RECENT PHYSICAL DEVELOPMENTS IN A LAGRANGIAN MODELLING SYSTEM FOR EMERGENCY RESPONSE PURPOSES

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INTRODUCTION

- In the framework of emergency preparedness and response to accidental, or malevolent atmospheric dispersal events, it is more and more often prescribed to use advanced (but also fast running) 3D simulation tools
- This is consistent with the recent impressive developments of
  - *Meteorological flows and dispersion processes modelling*
  - *Computing performances and speed (parallel versions of codes)*
- For regulatory purpose or in a first attempt in a crisis situation, the dispersion is still usually computed using Gaussian models (e.g. CERES platform at CEA)
- Unfortunately, these models are limited when simulating the dispersion in the urban environment or around the buildings of industrial sites
- At the same time, a CFD model adapted to the PBL is the reference way of investigation, but it is extremely demanding in computational resources, especially for two important applications
  - *Long term impact around a source near the ground*
  - *Emergency response or preparedness*

PRESENTATION OF MICRO-SWIFT-SPRAY (MSS)

- For some years, MSS has been developed by ARIA Technologies, ARIANET, and MOKILI, in partnership with CEA, as an intermediate quick response capability to simulate urban micro-scale flow and dispersion processes with CPU times significantly shorter than a full CFD solution

- MSS is the combination of Micro-SWIFT and Micro-SPRAY
  - *Micro-SWIFT is a mass consistent diagnostic 3D wind model in which the effects due to the buildings are represented by analytical flow zones*
  - *Micro-SPRAY is a 3D Lagrangian dispersion model taking account of the particles rebounds on buildings as well as local turbulence*

- MSS has been validated in numerous and various configurations by comparisons with analytical solutions or experimental measurements
  - *At reduced scale, in wind tunnels (e.g. Hamburg University)*
  - *At real scale, "in-field" campaigns Urban 2000 and Urban 2003*

- MSS is especially used for accidental or deliberate releases of noxious species
  → *Recent developments to evaluate together concentrations, depositions, and RC doses, in the streets network, and also inside the buildings*

NSWIFT 3D PRESSURE FIELD DIAGNOSTIC – PRINCIPLE

- Using mass balance and Navier-Stokes equations of an uncompressible flow, each variable being the sum of an ensemble average and a fluctuation, and neglecting the Reynolds stresses, the 3D pressure field verifies equation (1) where ρ designates the density, p the pressure and U the velocity

$$\Delta \overline{p} = -\rho \,\mathrm{div}\, \partial_j (\overline{U_j}\,\overline{U_i}) \qquad (1)$$

$$C_p = \frac{\overline{p} - \overline{p_0}}{0.5\,\rho\, U^2} \qquad (2)$$

- 3D pressure field is diagnosed by solving the Poisson equation (1) similar to the equation used for mass consistency of NSWIFT interpolated 3D wind field

- NSWIFT pressure solver results were compared with wind tunnel experimental results and / or with the pressure fields computed by QUIC (LANL – USA)

- Pressure field strongly depends on wind field preciseness near the obstacles
  - *Upwind displacement zone (Brown vs. Röckle) and canyon zone (CPB-PAR)*
  - *Implementation of rooftop recirculation zone (only for flat roofs)*

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CUBE WITH UPSTREAM SIDE NORMAL WIND

- NSWIFT numerical results compared with a 6 m edge cube "full scale" test
  - *Performed in 2001, at Silsø Research Institute*
  - *Neutral atmosphere and wind normal to the cube upstream side (9.5 m.s^{-1} at 6 m)*

- Best results with Brown upwind displacement zone and rooftop recirculation

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Pressure coefficient along the sides of a cube

