Analysis of simulation results issued by Lattice Boltzmann Method in complex urban environment

European city

La Défense, Paris

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May, 10th 2016

Agenda

- **Introduction**
  - *Introduction to Exa*
  - *Introduction to LBM methods and PowerFLOW and PowerFLOW*
- Application to an European city
  - *Simulation set-up*
  - *Simulation analysis*
- Application to La Défense
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- Conclusions and next steps

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Introduction to Exa

- Based in Burlington, MA, USA, Founded in 1991
- Employees: 28 (‘01) ➔ +300 (’16)
- Software publisher :
  - *PowerFLOW → CFD, Lattice Boltzmann based solver*

- Collaboration with CEA started in september 2015

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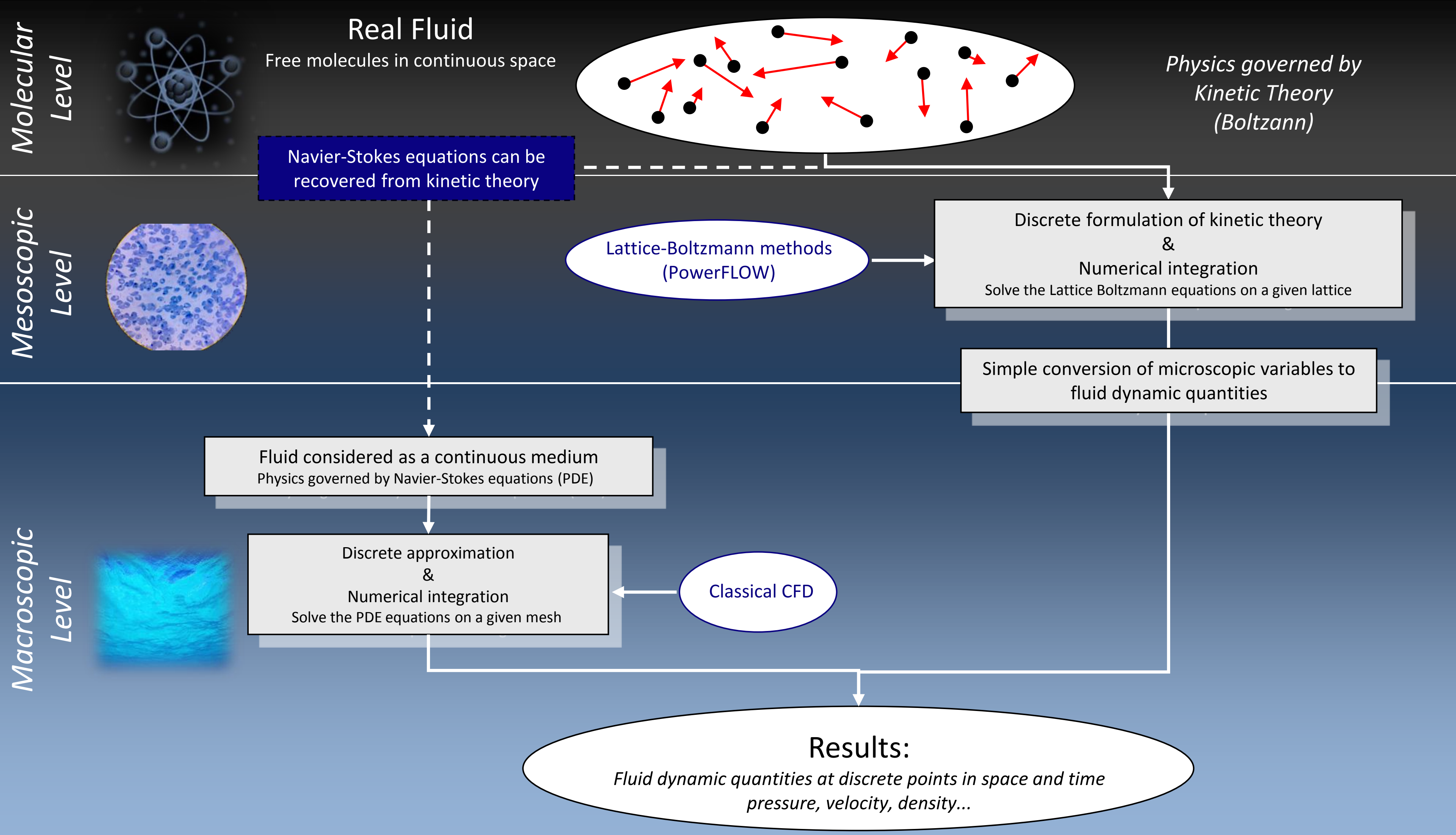
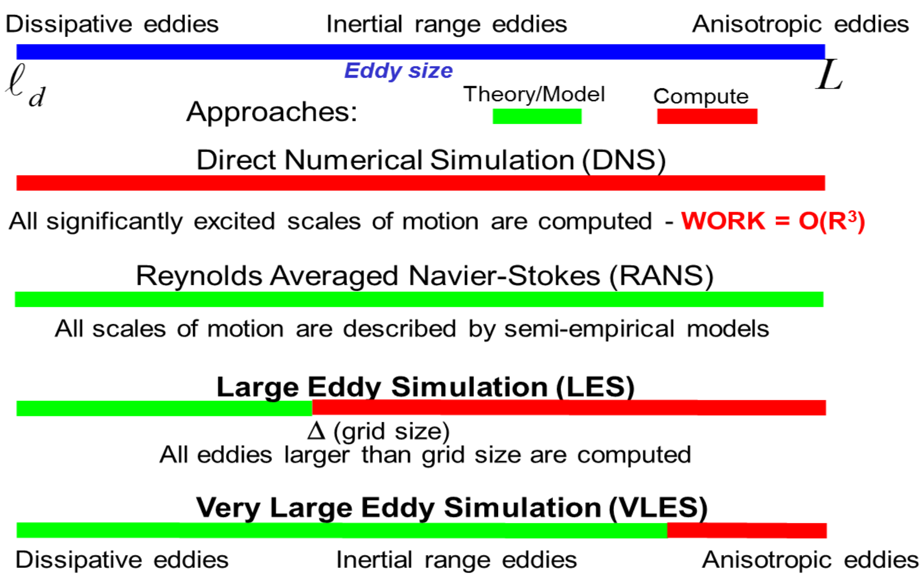
Introduction to LBM methods and PowerFLOW



Introduction to LBM methods and PowerFLOW

- Turbulence in PowerFLOW



Only statically anisotropic eddies outside the Kolmogorov range are computed

- Passive scalar are used to represent small particle field:
  - *Pollutant gases, pathogenic agent, radioactive agent, etc.*
  - *Closed or open environments*
  - *Up to 64 different scalars in the same simulation*
  - *PDE is solved for each scalar in addition of the flow field variables*

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Application to an European city

