Coupling the Code_Saturne CFD Model and the PMSS Lagrangian Particle Dispersion Model for indoor / outdoor applications.

Application on a railway station in downtown Paris

M. Nibart, A. Albergel, C. Olry, J. Moussafir, P. Armand, C. Duchenne

ARIA Technologies SA
8-10, rue de la Ferme – 92100 Boulogne Billancourt – France
Telephone: +33 (0)1 46 08 68 60 – Fax: +33 (0)1 41 41 93 17
E-mail: info@aria.fr – http:/ /www.aria.fr

Scope

In the framework of the development of **multi-scale emergency response systems** for large cities such as Paris, the indoor / outdoor simulation problem must be faced.

The present study experiments the **coupling** of:

1. A full **CFD model (Code_Saturne)** for the detailed micro-scale description of a given critical building (conference hall, railway station, stadium)

2. An **Urban simplified flow and dispersion model (PMSS)** for the description of the dispersion over the surrounding City, whether the contamination is generated inside the building or whether it impacts the building from outside.

Outline

1. **Models presentation**
2. **Which coupling strategy ?**
3. **Test cases**
4. **Application on *Gare du Nord* railway station**
5. **Conclusion**

PMSS

PMSS is the **parallel** version of the **MSS** tool, combining:

- a mass-consistent diagnostic model (**Micro SWIFT**)
- coupled to a Lagrangian particle dispersion model (**Micro SPRAY**)

PMSS is designed to model urban or industrial micro-scale dispersion phenomena with CPU times significantly shorter than the full CFD solutions.

Typical PMSS applications:

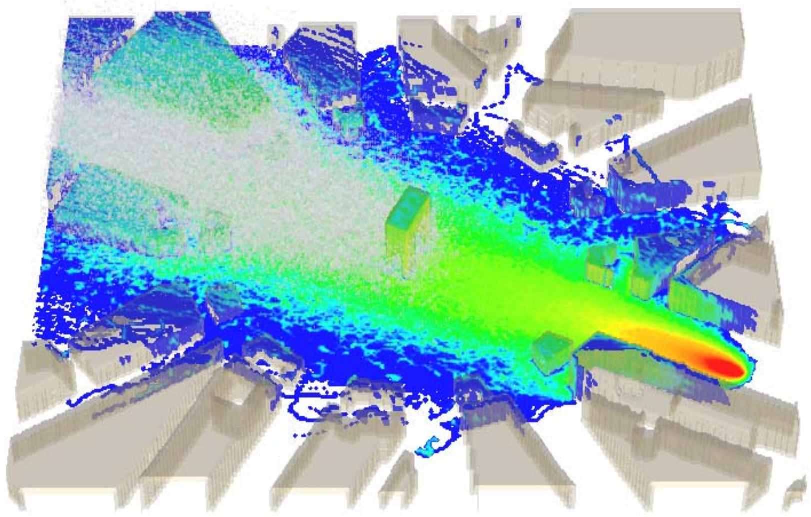
- Domain size: 1 to 10 km dimension / Cell size: 1 to 10 meters
- Single PC processor CPU time about 1/10th of real simulated time
- Response time: few minutes

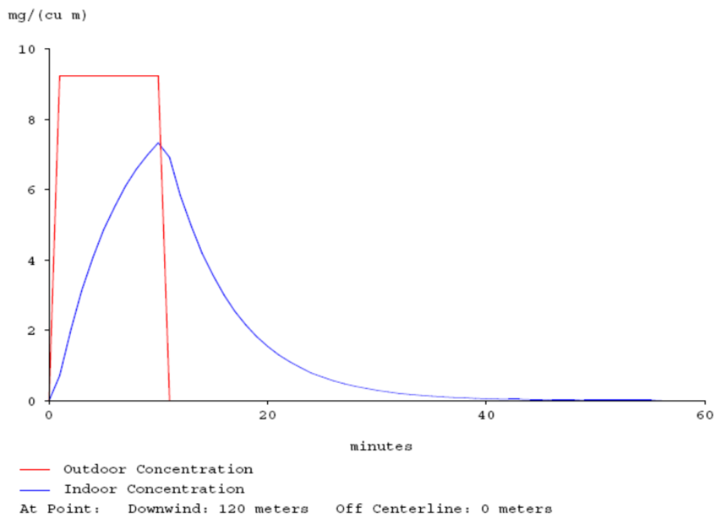
MSS is included into the HPAC 5 suite of models

- Coupled to SWIFT meteorological assimilation model
- Coupled to SCIPUFF (Particle to Puff conversion and handoff)

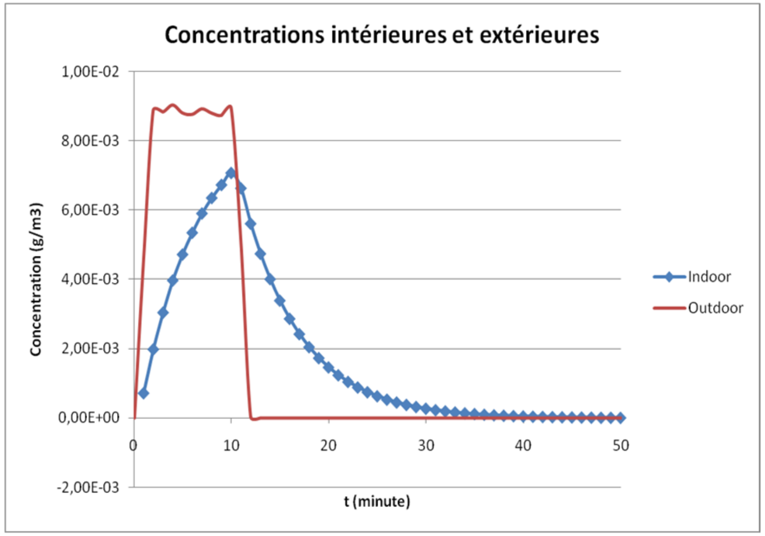
Indoor infiltration/exfiltration in PMSS

1. **Indoor/outdoor fluxes are driven by a time scale and Delta-P on façades**
2. **Rate of air renewal**
3. **Building interior is not described in detail**





ALOHA

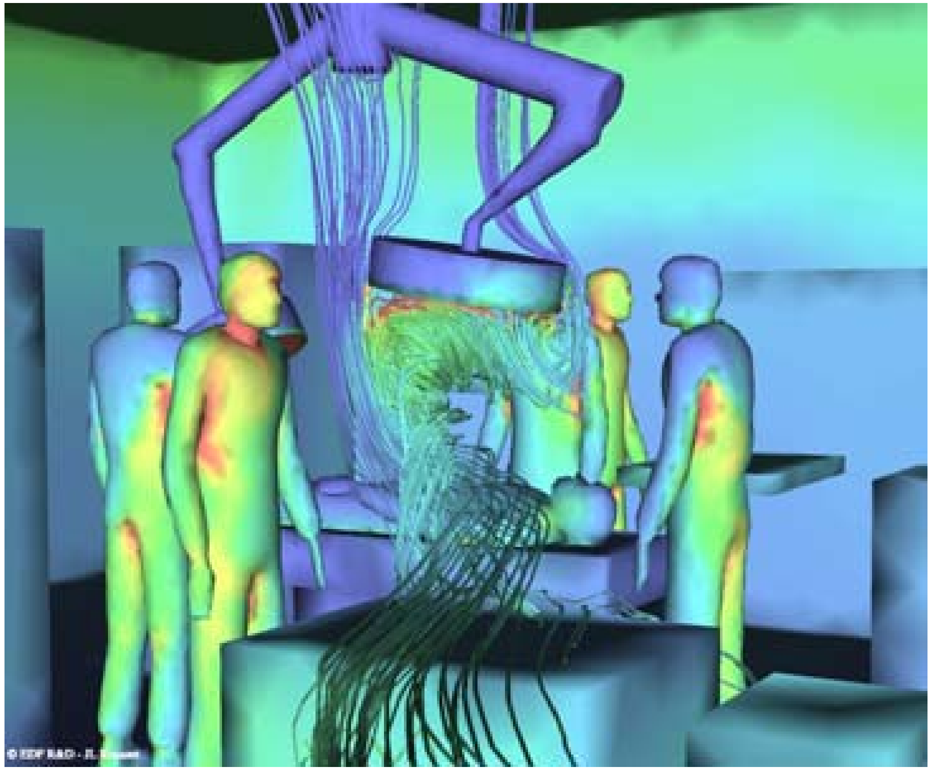


PMSS

Code_Saturne

Developed since 1997 at EDF R&D, it is based on a co-located Finite Volume approach that accepts meshes with any type of cell (tetrahedral, hexahedral, prismatic, pyramidal, polyhedral…) and any type of grid structure (unstructured, block structured, hybrid, conforming or with hanging nodes, …).

Code_Saturne is property of EDF and distributed under the GNU GPL licence (Open Source).



Coupling strategies

Where does CFD start ?

- Outer domain : part of the city/ the whole city
- Inner domain :

  inside of the building ?

  inside of the building + very close environment ?

Outer domain

Inner domain possibilities

Coupling strategies

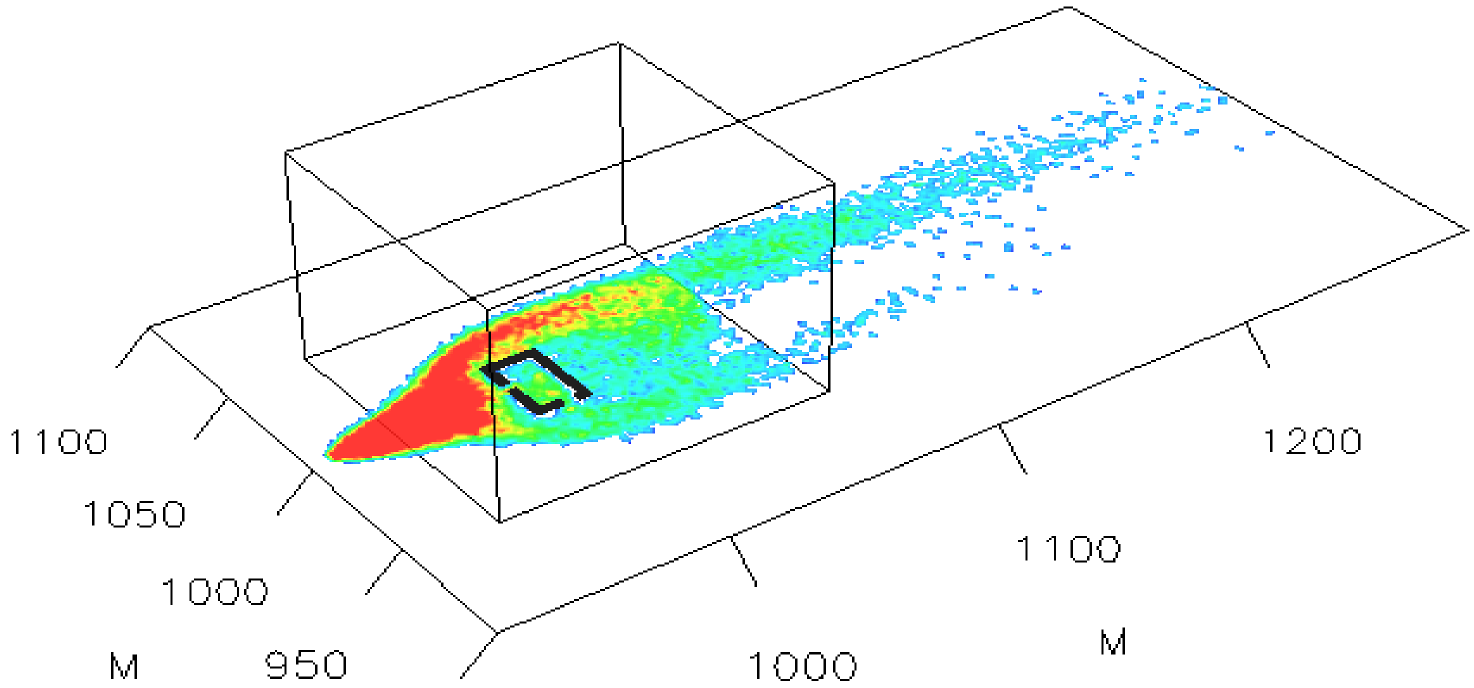
- **Method 1**

All the dispersion is done by SPRAY, in multi-scale mode.

Code_Saturne (k-eps) is used like SWIFT in the inner domain. The three models are called in one sequence:

SWIFT -> Code_Saturne -> SPRAY

The particles are moved by the flow computed by SWIFT or Code_Saturne depending on their location.



