Validation of the Safety Lagrangian Atmospheric Model (SLAM) against a wind tunnel experiment over an industrial complex area

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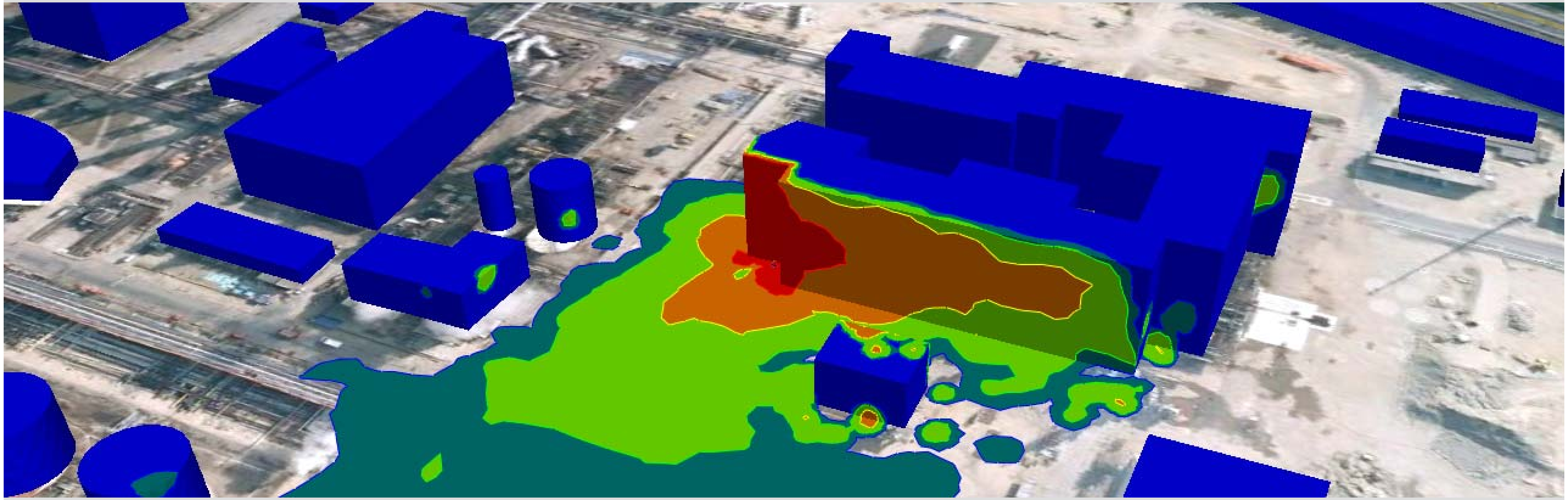
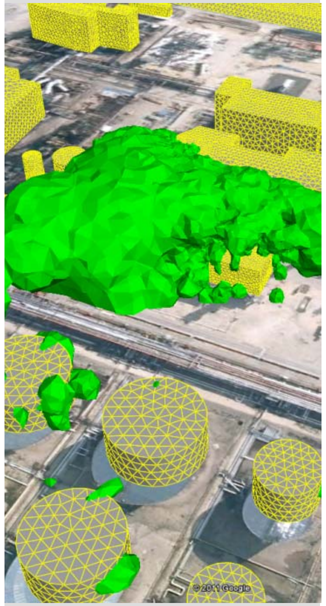
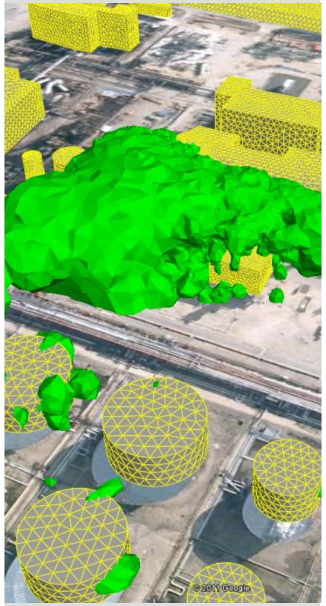


14th Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes Conference

Outline



1. Introduction and motivations
2. Description of the SLAM model
3. Experimental and numerical setup
4. Validation of the SLAM model
5. Conclusions and perspectives



1 – Introduction and motivations

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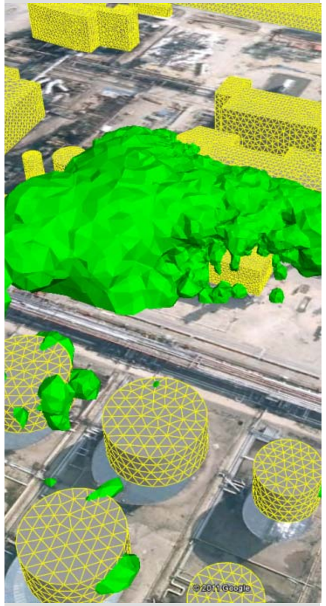
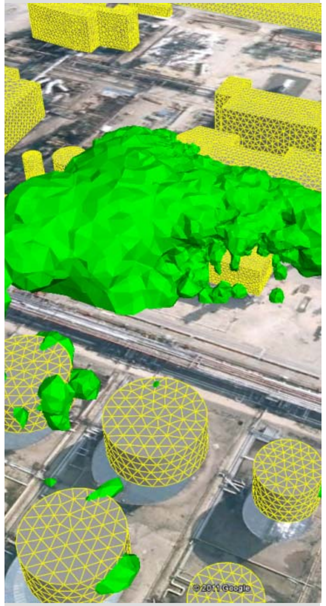


- **Need for local scale dispersion models on industrial site**
  - Monitoring of pollution for regulatory or safety applications
  - Identification of sources
  - Cartography of exposition and risk
- **Phenomenology to be taken into account**
  - Flow and dispersion around multiple complex obstacles
  - Interaction with stratification meteorological effects
  - Interaction with source effects (jet, plume, heavy gas, etc.)
- **Existing approaches**
  - Full CFD calculations ➔ CPU time expensive
  - Mass consistent model (MSS, Quic-Urb)

➔ **We have developed a new other modelling approach**



2 – Description of the SLAM model

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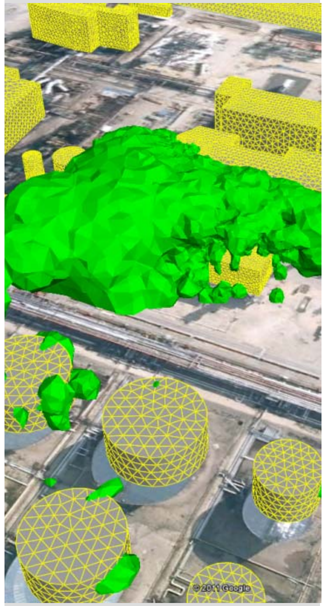
The Flow'Air 3D methodology