→ *Simulation set-up*

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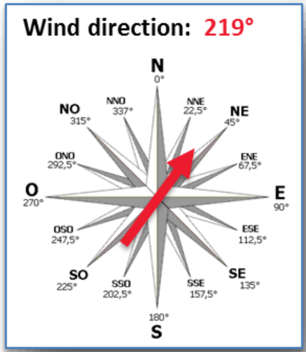
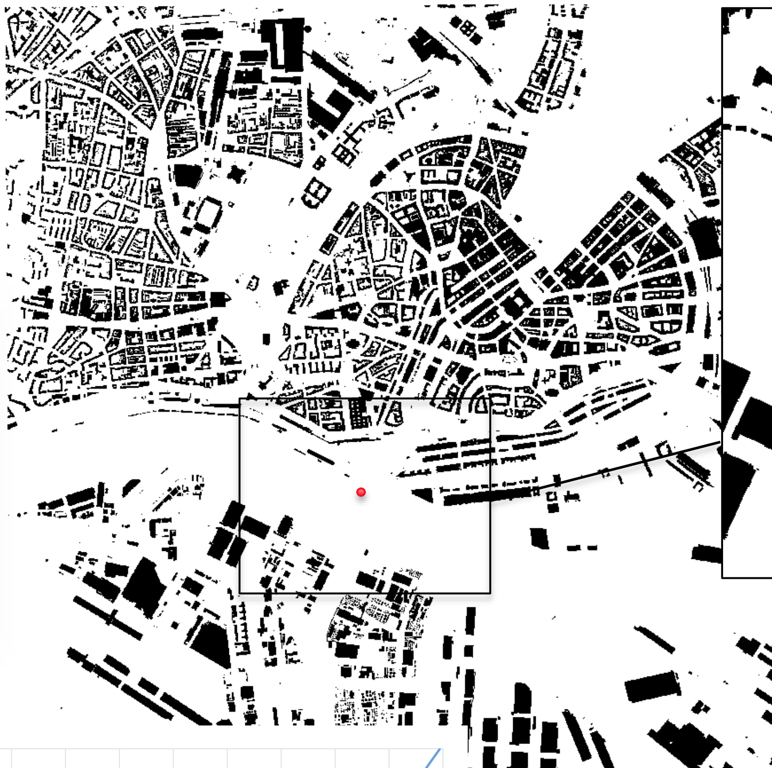
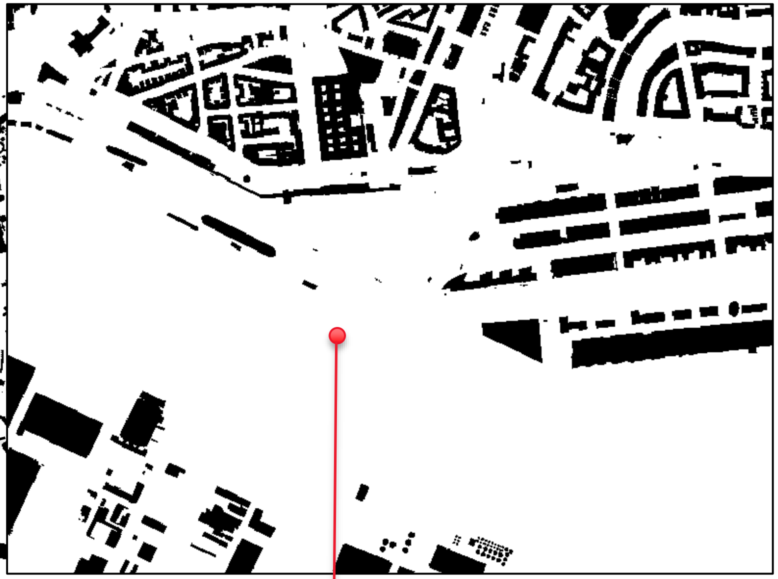


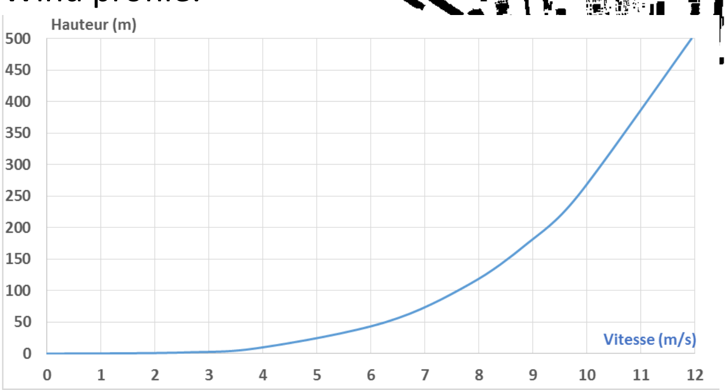




Gaz :

- Punctual source; from a boat on the river
- Q = 2g/sec (45min)
- Gas: SF6; C_d=1.5^e-05 m²/sec

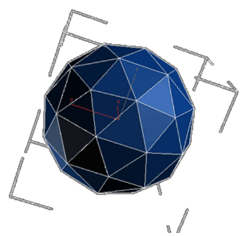
Wind profile:



- Wind direction and intensity is constant in time
- Profile reconstructed based on the Velocity at z=175m
- Neutral atmospheric stability

Application to an European city
→ Simulation set-up

- Surface mesh
  - *Ground + buildings*
  - *Triangular mesh, « stl » format*
  - *9M elements*



- Fluid mesh
  - *Cubic cells*
  - *66M elements*
  - *Variable resolution*
  - *Min resolution: 0.5m*

- Simulation parameters
  - *Characteristic velocity: 10m/s*
  - *Isothermal simulation*
  - *Turbulence intensity: 10%*
  - *TimeStep: 7ms*
  - *Results frequency acquisition: 10 sec*
  - *Flow simulation time: 75min*

- Simulation cost
  - *6432 CPUh*
  - *20h on 308 processors*

Exa

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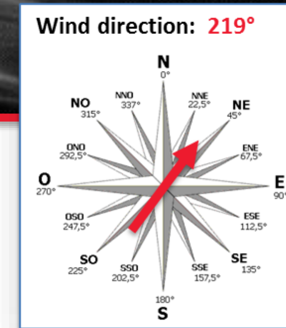
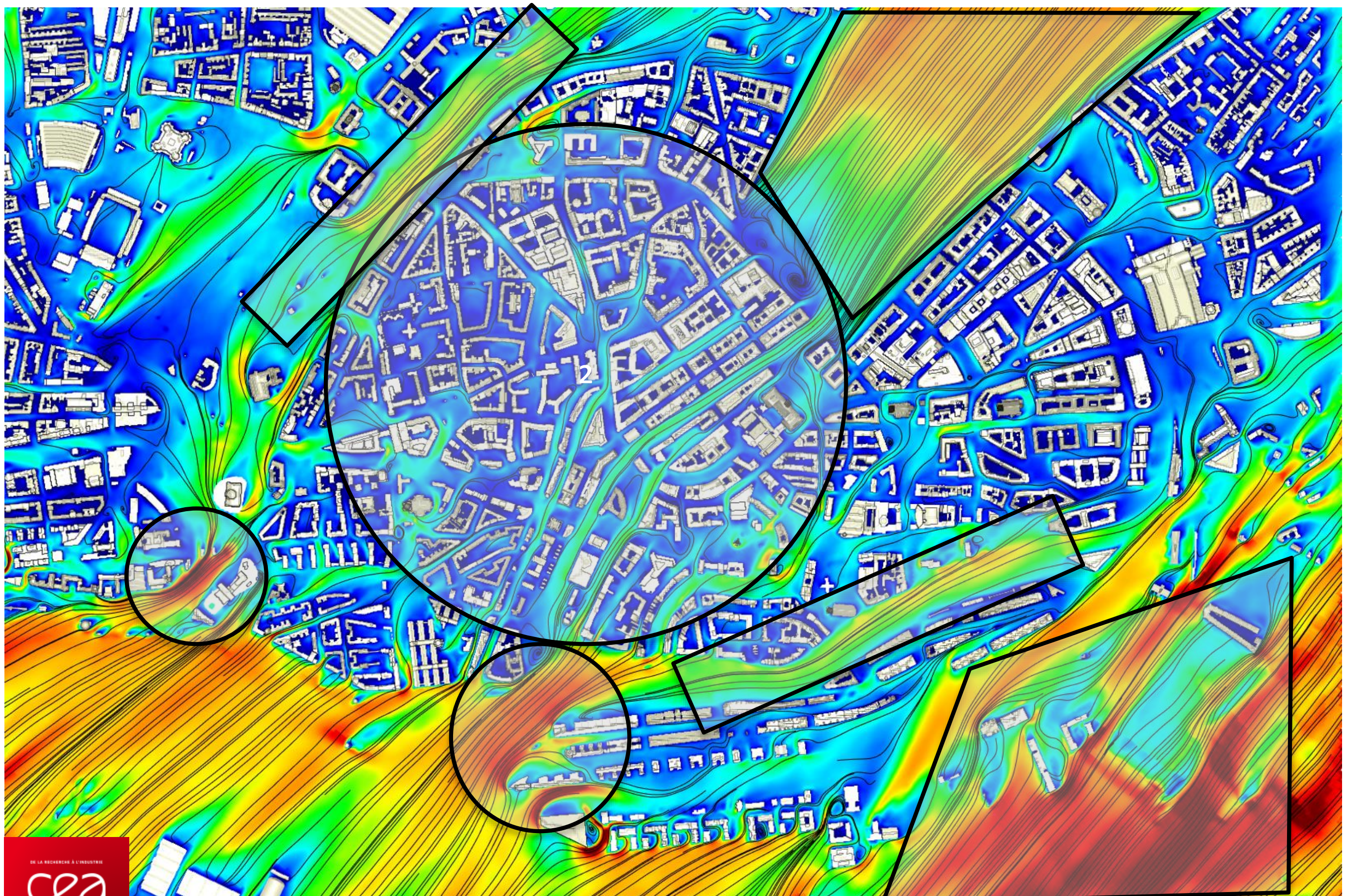
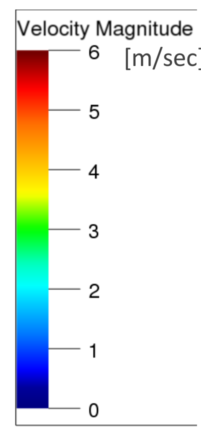
Application to an European city
→ *Simulation analysis*