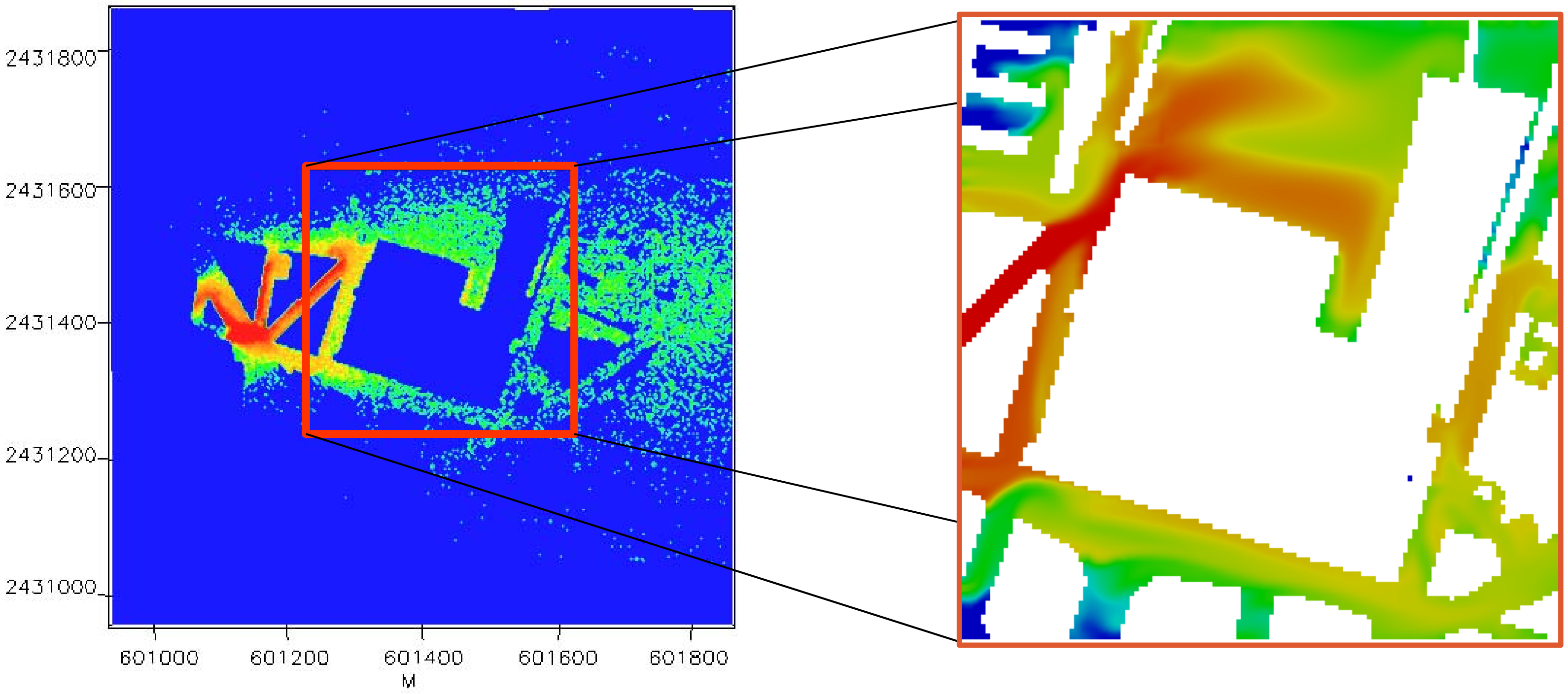
Coupling strategies

- **Method 2**

In the inner domain, dispersion is done by Code_Saturne

Code_Saturne and SPRAY are called in sequence at each time step.

All the “power” of CFD is available in the inner domain.



SPRAY   Code_Saturne

Coupling strategies comparison

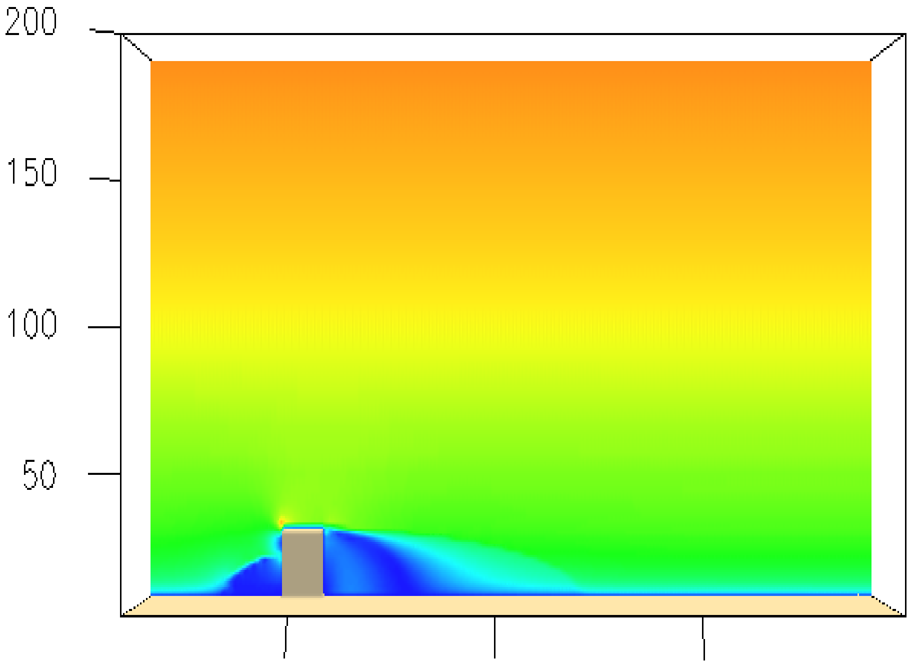
Strategy choice = dispersion model in inner domain choice

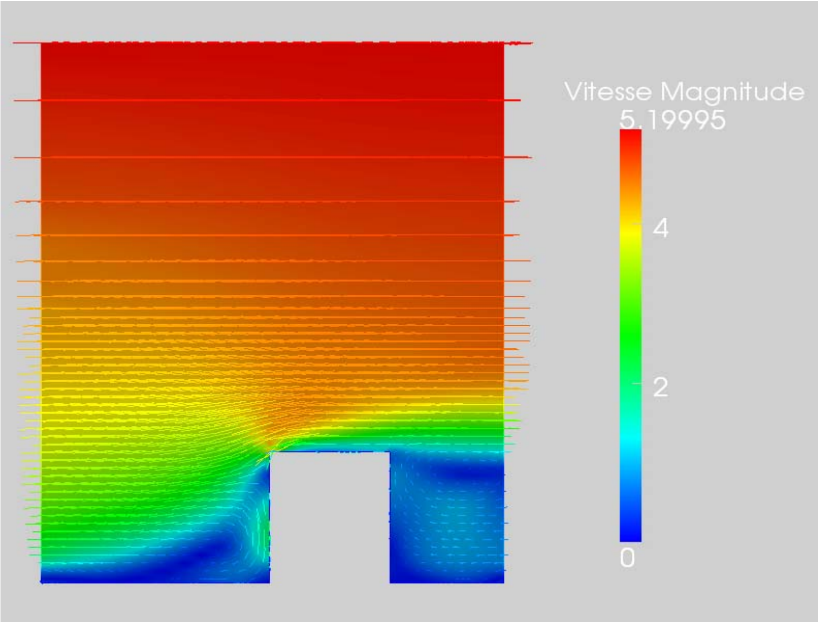
Dispersion Model	+	-
Micro-SPRAY	- Fast - One single model for inner and outer domains	- Coupling with wind field from Code_Saturne only for with structured mesh
Code_Saturne Lagrangian	- Non structured mesh	- Not parallel - Not used for atmospheric dispersion - One model in inner domain and one for the outer domain
Code_Saturne Eulerian	- Non structured mesh - Often used for atmospheric dispersion - Parallel - Better modeling of jet/dense gaz effect	- Slow - One model in inner domain and one for the outer domain

Wind coupling

SWIFT results are used :

- for the boundary conditions of Code_Saturne



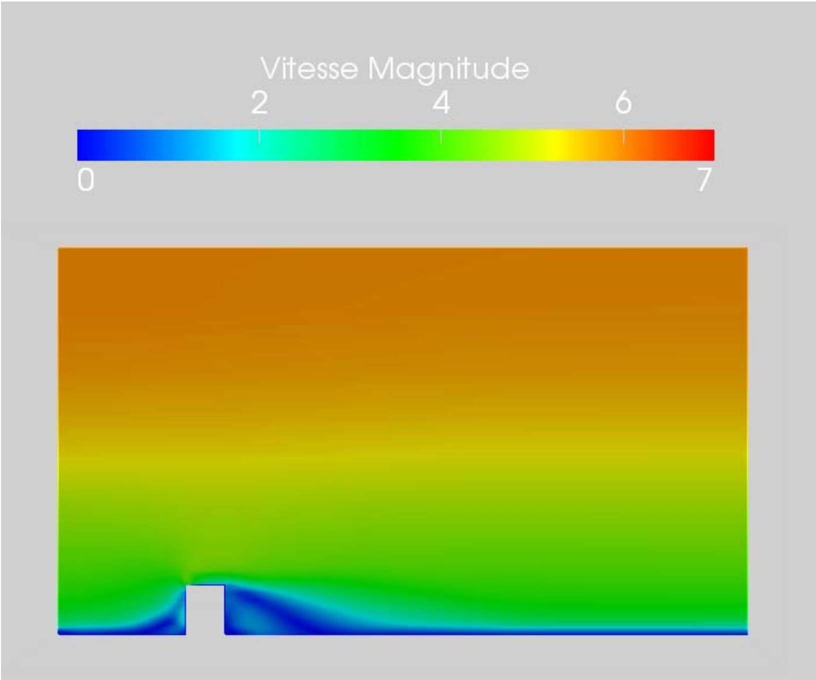


Outer domain : SWIFT

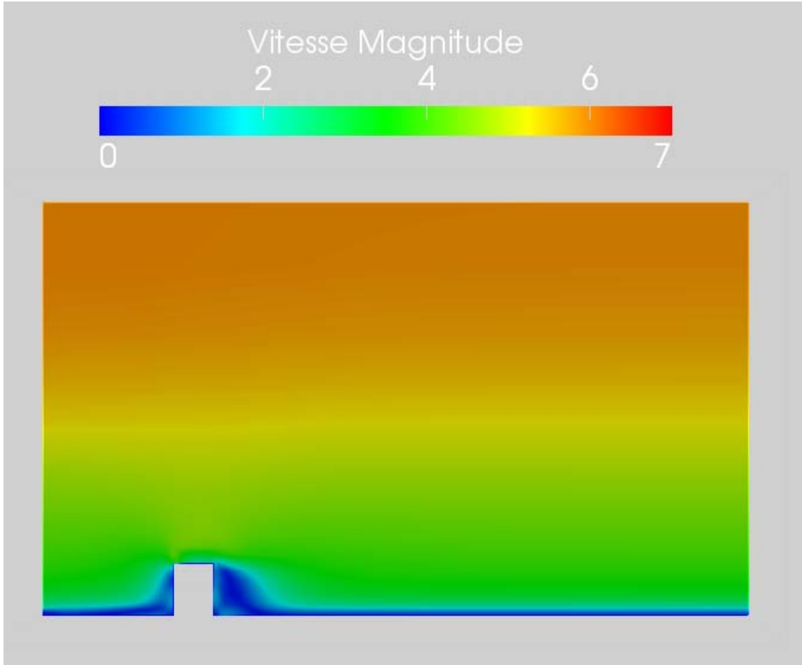
Inner domain :Code_Saturne

Wind coupling

SWIFT results are used for the initialization of Code_Saturne => significant speedup (convergence)



Code_Saturne
100 iterations + SWIFT 3D init.



Code_Saturne
100 iterations + 1D met profile init.

