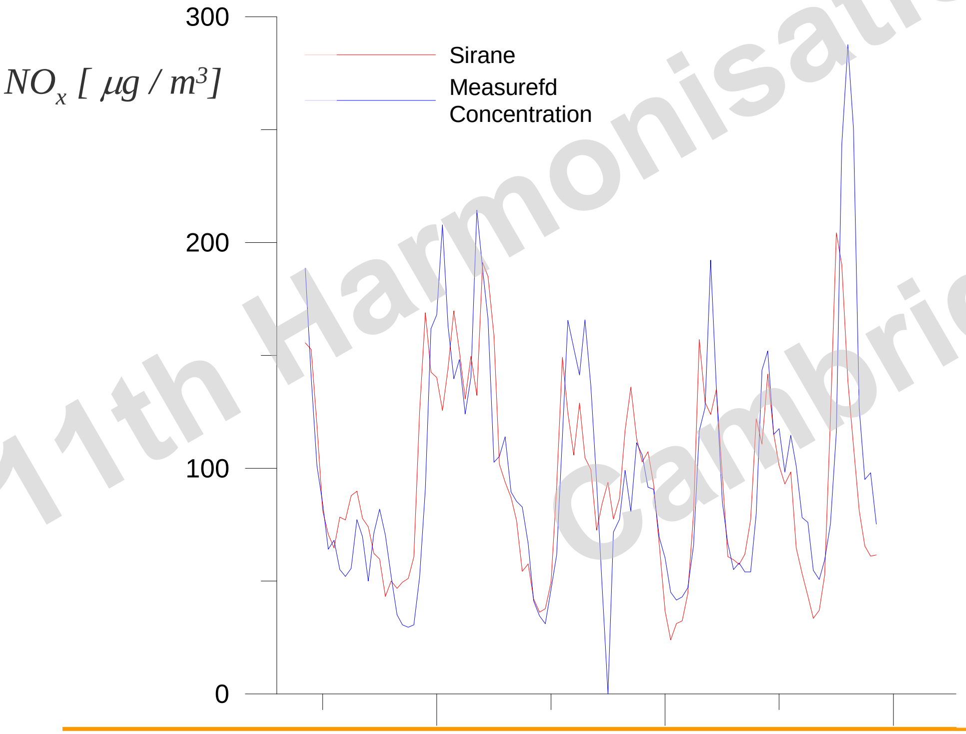
Introduction: Sirane / Siranerisk

Torino city center



SIRANE (Soulhac, 2000)

Operational model for air quality control and management in urban areas



t [hours]

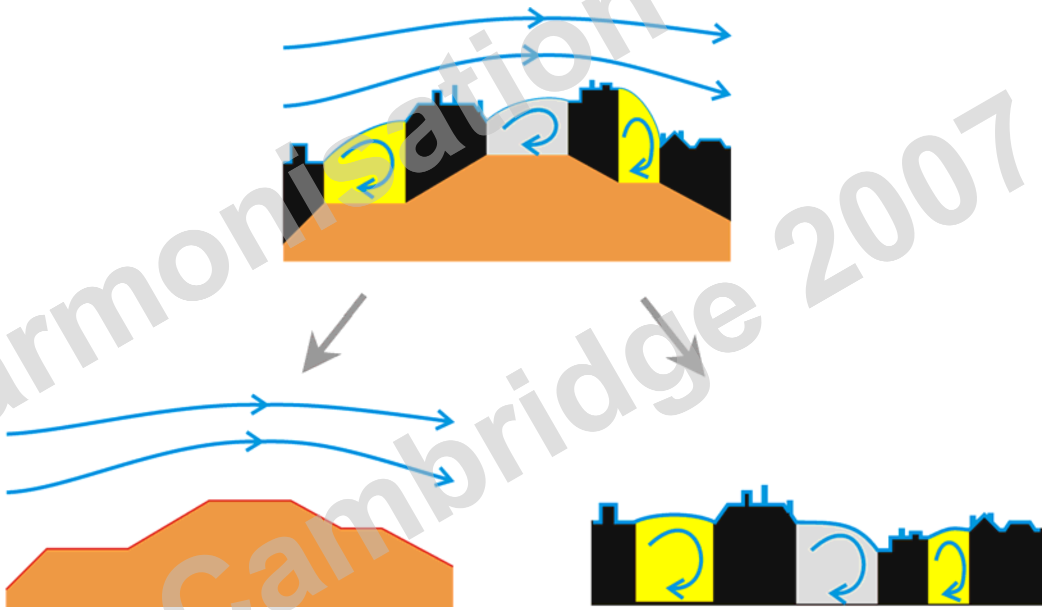
Urban dispersion modelling require the ability to predict the plumes behaviour in urban areas at local scale

Introduction: Sirane / Siranerisk

Decoupling of the computational domain

- ✓ **urban canopy**
- ✓ **external atmosphere**

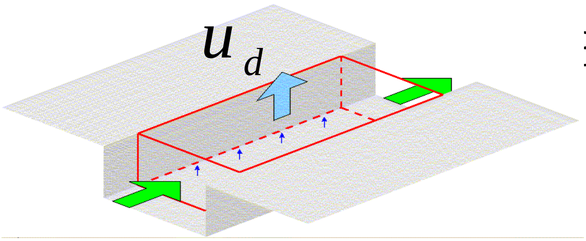
These two regions are characterised by different dispersion processes



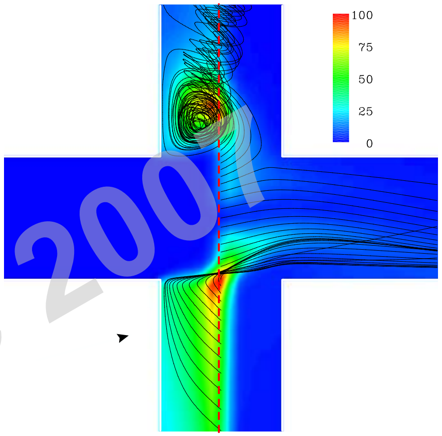
External atmosphere
↓
Puff model

Urban canopy
↓
Street network model

Mass exchange parametrisations



Between the urban canopy and the overlying atmospheric flow (Salizzoni et al., 2007)



b) Within the urban canopy

- intersections

c) Large squares

Can we define a boundary between urban canopy and the external flow?

