Large-eddy simulation of wind flows and comparisons with very-near field campaign data

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Cerea Centre d'Enseignement et de Recherche en Environnement Atmosphérique

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INERIS maîtriser le risque pour un développement durable

CONTENT

- Context and objectives : demonstration of the capability of FDS code (LES approach) to be accurate for atmospheric dispersion
- Ammonia dispersion INERIS field tests
- Modelling of a massive release (biphasic and dense gas)
    - Adaptation of an experimental flow signal for an input LES
    - Implementation of a release term source
    - Comparisons simulation/experiments
- Conclusion and future works

Context : Prediction of safety distances by modelling in the industrial risk assessment

Toxic/flammable release

→ **current approaches** :

Integral, Gaussian, Mass consistent , LPDM, LES,…

We focus on stable condition in a real atmospheric boundary layer :

Specific conditions because

→ often the most conservative

→ often the most difficult to simulate

Considering the specific turbulence intermittency and anisotropy (Wei, 2013) of such a flow, LES model appears as promising

Context : which LES code could we use ?

Is there any freely available LES code ?

FDS (Fire Dynamics Simulation) developed by NIST

Code_Saturne developed by EDF

OpenFoam,

Others

INERIS has been running FDS for 10 years for several applications of the industrial risk assessment : channel flow, fire simulation, confined toxic dispersion...

→ **Objective : to suit FDS for atmospheric flow modelling and to show its capability to be accurate**

→ Method : we rely on comparison between atmospheric release flow modelling and experimental release at scale representative of an industrial accident

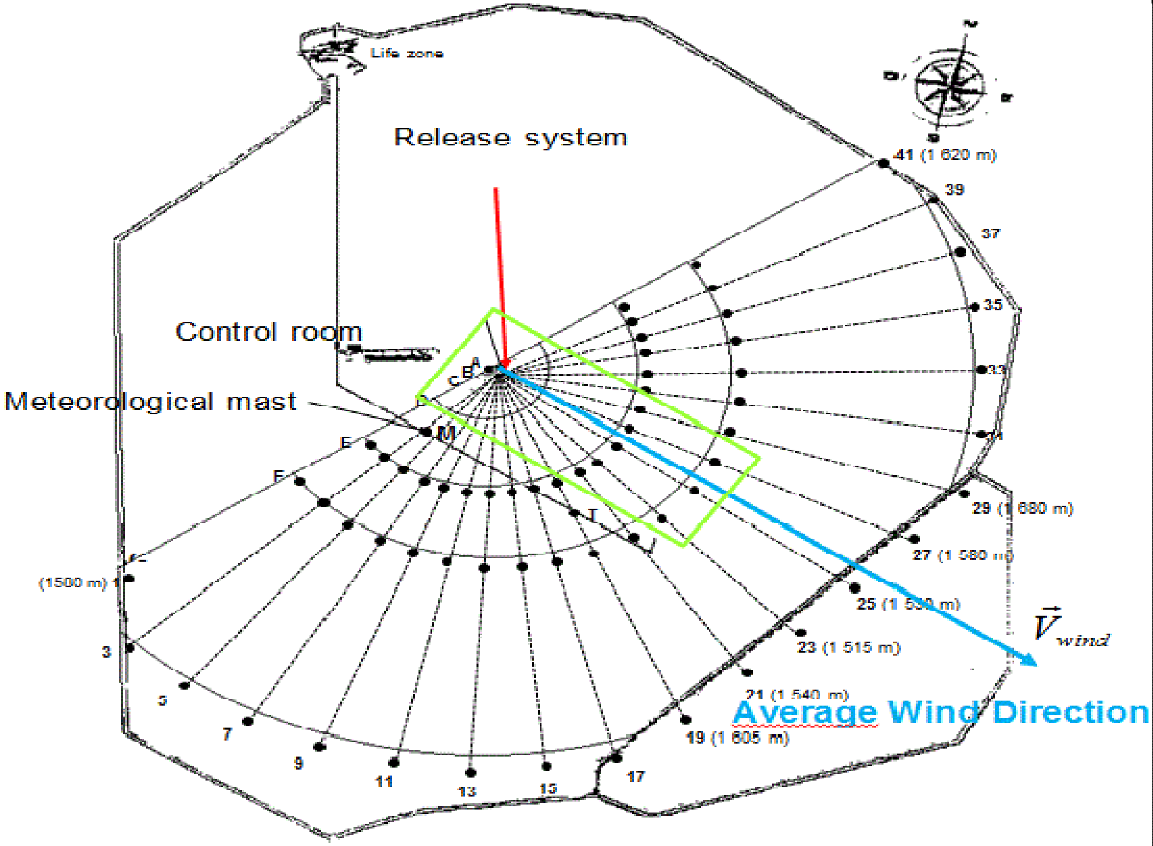
Ammonia dispersion INERIS field tests
(Bouet et al., 2005)

Tests were intended to reproduce as closely as possible an accidental scenario that may occur in a real industrial facility