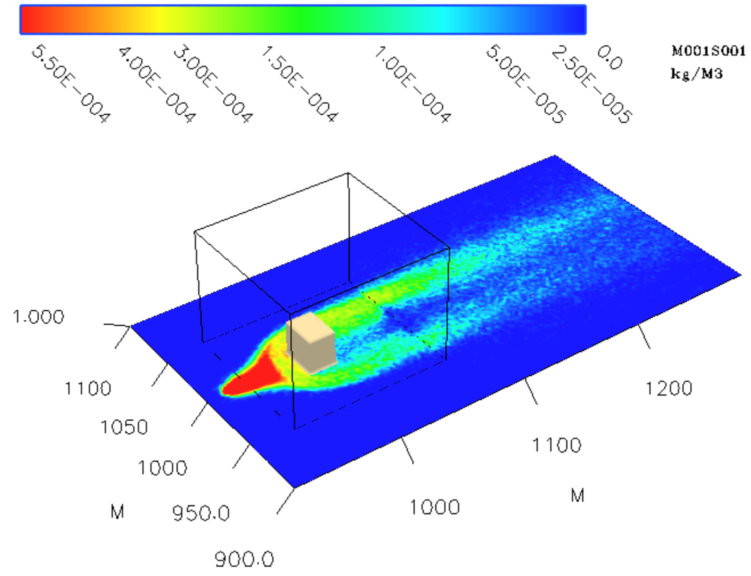
Dispersion coupling method 1

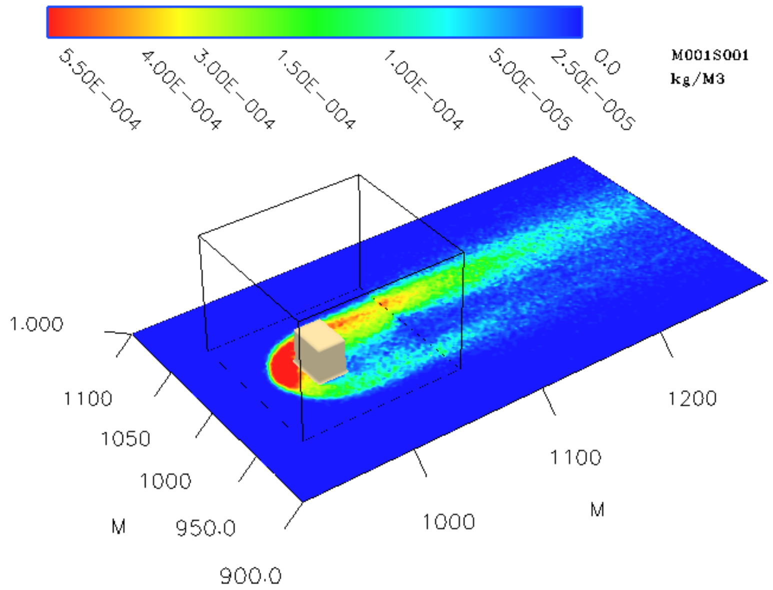
- SPRAY must be plugged to Code_Saturne wind/turbulence output
- SPRAY must have a nesting mode for at least one level

First tests – Method 1

Cubic building with two doors

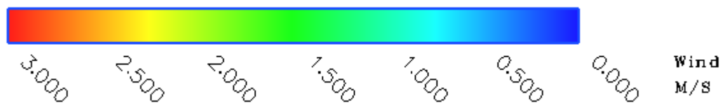
Ground concentration – Release in outer domain



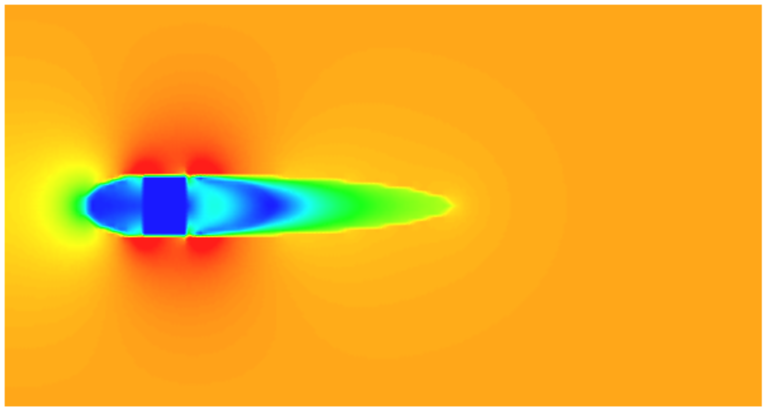


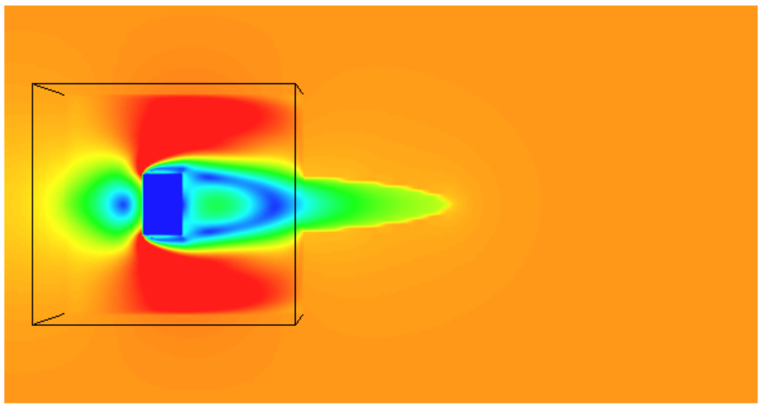
Ground concentration – Release in inner domain

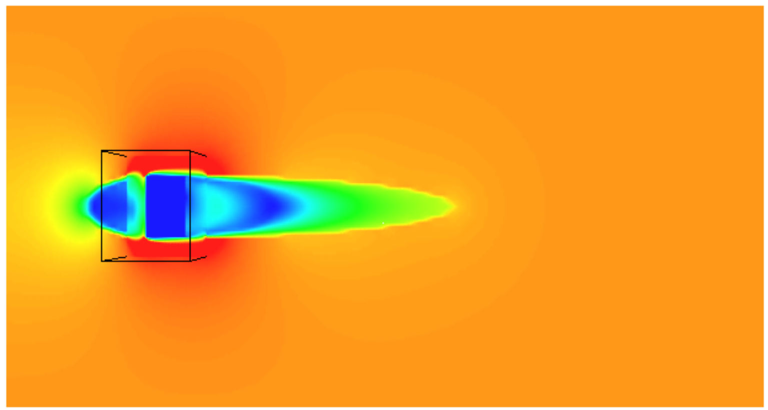
First tests – Method 1



SWIFT only



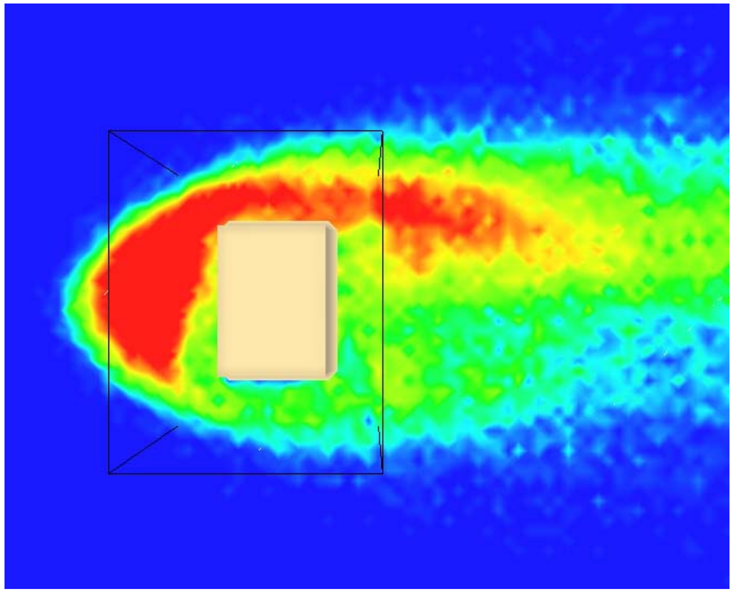


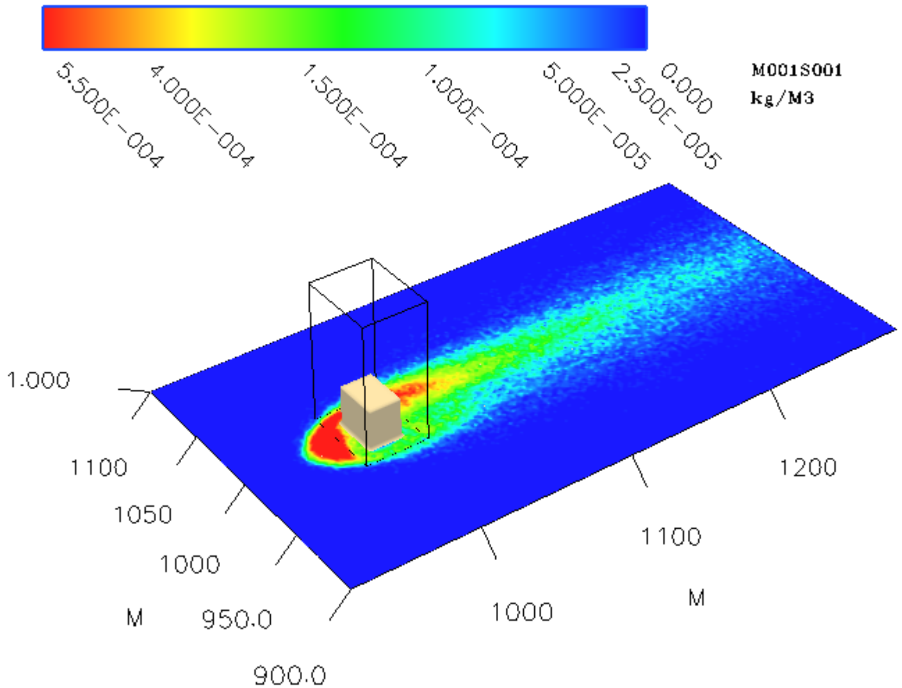


SWIFT + Code_Saturne

SWIFT + Code_Saturne on smaller domain

First tests – Method 1





Ground concentration – Release in inner domain – small inner domain

« Gare du Nord » case

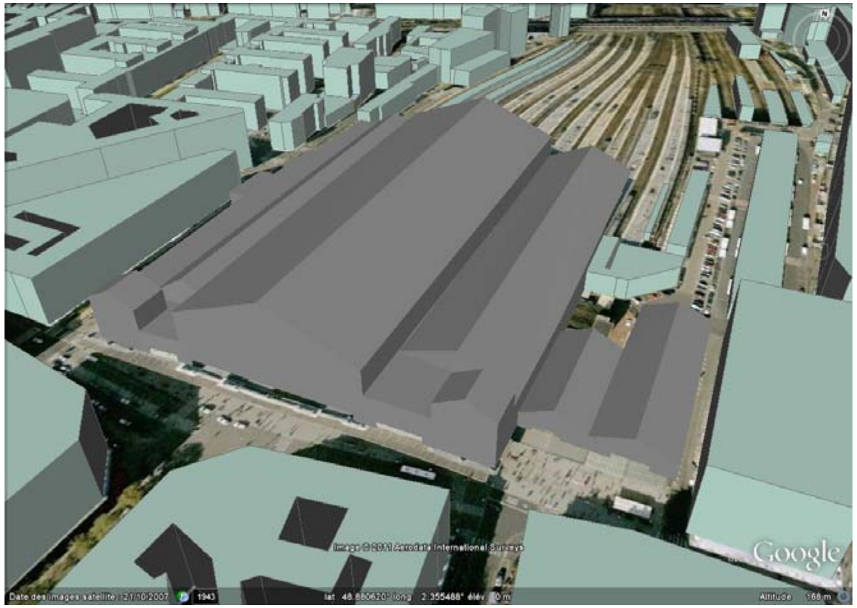
Glass roof

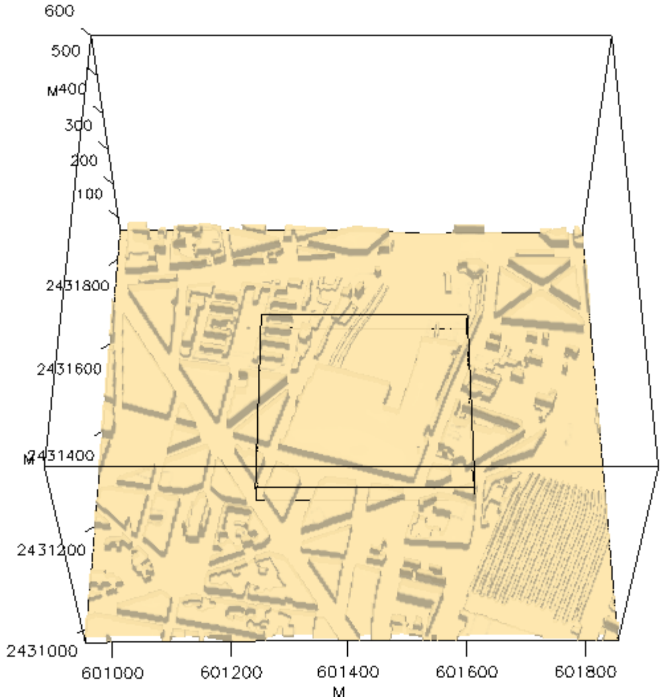
« Gare du Nord » railway station, Paris

Buildings of IGN BDTOPO seen in GE

« Gare du Nord » case

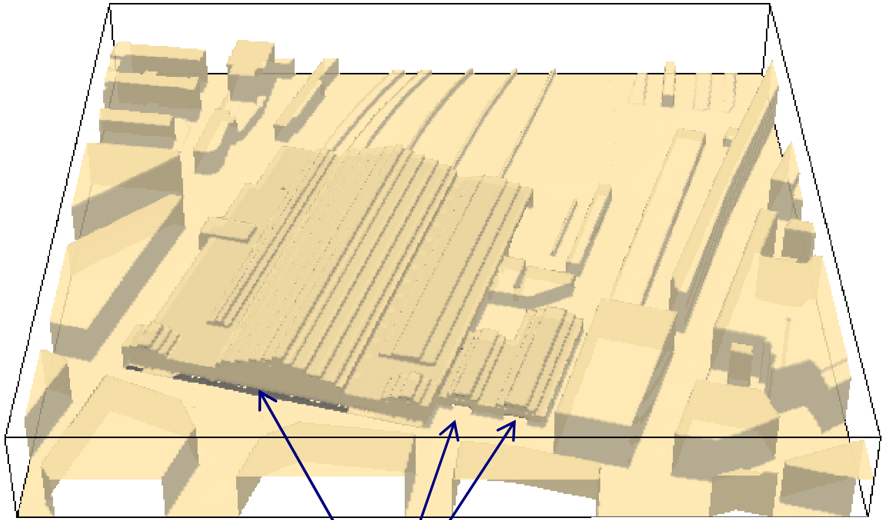
Outer domain resolution : 3 m
Inner domain resolution : 1 m
One 5 min release in front of the main entrance
One 5 min release in the station
West wind and South wind situations
Improved Station geometry