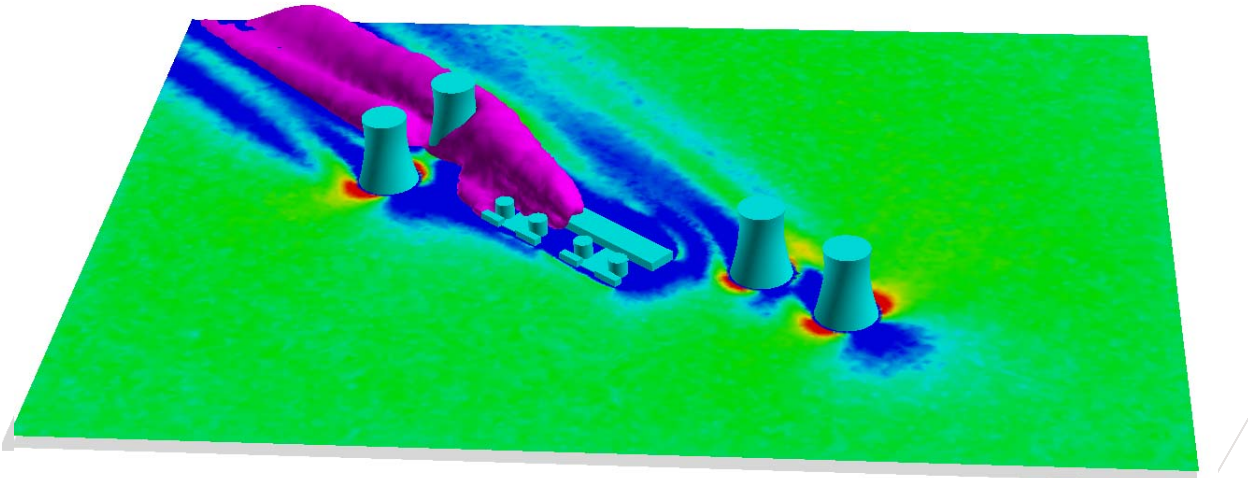
Principle of the Flow'Air 3D (Atmospheric Air Flow Database Methodology) methodology

- **Flow and dispersion on an industrial site depend on :**
  - 3D topography of the site

    ➔ constant for a given site
  - Upwind meteorological conditions in the boundary layer

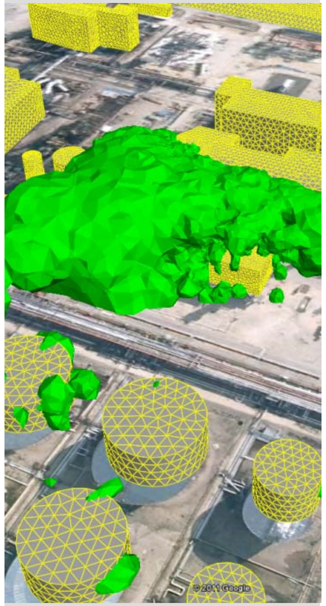
    ➔ limited number of parameters ➔ wind field database
  - Source and release conditions

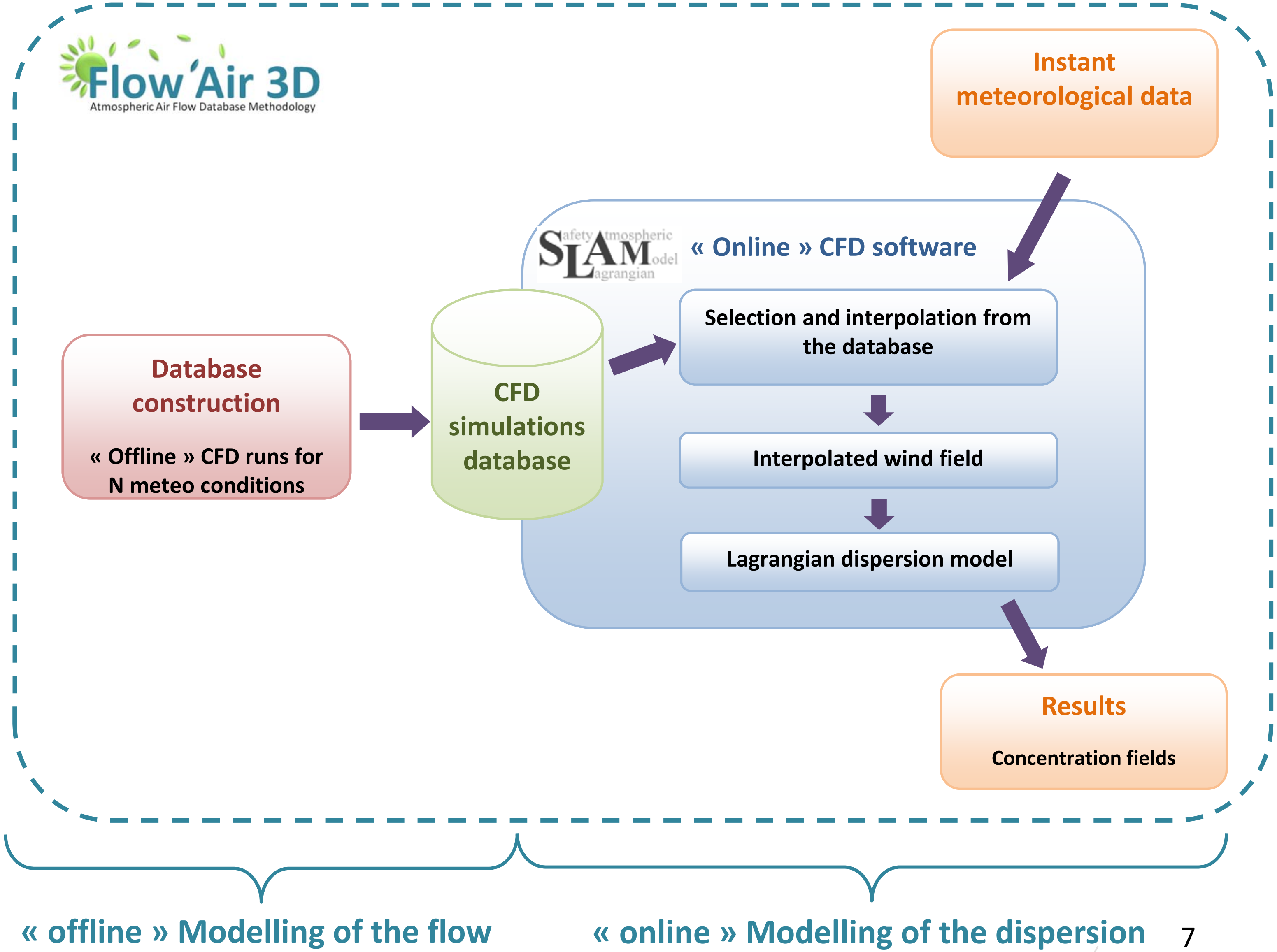
    ➔ a priori unknown ➔ operational dispersion model



