Ecole Centrale de Lyon
Centre d'Etudes des Tunnels

Modelling pollutant dispersal at the portals of road tunnels

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Contents

- Problematic of pollution dispersion around a tunnel exit
- Wind tunnel study
  - Experimental setup
  - Presentation and analysis of the results
- Simple empirical model based on a line source approach
- Conclusions and perspectives

Problematic

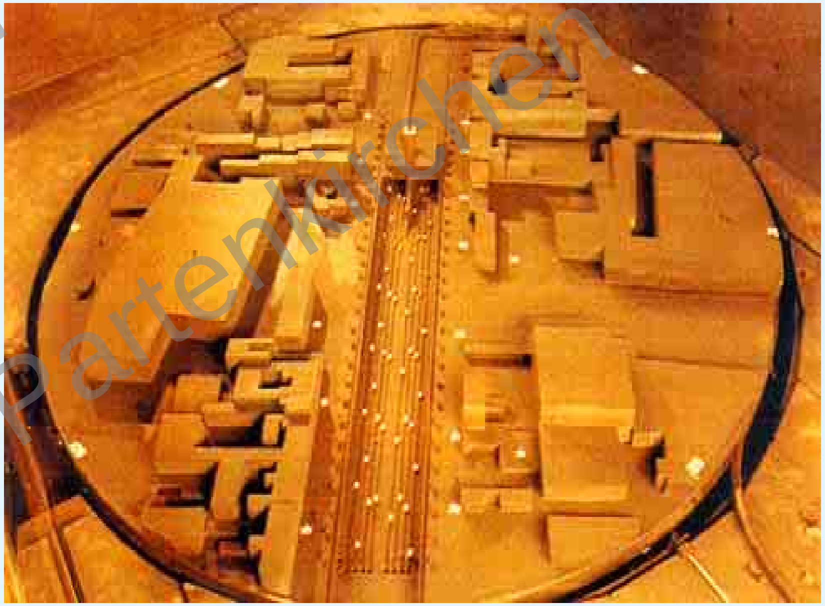
- Specificities of a road tunnel portal exhausts:
  - Complex three-dimensional flow caused by the interaction between a wall jet and an atmospheric boundary layer;
  - Properties of the pollutant source (portal geometry, steadiness of the jet);
  - Small scale (hundreds meters).

- « Classical » processes:
  - Thermal effect: atmospheric stratification, jet temperature.
  - Traffic: entrainment, turbulence generation;
  - Chemical reactions;
  - Buildings.

Existing solutions

- Wind tunnel or hydraulic flume modelling: reliable but expensive at first stage of a project;
- CFD: also inappropriate at first stage of a project;
- Analytical and empirical models: easy to use but still limited to simple or particular cases (Ukeguchi-1978, Mlus, Burgi-1996, Matsumoto-1998, Oettl-2002)

Small scale model of a tunnel portal



Approach chosen

A comparative study on a real case has been done and have shown poor results ⇒ Real problem too complex

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Necessity to study a simple case to obtain a better understanding of the phenomena involved in the interaction of the jet and the ABL.

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Study case: simple partially covered cutting (common case in urban environment) without any effects of stratification, traffic, chemistry or buildings

⇒ 2 steps:

1. Experimental study in a wind tunnel,
2. Development of a simple model

Wind tunnel study

- Objectives:
  - Characterize the flow and the dispersion following the study parameters:
    - Orientation between the wind and the tunnel axis.
    - Speed ratio U_r/V (initial jet speed on wind speed);
  - Obtain a database to build a simple model;
  - Define a test case for the specific problem of tunnel portal.

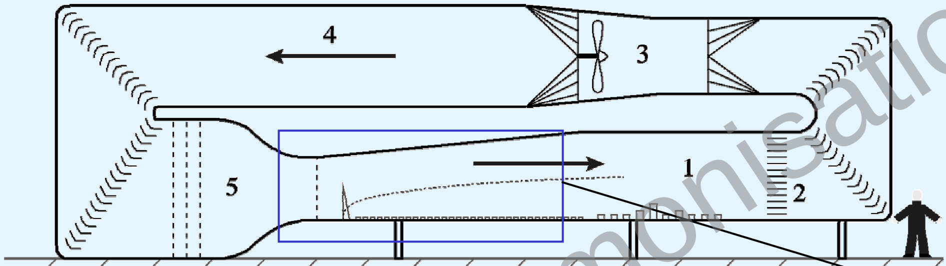
- Campaign realized: 28 cases studied with 4 ratios (1/4, ½, 1 and 2) and 7 orientations (between 0° and 180° with a 30° step).

- Measurements techniques:
  - Flame Ionisation Detection (tracer gas used is ethane);
  - 3-components Laser Doppler Anemometry.