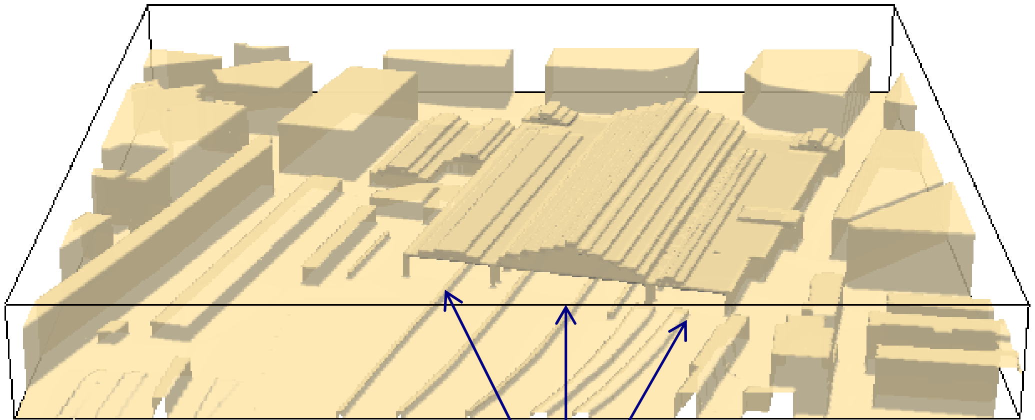
Outer and inner domains

« Gare du Nord » case



Inner domain view from South

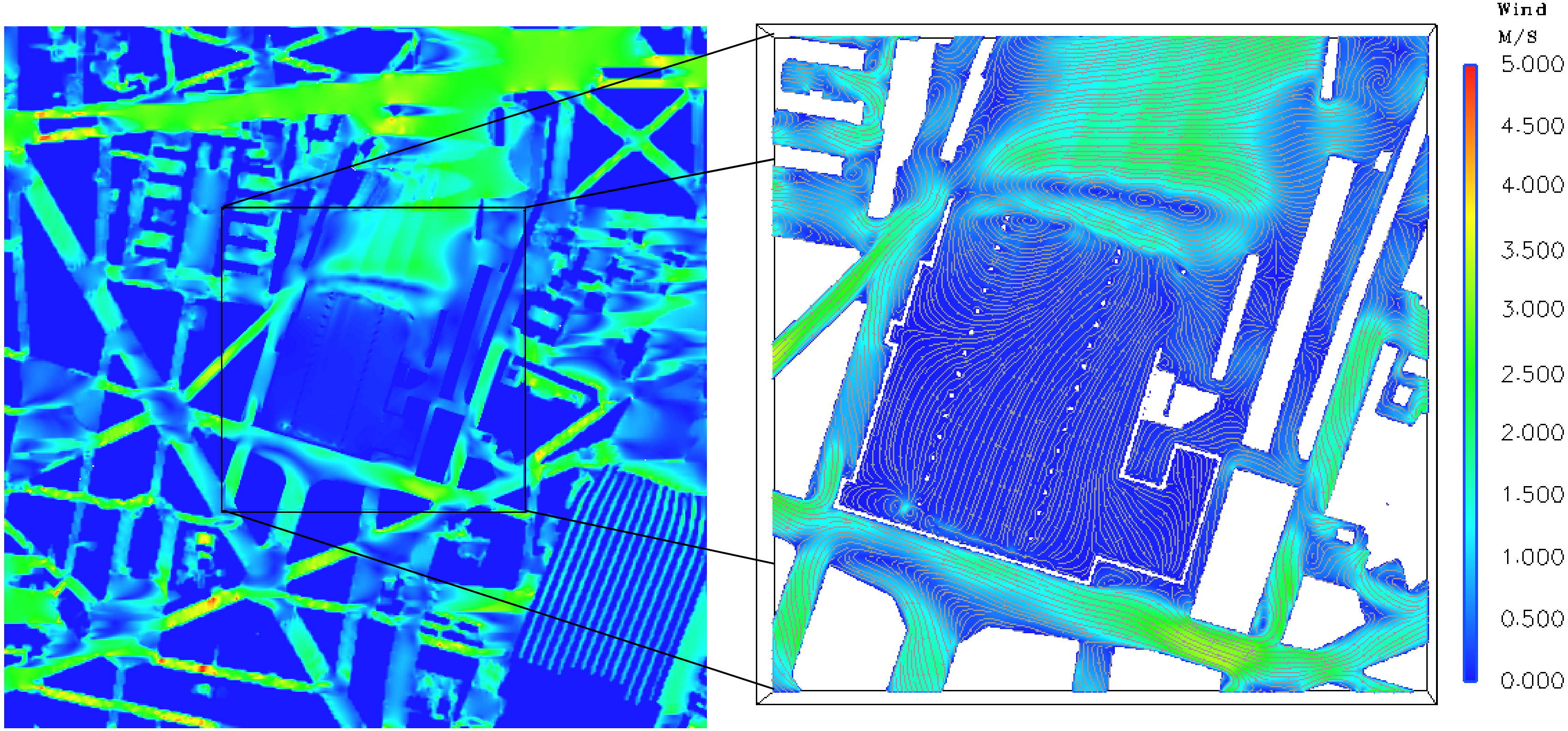
Open doors



Inner domain view from North

Large opening for trains exit

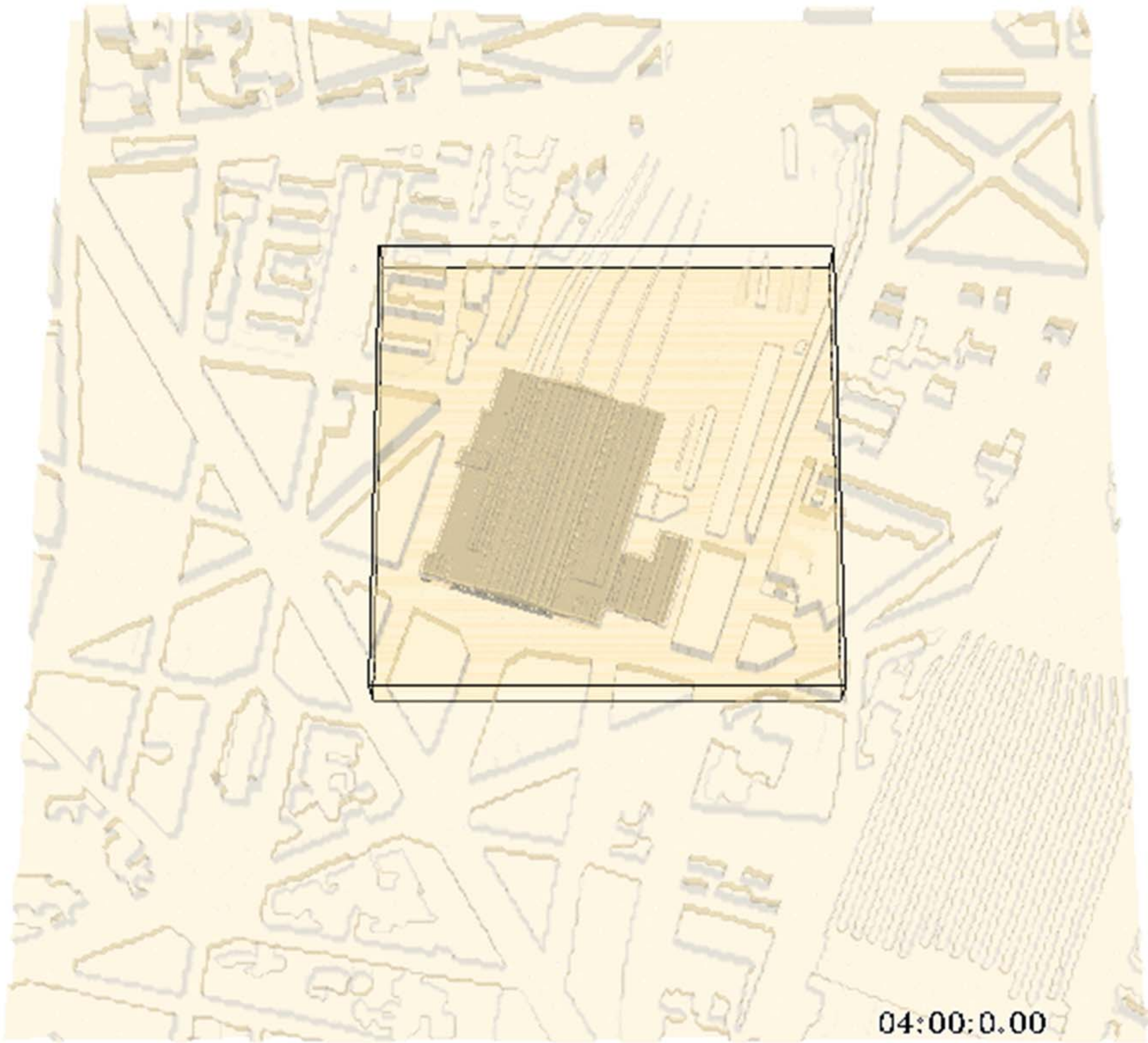
« Gare du Nord » case – Wind from West



Wind from West – Wind speed and stream lines at 5 m a.g.l.