2 – Description of the SLAM model

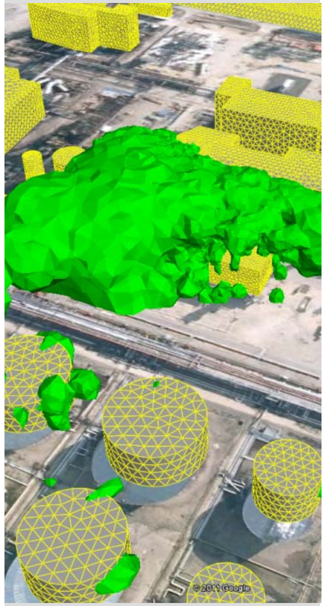
The Flow'Air 3D methodology

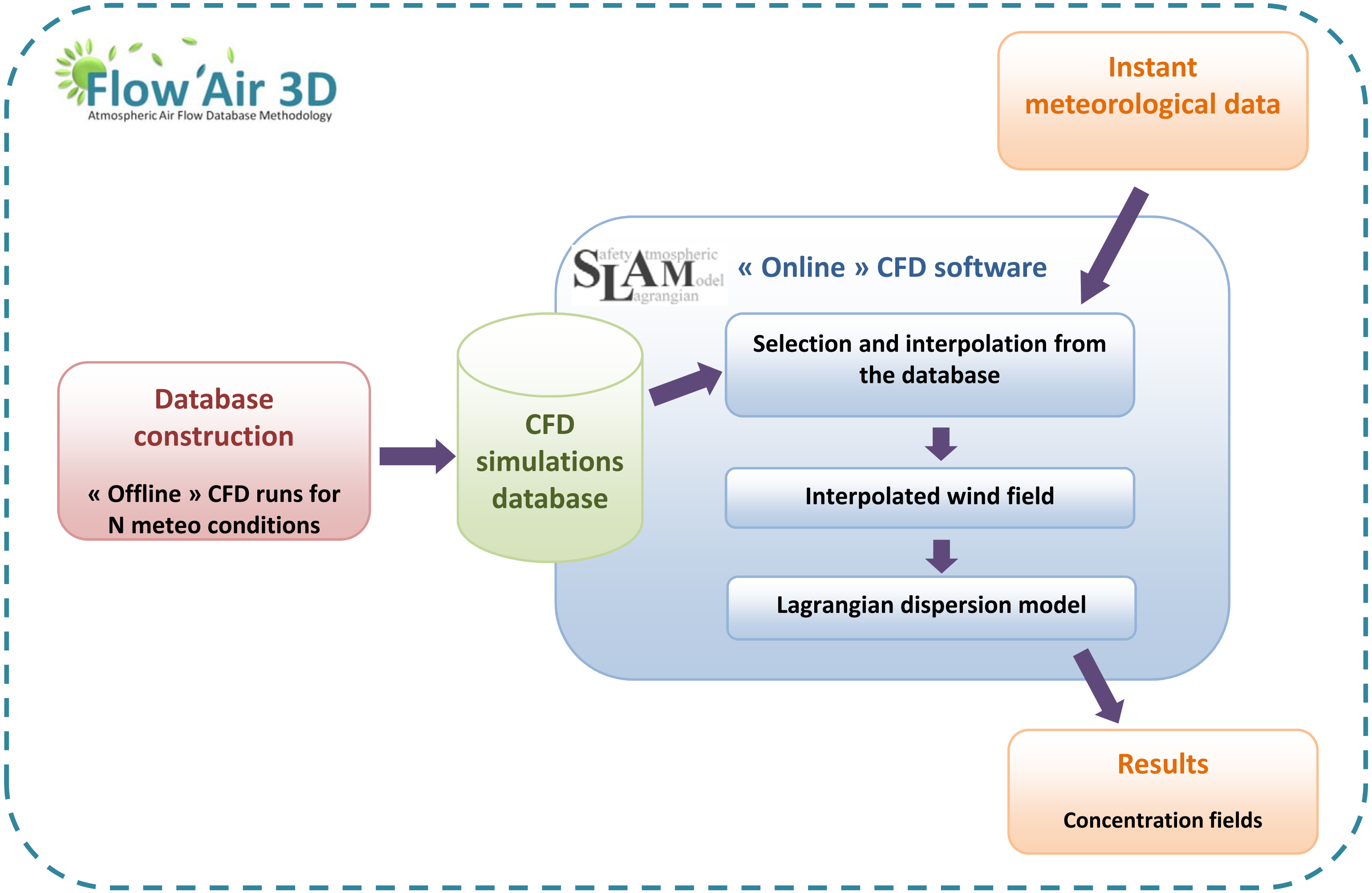




2 – Description of the SLAM model

The Flow'Air 3D methodology



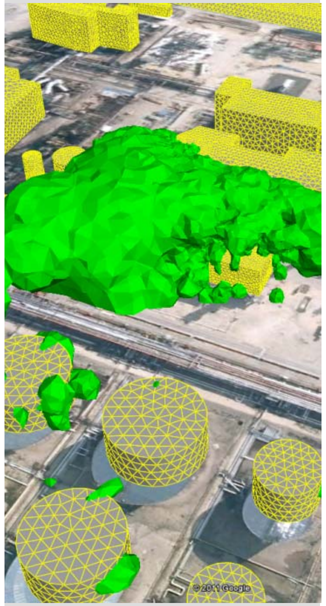


- **The interpolation process has been validated by Vendel et al. (2010)**

Vendel, F., G. Lamaison, L. Soulhac, L. Donnat, O. Duclaux and C. Puel, 2010: A new operational modelling approach for atmospheric dispersion in industrial complex area. *13th Int. Conf. on Harmo. within Atmos. Disp. Modell. for Regul. Purposes*, Paris, France.

2 – Description of the SLAM model

Main characteristics

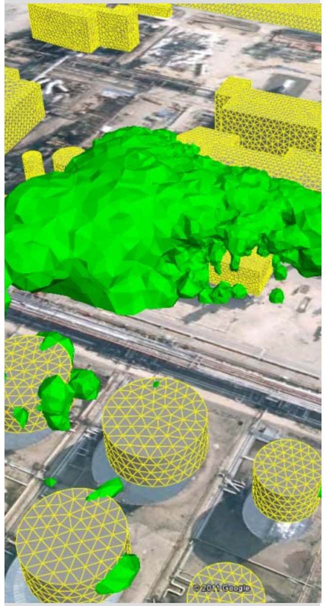


Safety Atmospheric Lagrangian Model

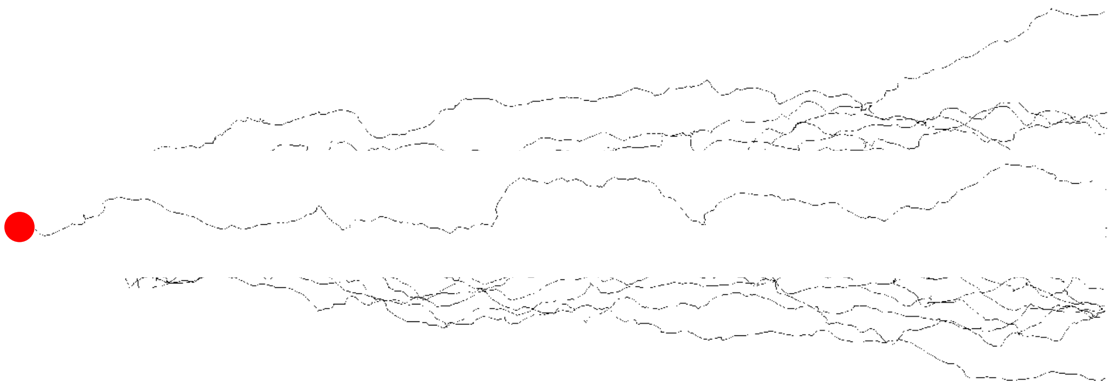
- **Particle Lagrangian dispersion model**
- **Based on different kind of wind fields**
    - 1D atmospheric boundary layer profile (MOST model)
    - 3D unstructured wind fields
    - 3D wind field database
- **Includes several physical processes**
    - Momentum or thermal plume rise
    - Deposition
- **OpenMP parallelization**