Wind tunnel study

Experimental set-up

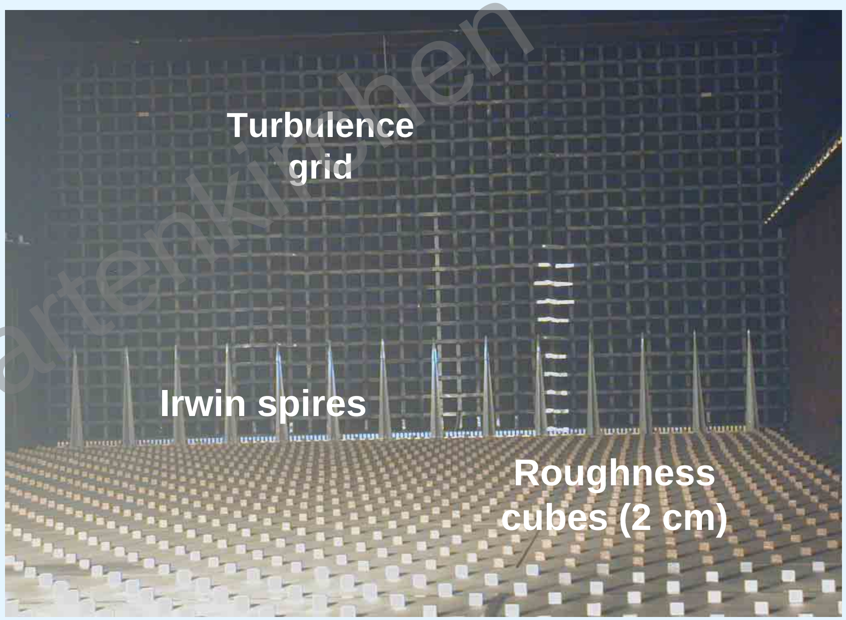
Wind tunnel



1) Test section
2) Heat exchangers
3) Fan
4) Diverging section
5) Tranquilisation room, converging section and turbulence grid

Dimensions of the test section:
Length=14 m, width=3,7 m and height=2 m

Generation of the boundary layer



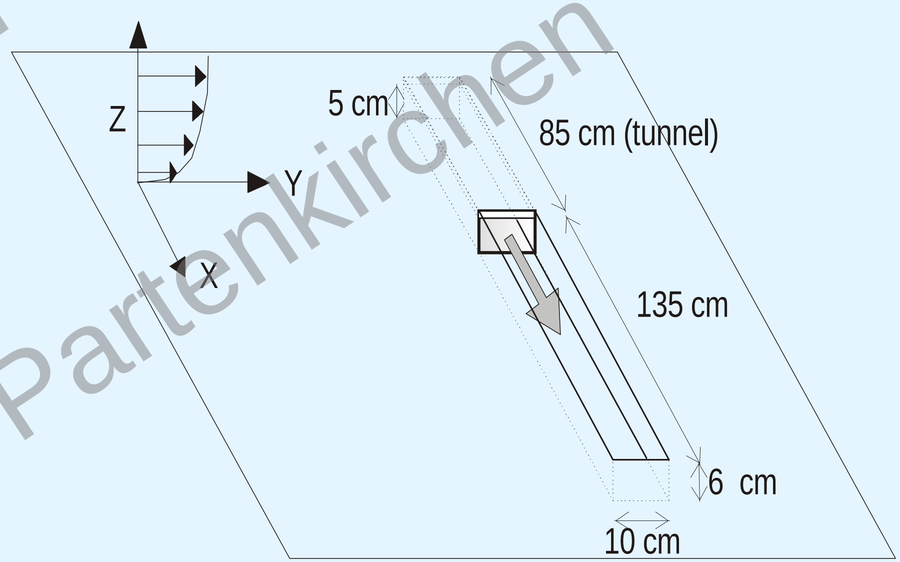
Wind tunnel study

Small scaled model studied

•Objective: represent at a 1/100 scale a cut-and-cover followed by a street canyon;

•Description: tunnel of rectangular section (5cm-high by 10 cm-large). The street canyon is 6cm-high and 135 cm-long.