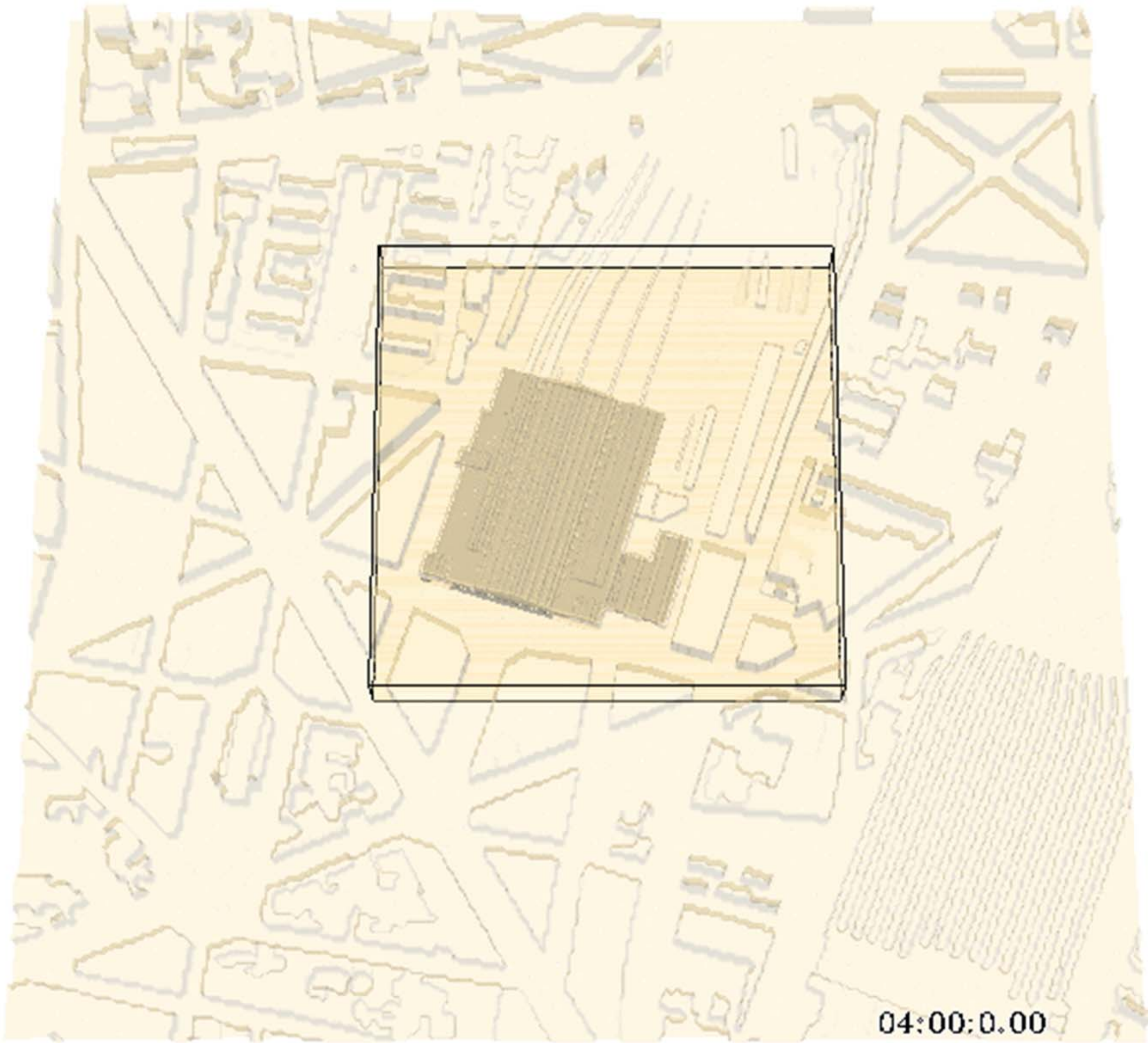
Wind is not in the axis of openings ➡ no Draft

« Gare du Nord » case – Method 1



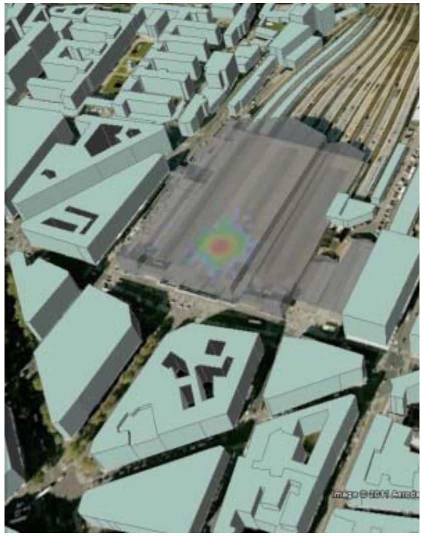
Wind from West – Ground concentration – Indoor release

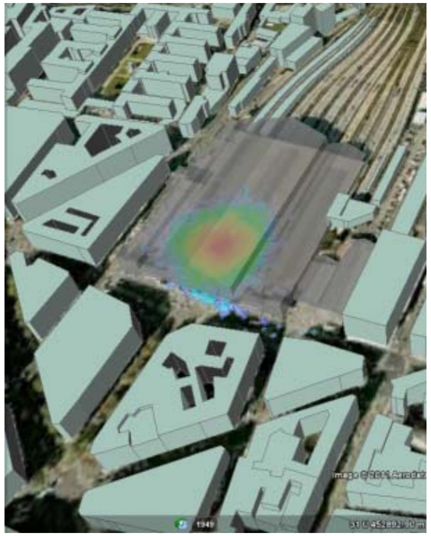
« Gare du Nord » case – Method 1

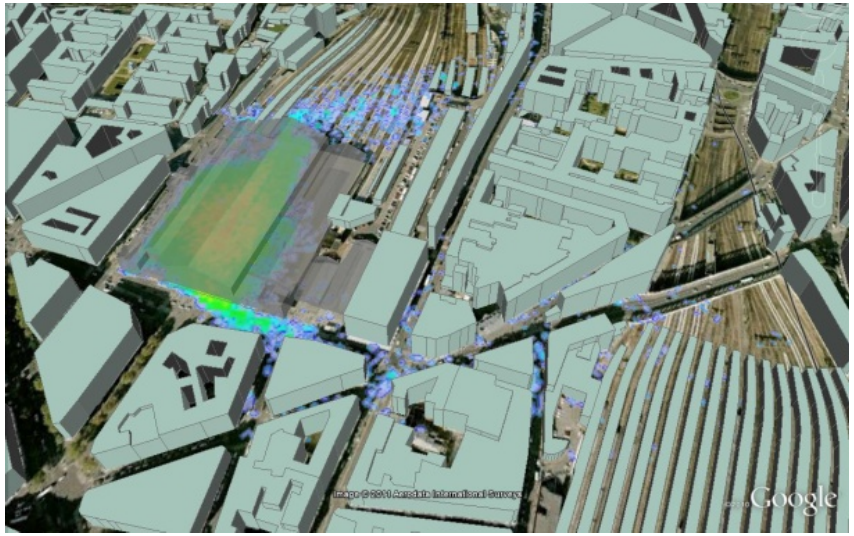


Wind from West – Ground concentration – Outdoor release

« Gare du Nord » case – Method 1

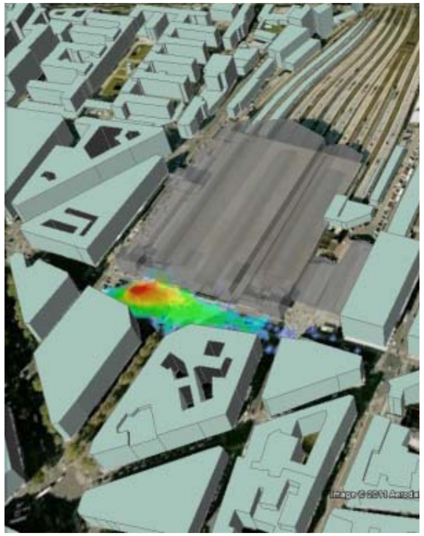


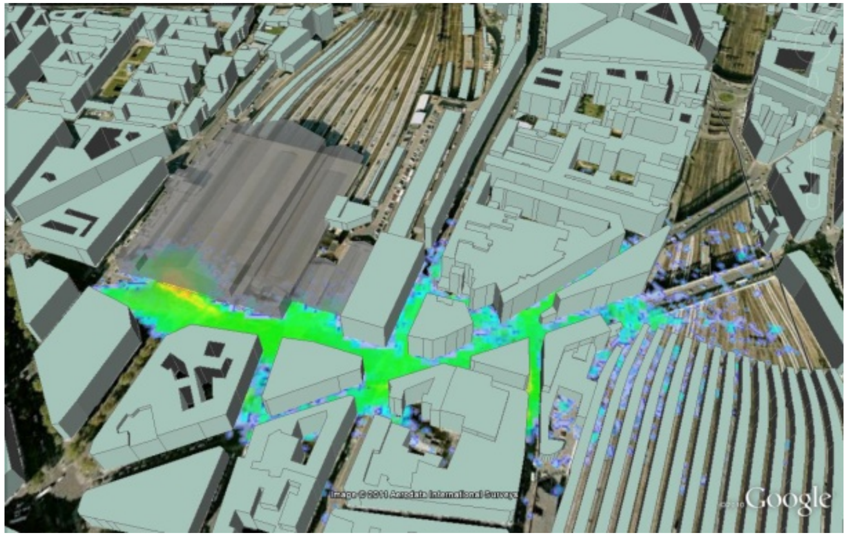


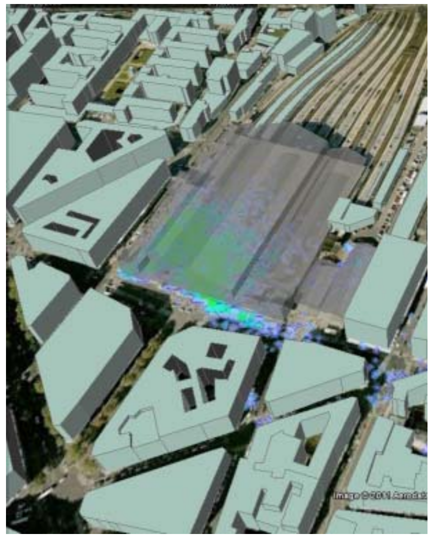


Indoor release - View in Google Earth (2, 8 and 32 minutes after release)

« Gare du Nord » case – Method 1

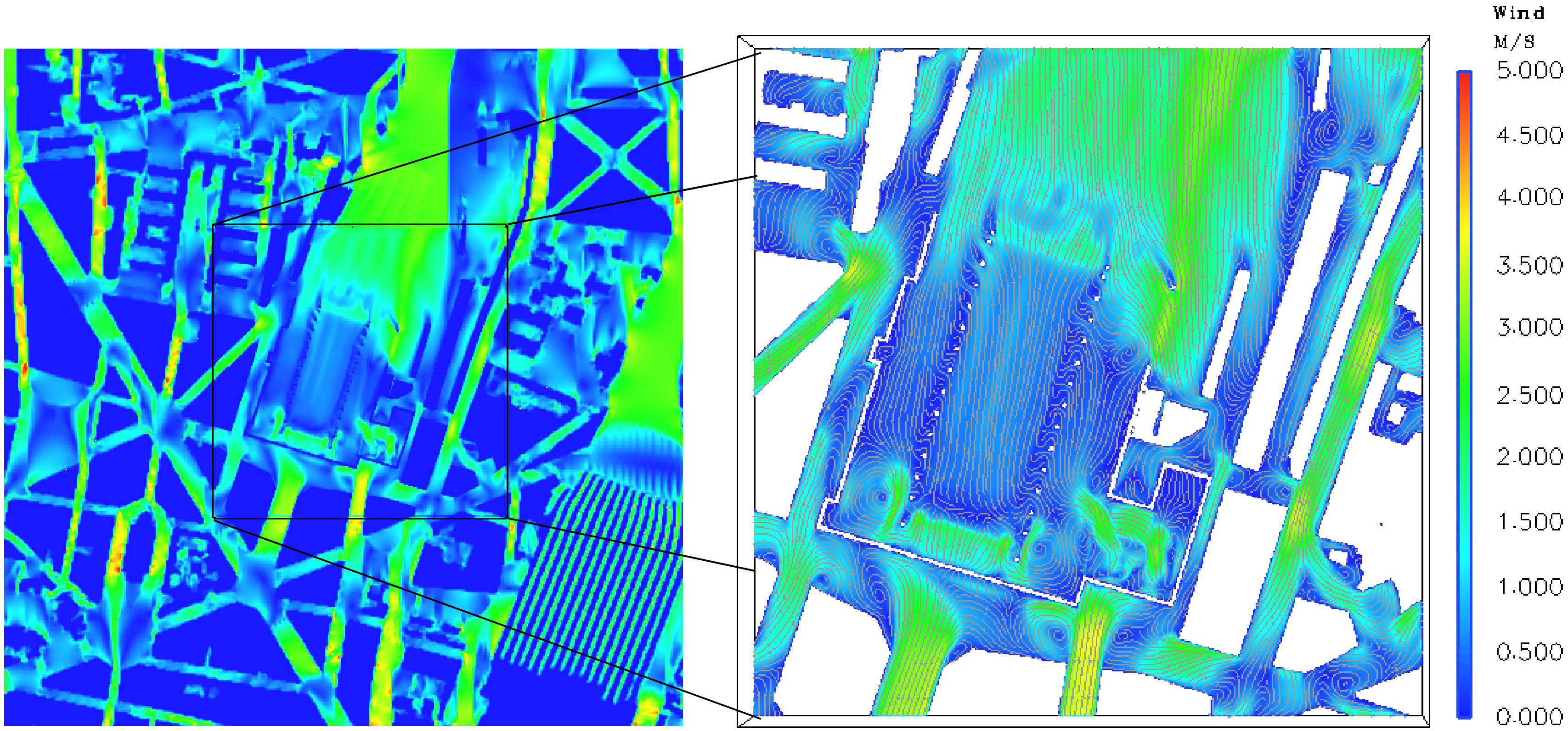






Outdoor release - View in Google Earth (2, 8 and 32 minutes after release)

