Adaptation of the Lagrangian module of the CFD code *Code_Saturne* for near-field atmospheric dispersion of pollutants

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CONTEXT AND OBJECTIVES

This work is part of the PVA2014-17 project which aims at developping and validating the atmospheric module of *Code_Saturne* in order to perform atmospheric dispersion calculations, especially in configurations that are not within the scope of validity of the models currently used by engineering centers. Applications mainly concern emissions from nuclear power plants and are carried out through the DIAMANTAIRE project.

In this context, the objective of this work is to adapt the Lagrangian stochastic model of *Code_Saturne* in order to simulate near-field dispersion of pollutants in complex environments including buildings and taking into account atmospheric stratification. This intends to complete the existing Eulerian modelling of these phenomena and one of the objectives is the comparison of the two approaches, making use of the same CFD code.

THE DISPERSION MODELLING: METHODOLOGY

FLOW FIELD – EULERIAN FRAME (NAVIER-STOKES EQ.)
[calculated by *Code_Saturne*, RANS turbulence model]

$$\begin{cases} \dfrac{\partial \bar{\rho}}{\partial t} + \dfrac{\partial (\bar{\rho}\tilde{u}_i)}{\partial t} = 0 \\ \dfrac{\partial (\bar{\rho}\tilde{u}_i)}{\partial t} + \dfrac{\partial (\bar{\rho}\tilde{u}_i\tilde{u}_j)}{\partial x_j} = -\dfrac{\partial \bar{p}}{\partial x_i} + \dfrac{\partial}{\partial x_i}\left(\overline{\tau_{ij}} - \bar{\rho}\overline{u_i' u_j'}\right) - \bar{\rho} g \delta_{iz} \end{cases}$$

EULERIAN APPROACH

ADVECTION-DIFFUSION EQUATION FOR A SCALAR C

$$\frac{\partial \bar{c}}{\partial t} + \bar{u}_j \frac{\partial \bar{c}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(D \frac{\partial \bar{c}}{\partial x_j} - \overline{u_j' c}\right) + \bar{S} + \bar{R}$$

LAGRANGIAN APPROACH

PARTICLE'S EQUATION OF MOTION

$$\begin{cases} \dfrac{\mathrm{d}x_p}{\mathrm{d}t} = U_p \\ \rho_p \dfrac{\pi D_p^3}{6} \dfrac{\mathrm{d}U_p}{\mathrm{d}t} = \dfrac{U_s - U_p}{\tau_p} + \dfrac{\pi D_p^3}{6}(\rho_p - \rho) g + F_{m.a} + F_{grad.P} + F_{hist.} \end{cases}$$

$U_s = U_f(x_p, t)$ — *Velocity of the fluid seen by the particle*

HOW TO CLOSE THE SYSTEM?

- *Code_Saturne* with RANS models → $< U_f(x,t) >$
- Stochastic model for the turbulence:

$$dU_{s,i} = a_i(\boldsymbol{X}, \boldsymbol{U}, t)dt + \sum_j b_{ij}(\boldsymbol{X}, \boldsymbol{U}, t) dW_j$$