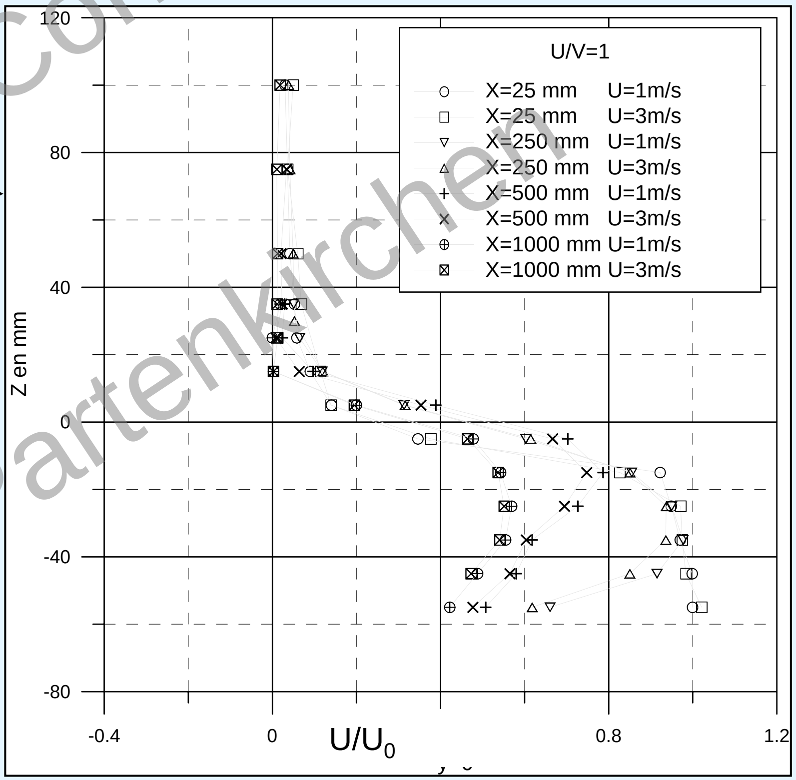
•Smooth boundary layer with a roughness height of 0,14mm.



Wind tunnel study

Preliminary experiences

- Verification of the representativity of the ratio U_r/V
- Verification of the Reynolds-independency
- Homogenisation of the jet exhausted at the exit



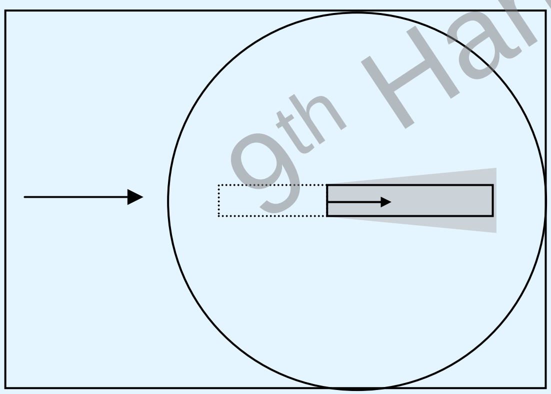
90° - Vertical profiles of the along-the-street component

Wind tunnel study

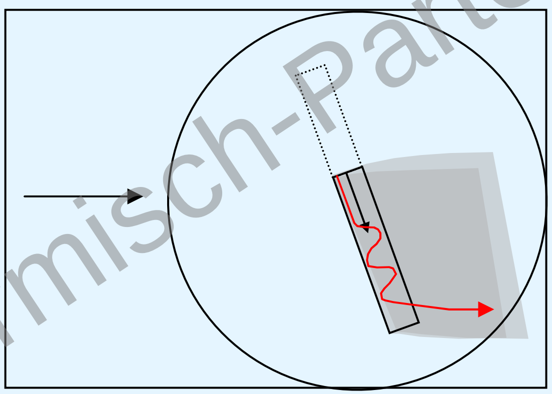
Results

3 differents types of flow depending on the orientation between the wind and the jet:

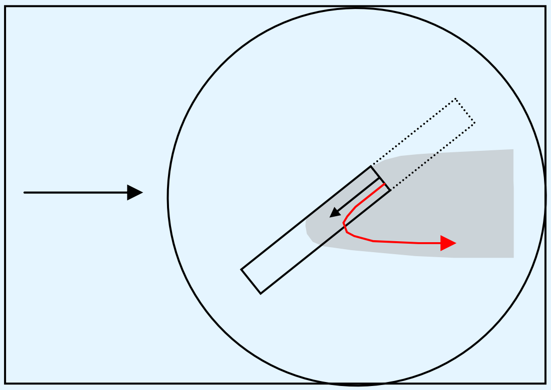
0°: weak spreading of the jet outside the street. Pollutants remained trapped in the street.



between 30° and 90°: a recirculation appears in the street canyon, creating an helicoidal flow.



between 120° and 180°: reversal of the jet at a distance growing with the ratio U_r/V.