- Averaged velocity field with streamlines: z=10m
  - *30minutes averaged*

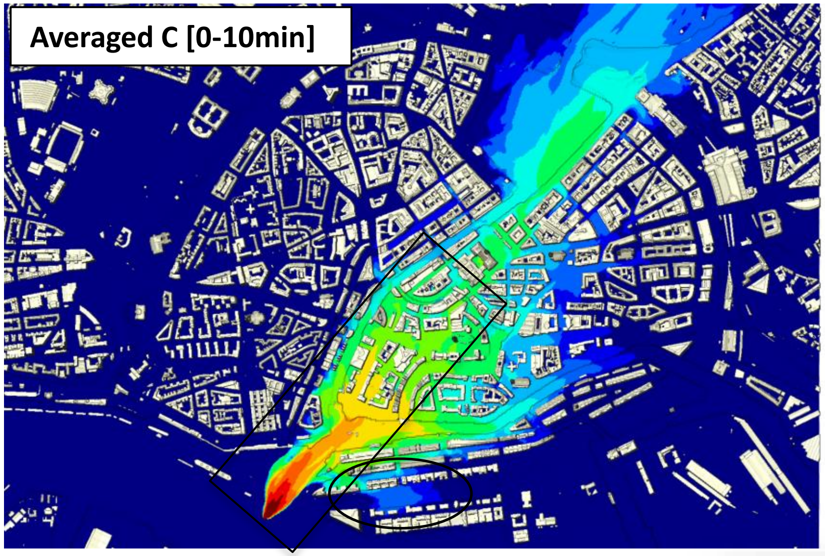


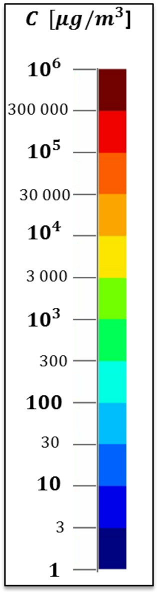
- Low velocities in the city center due to an important concertation of buildings
- High velocities are found in areas with few buildings
- Local increase of the velocity magnitude by Venturi effect
- Wind hallways are present around the city center

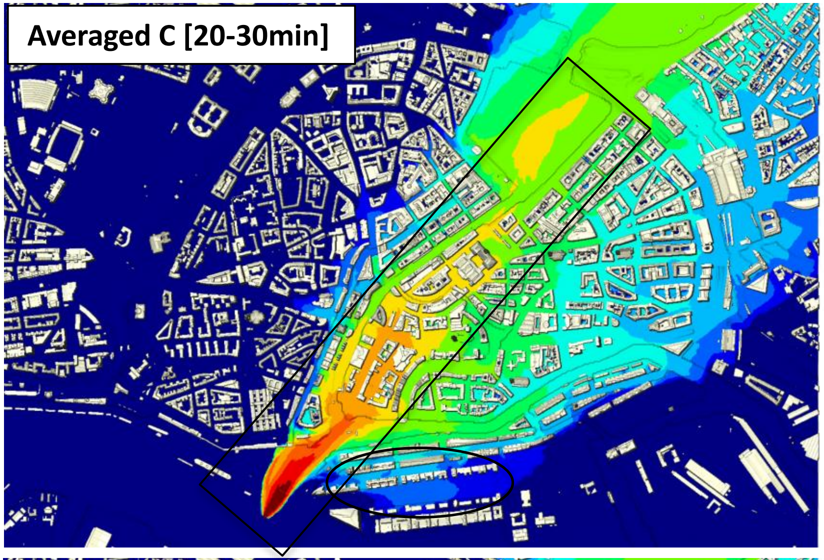


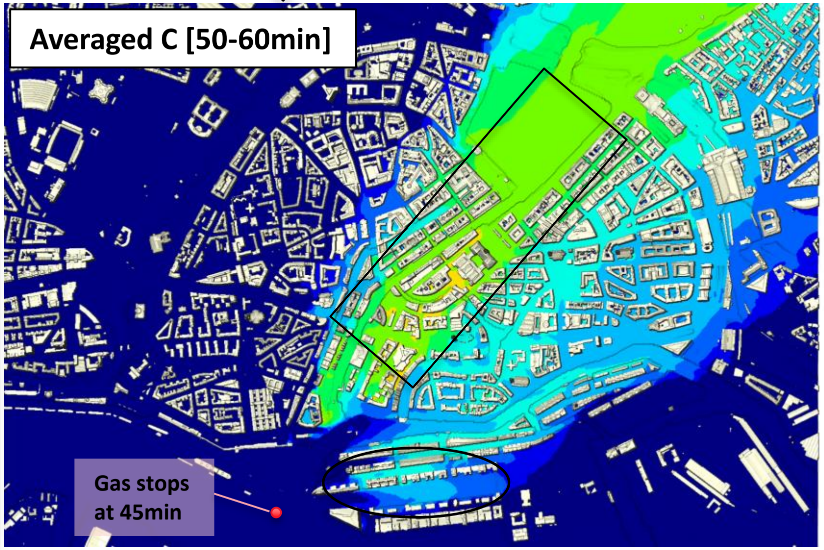
Application to an European city
→ *Simulation analysis*

- Averaged Concentration, z=2m
  - *10minutes averaged*

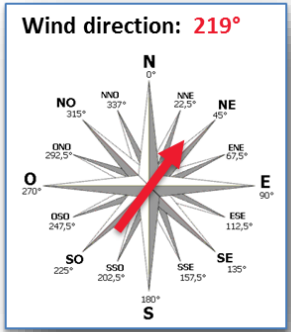






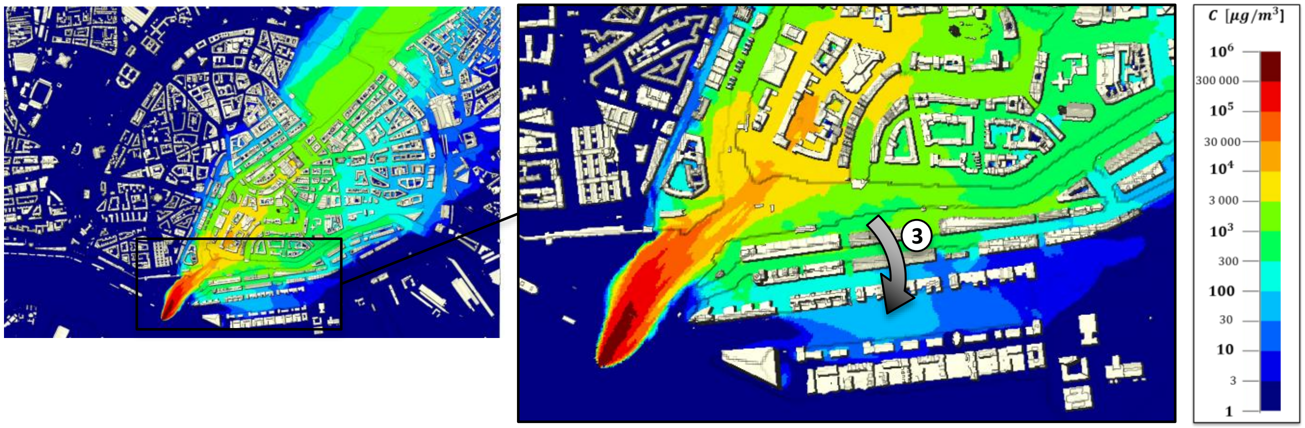


- Gas is spreading in the direction of the wind
- Some gas is present upstream of the main flow direction