2 – Description of the SLAM model

Lagrangian approach



- **In a Lagrangian model, the plume is represented as an ensemble of individual particles trajectories**



- **Each individual trajectory is described by a simple advection process**

$$\frac{dX(t)}{dt} = U_x(t)$$

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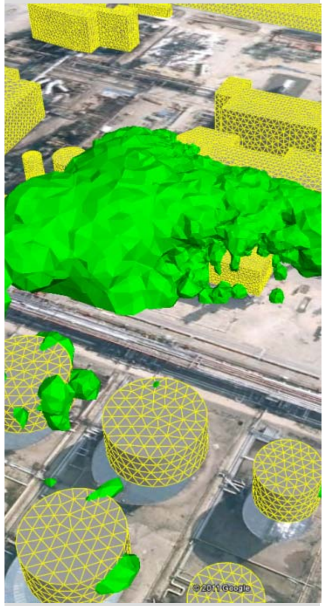


2 – Description of the SLAM model

Stochastic differential equation

$$\frac{dX(t)}{dt} = U_x(t)$$

Reynolds decomposition

$$U_x(t) = \underbrace{\overline{u_x}\left(X(t),Y(t),Z(t)\right)}_{\overline{U_x}(t)} + \underbrace{u_x^{'}\left(X(t),Y(t),Z(t),t\right)}_{U_x^{'}(t)}$$

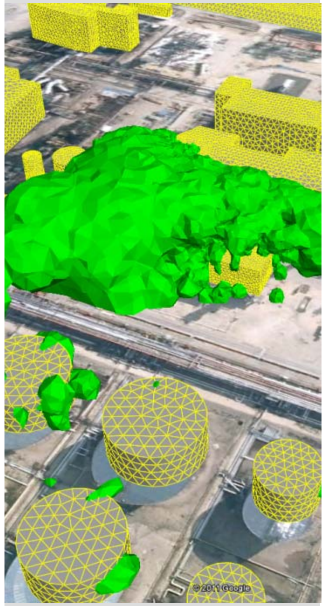
Mean velocity, given by the CFD wind field

Modelling of velocity fluctuation using a stochastic differential equation

$$dU_x^{'} = a_x\left(\boldsymbol{X},\boldsymbol{U}^{'},t\right)dt + \sum_j b_{xj}\left(\boldsymbol{X},\boldsymbol{U}^{'},t\right)d\xi_j$$

The terms of the stochastic differential equation depend :

- on the velocity standard deviations σ_{u_i}
- on the Lagrangian time scales $T_{L,x}$



2 – Description of the SLAM model

Relationship with the k-ε model parameters

- **For the velocity standard deviation, we assume isotropy :**

$$\sigma_u = \sigma_v = \sigma_w = \sqrt{\frac{2}{3}k}$$

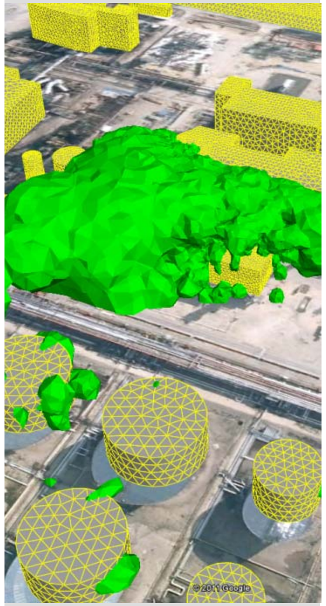
- **The Lagrangian time is given by** ***(Wilson et Sawford, 1996) :***

$$T_{L,x} = \frac{2\sigma_{u_x}^2}{C_0\,\varepsilon}$$

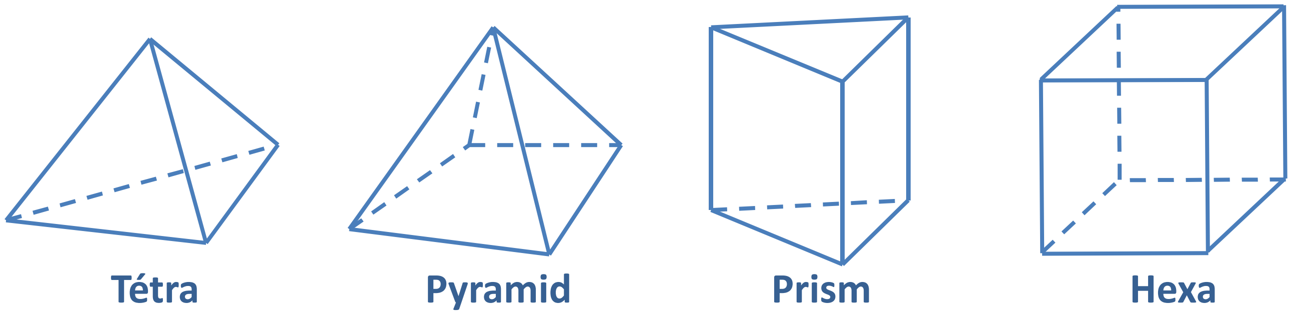
- **We choose** $C_0 = 4{,}0$ **so that** $T_{L,x} = T_{L,y} = T_{L,z} = 0.33\ \frac{k}{\varepsilon}$

2 – Description of the SLAM model

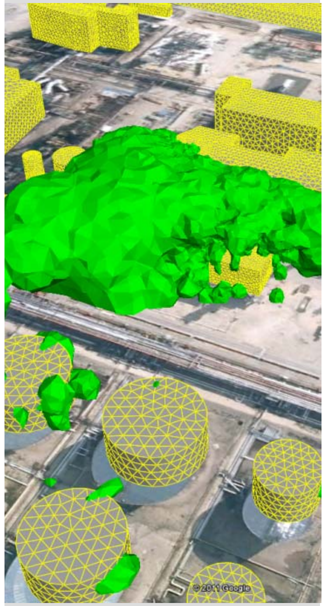
Others model characteristics



- **SLAM describes advection in several grid elements**



- **Source modeling**
  - Moving point, surface or volume sources
  - Integral plume rise or jet model added to the particle trajectories
- **Concentration evaluation**
  - Box count approach
  - Kernel approach



3 – Experimental and numerical setup

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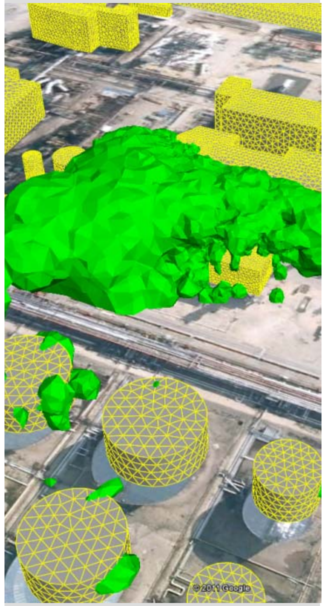
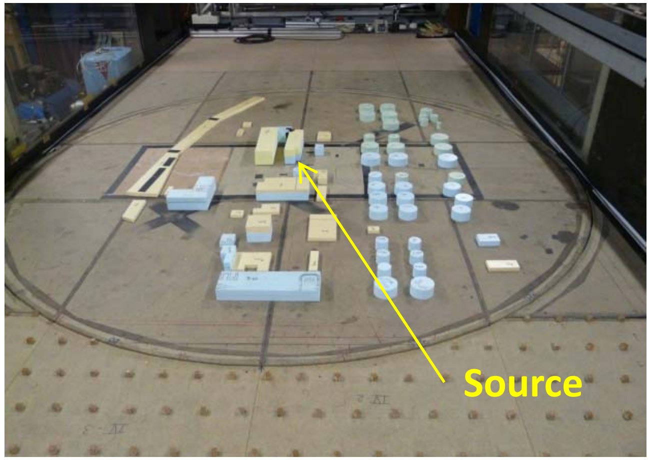
Description of the industrial site