Objective of the study

Investigate the pollutant exchange mechanisms within the urban canopy

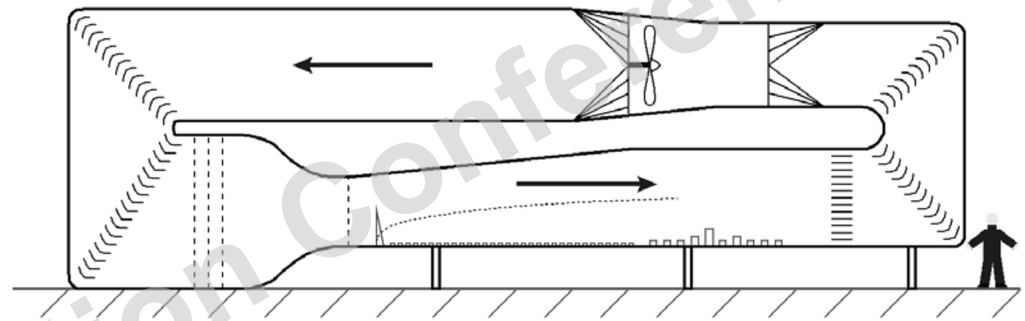
Wind-tunnel experiments and Computational Fluid Dynamics simulations

- ✓ investigate flow dynamics and pollutant dispersion in typical urban configurations, pointing out the influence of the geometrical layout
- ✓ to evaluate CFD's performance in simulating flow and dispersion in complex geometries

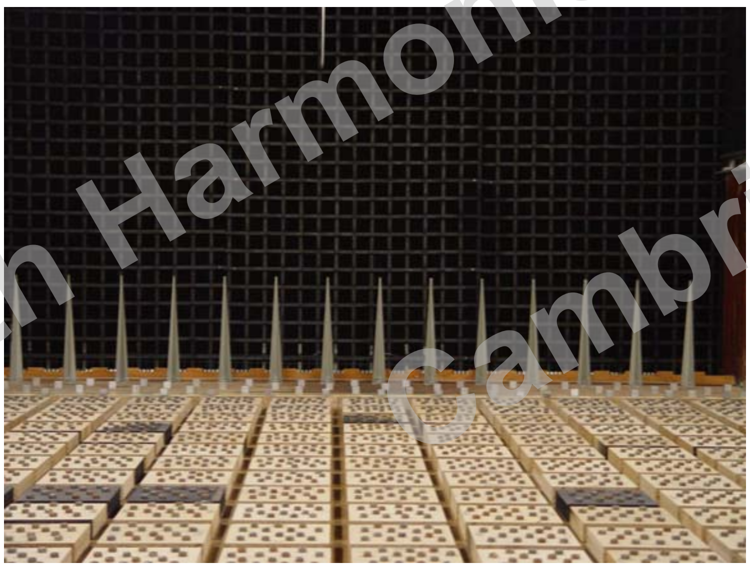
Experimental setting

Recirculating wind tunnel
at the Ecole Centrale of Lyon

Dimensions:
14m x 2.5 m x 3.7m



The external flow simulates a neutral atmospheric boundary layer



$$U(z) = \frac{u_*}{k} \ln\left(\frac{z-d}{z_0}\right)$$

- ✓ scale factor1:400
- ✓ friction velocity u_*=0.27 m/s
- ✓roughness length z_0=0.5 mm
- ✓displacement height d=35 mm

Experimental setting

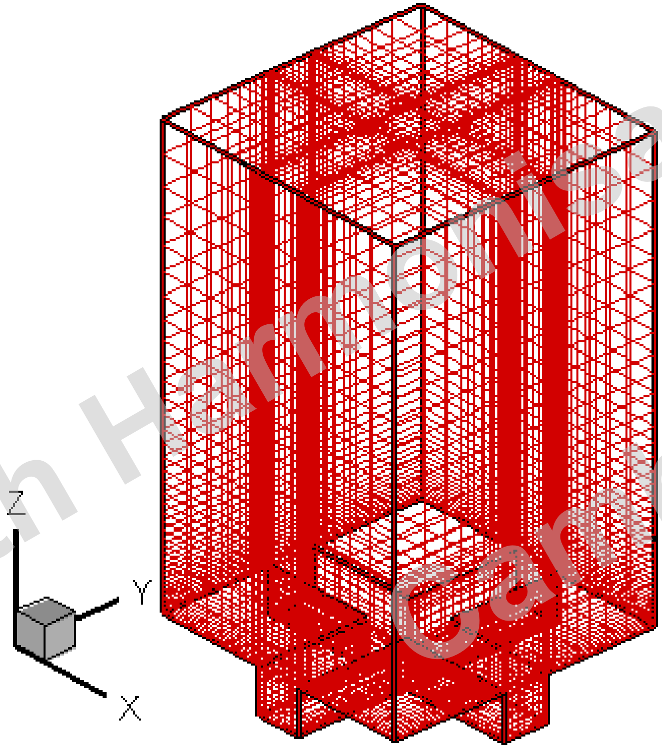
Flow field measurements have been performed by Laser Doppler Anemometer (3000 Hz)

Concentration measurements have been performed by Flame Ionisation Detector (300 Hz)

along the street parallel to y-axis at z=H/2

Numerical set up

Numerical simulations have been performed by means of RANS CFD code, based on the volume finite method



K-ε turbulence model

Periodic domain(1)

Inlet and outlet: periodic condition

Lateral and top: symmetrical condition

Bottom: rough wall condition

(1) Only for the intersection; for the square, as the configuration is not symmetric all the domain is simulated

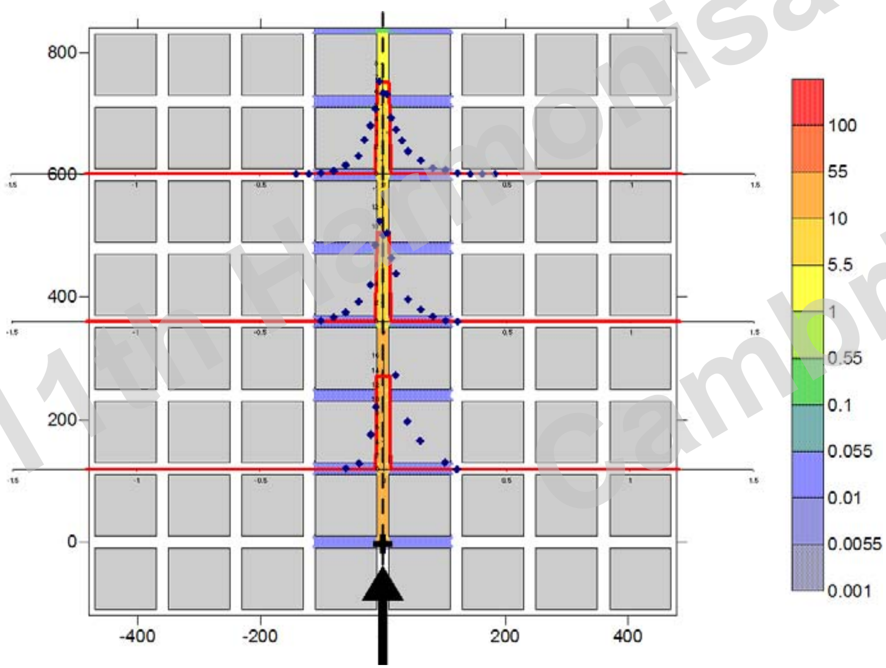
Problem setting – Mass exchange within the canopy