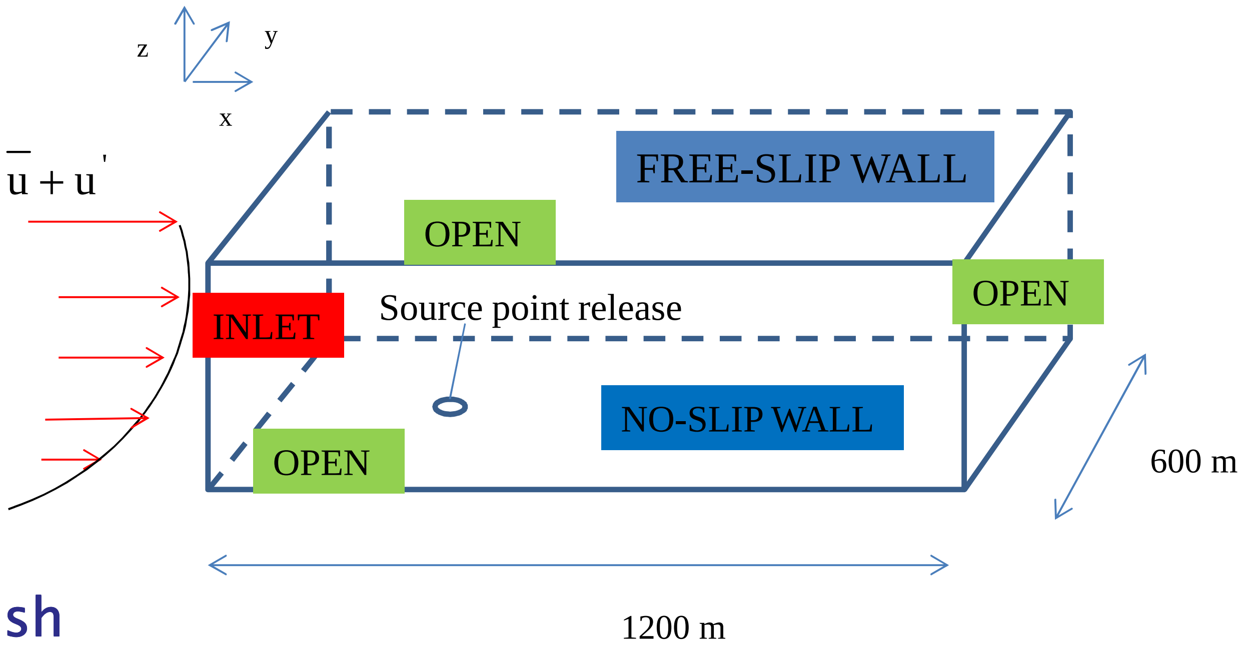
A dozen of tests release cases : mass flow rate up to 4 kg/s, ~ 600 s, free jet , impinging jet

In this study : the “most simple case”

	Sensors arcs	Distance (m)
Near Field	A	20
	B	50
Far Field	C	100
	D	200
	E	500
	F	800



Modelling of a biphasic and dense gas release : computational FDS domain



Single right parallelepiped mesh

- grid cell size :
  - Near field of the release : ΔX= ΔY=ΔZ=0.5 m
  - Far field : ΔX= ΔY=ΔZ=1 m
  - → ~30 Millions of cells

Adaptation of an experimental signal for an input LES: Inlet wind velocity

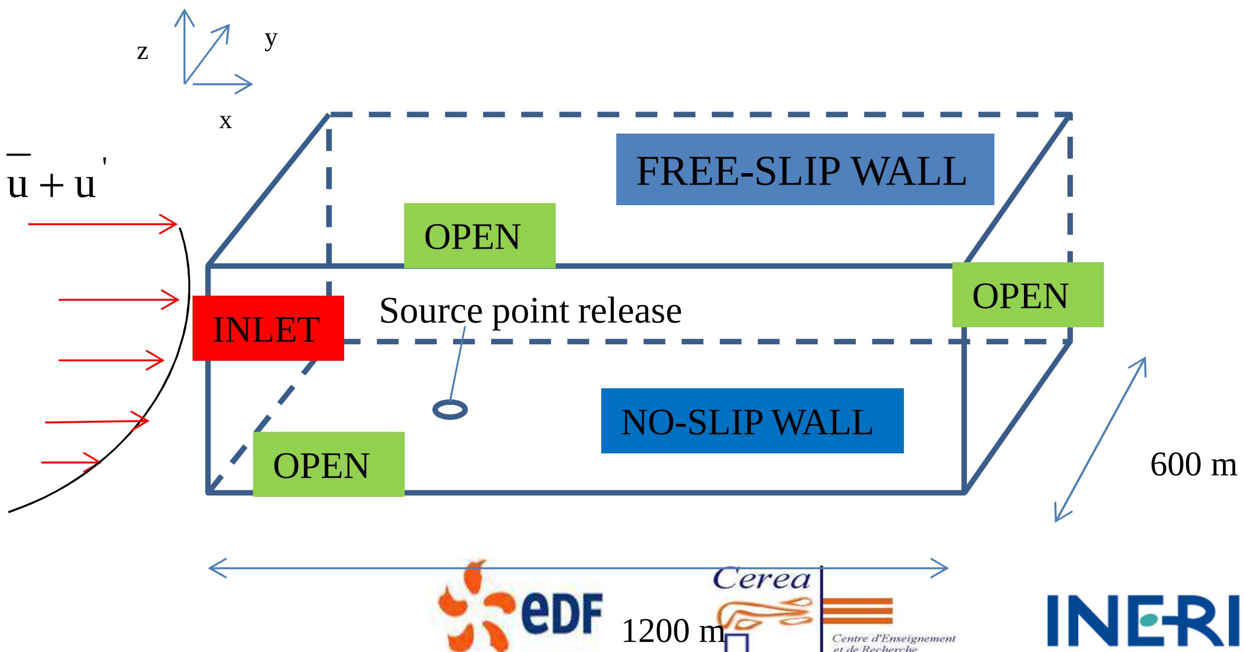
A lot of efforts have been done to reach the inlet conditions !

→ **Reconstruction of the instantaneous velocity :** $\overline{U} + U'$

→ **Applying the profile to the inlet of the domain**

→ **Simulations of the flow carried out before dispersion modelling of the release**