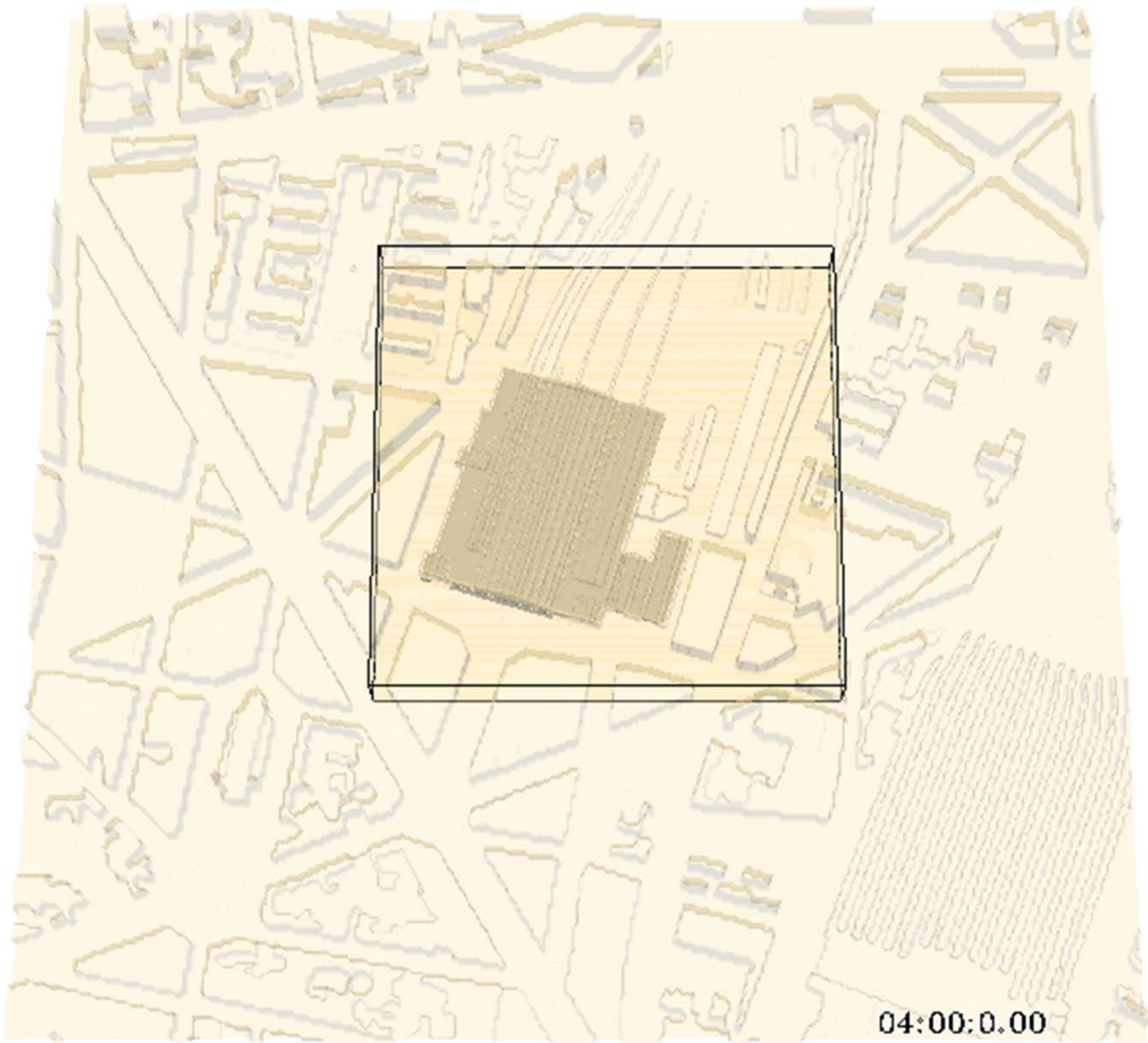
« Gare du Nord » case – Wind from south



Wind from South – Wind speed and stream lines at 5 m a.g.l.

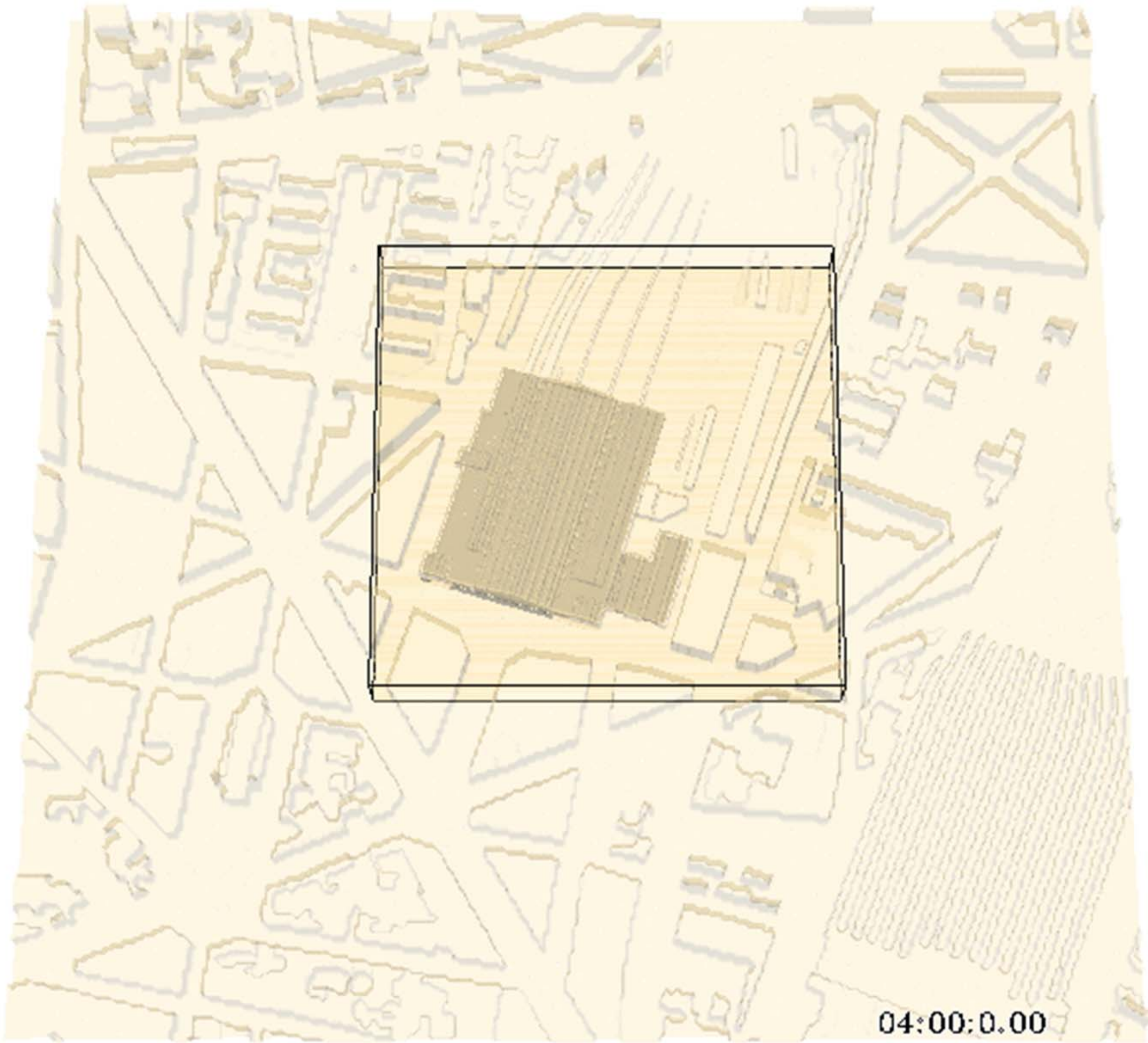
Wind is in the axis of openings ➡ Drafts

« Gare du Nord » case – Method1



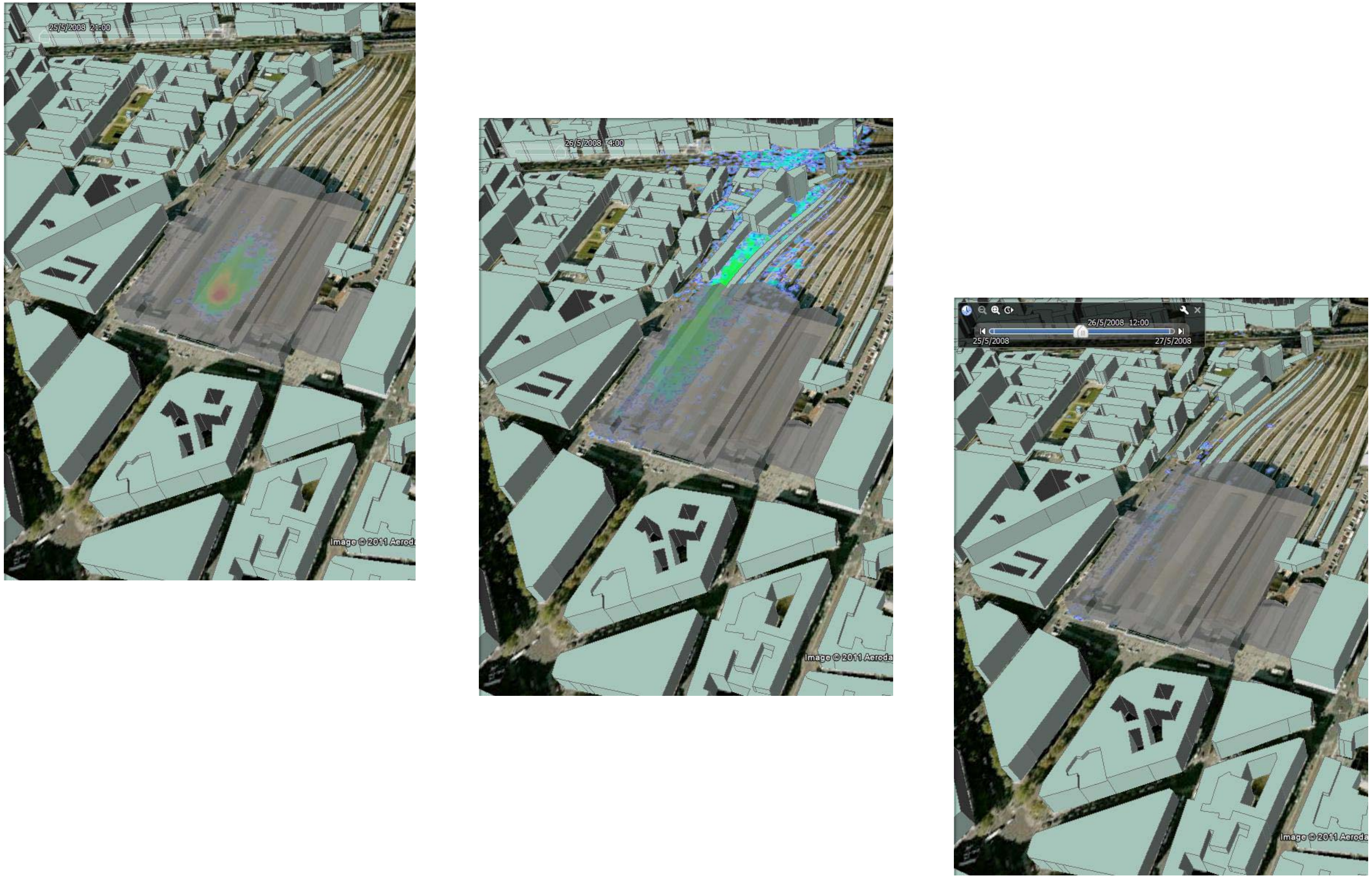
Wind from South – Ground concentration – Indoor release

« Gare du Nord » case – Method1



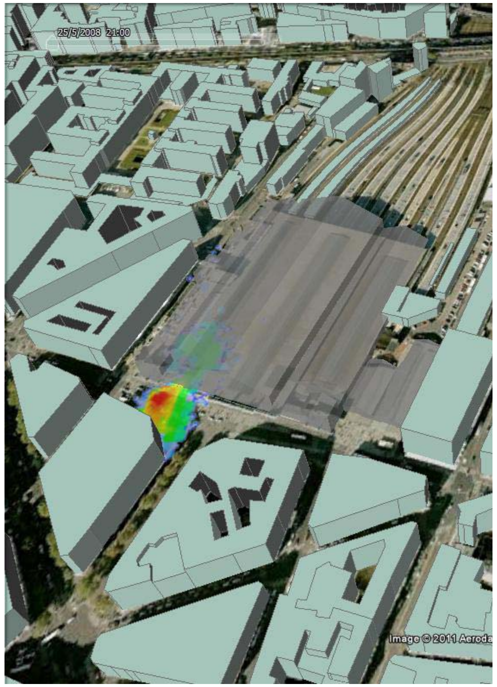
Wind from South – Ground concentration – Outdoor release