SIRANE / SIRANERISK

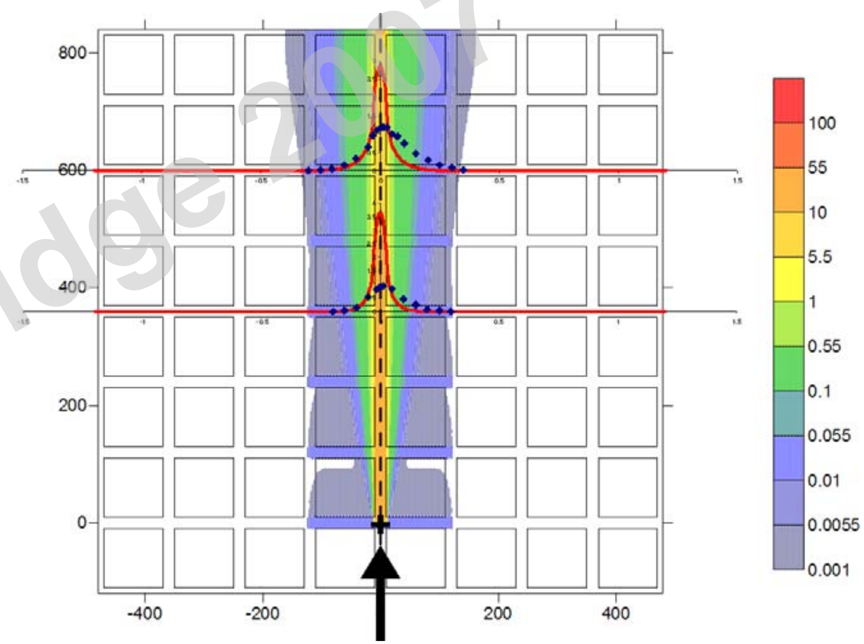
Critical condition for the dispersion model