Langevin equation

***Simplified Langevin Model* (POPE, 2001)**

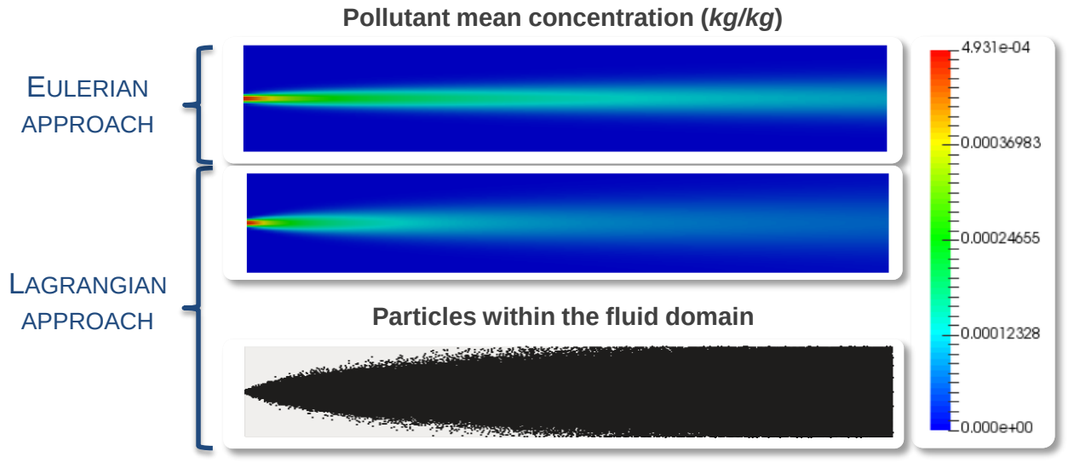
$$dU_{s,i} = -\frac{1}{\rho}\frac{\partial \bar{P}}{\partial x_i}dt - \frac{U_{s,i} - \overline{U_{f,i}}}{T_{L,i}^*}dt + \sqrt{C_0 \epsilon} dW_i$$

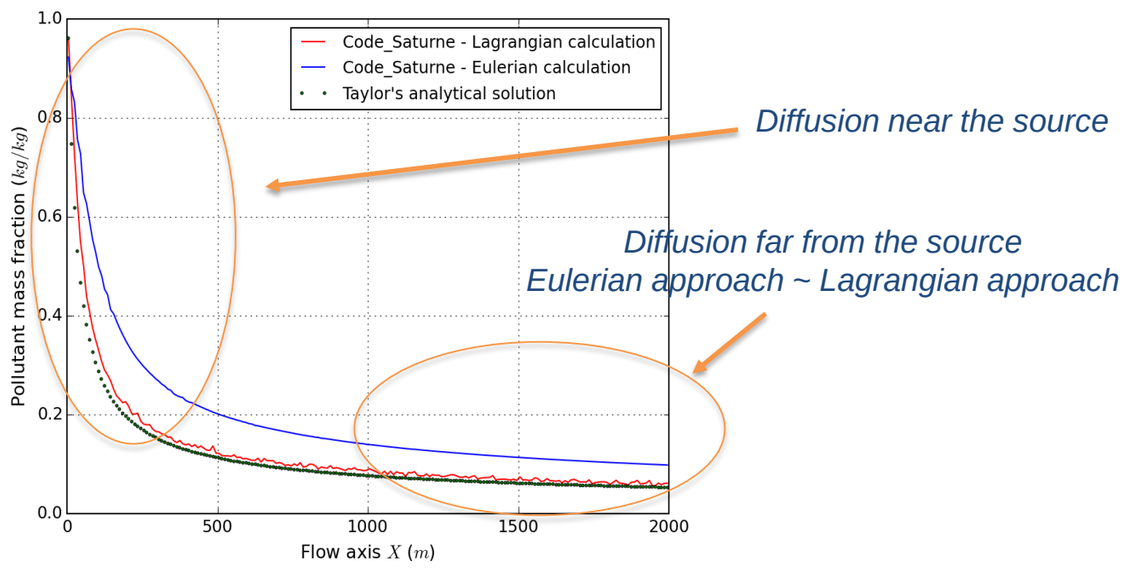
VALIDATION CASE: Continuous punctual release with uniform mean speed and turbulent diffusivity

Taylor's analytical solution:

$$\frac{c}{Q} = \frac{1}{\sqrt{2\pi} U \sigma_x} \quad with: \ \sigma_x = \sqrt{\frac{2}{3}k}\, \frac{x}{U\sqrt{1 + \frac{x}{2UT_L}}}$$