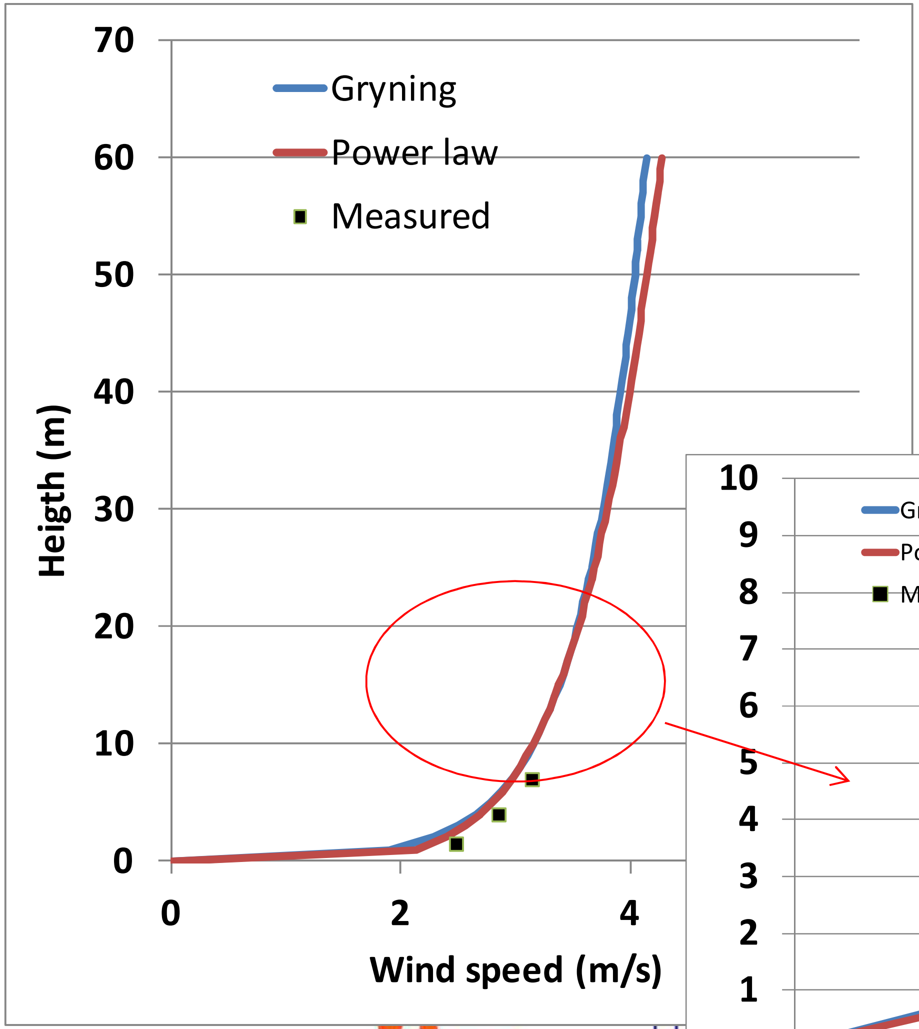
→ **FDS generates its turbulence**

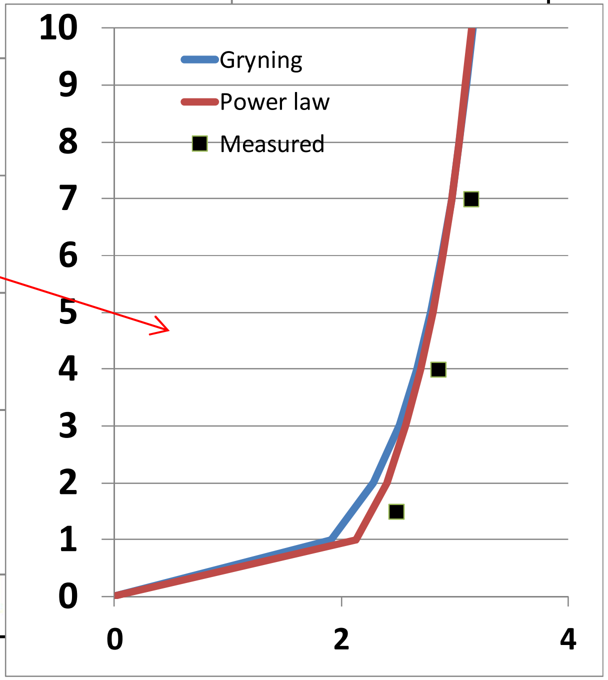


Adaptation of an experimental signal for an input LES: Inlet wind velocity

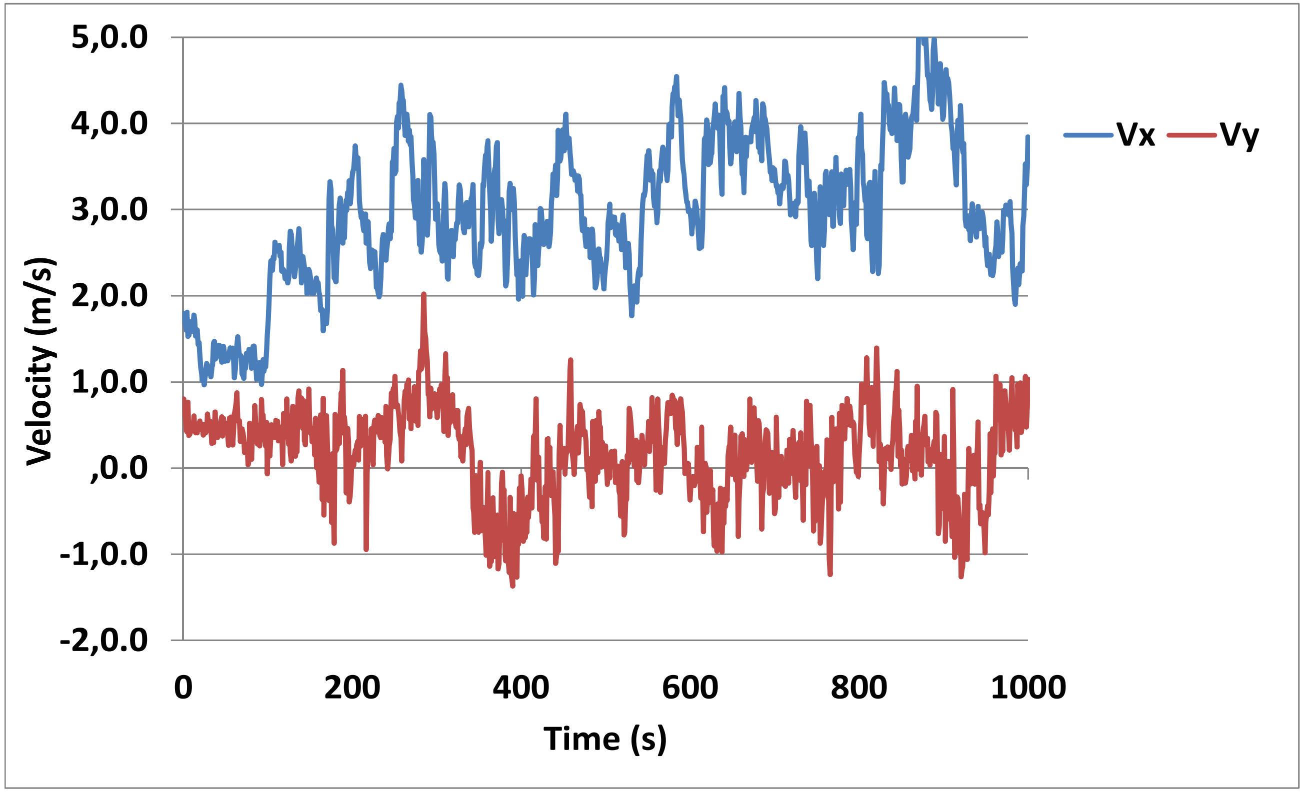
→ mean velocity profile $\overline{U}$

- **Atmospheric conditions**
  - Neutral (D)
- **Wind velocity**
  - 3 m/s (7 m high)
- **Fitting curves tested:**