Wind direction = 0°

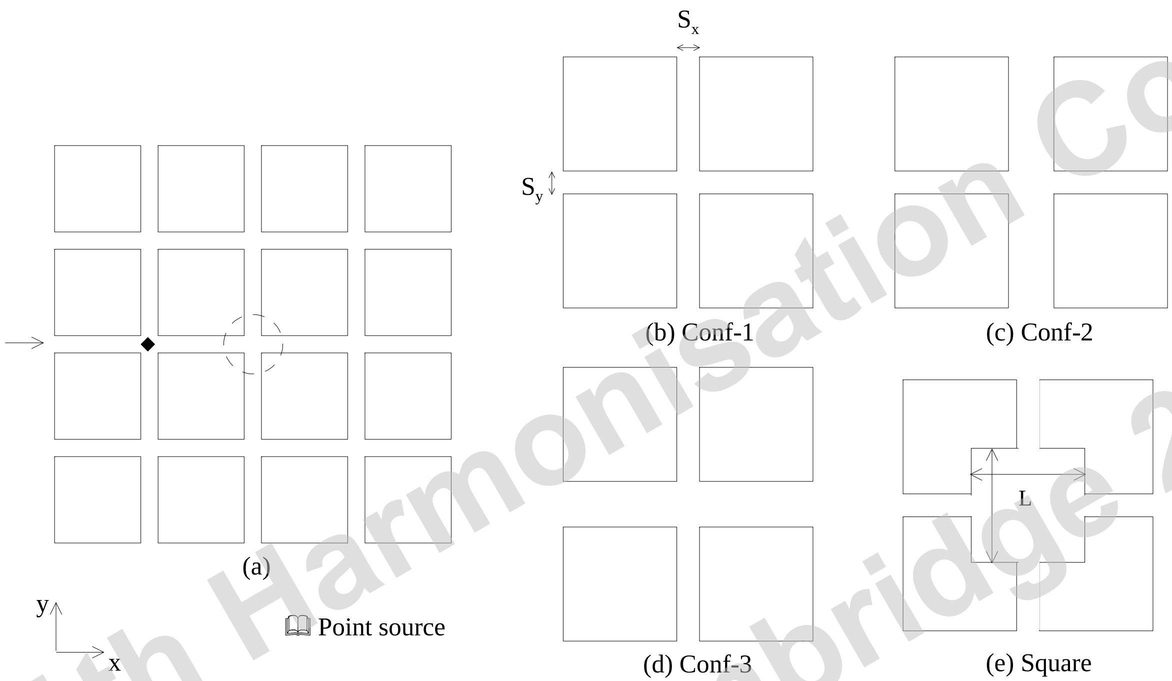
ground level



roof level



Configuration studied



Street intersection

<u>Conf-1</u>

$S_x = S_y = H$

<u>Conf-2</u>

$S_x = H \quad S_y = 2H$

<u>Conf-3</u>

$S_x = 2H \quad S_y = H$

Square

$S_x = S_y = H = 50$ mm

$L = 5H = 250$ mm

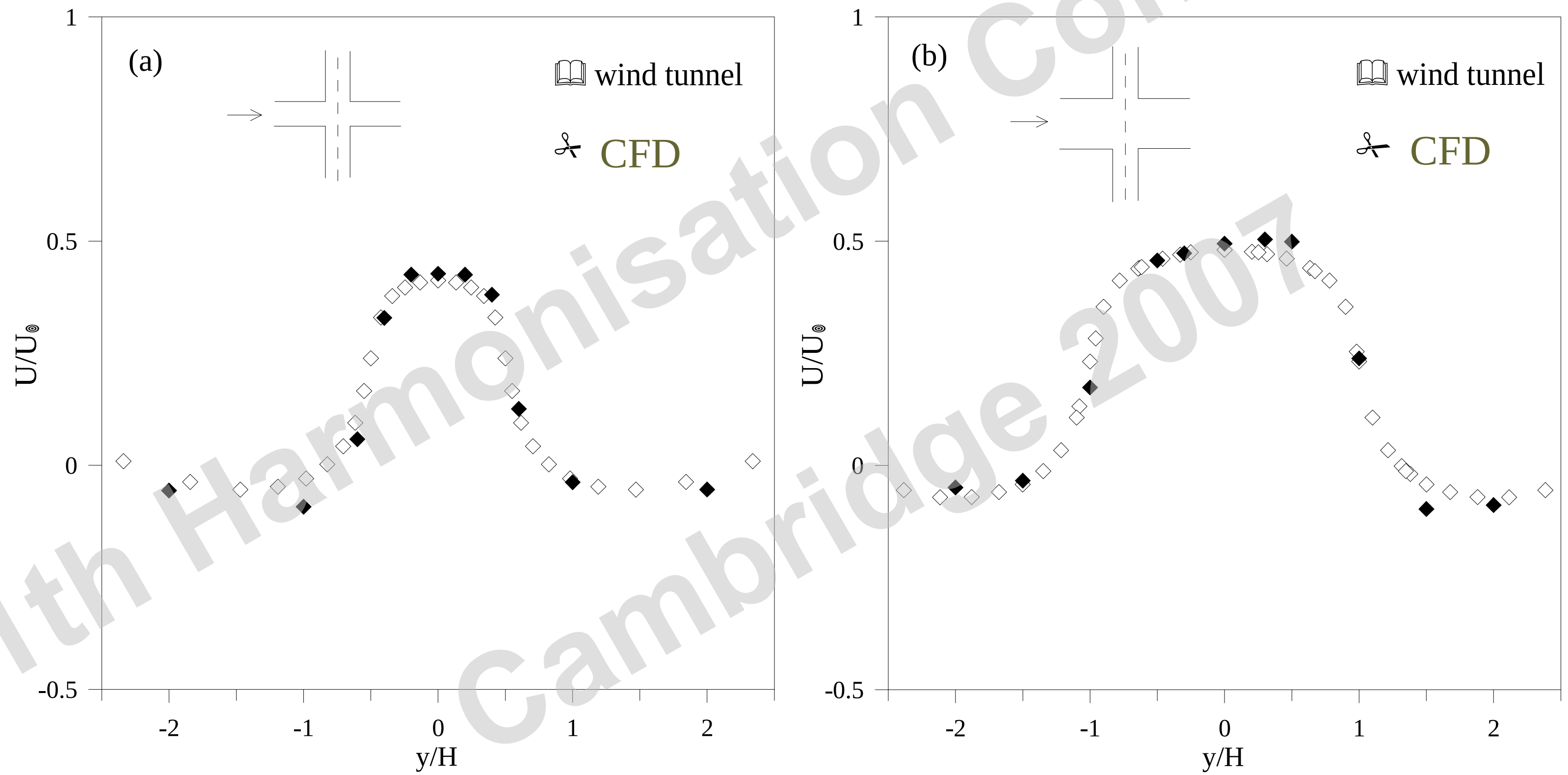
Wind parallel to x-axis

Obstacles simulating blocks of buildings : H=50 mm $L_x = L_y = 5H = 250$ mm

Variation of the **spacing S** between the obstacles

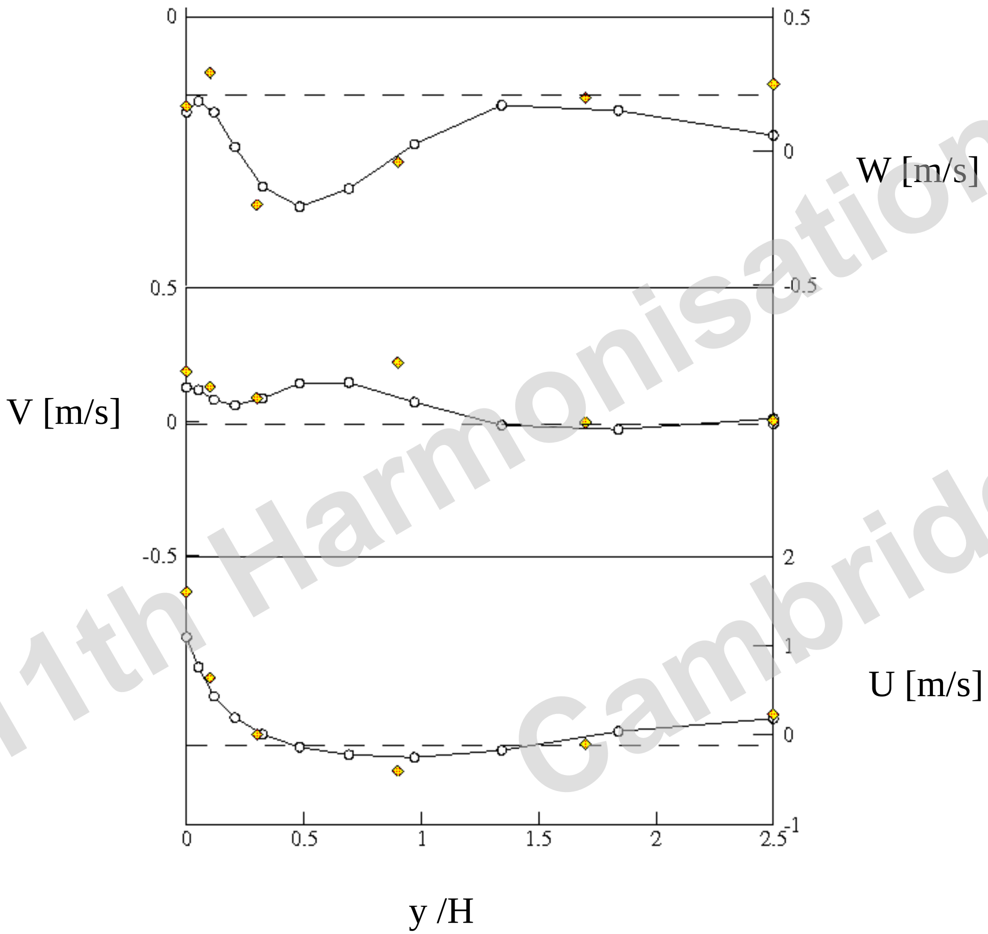
Results: intersection – velocity field

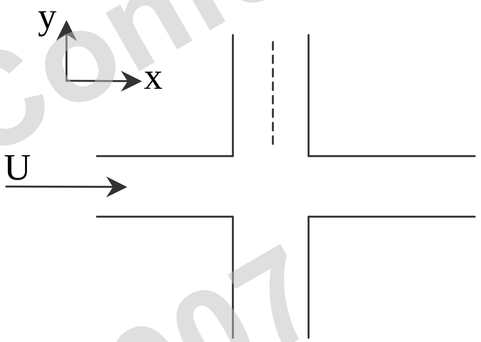
Transversal profiles at z=H/2 of the mean velocity U. (a) Conf-1; (b) Conf-3