Comparison of NSWIFT pressure solution with

- "Full scale" and wind tunnel experimental results
- QUIC numerical results

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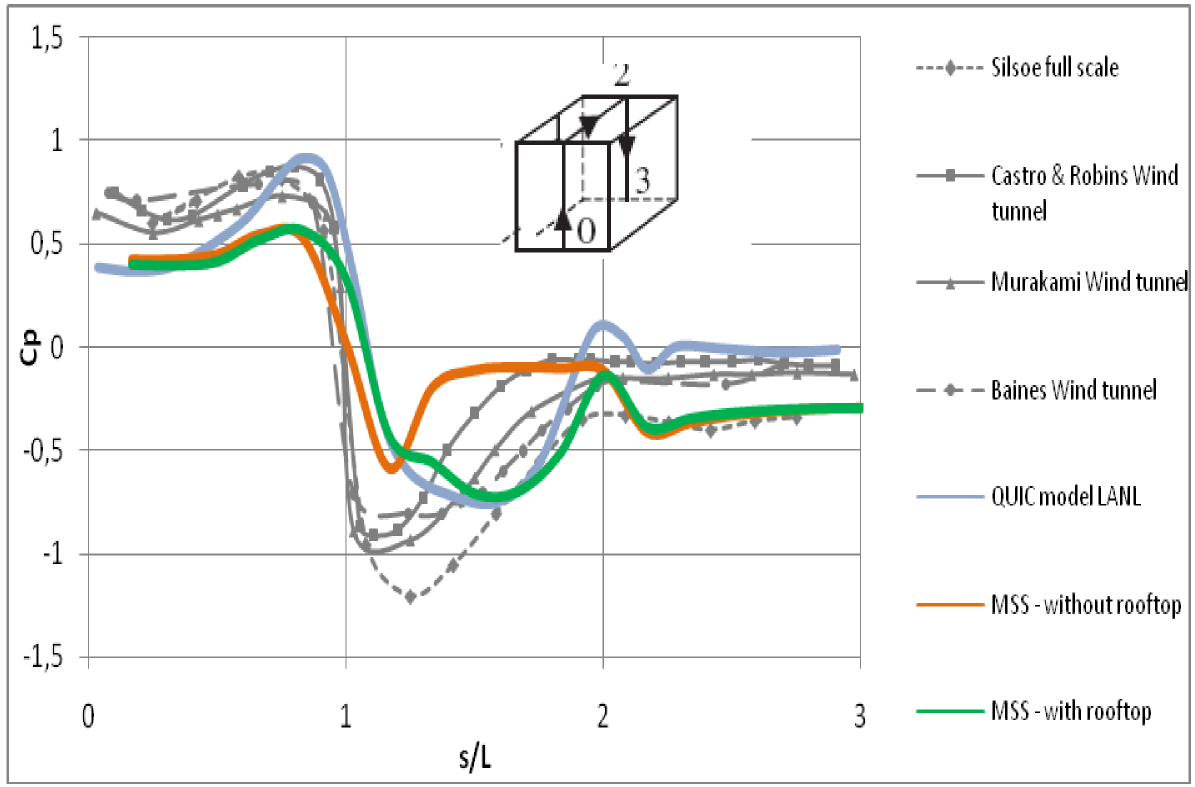
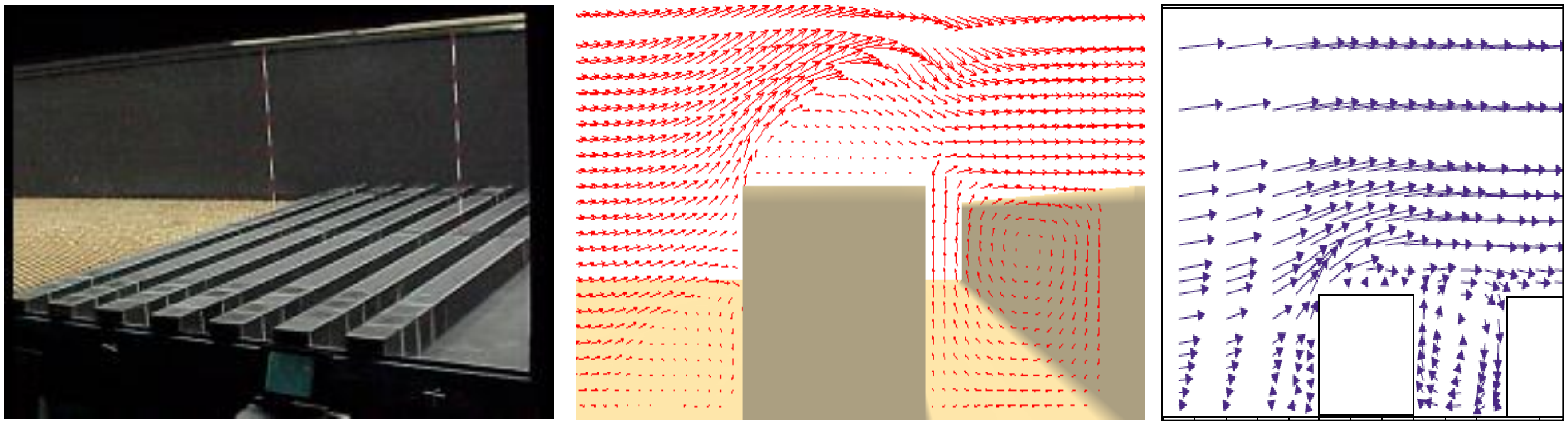


NSWIFT 3D PRESSURE FIELD DIAGNOSTIC – VALIDATION #2

CANYON GEOMETRY – 2D ARRAY OF SEVEN WIDE BUILDINGS

- NSWIFT pressure diagnosis evaluated with US-EPA data (Brown *et al.*, 2001)
  - *Parallel buildings (length: width: height = 3.7: 0.15: 0.15, space betw. block = 0.15)*
  - *Neutral atmosphere and wind perpendicular to the obstacles*
- CPB-PAR parametrization for the skimming zone (Hotchkiss and Harlow, 1973)