  - Gryning approach
  - Power law



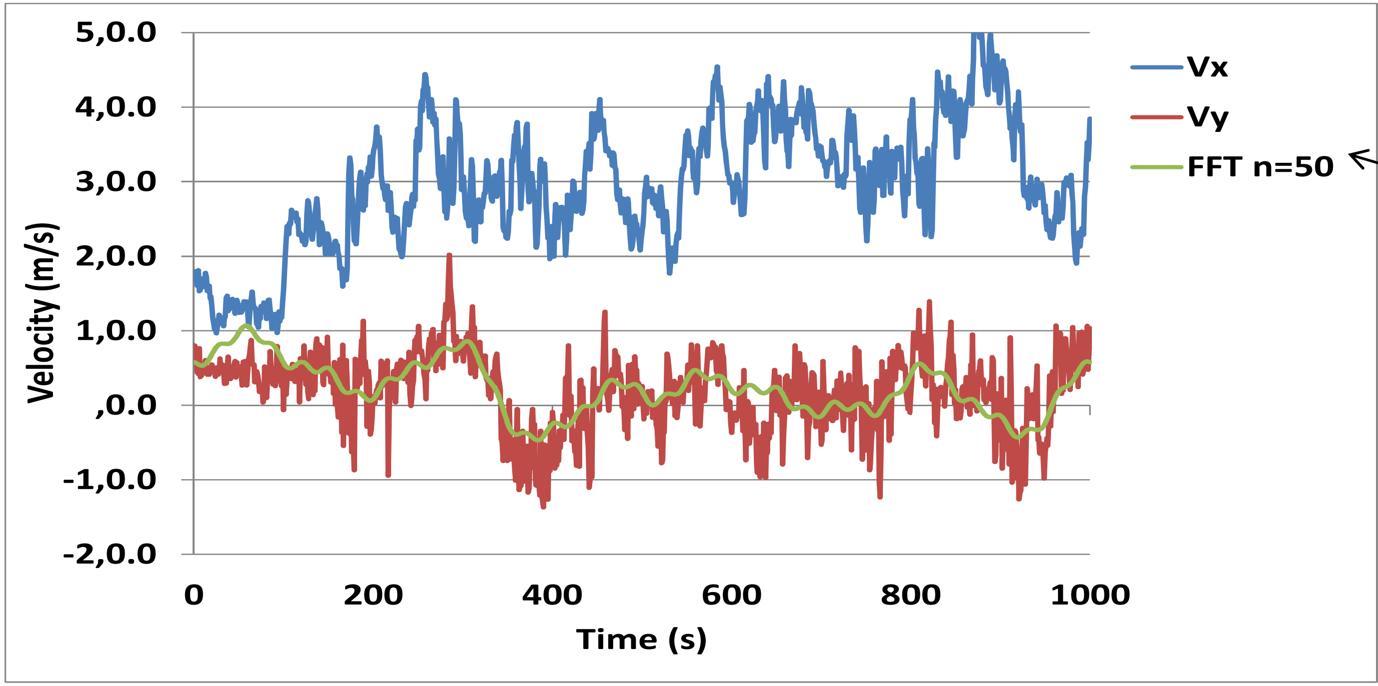


Adaptation of an experimental signal for an input LES: Inlet wind velocity
→ fluctuation velocity profile U'



Measurements on the meteorological mast (vane anemometers, weather-cock) : two velocity components (1 Hz)

Adaptation of an experimental signal for an input LES: Inlet wind velocity → fluctuation velocity profile U'