Results: intersection – velocity field

The numerical results show good agreement with the experimental data

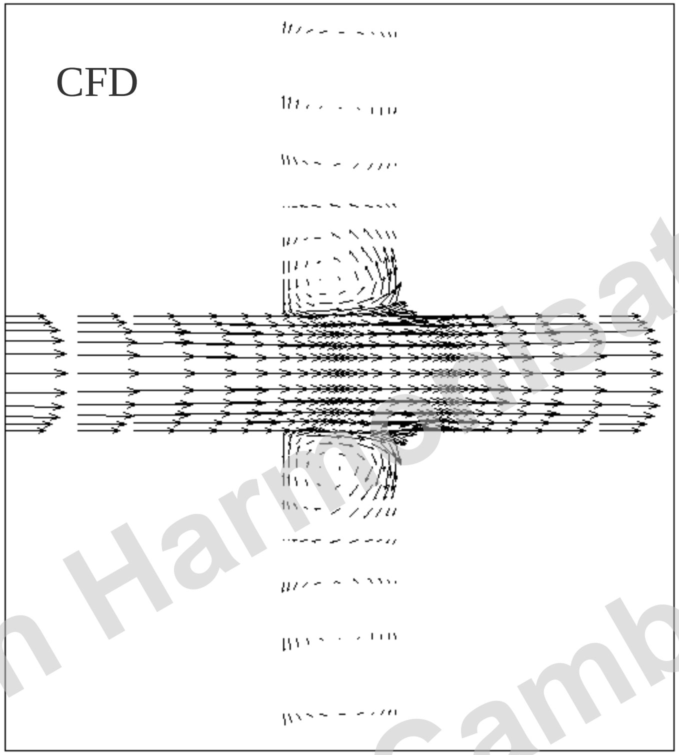


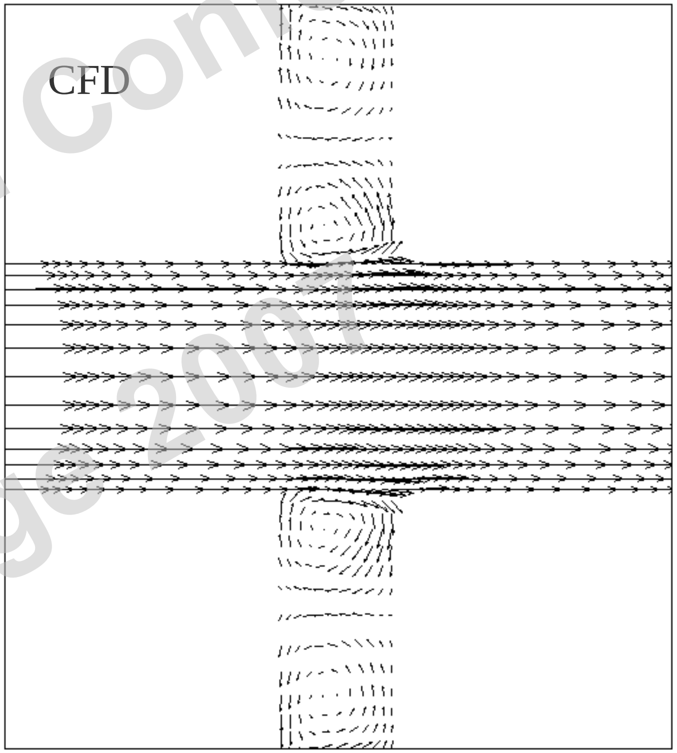


Transversal profiles at z=H/2 of the three component of the mean Velocity U, V and W in case of Configuration 1

Results: intersection – velocity field

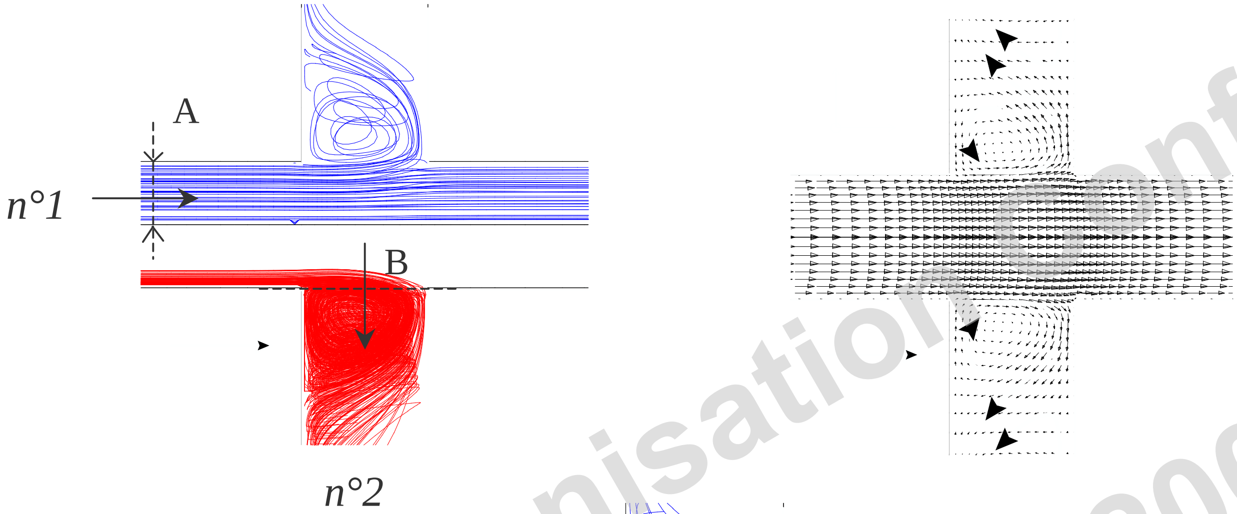
Mean velocity field in the horizontal plane at z=H/2 (a) Conf-1; (b) Conf-3



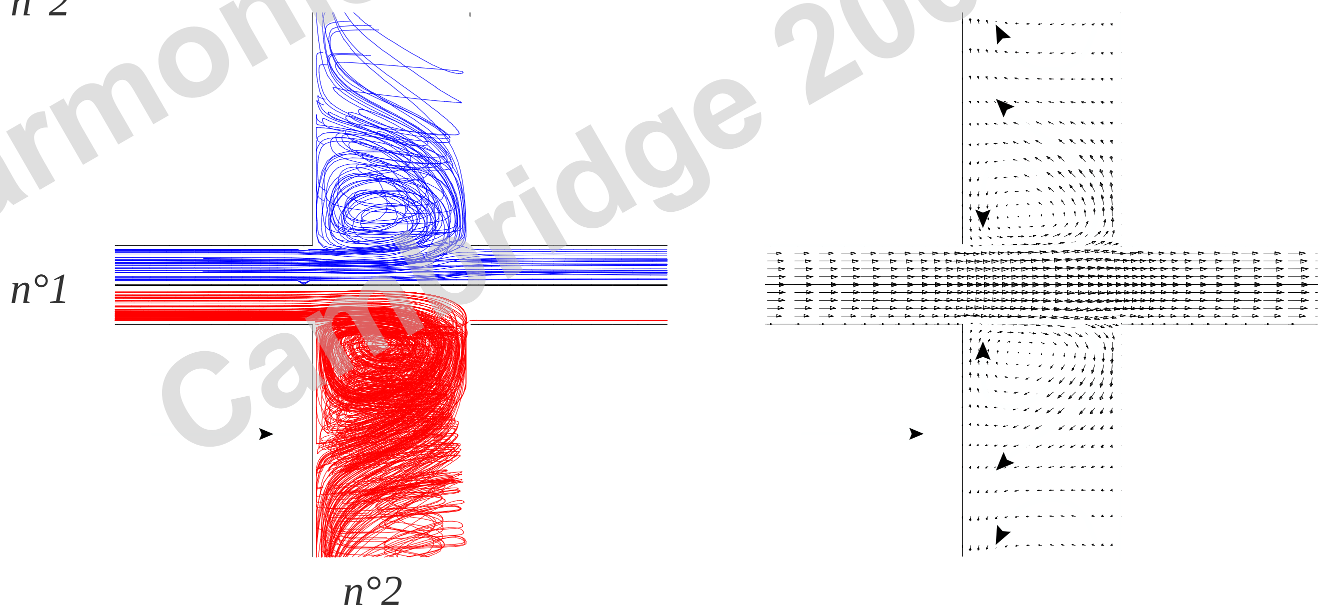


- **Similar topology for the different configurations**
- **The flow within the intersection is parallel to external wind and drives the recirculating motion into the adjacent streets**