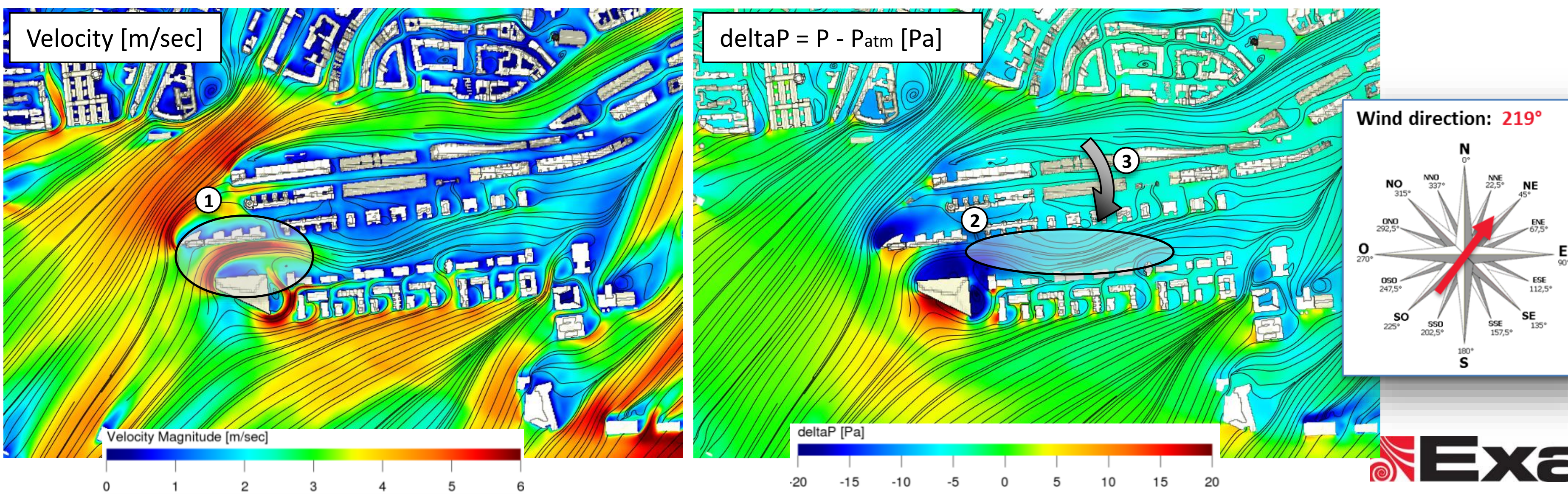


Application to an European city
→ *Simulation analysis*

- Local analysis [east side of the source]

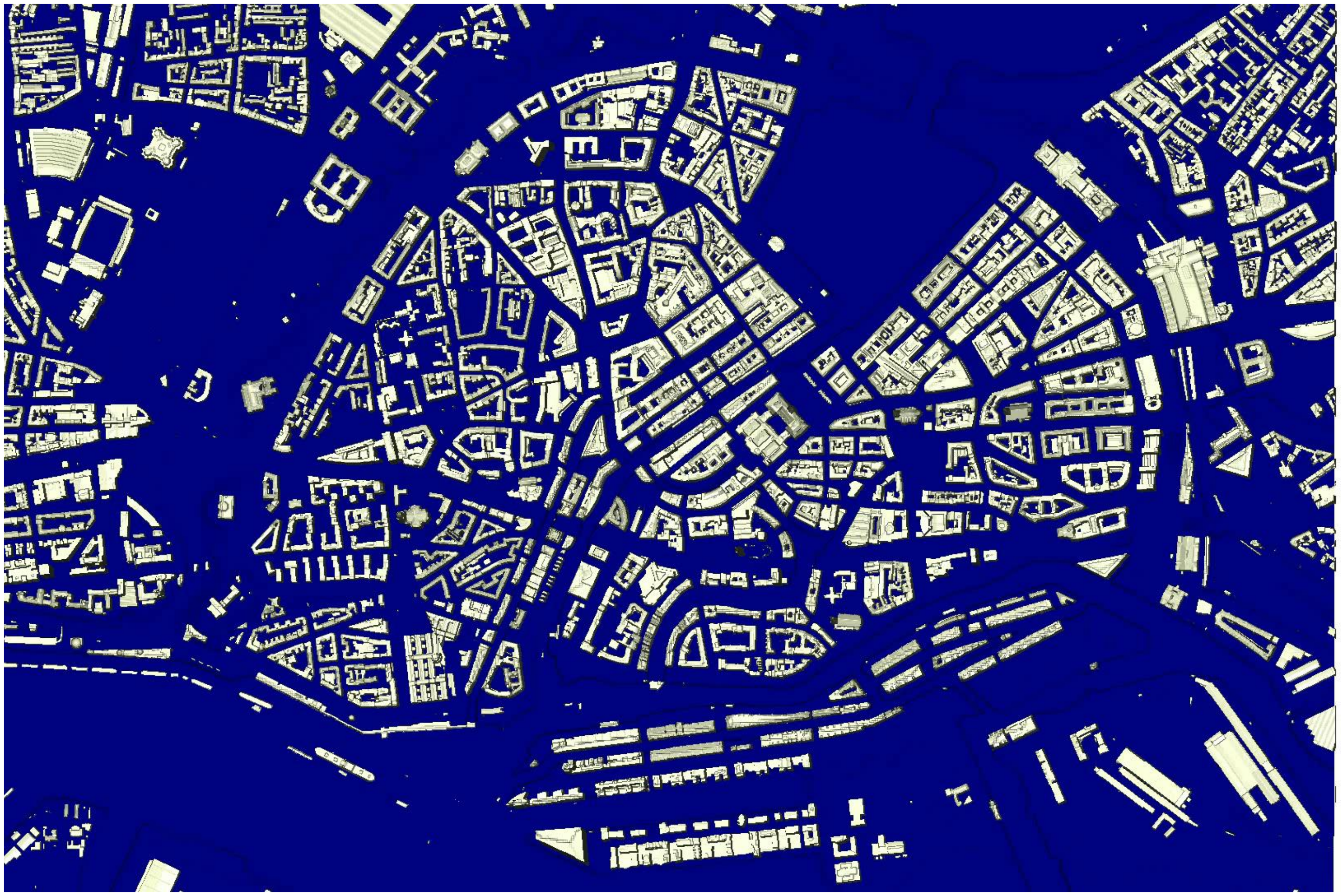


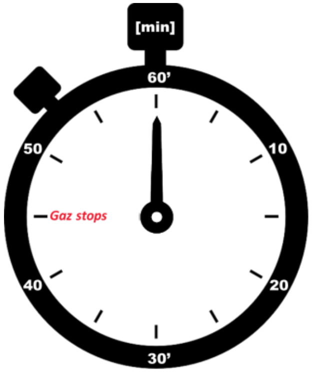
1. strong detachment of the flow behind the front building
2. Low pressure in the wake of the building
3. adverse pressure gradient, which enables the gas to move upstream

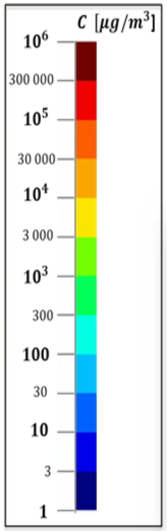


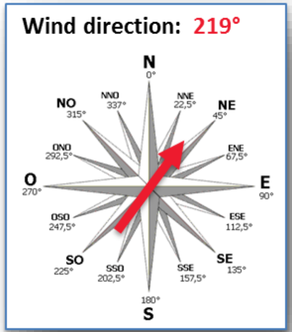
Application to an European city
→ *Simulation analysis*