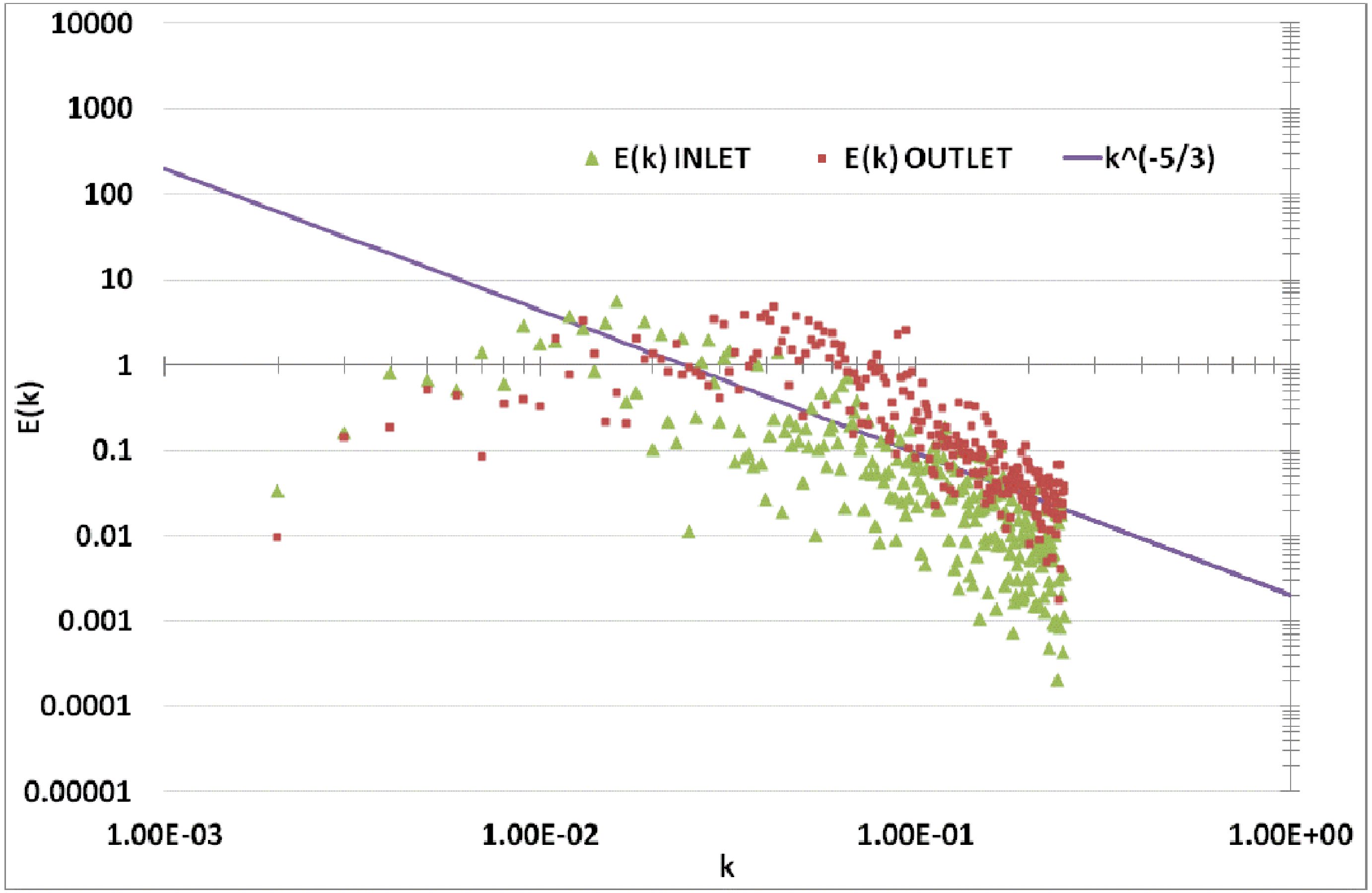


50 most significant modes (proportional to the turbulence intensity) were introduced

FFT: Fourier Mode Analysis in time

$$u' = \sum_{k=1}^{n} a_k \cos(2\pi \cdot f_k \cdot t) + b_k \sin(2\pi \cdot f_k \cdot t)$$

Comparison of the turbulent energy spectrum at the inlet and outlet conditions of the simulated flow



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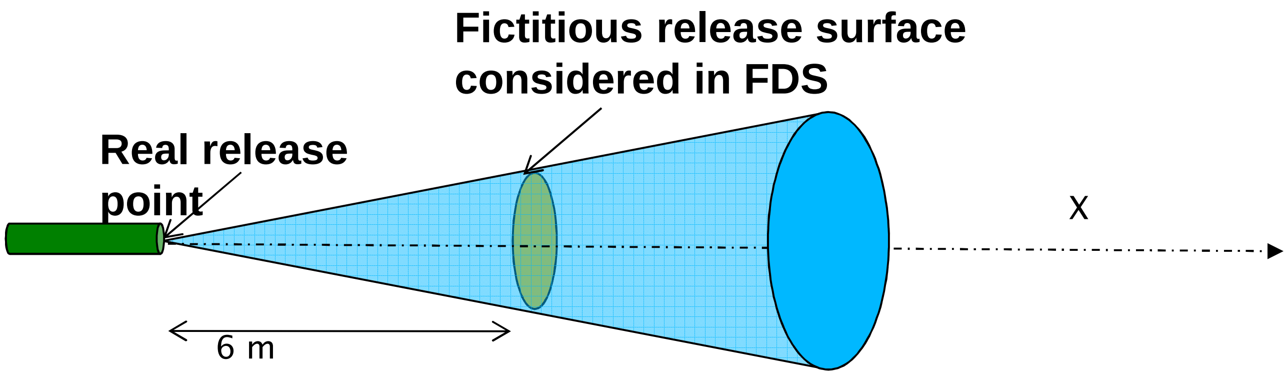
Implementation of a release term source

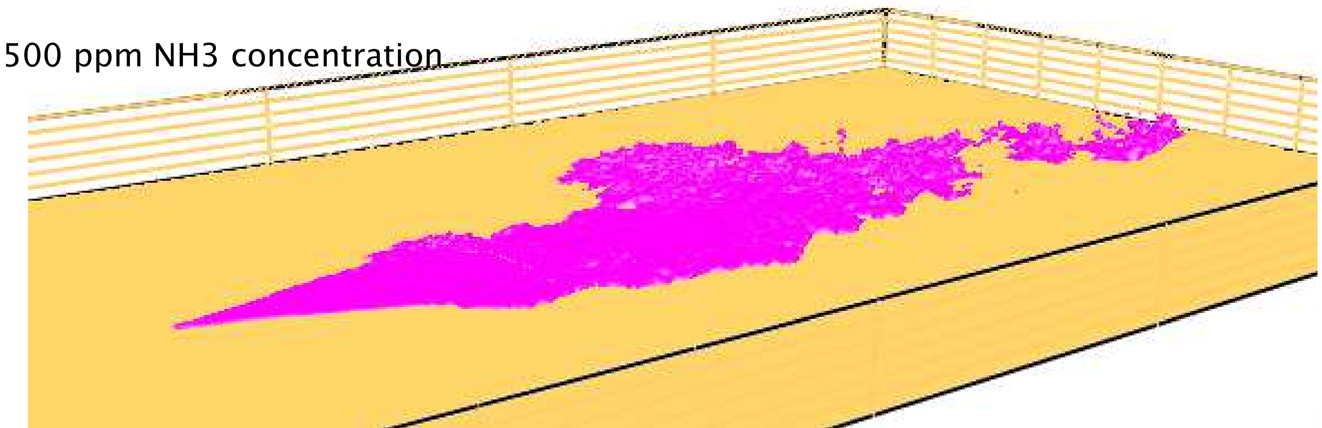
Biphasic massive release at the orifice is very complex to model : Thermodynamic Flash,high velocity, strong cooling…
→ we create an equivalent simplified term source further from the orifice : only gas, lower velocity, entrained air