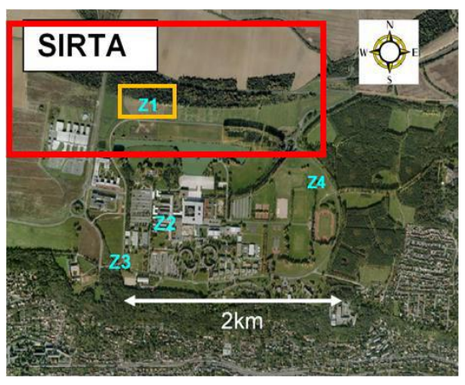
Pollutant mean concentration (*kg/kg*)

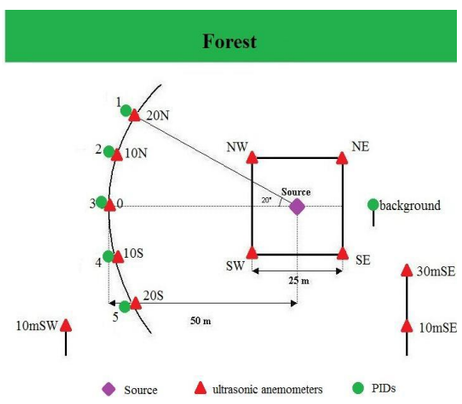




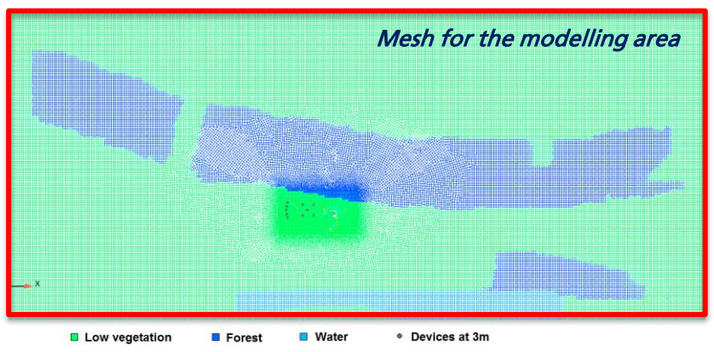
Maximum concentration (*kg/kg*) along the flow axis
Comparison of the two approaches

INDUSTRIAL CASE: SIRTA (*Site Instrumental de Recherche par Télédétection Atmosphérique*)

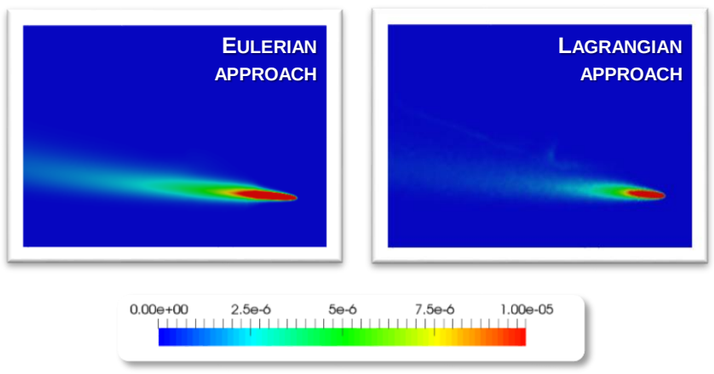


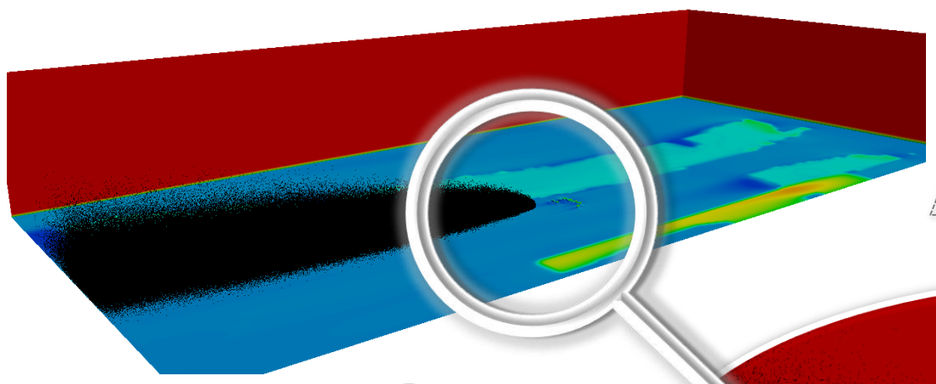


SIRTA DISPERSION EXPERIMENT (03/2015)
Campaign carried out in Zone 1, neutral conditions.
- Source (at 3 *m* height)
- 12 ultrasonic anemometers
- 6 photoionization detectors (PID)