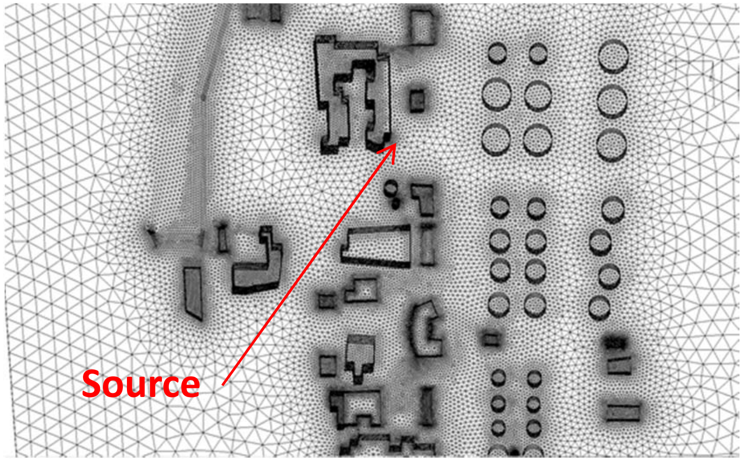
Industrial site, representative of an oil refinery

Wind tunnel model



- **Wind tunnel parameters**
  - Wind tunnel of the Ecole Centrale de Lyon
  - 1/250 scale model
  - FID concentration measurements

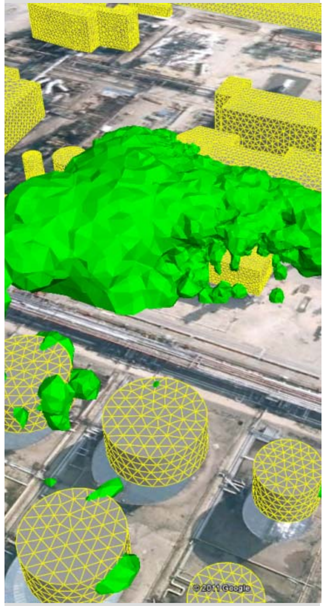
Numerical grid mesh



- **CFD parameters**
  - Use of Fluent CFD code
  - Unstructured grid mesh
  - 1.4 million of tetra elements
  - RANS k-ε turbulence model

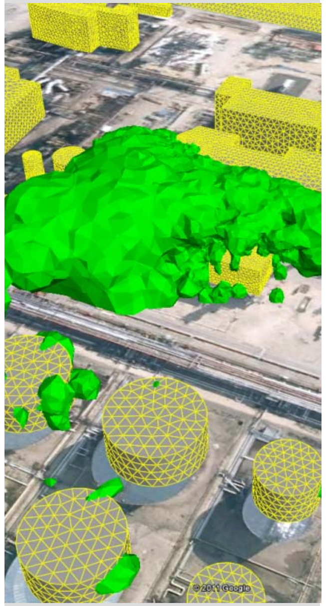
3 – Experimental and numerical setup

Description of Flow'Air 3D database and SLAM simulations



- **Discretization of the database** ***(Vendel et al., 2010)***
  - 18 wind directions (angle step of 20°)
  - 7 values of Monin Obukhov length
  - Normalization by the friction velocity
  - ➔ 126 full CFD runs = 21 days of simulation

- **SLAM parameterization**
  - Continuous point source without momentum or thermal effects
  - 1000 particles by time step
  - Simulation until a steady state was achieved



4 – Validation of the SLAM model

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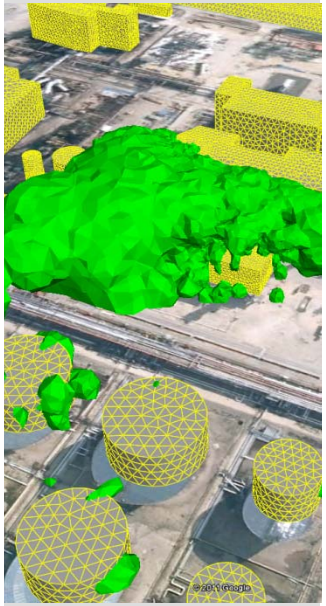
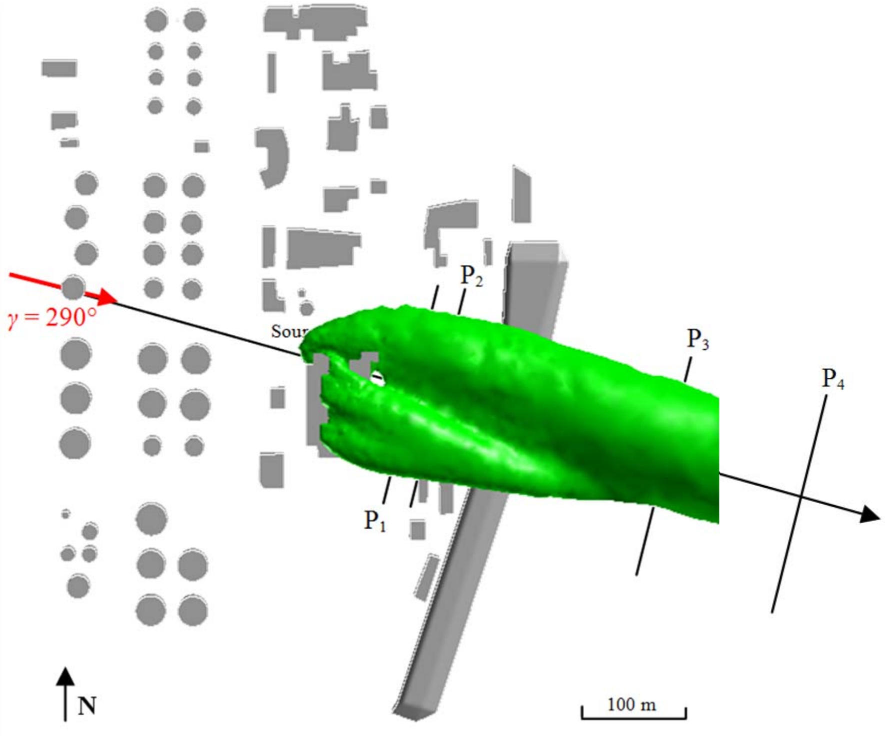
Comparison overview