Results: intersection – velocity field



<u>Conf-1</u>
Sx=2H
Sy=H



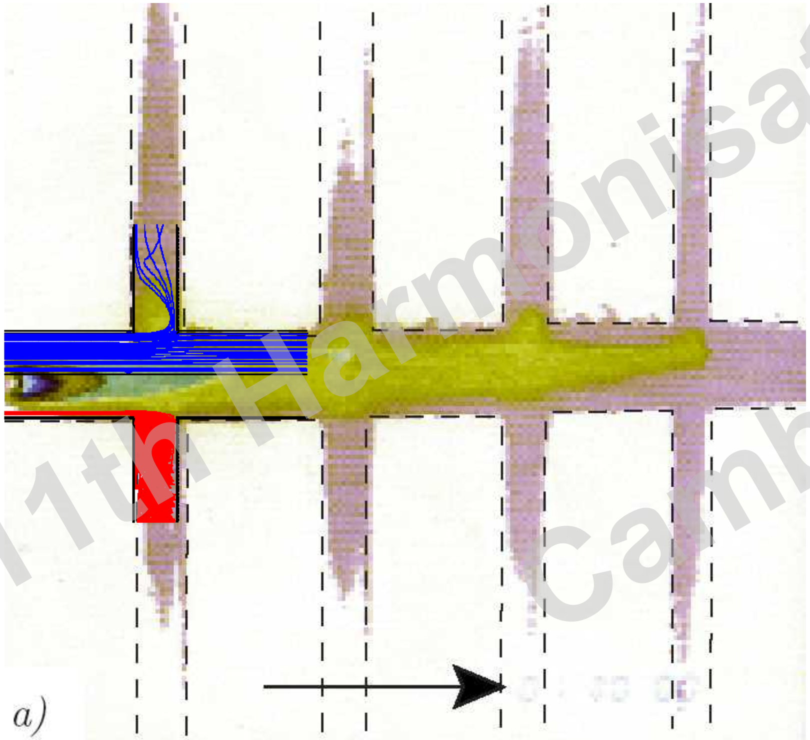
<u>Conf-2</u>
Sx=H
Sy=2H

Comparison with a previous study

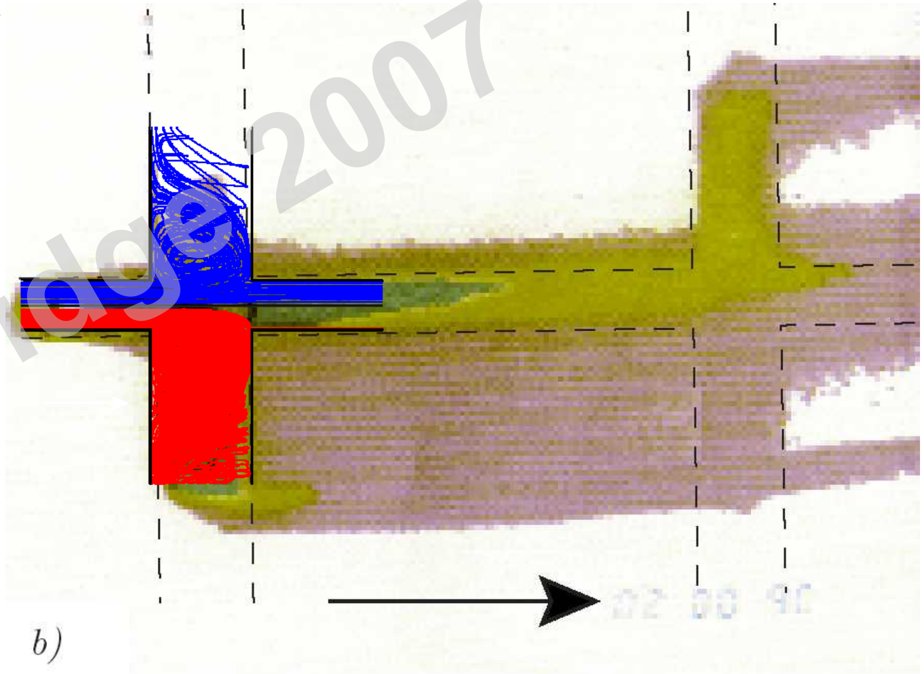
Hoydysh and Dabberdt (1994)