Wind tunnel study
Orientation of 0°

- Weak impact outside the street.
- Poor dispersion occurs high levels of pollution far from the tunnel exit.
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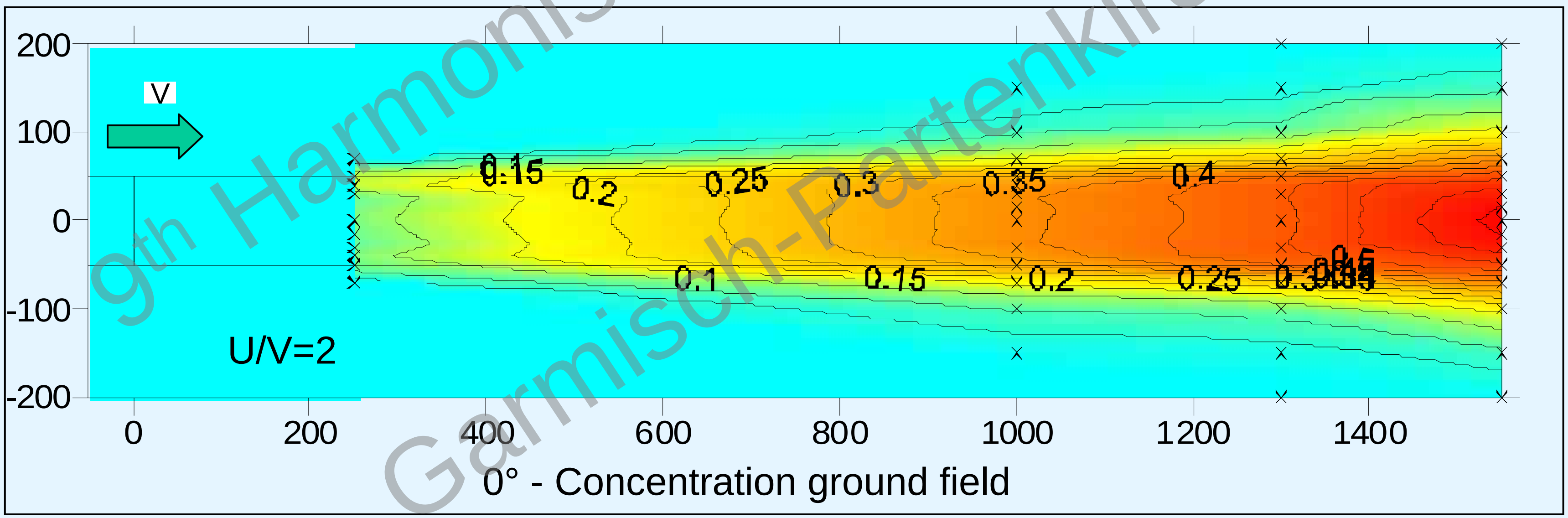
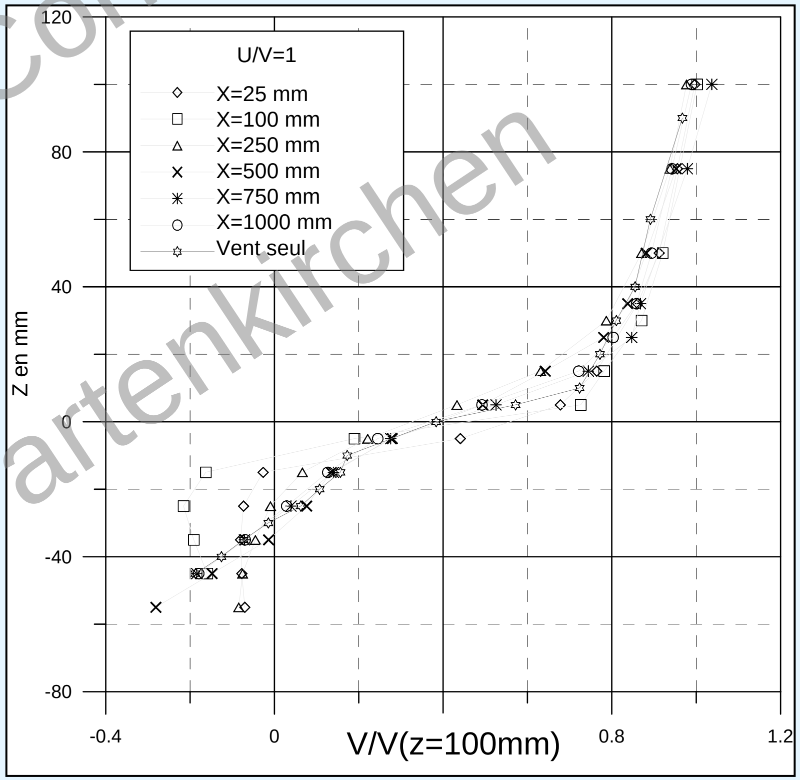


Wind tunnel study

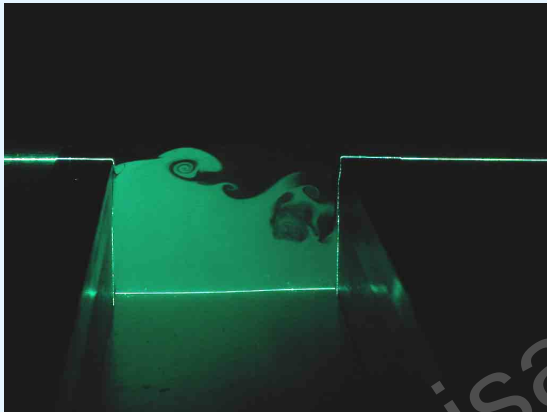
30° to 90°

- Into the street, 2 zones can be distinguished:
  - Firstly, a transitory zone with strong gradients of concentration and speed in a section of the street
  - Then a zone with an established recirculation with across-the-street components independant with the distance from the tunnel mouth and where concentration and along-the-street speed become more uniform in a section. The speed jet continues to decrease with the distance.
- The recirculation depends only on the external wind field and is the one observed in the same conditions without the jet.