- **4 ground transverse profiles**

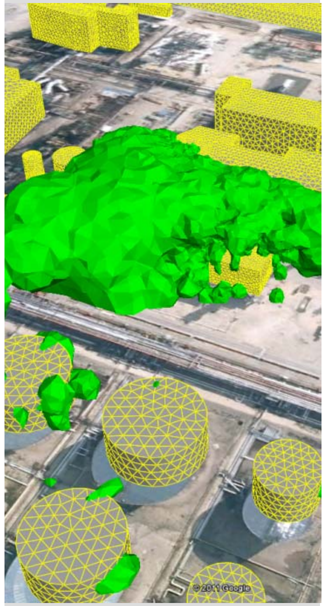


- **Definition of dimensionless parameters**

$$c^* = CU_\infty L^2 / Q \quad \text{and} \quad y^* = y/L$$

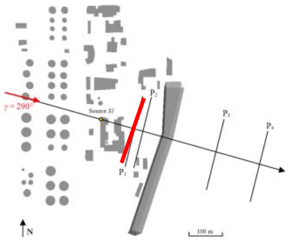
4 – Validation of the SLAM model

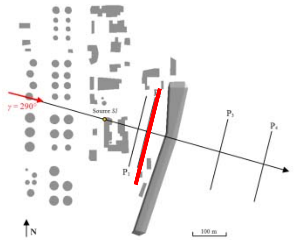
Source 1 – Direction 290°



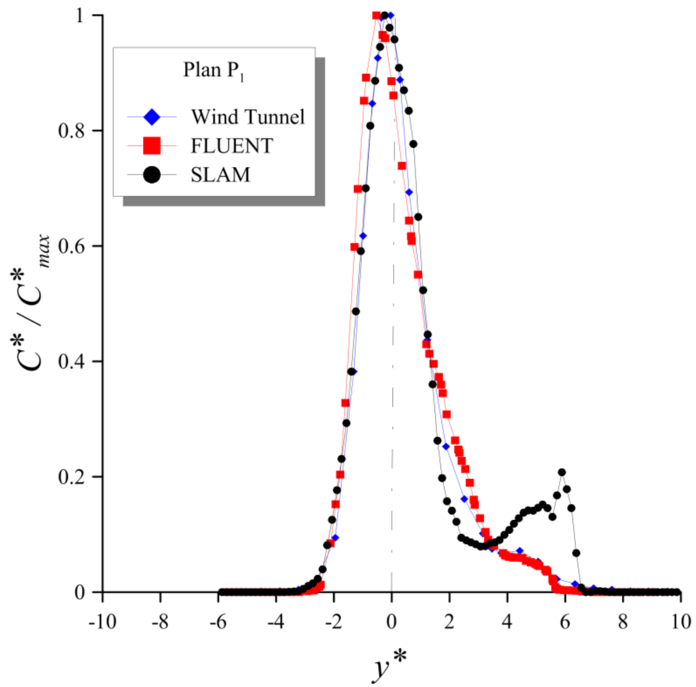
Transverse normalized concentration profile

$C^*/C^*_{max}=f(y^*)$

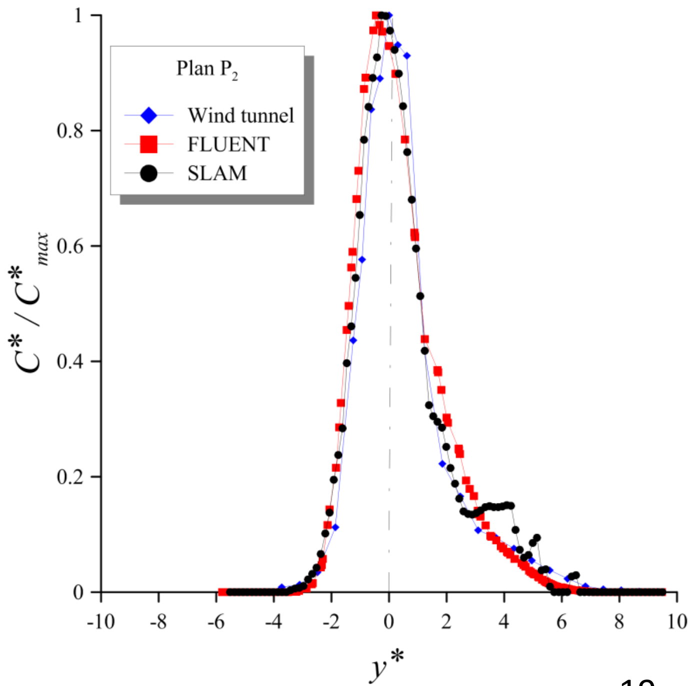




P1 cross section

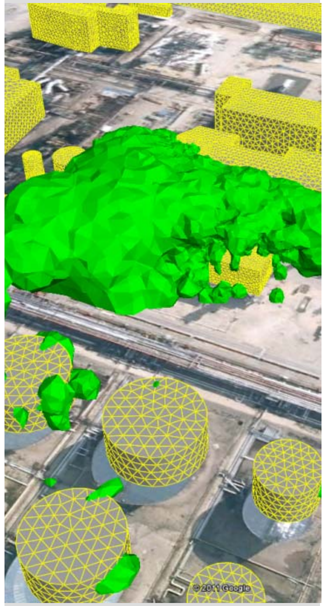


P2 cross section



4 – Validation of the SLAM model

Source 1 – Direction 290°



Transverse normalized concentration profile

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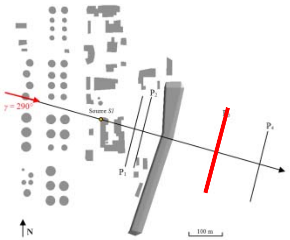
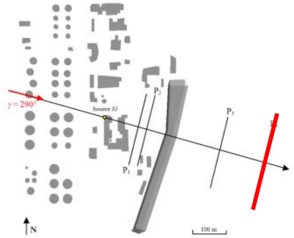
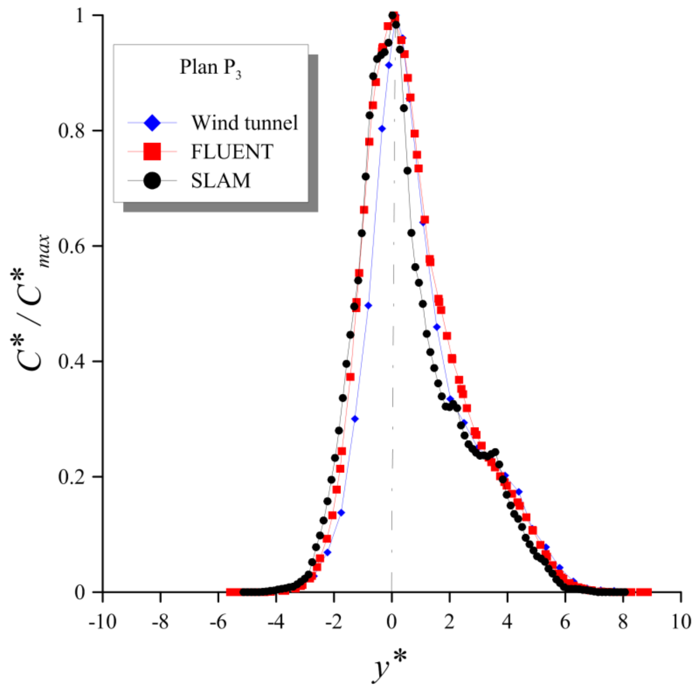
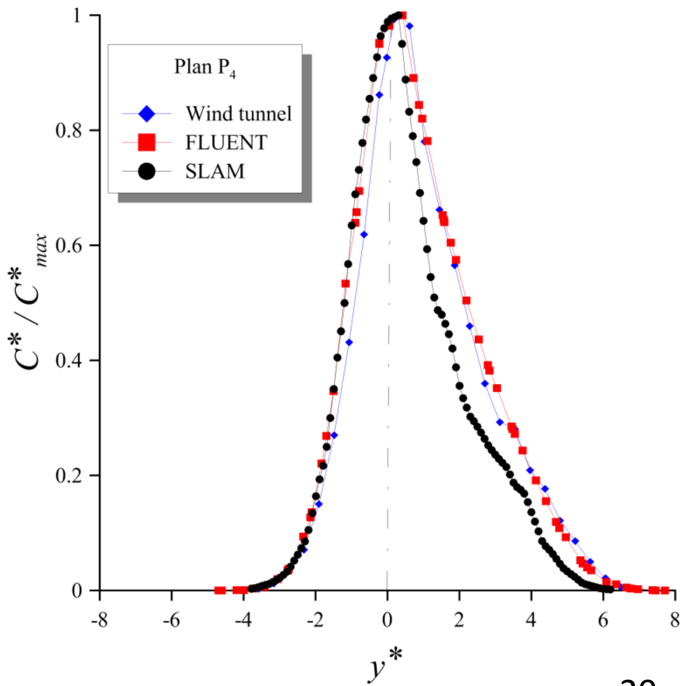