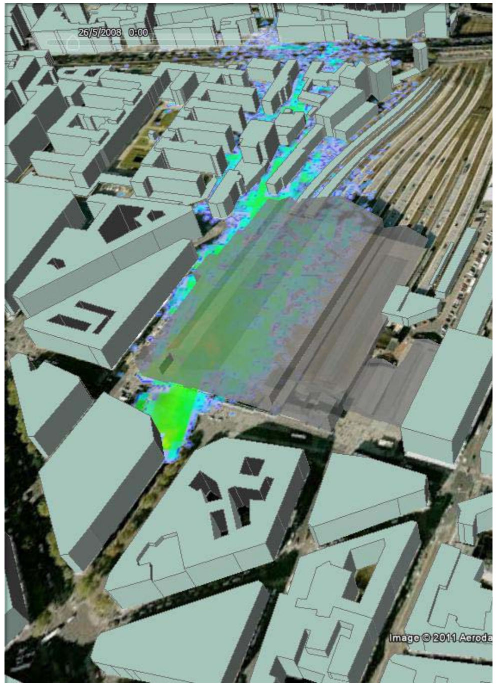
« Gare du Nord » case – Method 1

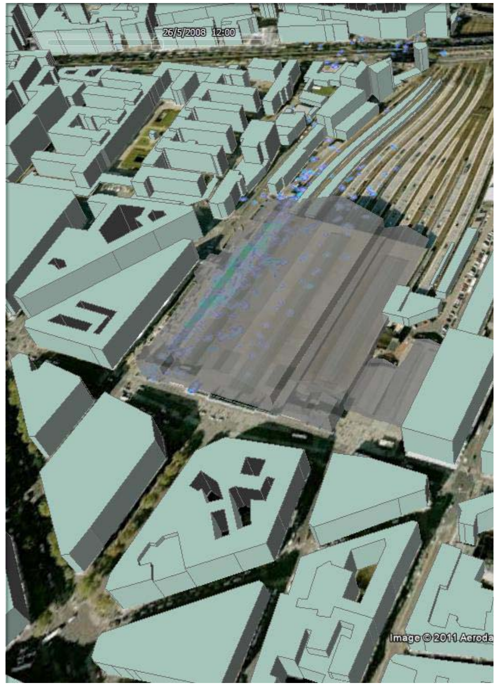


Indoor release - View in Google Earth (2, 8 and 32 minutes after release)

« Gare du Nord » case – Method 1

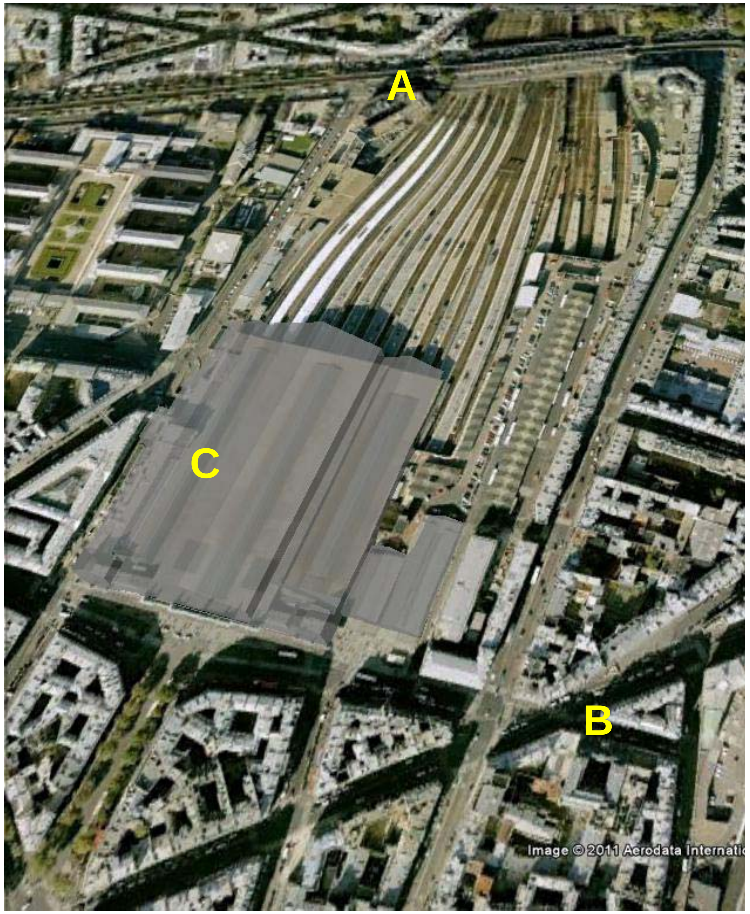






Outdoor release - View in Google Earth (2, 8 and 32 minutes after release)

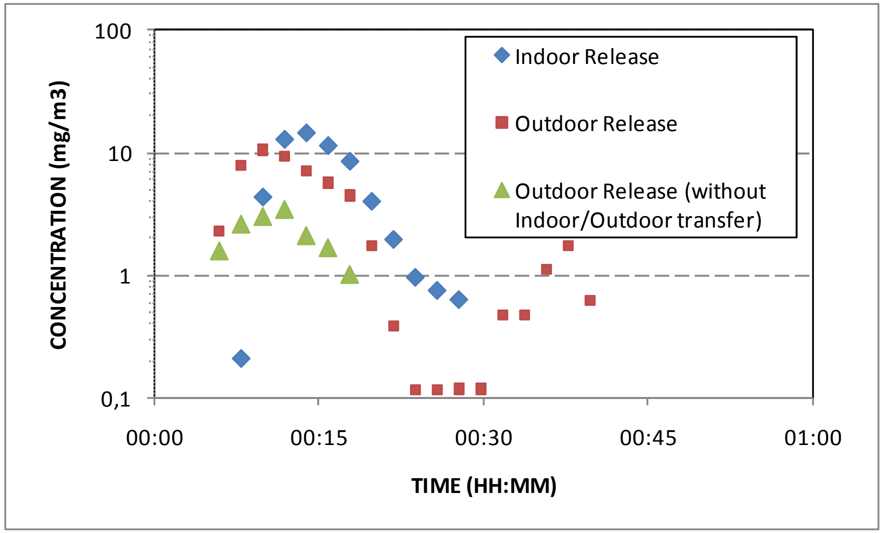
« Gare du Nord » case – Method 1



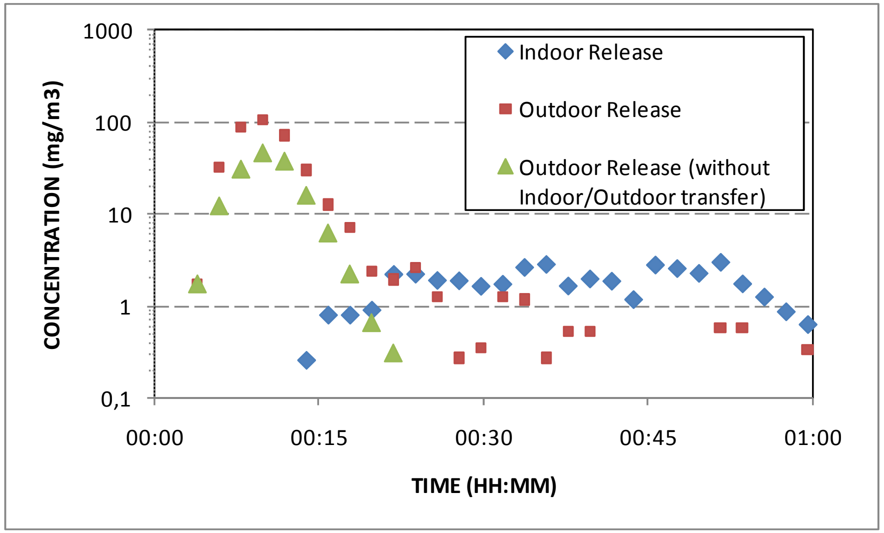
Location of virtual sensors

« Gare du Nord » case – Method 1

Concentrations Time Series – Outdoor Sensor



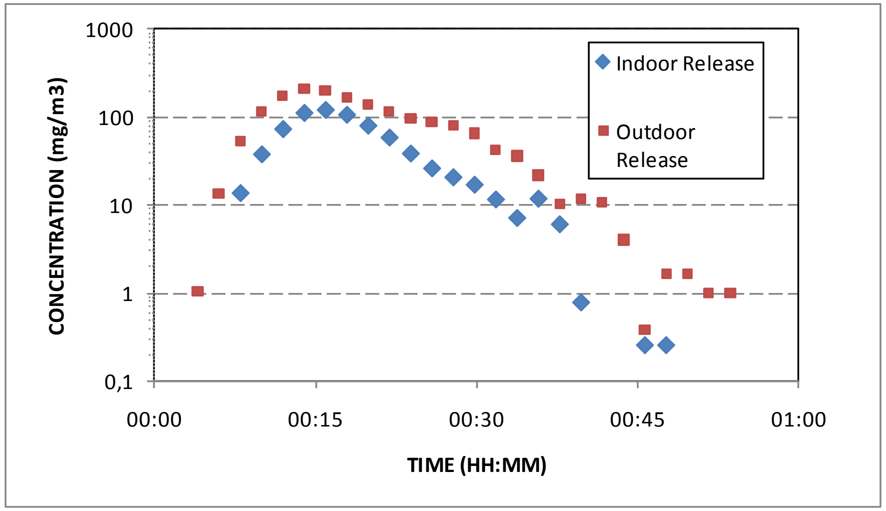
South Wind - point A



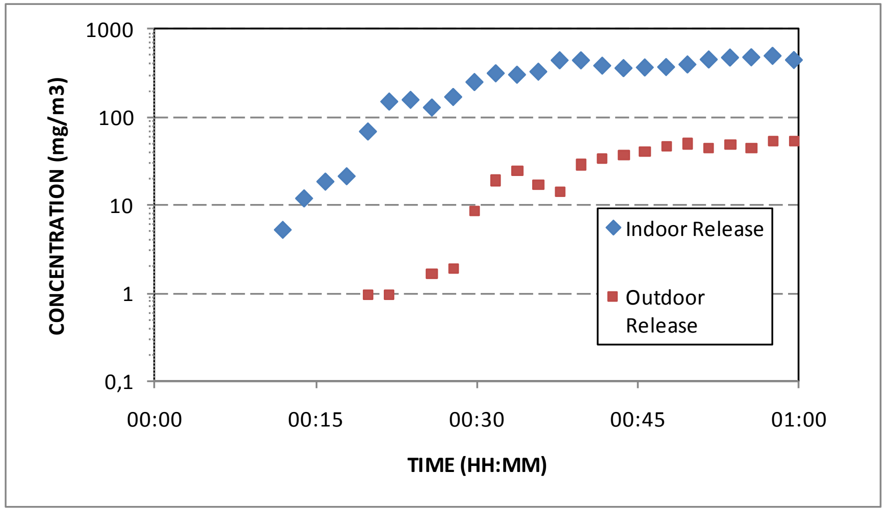
West wind - point B

« Gare du Nord » case – Method 1

Concentrations Time Series – Indoor Sensor



South Wind - point C



West Wind - point C

CPU times

Model	1 core	24 cores	50 cores	100 cores
SWIFT	3 min(2)	-	-	-
SPRAY	1h15(2)	312 s (3)	167 s(3)	105 s(3)
Code_Saturne	-	18h(1)	?	?

(1) 2×12 Cores Intel(R) Xeon(R) CPU E5410 @ 2.33GHz (ARIA cluster)

(2)1 Core Intel(R) i7 CPU Q720 @ 1.60GHz (laptop)

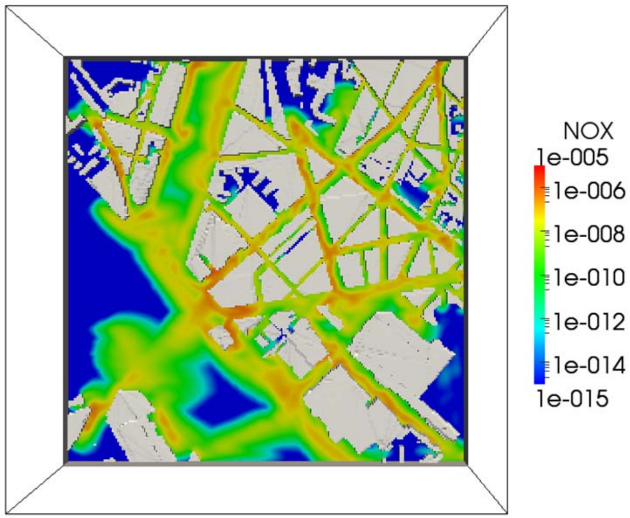
(3) Platine CCRT

CPU times – Code_Saturne

CPU times obtained with other urban modeling

Nb cells	Nb cores	CPU time
2.5M	24	18h
3M	12	15h
1.1M	12	4h

Gare du Nord Case



Conclusions

- Application of the less CPU time consuming coupling method on the target case

- A fisrt “Nest version” of SPRAY. Code_Saturne and SPRAY plugged (Limitation to structured meshes)

- No validation on *Gare du Nord* application. Proof of concept.