Source term characteristics predicted before with a two-phase jet model (Papadourakis et al., 1993)

Jet characteristics at X =6 m:
NH_3 Mass flow rate : 4.2 kg/s
Air mass flow rate: 19.1 kg/s
Total mass flow rate = 23.3 kg/s
Axis jet velocity: 25 m/s
Vapor Temp: -50 °C
Section area : ~1 m²

Some Results : Plume shape comparison



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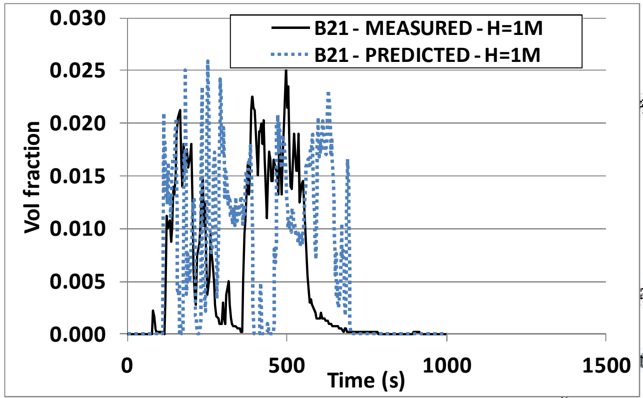
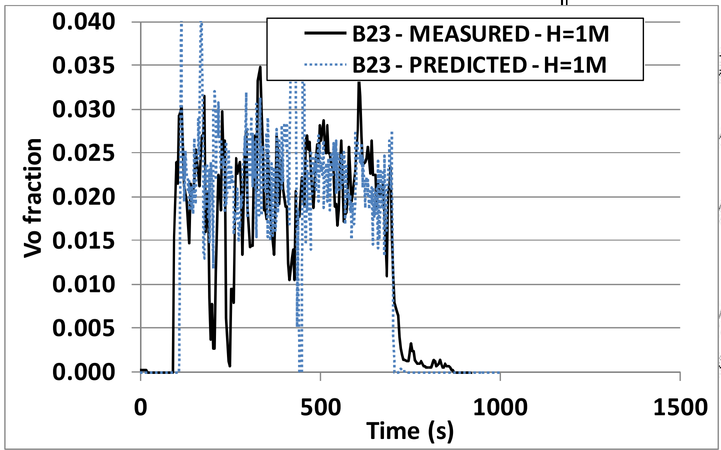
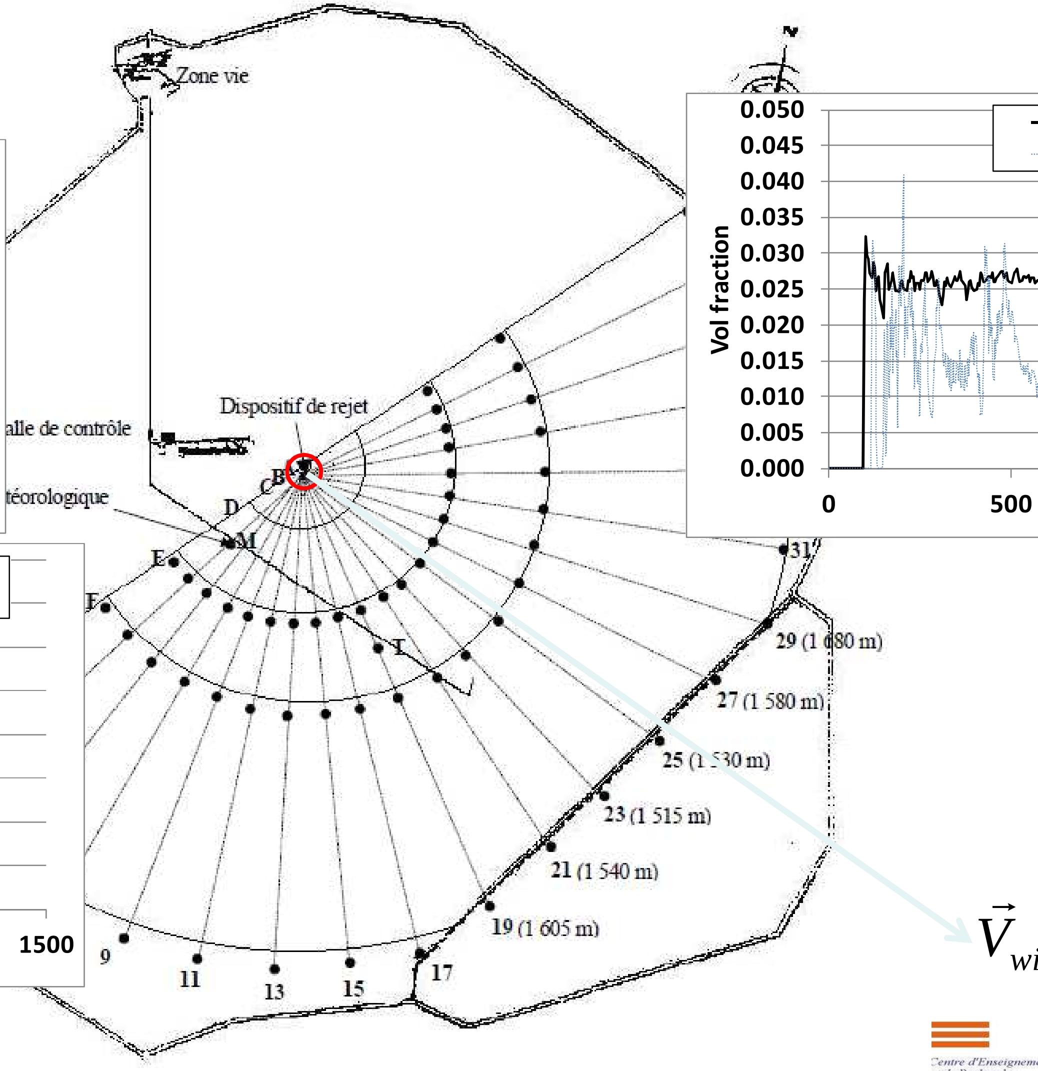
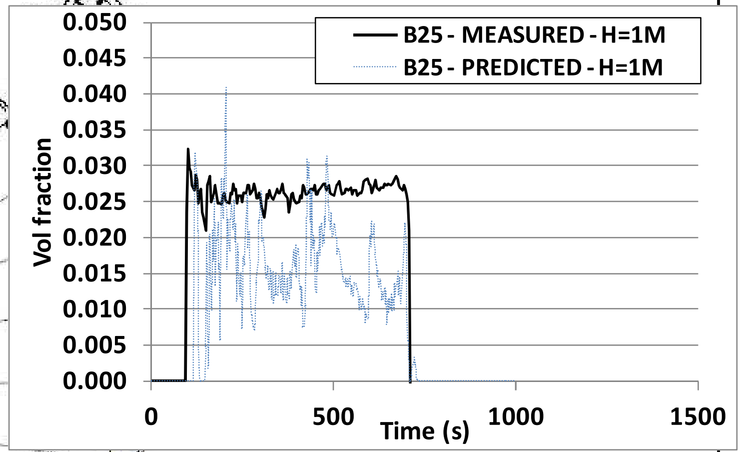
NH3 Concentration: Near Field