90° - vertical profiles of transverse velocity at different distances

Visualization of the flow at growing distances from the tunnel exit



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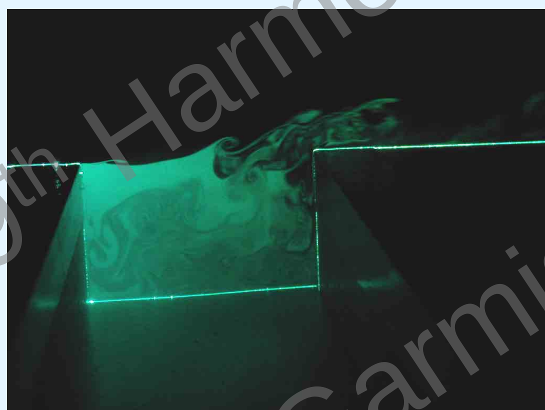

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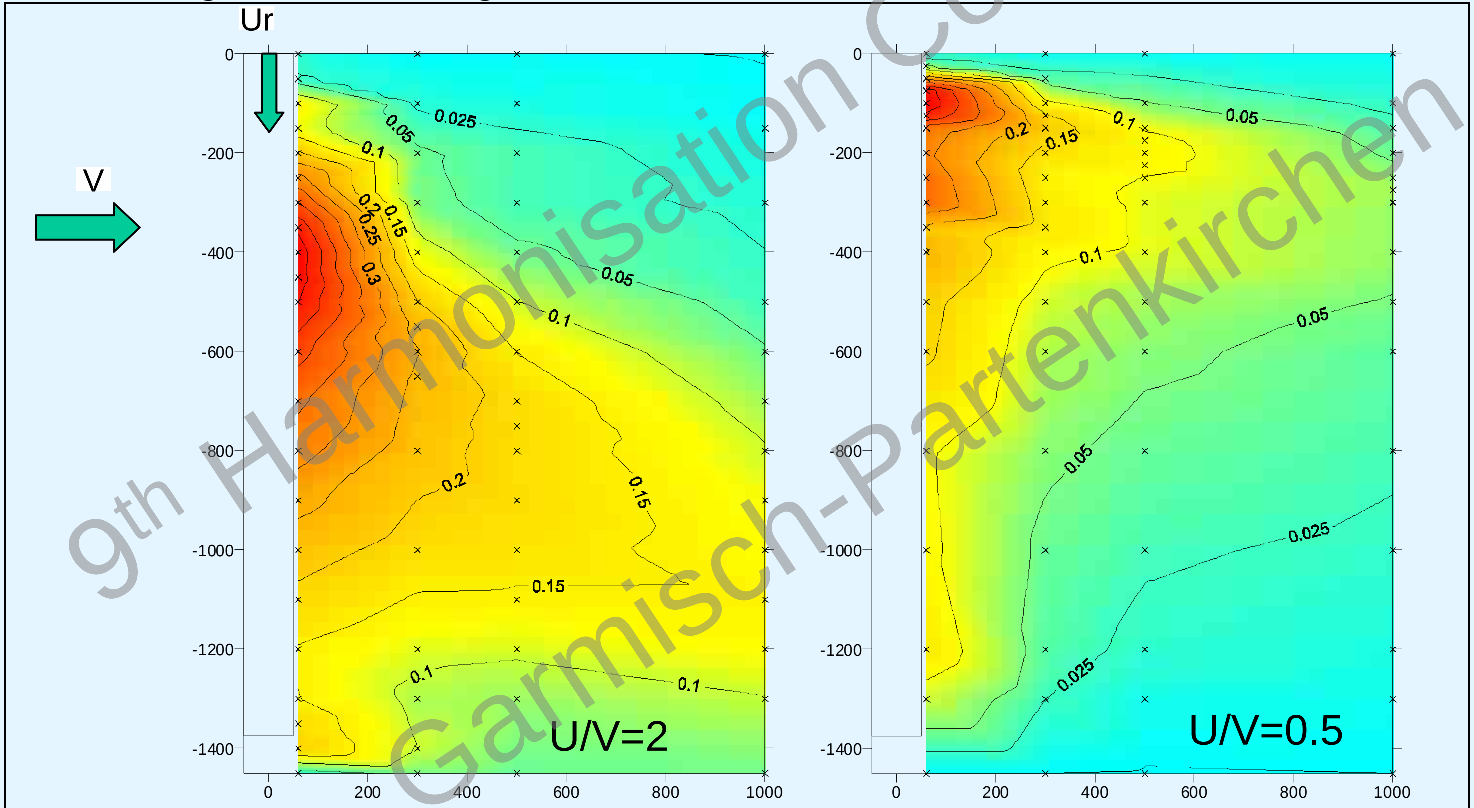
Wind tunnel study

- Downwind the street, the behavior of the plume depends on the speed ratio.
- The exchange of pollutant at the interface presents similar patterns for differents cases with a peak at a distance from the exit growing with the speed ratio and decreasing with the angle.