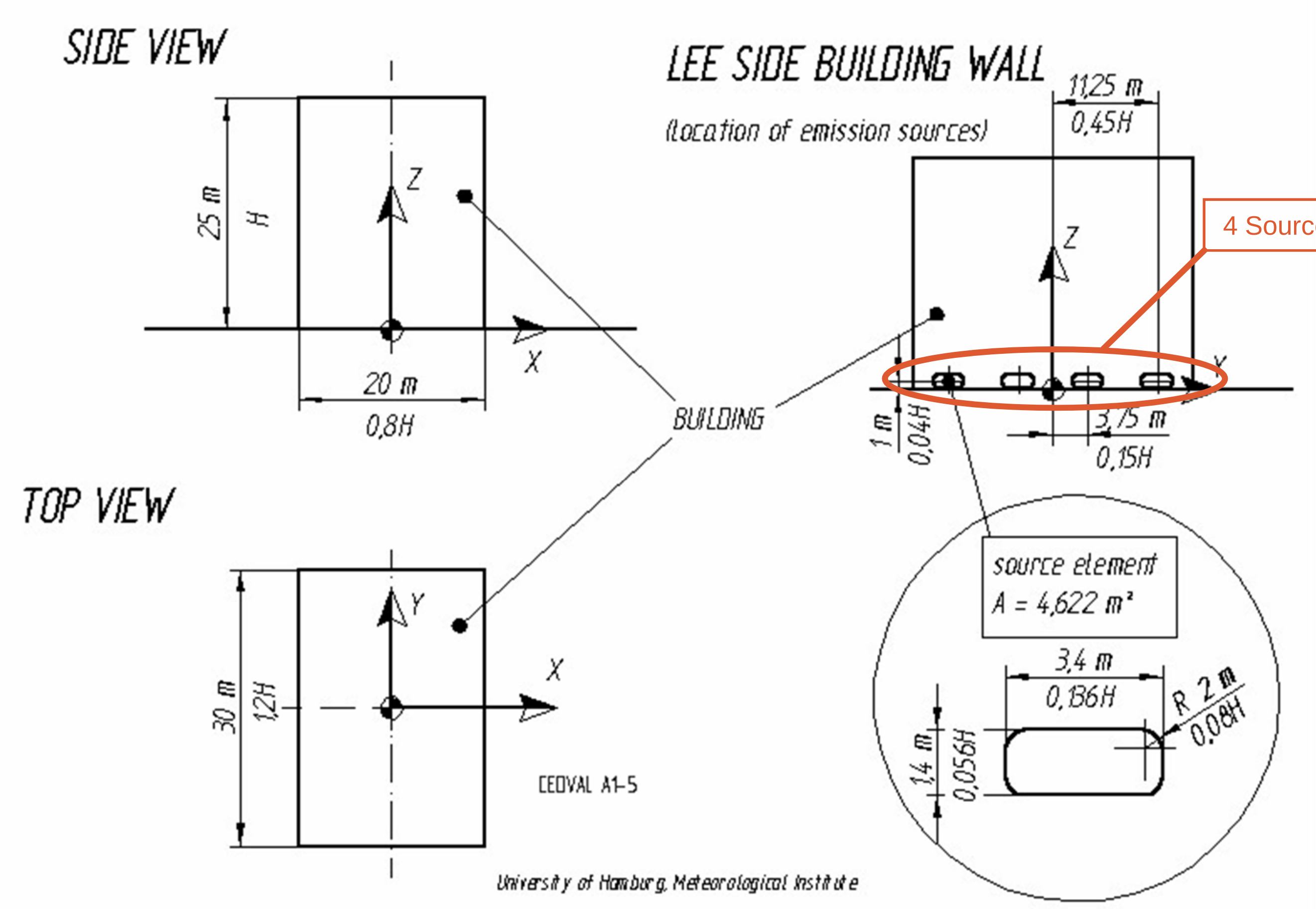
- CFD setup improvements :
  - More accurate geometry
  - Natural convection (green house effect)
  - forced ventilations/extractions
  - CPU time (massively parallel – stationary scheme – Mesh size)

- Code_Saturne CFD model could be used as the wind model for the smallest scale in multi-scale emergency response systems (WRF/MM5 –MSS – Code_Saturne).

Thank you for your attention.

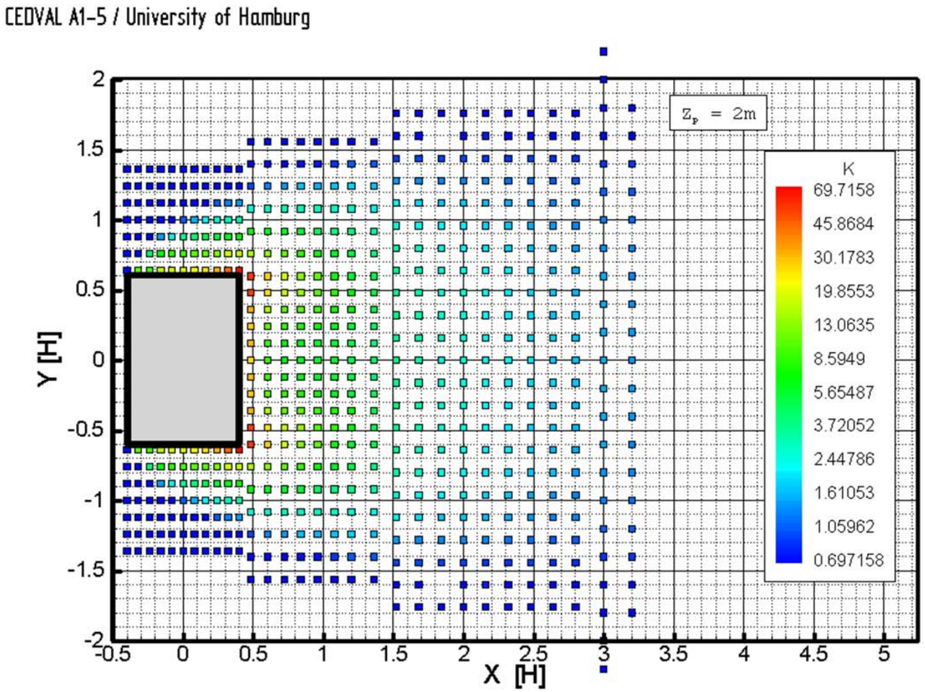
Questions ?

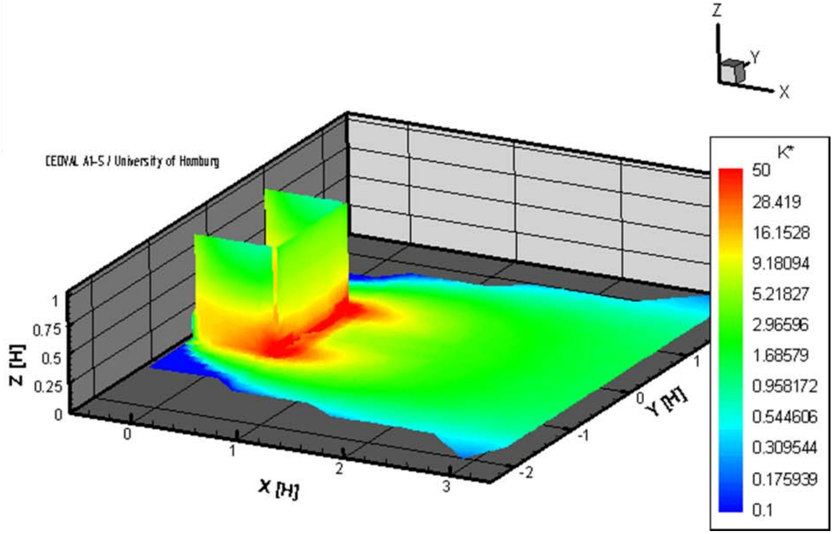
Case description



Data avalaible at http://www.mi.uni-hamburg.de/Data-Reports-Research-Results.309.0.html

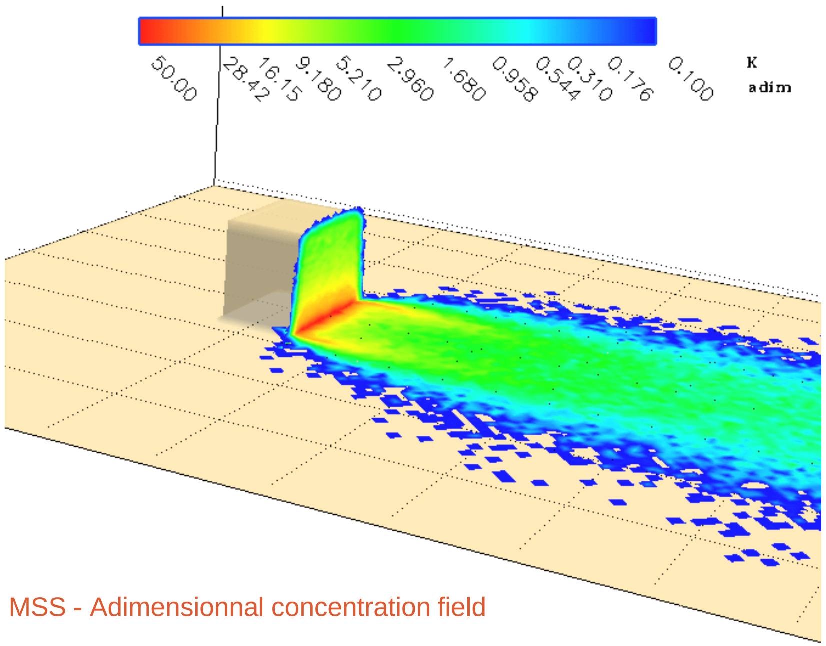
Measurements results



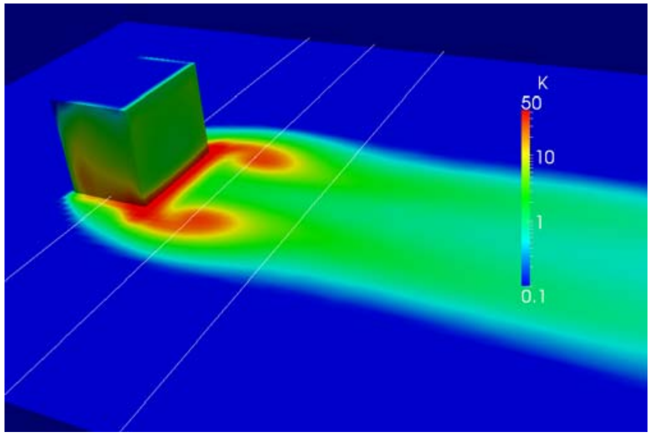


Adimensionnal concentration field

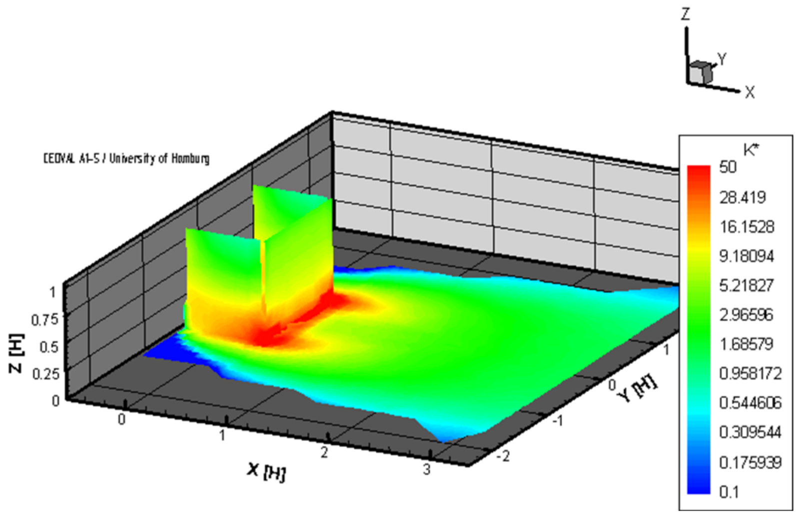
Models results



MSS - Adimensionnal concentration field



Code_Saturne (lagrangian) - Adimensionnal concentration field



Measurements –
Adimensionnal concentration field