Config 1 : $S_x / S_y = 2$

Config 2 : $S_x / S_y = 1/2$



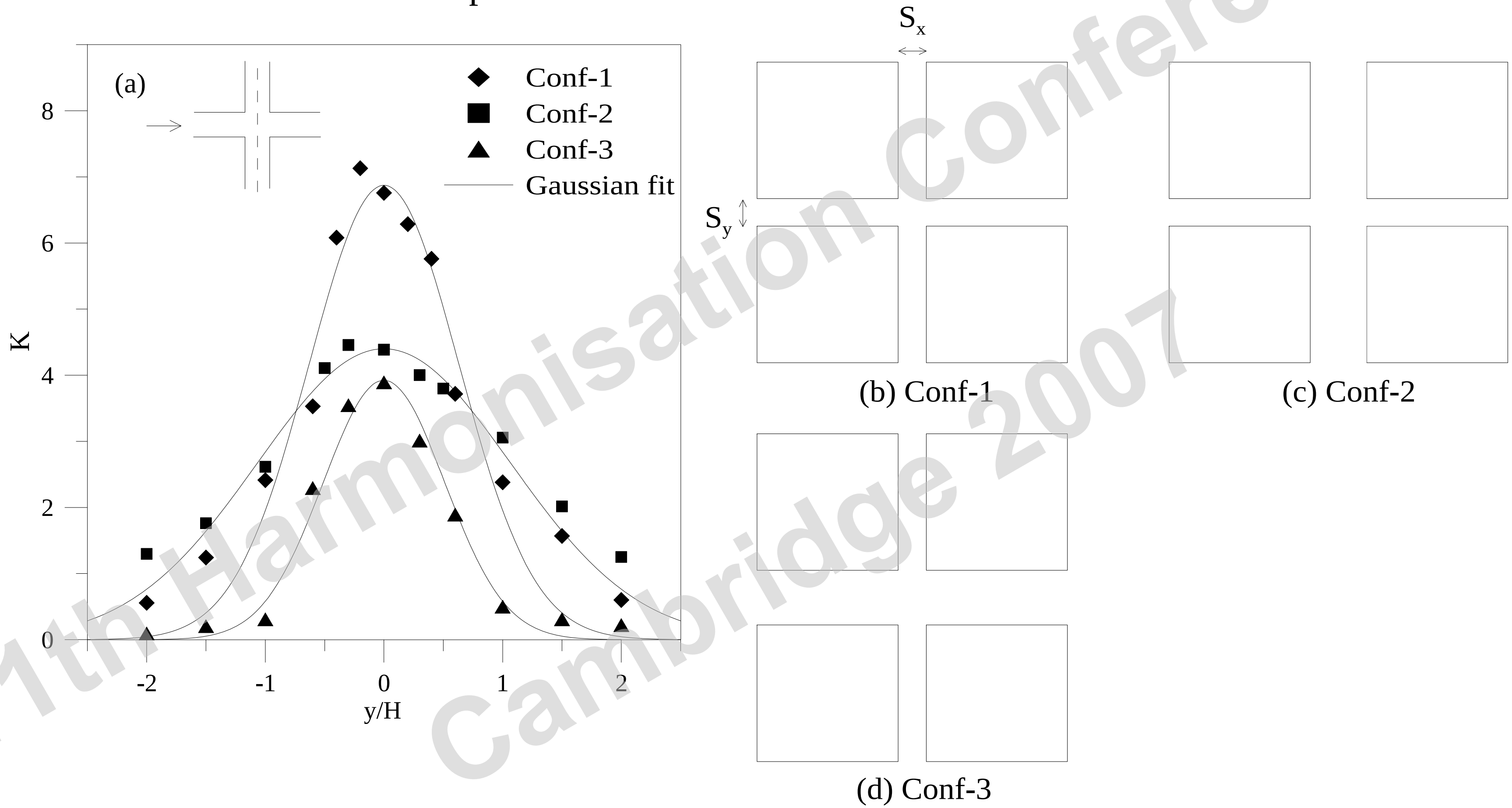
a)



b)

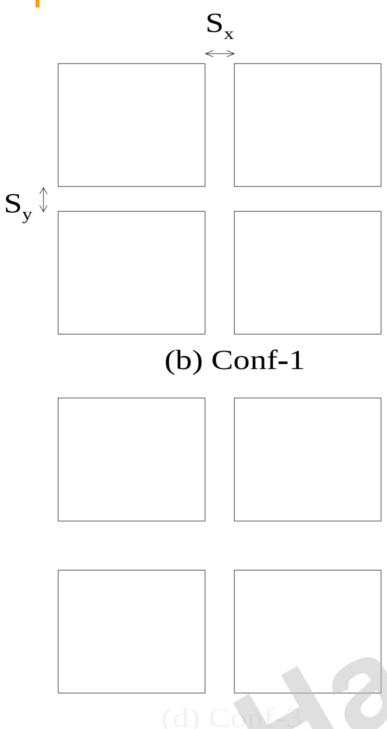
Results: intersection – dispersion

Transversal profiles at z=H/2 of the mean concentration K

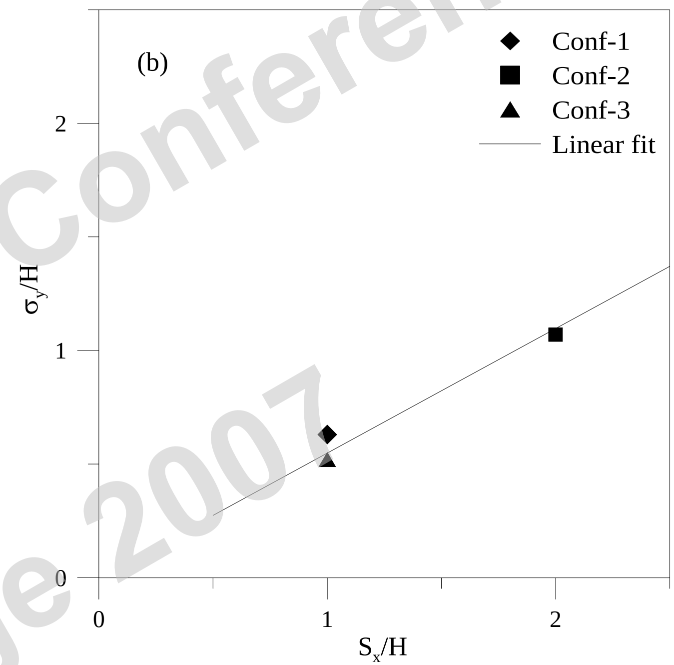


The horizontal dispersion is controlled by the dimension of the exchange interface (S_x)