- Unsteady analysis
  - *Gas concentration, 2m above ground*









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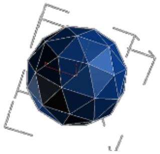
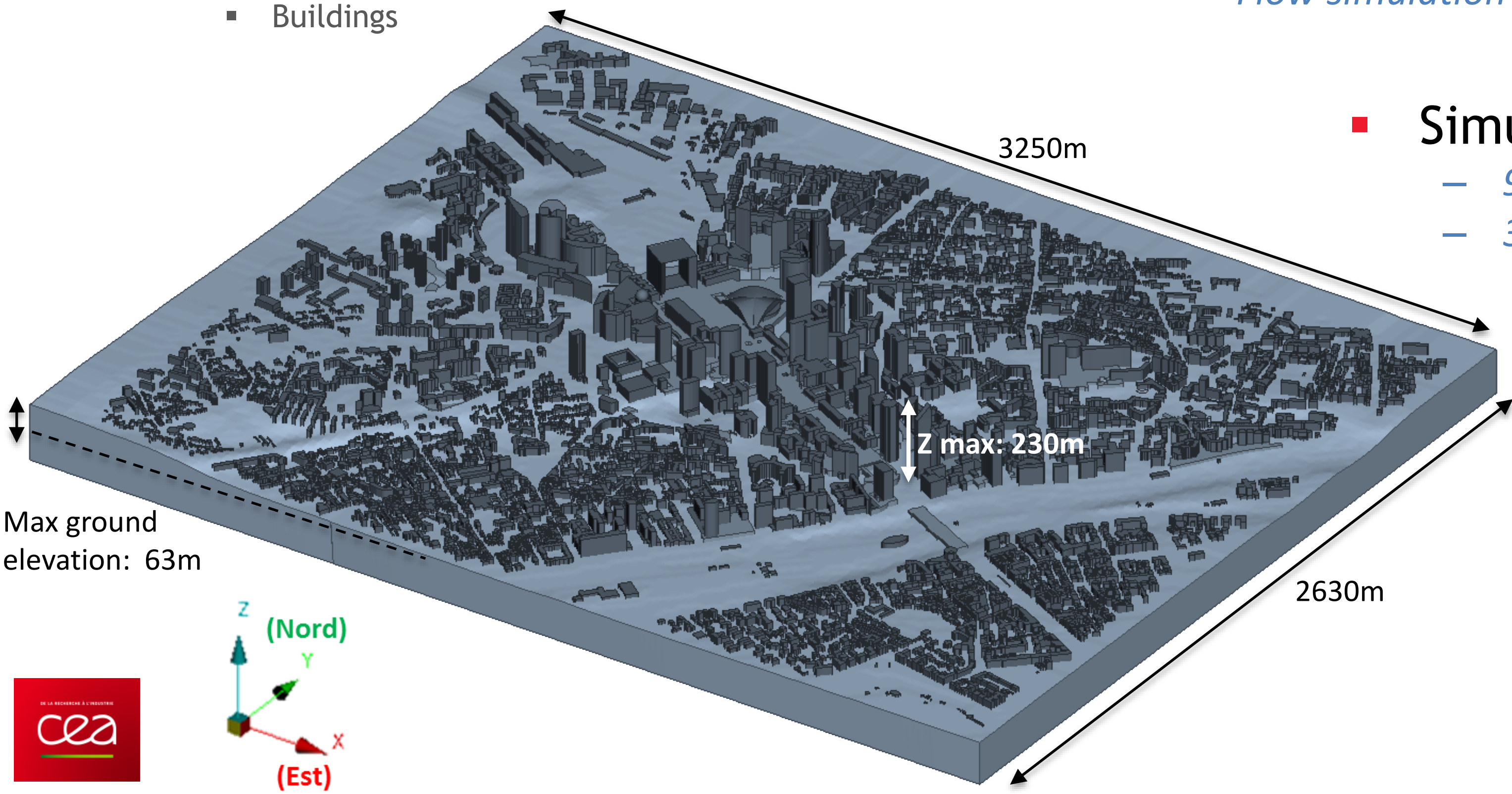
Application to La Défense
→ Simulation set-up

- **Surface mesh:**
  - *Stl file (tri elts.)*
  - *1.5 M elts*
  - *Domain:*
    - Ground
    - Slab
    - Buildings



- **Fluid mesh**
  - *Cubic cells*
  - *87M elements*
  - *Variable resolution*
  - *Min resolution: 0.5m*

- **Simulation parameters**
  - *Isothermal simulation*
  - *Turbulence intensity: 10%*
  - *TimeStep: 20ms*
  - *Results frequency acquisition: 10 sec*
  - *Flow simulation time: 105 min*



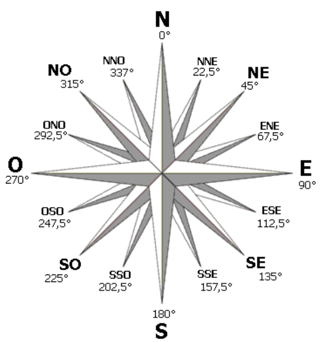
- **Simulation cost**
  - *9400 CPUh*
  - *30h on 308 proc.*

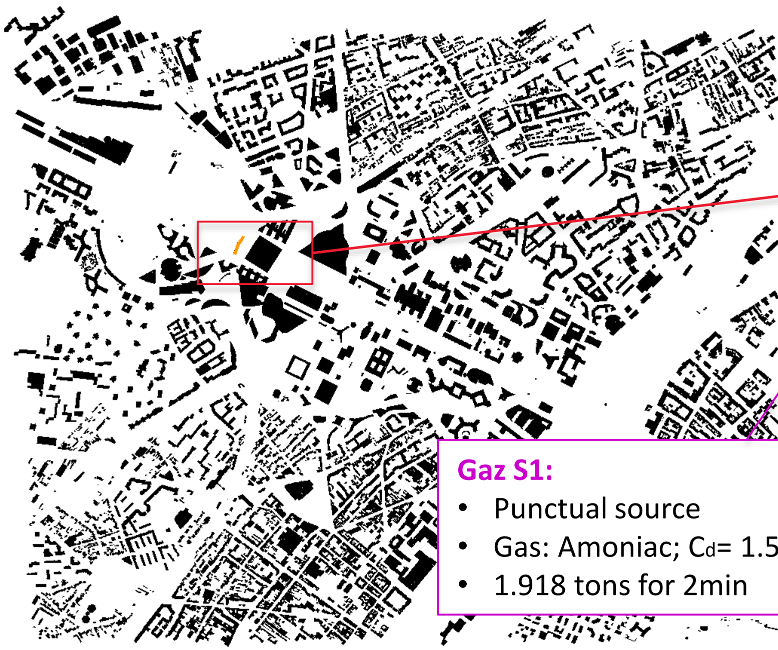
Application to La Défense

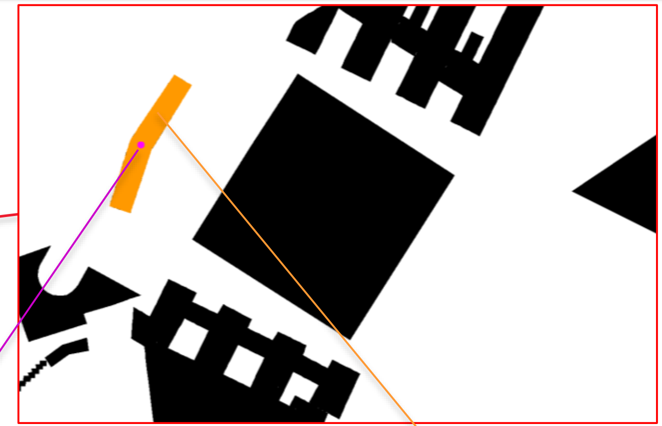
→ *Simulation set-up*

- Boundary conditions

Wind direction is varying in time

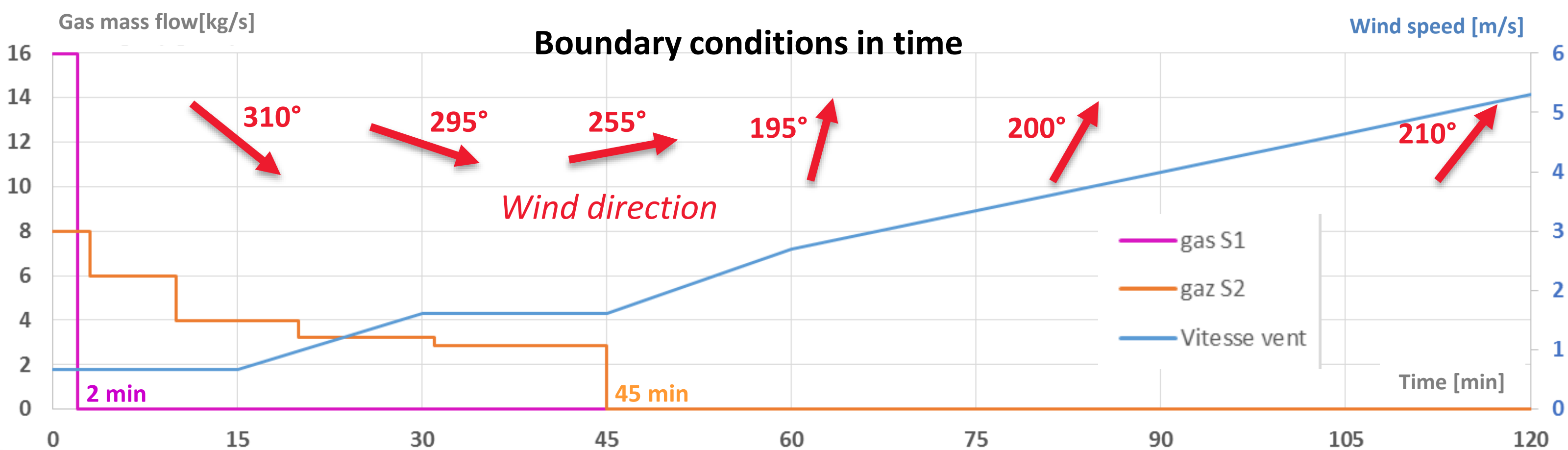






Gaz S1:
- Punctual source
- Gas: Amoniac; C_d= 1.59e-05 m²/s
- 1.918 tons for 2min