P3 cross section



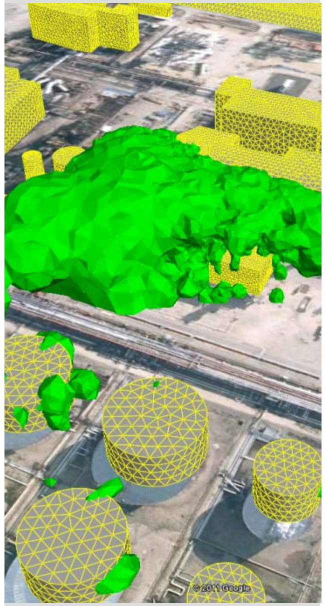
P4 cross section

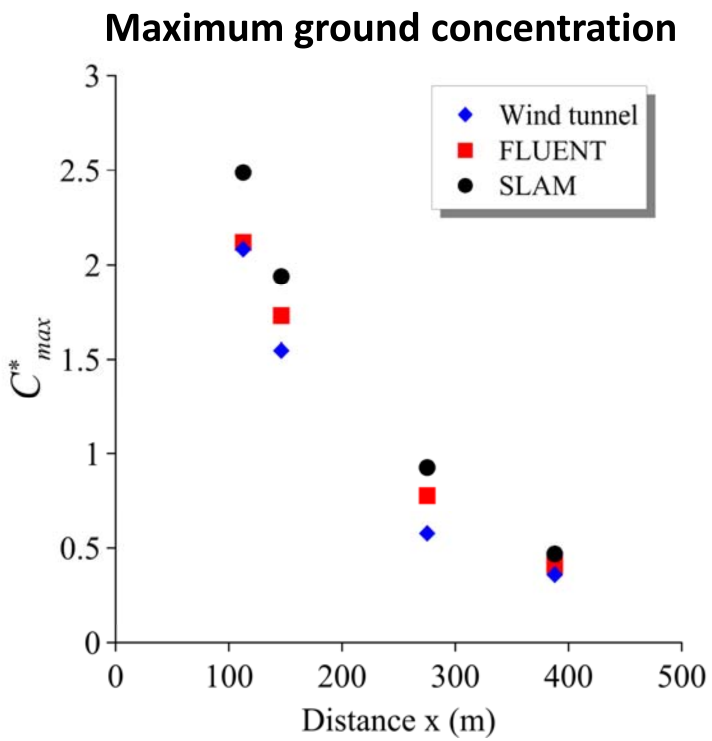


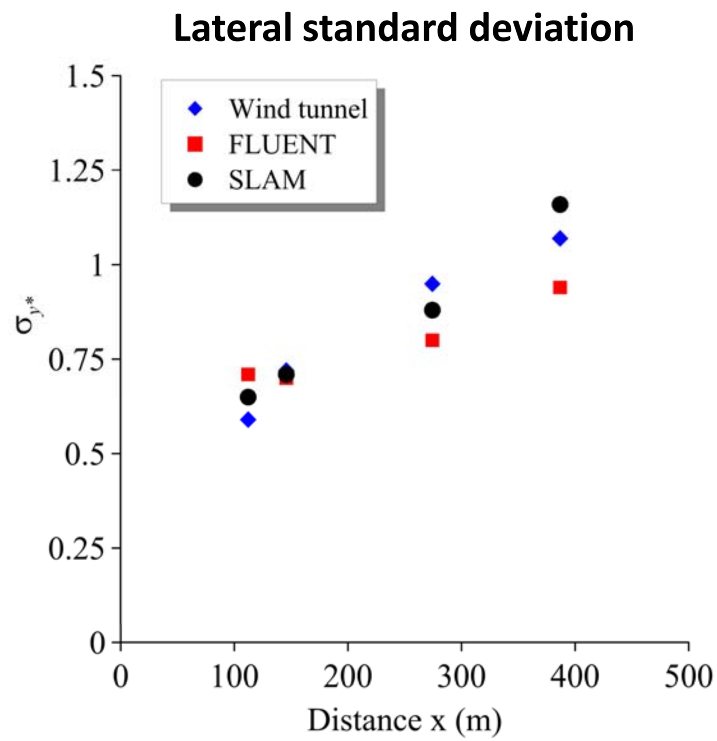
4 – Validation of the SLAM model

Source 1 – Direction 290°

Plume normalisation parameters C^*_{max} and σ_{y*}

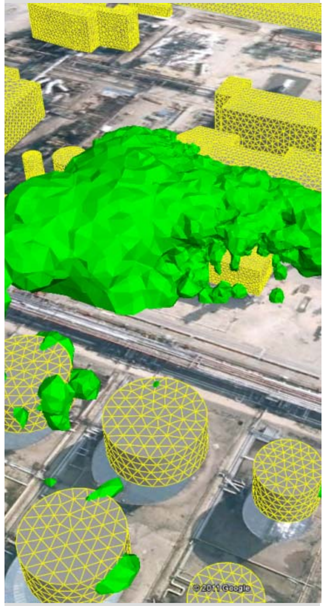






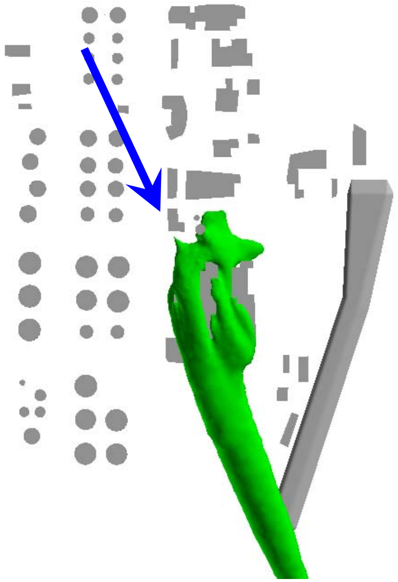
4 – Validation of the SLAM model

Source 1 – Direction 335°

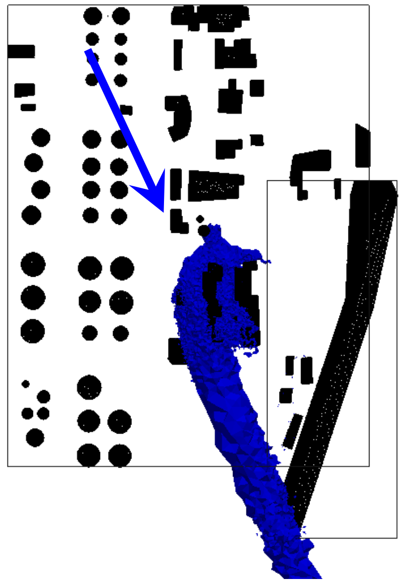


Comparison of the plume general behaviour

Fluent Eulerian dispersion



SLAM Lagrangian dispersion

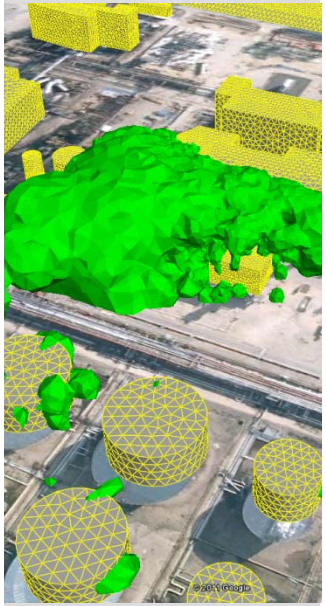


Isosurface of C* = 0.3

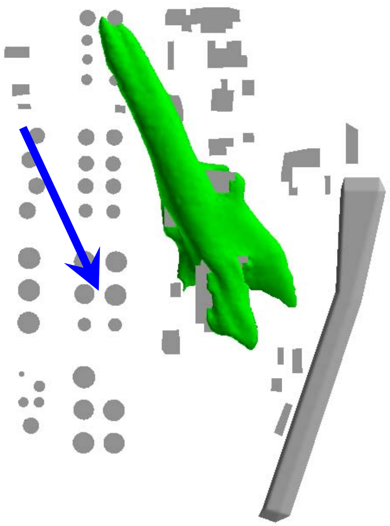
4 – Validation of the SLAM model

Source 2 – Direction 335°

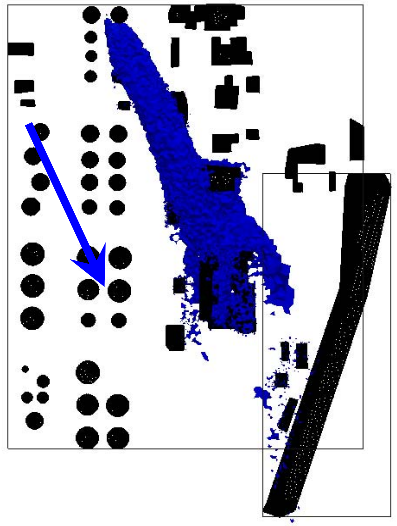
Comparison of the plume general behaviour



Fluent Eulerian dispersion



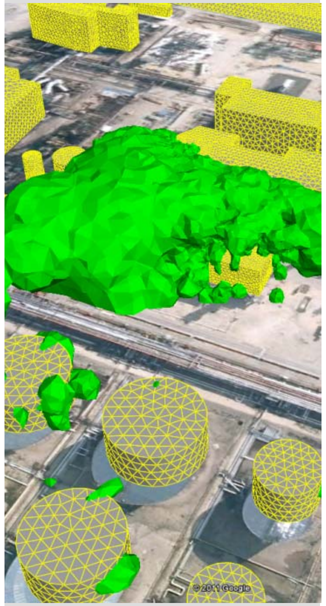
SLAM Lagrangian dispersion



Isosurface of C* = 0.03

4 – Validation of the SLAM model

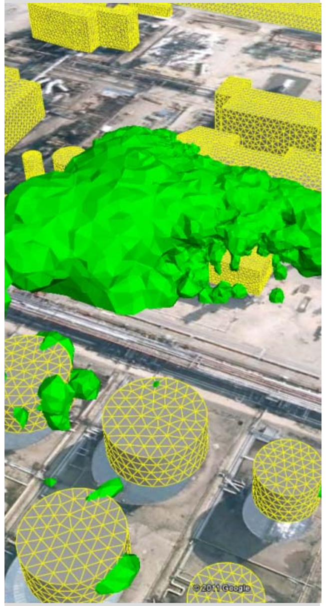
Computational performance



- **Overview of computational performance**
  - The full CFD simulation (flow + dispersion) with FLUENT requires 4 h CPU