Distance (m)	Height (m)
50	1









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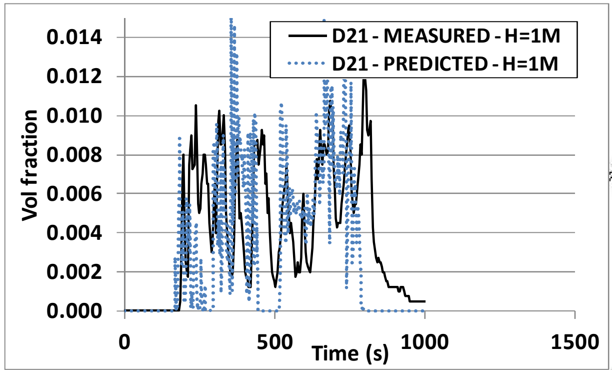
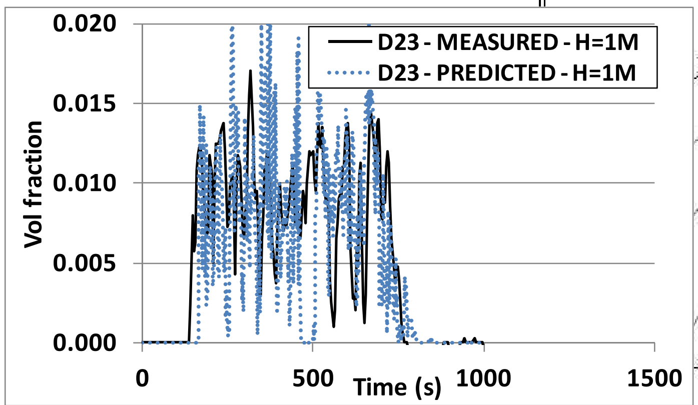
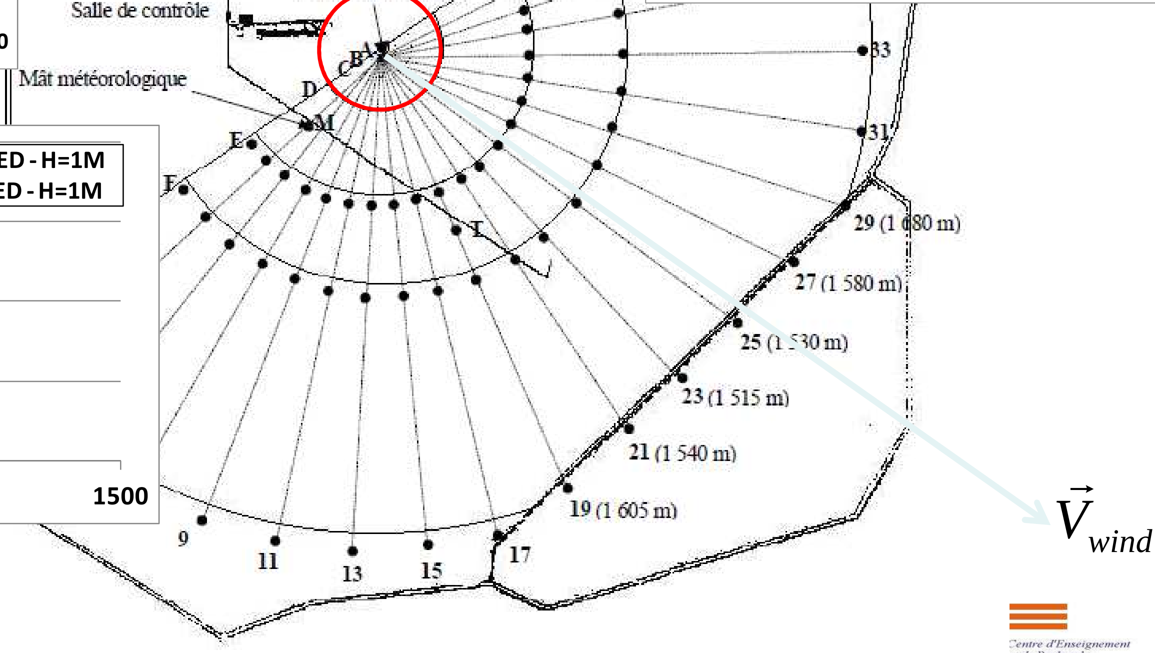
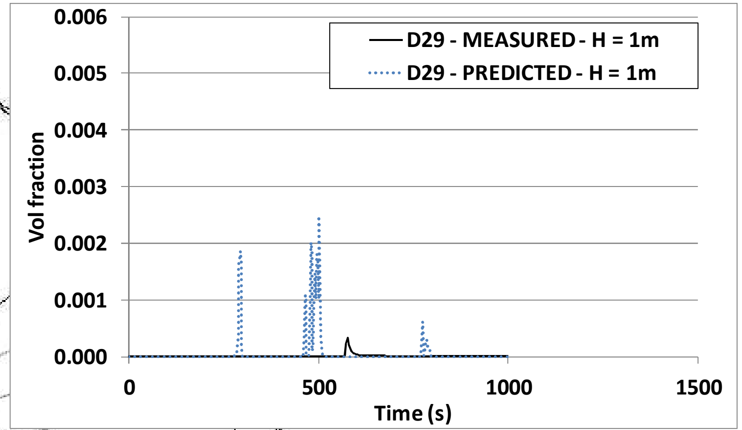
NH3 Concentration: Far Field