Gaz S2:
- Surface source (puddle)
- Gas: Amoniac; C_d= 1.59e-05 m²/s
- Decrease step by step during 45min



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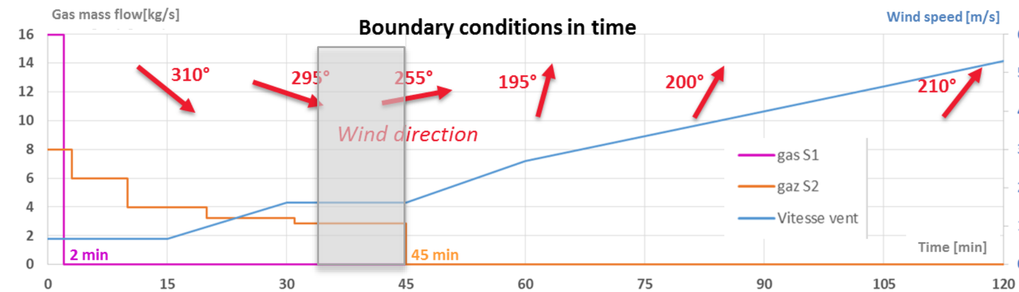
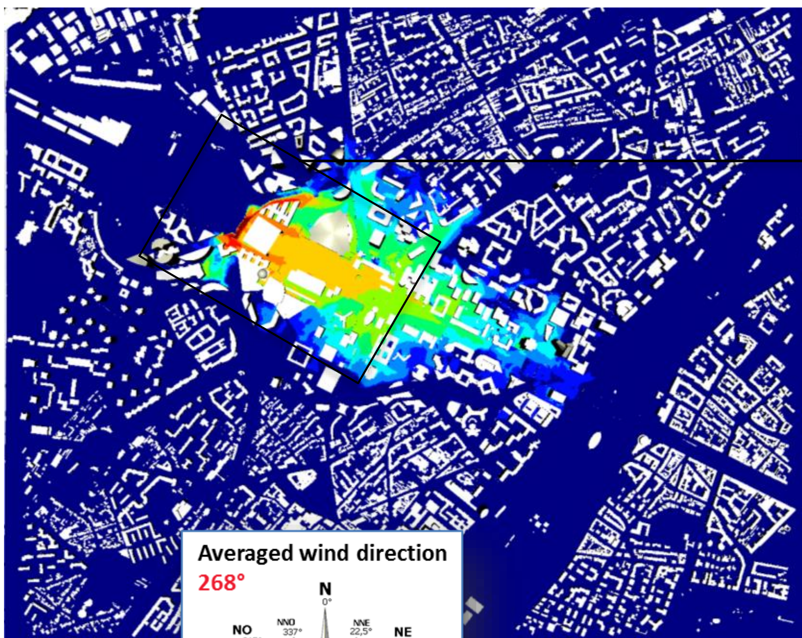
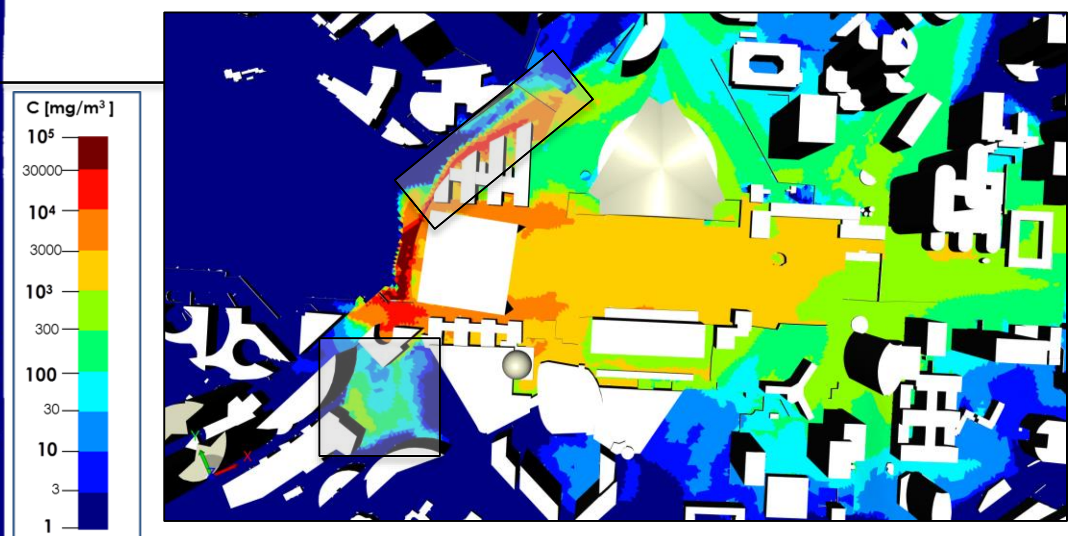
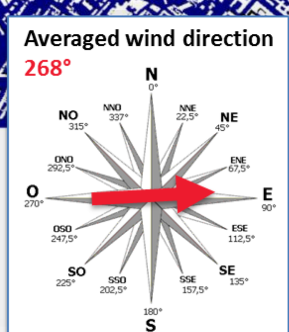
Application to La Défense
→ *Simulation analysis*

- Averaged results
  - *[35min-45min]*
  - *Gaz concentration, ground+2m*
  - *Average wind direction: 268°*









- High concentration of gas is directing northward
- Region with gas upstream of the main flow direction

Application to La Défense
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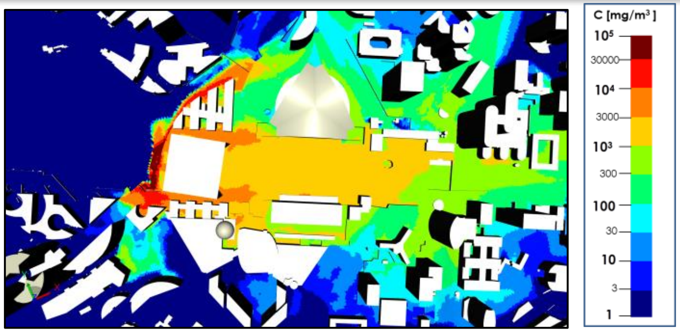
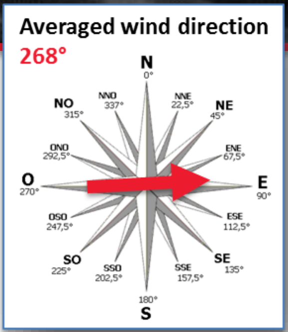
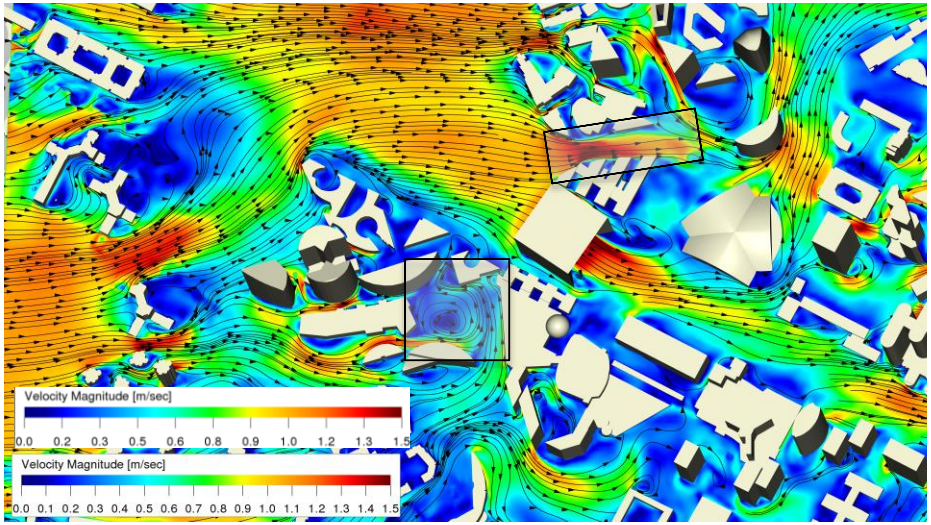
  - *[35min-45min]*
  - *Gaz concentration, ground+2m*
  - *Average wind direction: 268°*