Results: intersection – dispersion



Plume lateral spreading σ_y as function of the spacing S_x

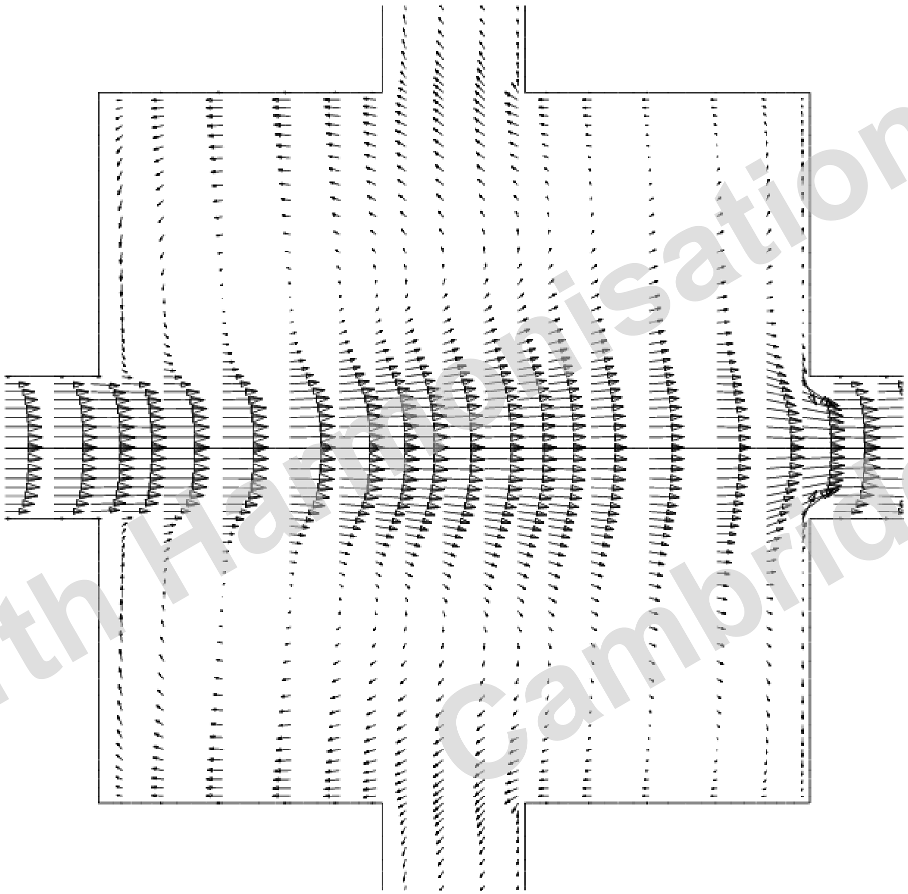


$S_x/H=1$ [conf-1, conf-3] **skimming flow regime:** limited exchange phenomena

$S_x/H=2$ [conf-2] **wake interference flow regime:** vortices induced by obstacles interact with mean flow, enhancing mass exchange and smoothing concentration distribution

Results: square – velocity field

Mean velocity field in the horizontal plane at z=H/2 (CFD)



Recirculation vortex at the leeward corners have been observed

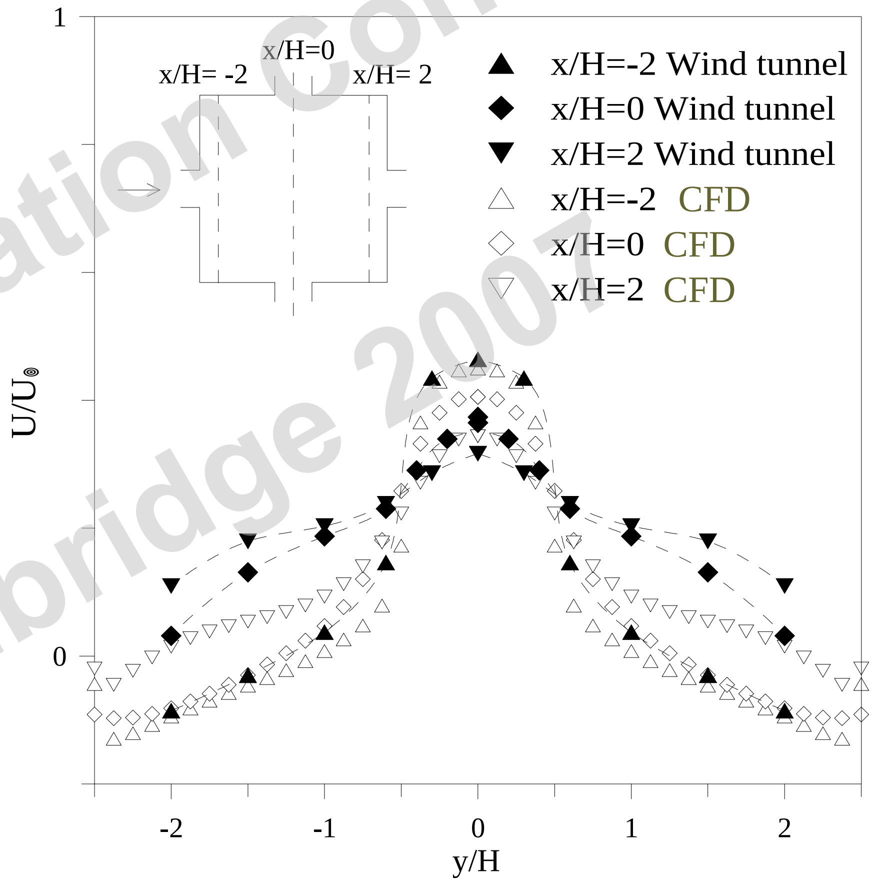
A mean flow directed towards the perpendicular streets seem to occur

Results: square – velocity field

Transversal profiles at z=H/2 of the mean velocity U at different positions

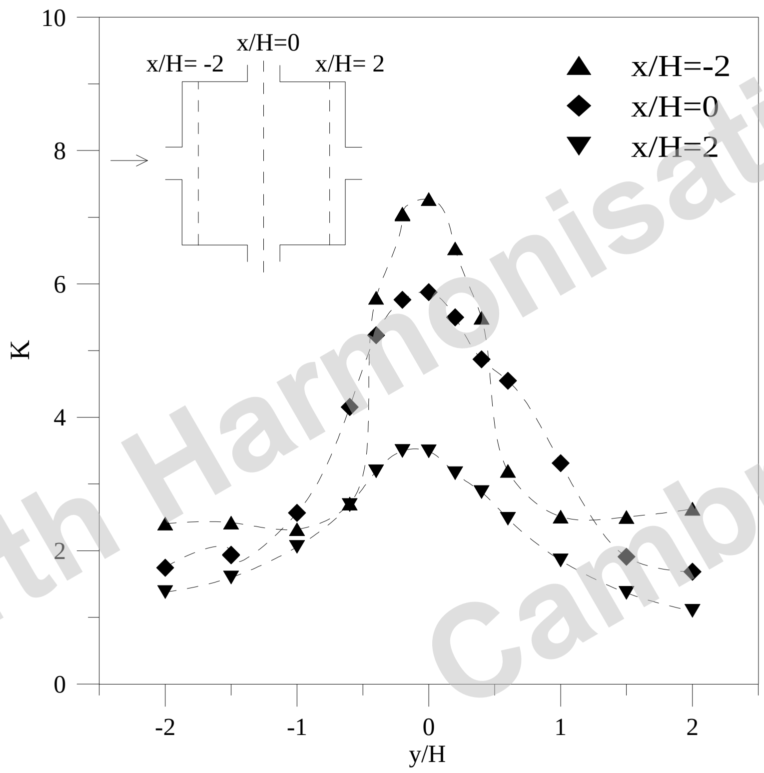
The numerical results show poor agreement with the experimental data in determining the extension of the recirculation cells

Experiments don't confirm the existence of a flux directed towards the perpendicular streets



Results: square – dispersion

Transversal profiles of mean concentration for different positions at z=H/2



Mean component of the velocity field transports pollutants witin the intersecton along the stream-wise axis

Fluctuating component of motion diffuses pollutants and makes homogeneous the concentration within the square

Conclusions

Flow patterns and plume spreading are strongly affected by the geometrical layout.

For $S_x/H=1$ skimming flow regime takes place; decoupling between the flow within the intersection and that into the adjacent streets : limited the mass exchange.

For $S_x/H=2$ a wake-interference flow regime; interaction between shear generated insabilities and recirculating flow in the adjacent street : enhanced mass exchange.

Numerical simulations describe quite well flow pattern in complex geometries when the obstacles are sufficiently packed together.