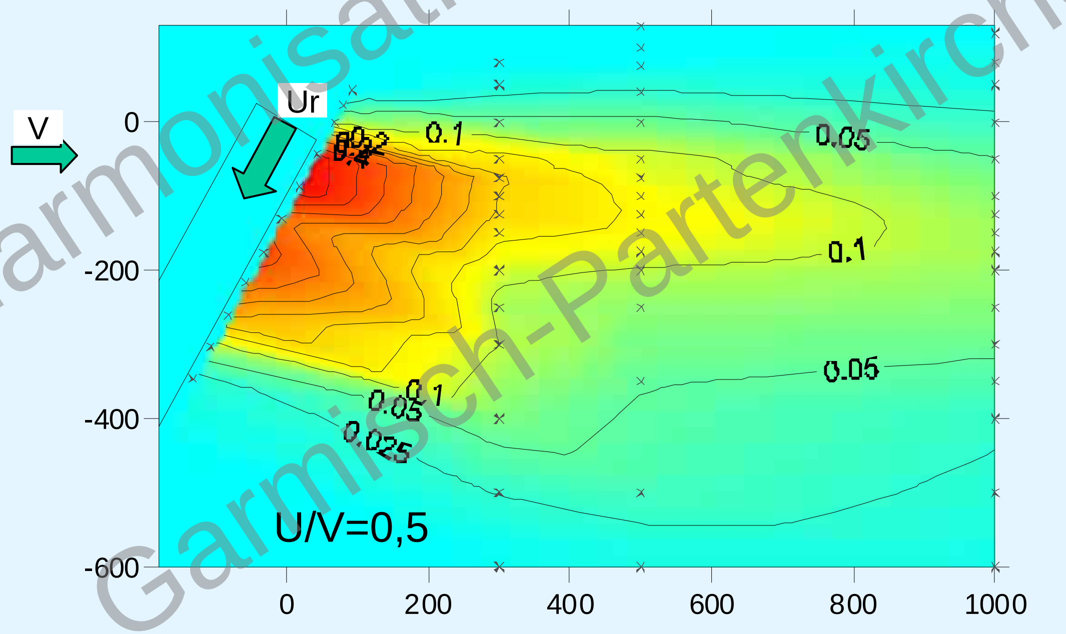


90° - Concentration ground field

Wind tunnel study

Wind opposed to the jet

- No more recirculation in the street
- Enhanced vertical dispersion due to the reversal of the jet