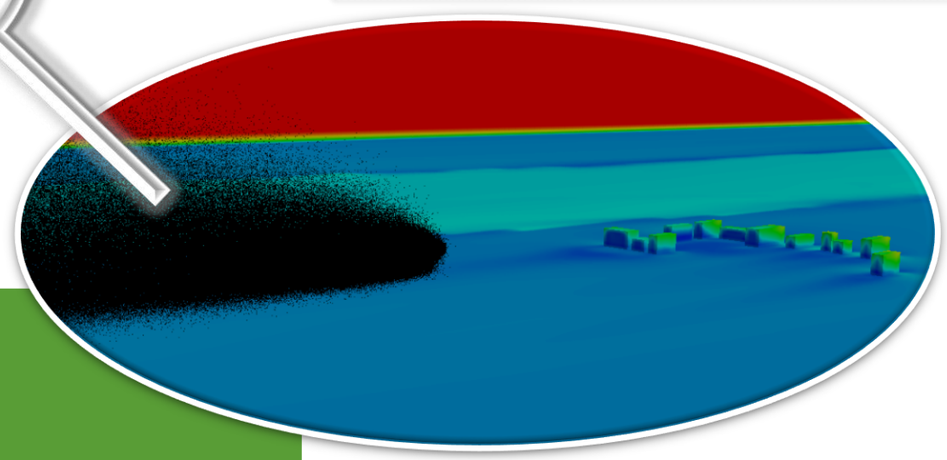
Pollutant mean concentration (*ppmv*) at height *Z = 3 m*

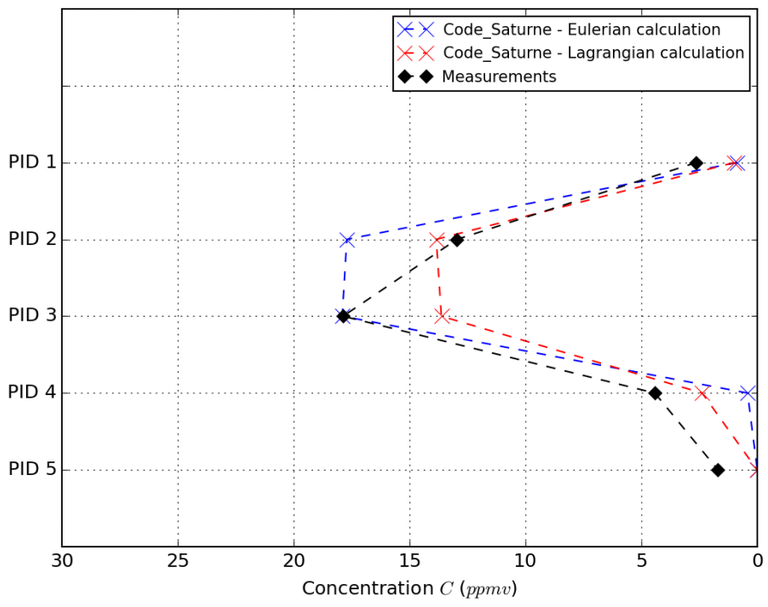




SIMULATION DOMAIN:
1600 *m* (N-S) * 700 *m* (E-W) * 200 *m* (vertical)

SETUP FOR THE CONTINUOUS PHASE:
- RANS k-ε model
- Porous media to simulate momentum losses and turbulence generation within the forest
- Ground and shelters surfaces (lake and low vegetation area): constant roughness according to the land use cover map





Comparison of the mean concentrations (*ppmv*) between measurements and simulations

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