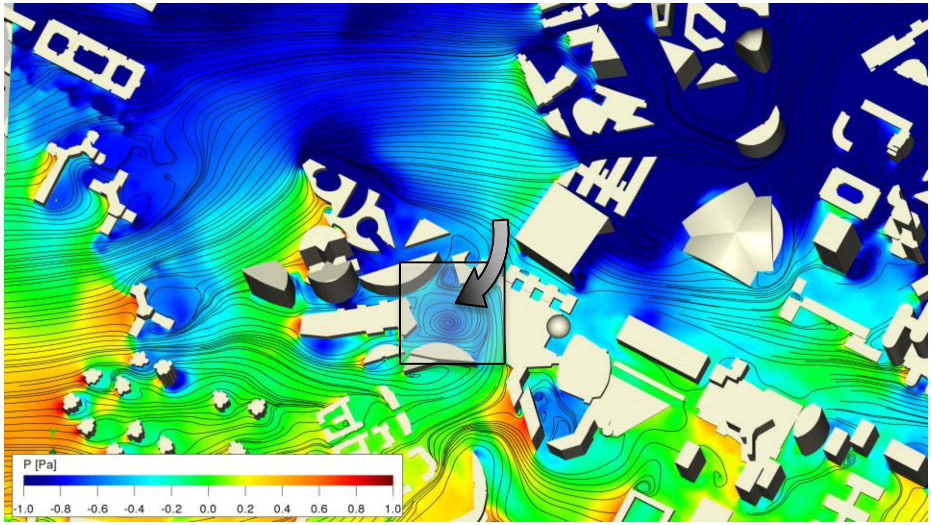




Velocity magnitude [m/s]

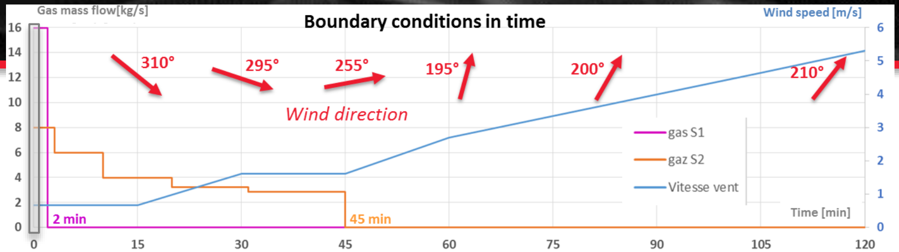


Delta Static pressure [Pa]

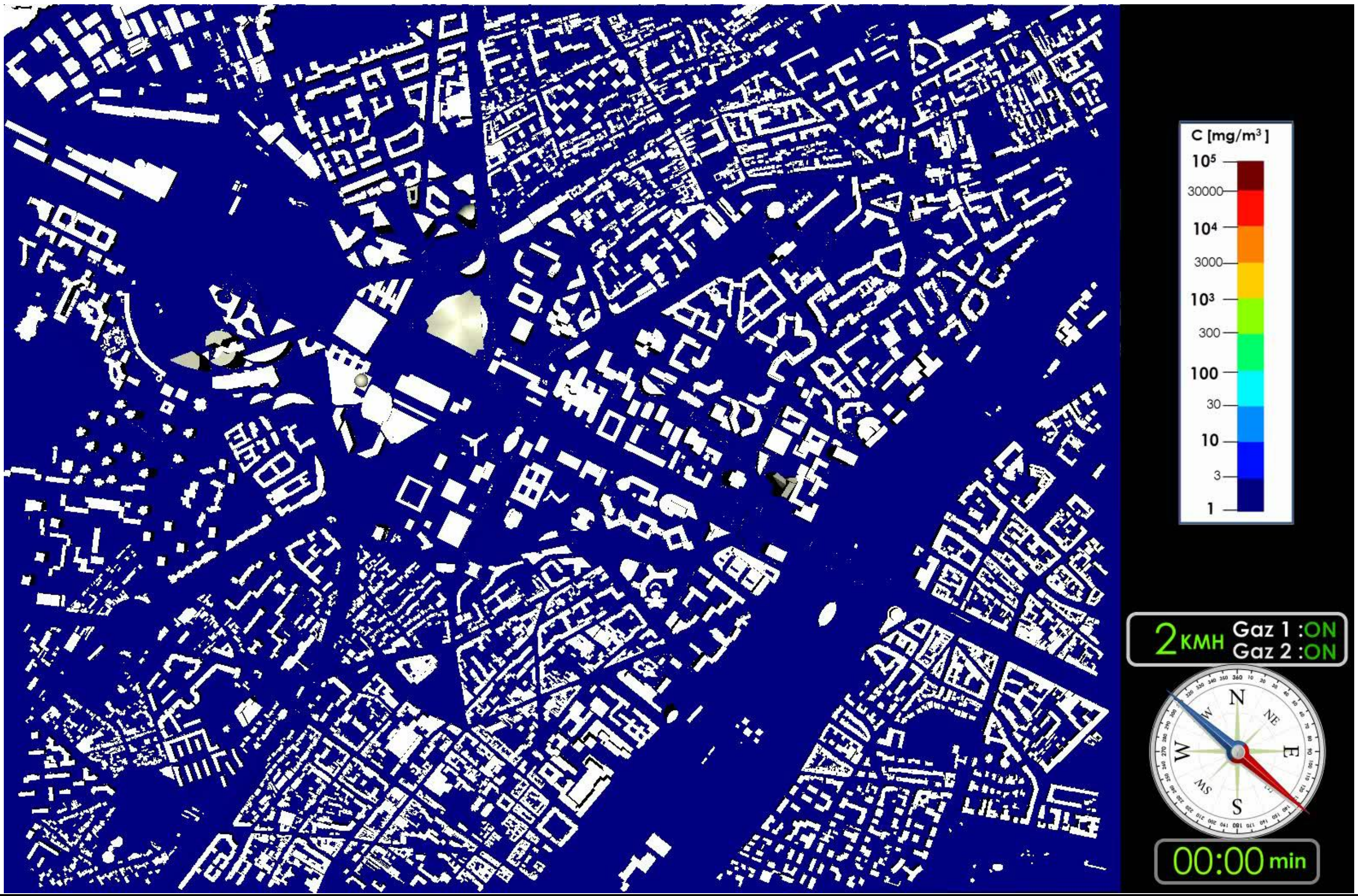


- Acceleration by Venturi effect → Brings gas in this direction
- Recirculation, with low pressure ⇒ Pressure gradient which brings gas in the area

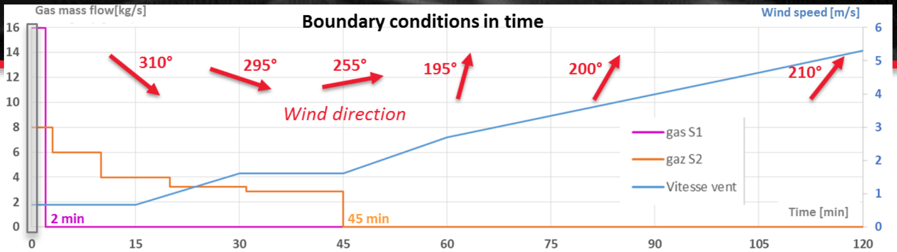
Application to La Défense
→ *Simulation analysis*