120° - Concentration ground field

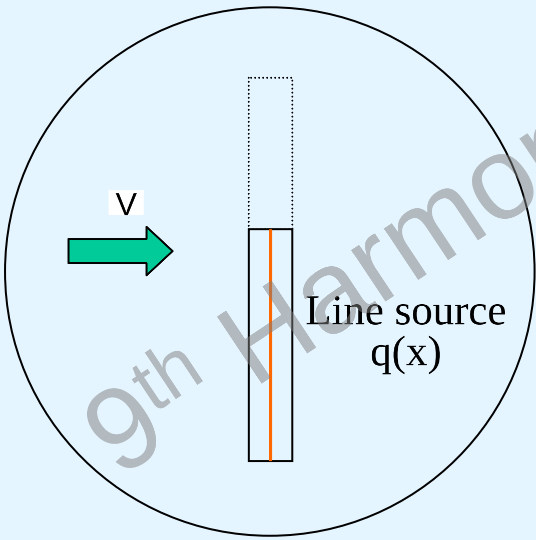
Wind tunnel study

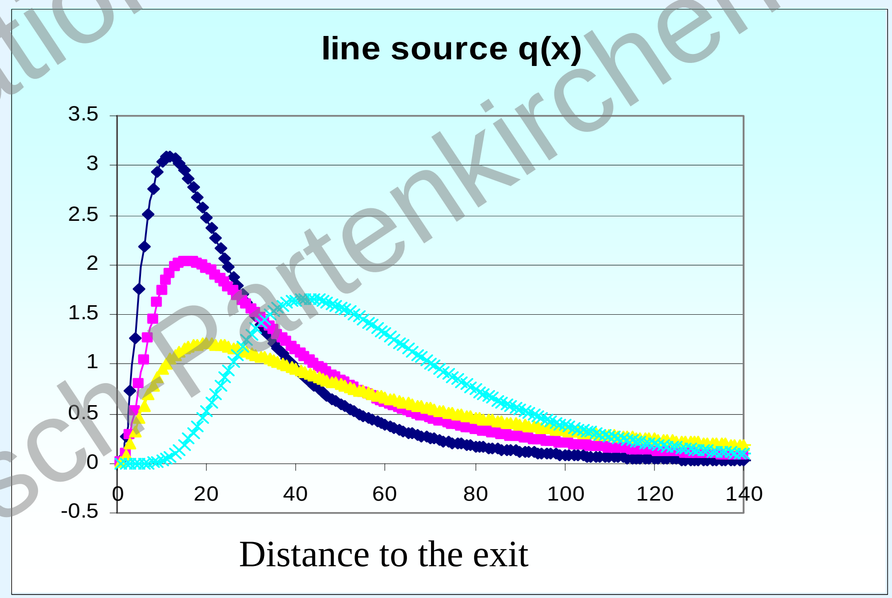
Conclusions of the wind tunnel study

- Obtention of an important database (speed and concentration) which can be used as test cases to validate some models.
- Differents types of flows can be identified as function of the wind orientation.
- Comparing with a tunnel on a flat terrain, the jet is channeled by the cavity
- As the jet has little influence on the flow outside the street, it appears that the impact may be simply modelled by considering the tunnel exit as an equivalent line source on the axis of the street.

Simple empirical model

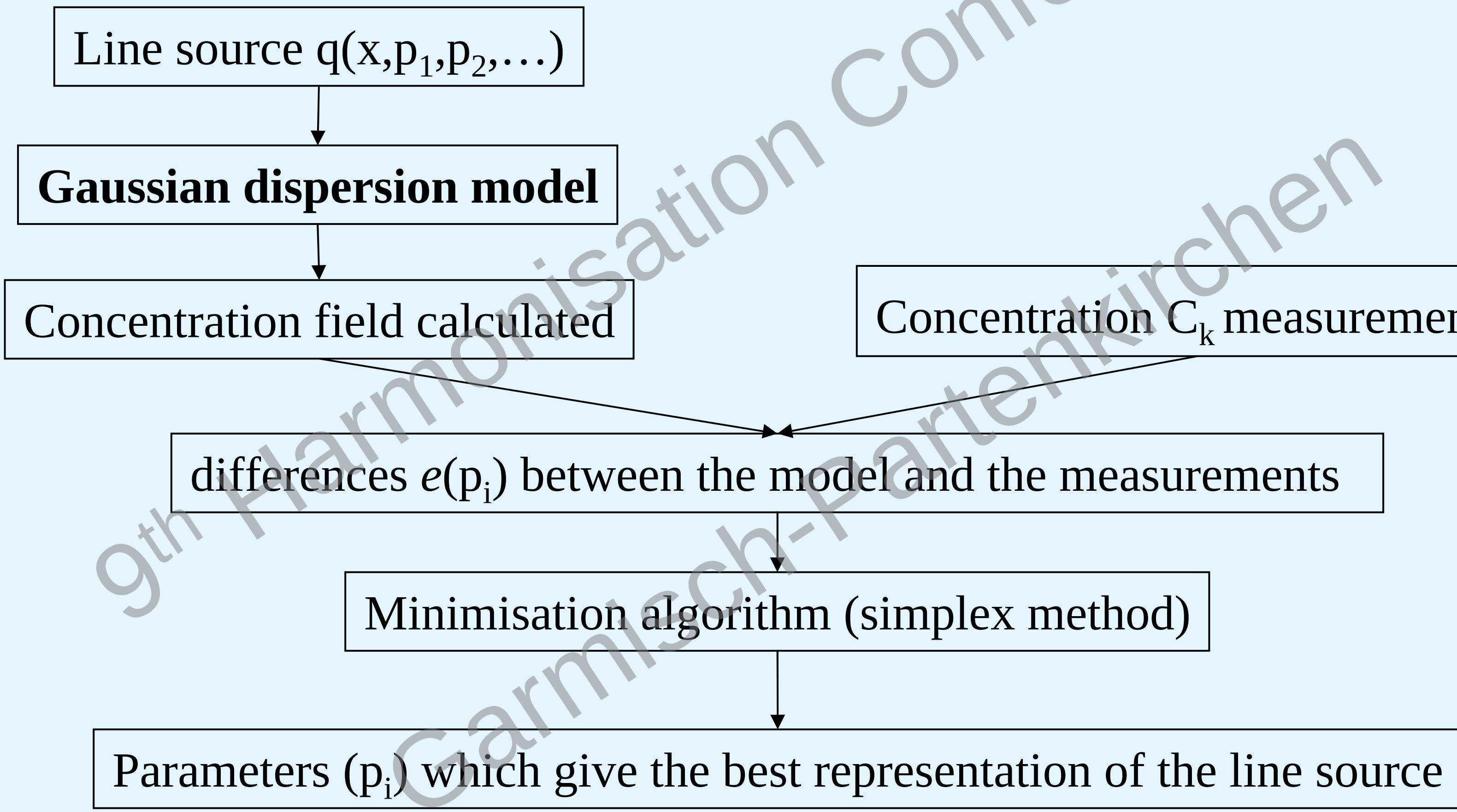
- Method: to reproduce the real exchange between the cavity and the external flow by a line source with a variable emission rate q(x) along the cavity