  - The SLAM simulation (interpolation in the database + Lagrangian dispersion) requires 6 min CPU on the same computer

➔ Speed up of about 40

➔ CPU time compatible with operational applications



5 – Conclusions and perspectives

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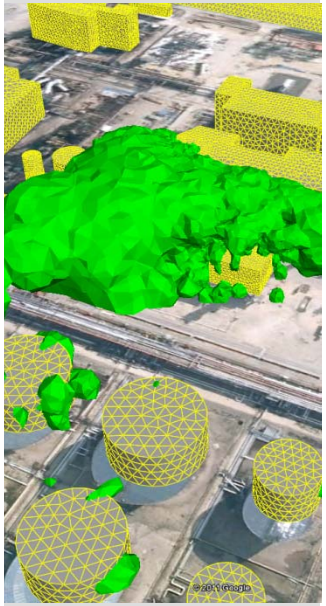
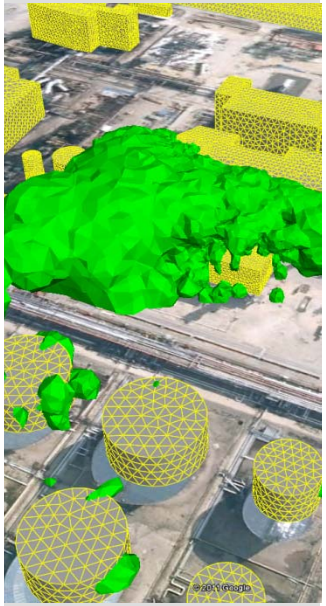
Conclusions



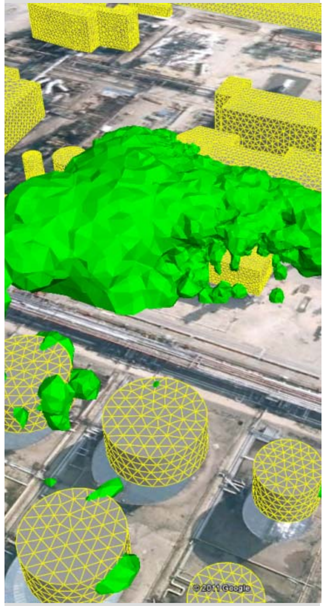
- **SLAM is an operational Lagrangian dispersion model**
  - Adapted to describe dispersion around complex obstacles
  - Coupled with the Flow'Air 3D database methodology
  - Compatible with unstructured 3D wind field
  - Plume rise and deposition parameterization
  - OpenMP parallelization
- **Validation results against full CFD and wind tunnel data**
  - Comparison on a typical industrial site
  - Good agreement for the behaviour of SLAM results
  - CPU time compatible with operational application

5 - Conclusions and perspectives

Perspectives



- **Parameterization of the complete atmospheric boundary layer (including Ekman effects) in CFD calculations**
- **Modelling chemical and heavy gas processes**
- **Introduction of nested domains to describe dispersion from the near to the far field**



Thank you for your attention ☺

Questions ?