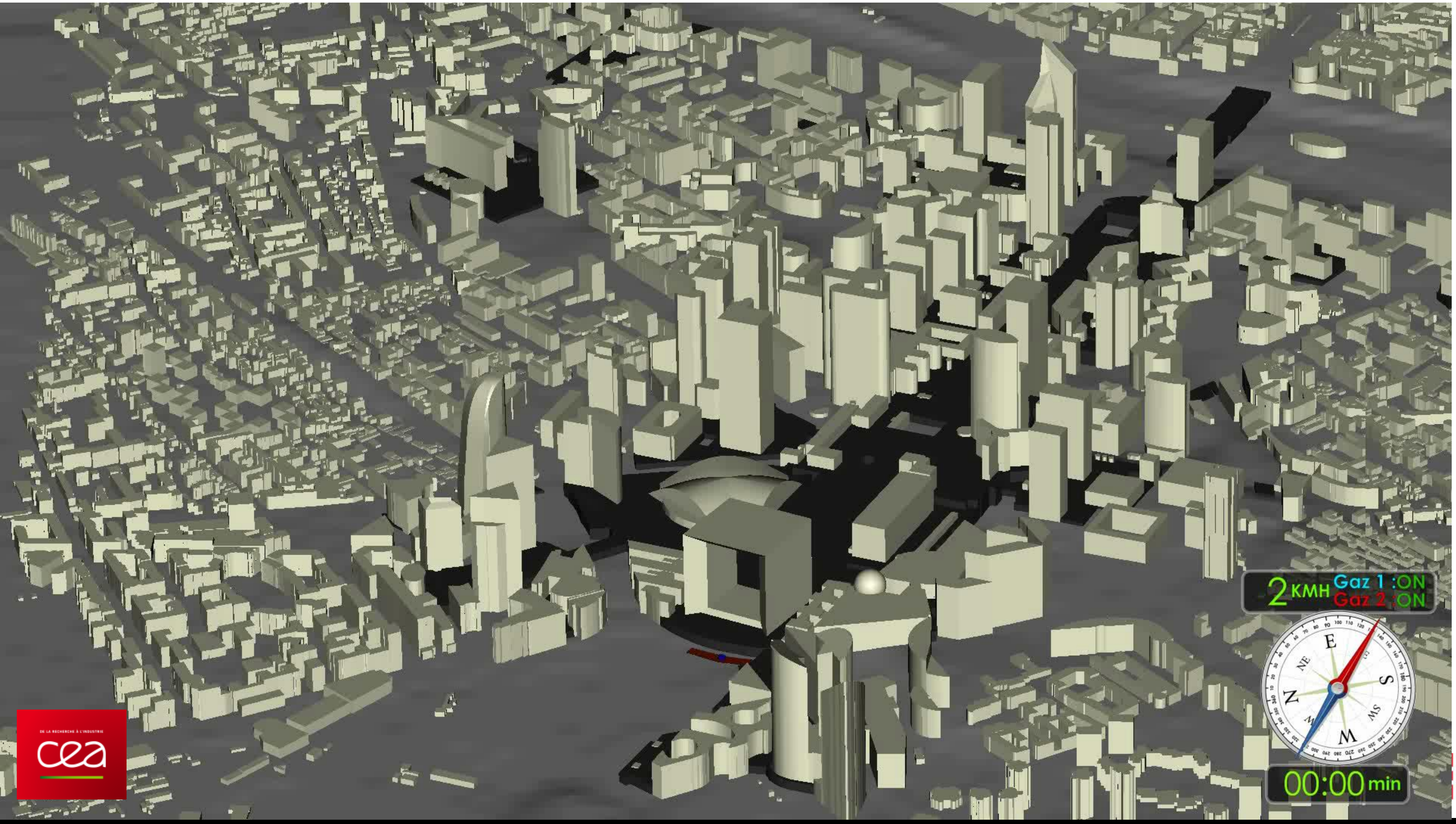
- Transient results:
  - *Log of concentration, ground+2m*



Application to La Défense
→ *Simulation analysis*

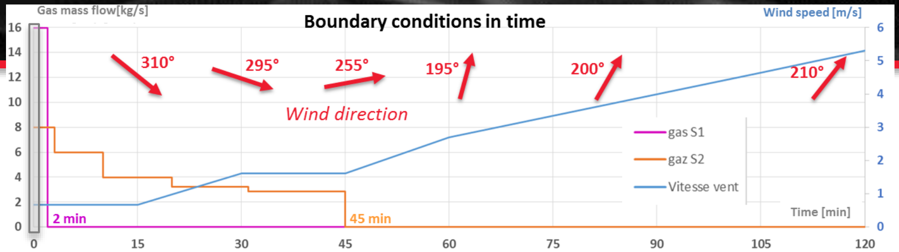


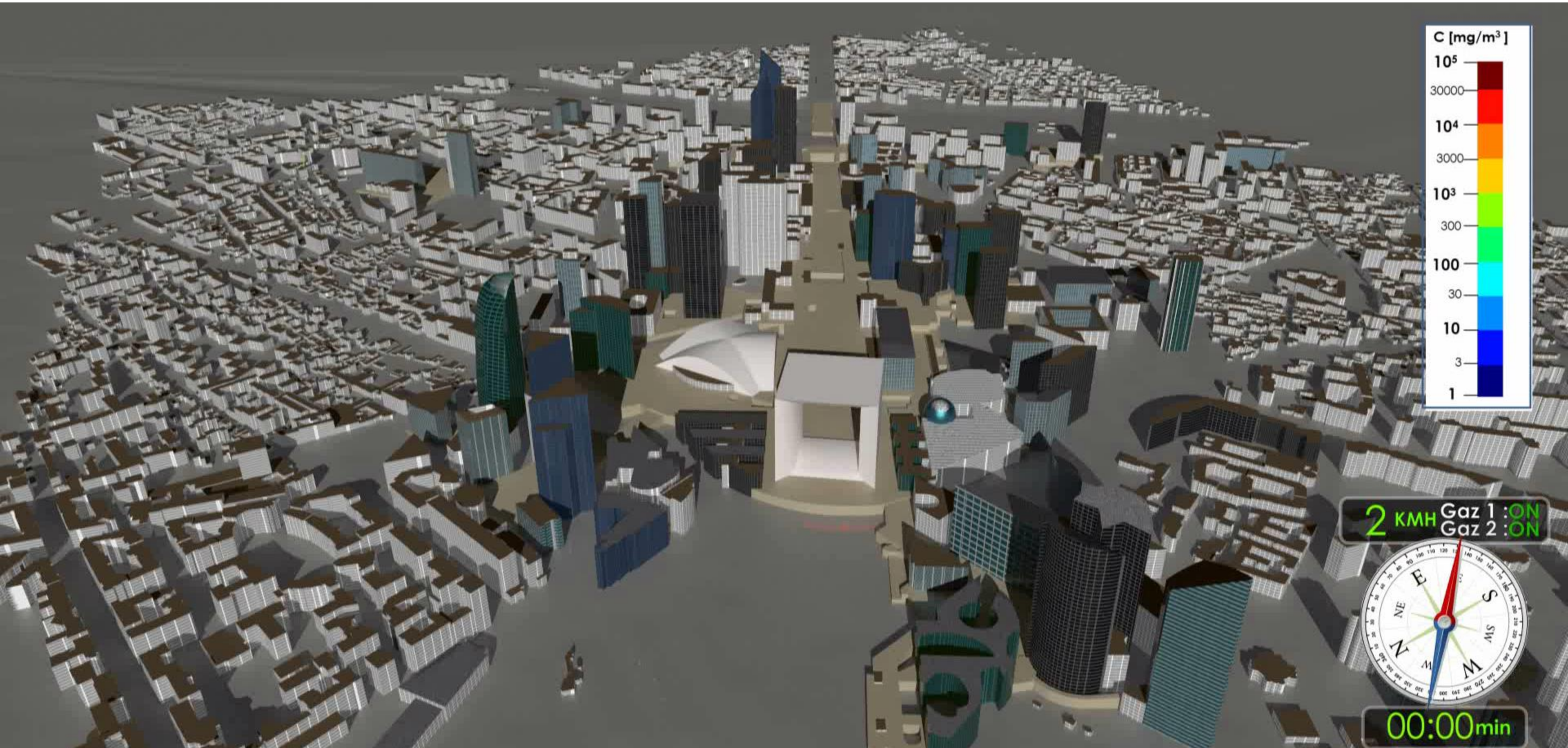
- Transient results:
  - *Isosurfaces*
    - C = 100 mg/m3



Application to La Défense
→ *Simulation analysis*

- Transient results:
  - *Volume visualization*





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Conclusions and next steps

- Benefits of the PowerFLOW LBM transient solver
  - *Native transient simulation with passive scalar capabilities :*
    - Capture multi-species dispersion in time, in 1 simulation only
    - Capture fluctuations with a high level of resolution making it possible to observe very local specific phenomenon
  - *Quick turnaround time regarding the level of precision*
  - *Very good scalability :*
    - PowerFLOW can be paralyzed up to thousands of cores
  - *Powerful tools to visualize and analyze the results*

Conclusions and next steps

- Next Steps…
  - *Validation with experimental results*
  - *Simulate dispersion with unsteady gas conditions (gas puffs,…)*
  - *Evaluate sanitary impacts of rejection on local population*
  - *Evaluate concentration effects inside buildings :*
    - HVAC systems
    - Rooms…
  - *Usage for building databases or response surfaces to qualify multiple scenarios*

Questions ?

- Thank you for your attention !

- For any question or comment, please contact :

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