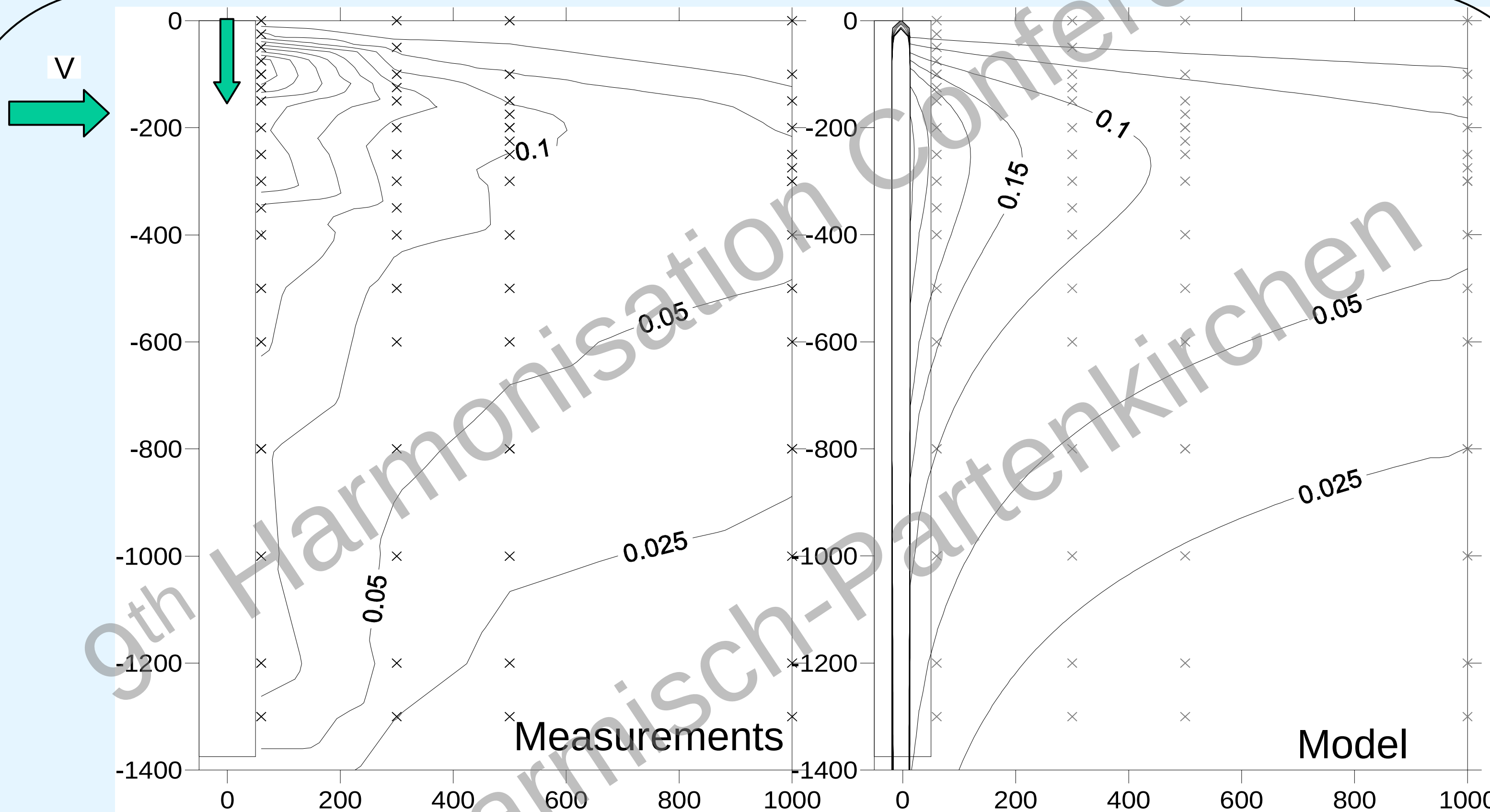
⇒How can we rely the line source characteristics to study parameters (wind direction, speed ratio) ?

Simple empirical model
Inverse Modelling



Simple empirical model

Comparison measurements/line source



Comparisons between measurements and the model
90° - U/V=0.5 – ground field

Simple empirical model

Results

Weak Jet (U/V=0.25 -> 1) → Line source approach give good description of the concentration field

Strong Jet → Initial mixing height is not well described

⇒ Development of a physical model in order to estimate the flux at the interface to obtain a better representation of the line source.

Conclusions and perspectives

Conclusions:

- Wind tunnel study of an idealized urban tunnel portal;
- Characterisation of the general topology of the flow;
- Generation of an important available database which can be used as a test case for validation;
- A line source approach can give good results to model the impact of a tunnel mouth.

Perspectives:

- Develop a physical model to evaluate the pollutant flux escaping the cavity;
- An other experimental campaign with a ramp (around 4%) at the exit of the tunnel.
- Confront this approach with a real case and numerical simulations.