Distance (m)	Height (m)
200	1

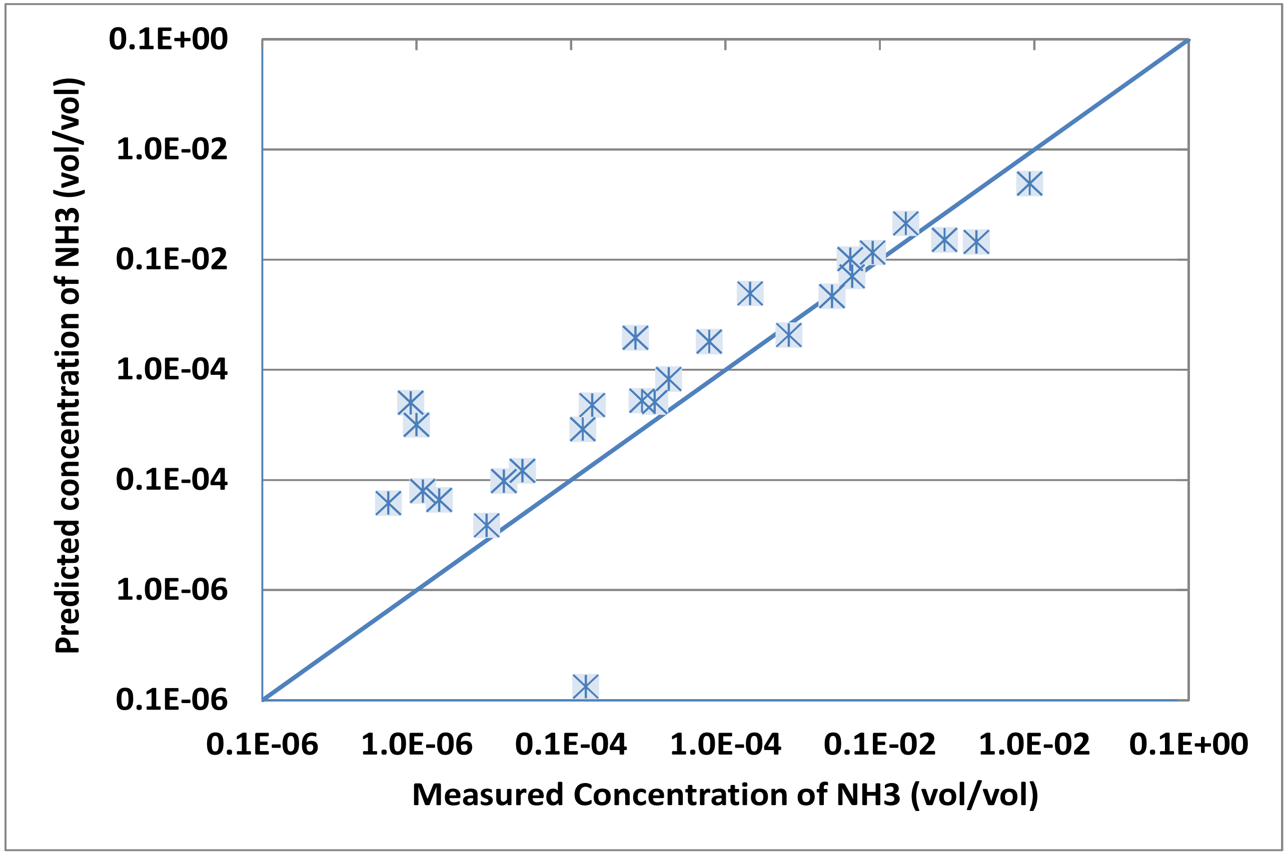








Averaged comparison on signal duration



Comparison (logarithmic scale) between predicted and mesured mean (arrival time and departure time of the cloud) concentration

$\Rightarrow$ Order of magnitude acceptable

Concluding comments

- Reconstruction of the signal velocity with a simple approach : (Fourier analysis) turbulence in time only (Input horizontally homogeneous),
- Promising results by LES approach regarding the complexity to describe both the release in the near field and the far field

Towards Predictive modelling for stable conditions

- But to go further it is worth using methods that introduce turbulence in space as well as in time.

→ To reach this objective we propose to use experimental velocity data from SIRTA experiment (Wei et al., 2014)

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- Bouet et al, 2005. "Ammonia large scale atmospheric dispersion experiments in industrial configurations", Journal of Loss Prevention in the Process Industries, vol. 18, pg 512 - 519, 2005.
- Xiao Wei, Eric Dupont, Bertrand Carissimo, Eric Gilbert and Luc Musson-Genon. A preliminary analysis of measurements from a near-field pollutants dispersion campaign in a stratified surface layer . 15th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. Madrid, 2013.
- Xiao Wei, Eric Dupont, Bertrand Carissimo, Eric Gilbert and Luc Musson-Genon. Experimental and numerical study of a near-field pollutants dispersion campaign in a stratified surface layer. 16th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. Varna, 2014.

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