View of the buildings array (left) – Wind field issued by NSWIFT (middle) and measured in a wind tunnel (right) in the vicinity of the first obstacle

N.B. The pressure field is correctly diagnosed by NSWIFT on the front side, but slightly under-estimated at the rear of the obstacle

NSWIFT 3D PRESSURE FIELD DIAGNOSTIC – CONCLUSION

- Many validation cases have been carried out in various geometries
  - Cube with upstream side normal or 45° incident wind
  - Tall building, low and flat building or L-shaped building
  - 2D array of seven wide buildings…

- NSWIFT pressure solver gives excellent results on buildings upwind sides and satisfying results on flat roofs where rooftop recirculation improves diagnosis
  → *In these regions, pressure gradients are mainly governed by mean wind*

- On lateral and back sides, calculations are less consistent with measurements
  → *Insufficient recirculation along the lateral sides*
  → *Not fully satisfying wake zone model disregarding the Reynolds stresses*

- NSWIFT pressure solution is at least as good as QUIC, or better in some cases

INDOOR / OUTDOOR POLLUTANTS TRANSFER – PRINCIPLE

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- Contamination infiltration in the buildings is useful to estimate the health effects on public or rescue teams of both chronic and accidental releases
- Linked to the surface pressure distribution on buildings frontages, the interior concentrations also depend on ventilation, airtightness and species properties
- Method #1 – Internal concentration is a function of the atmospheric mean concentration and of an infiltration constant (overall air renewal duration)
  - *No entrance of particles, no exit of the contaminant, and no external depletion*
  - *Good comparison of MSS with emergency response code ALOHA (US-EPA)*
- Method #2 and #3 – All the virtual particles dispersed in the atmosphere have a probability to enter the obstacles where they stay till being expelled
  - *Probability for each particle to be physically in the inflow air, determined from the infiltration time constant, the obstacle volume, and the fluid meshes volumes*
  - *In method #2 (comparable to #1), air penetrates the buildings through all sides*
    → Validation to use the probabilistic approach and NSWIFT pressure diagnosis
  - *In method #3, air enters the buildings only through the meshes with positive ΔP*
    → Most rigorous and precise approach

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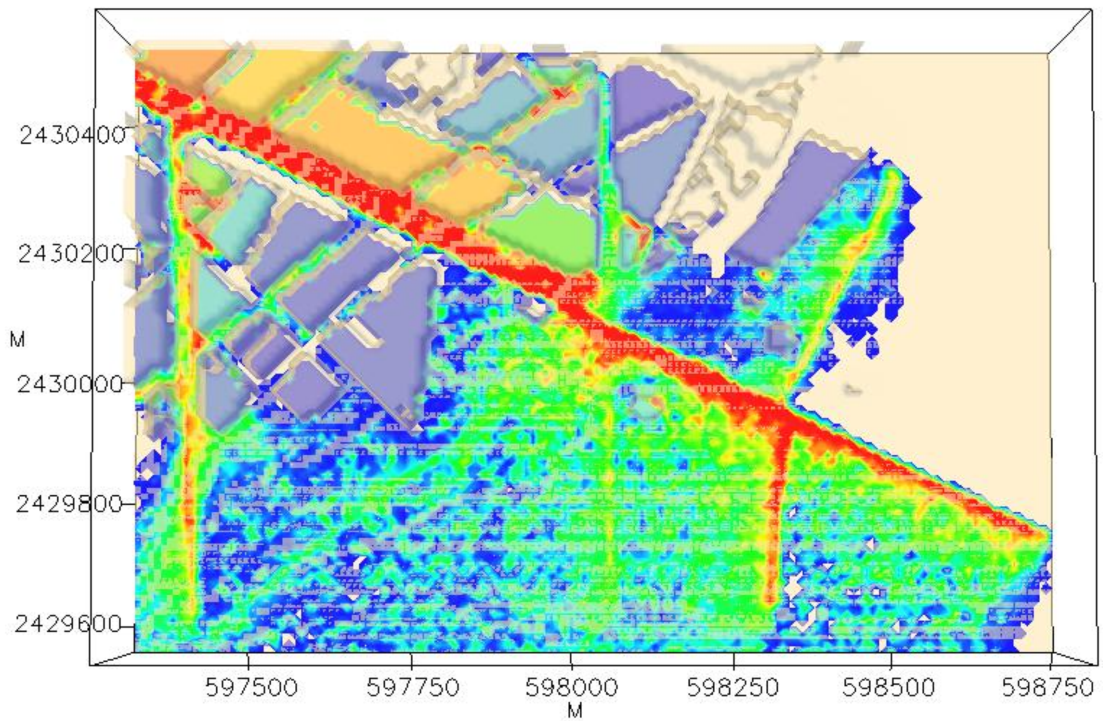
INFILTRATION IN BUILDINGS BLOCKS IN REAL URBAN LANDSCAPE

- First attempt to introduce the indoor / outdoor transfers in MSS
- Identified limitations
  - Infiltration "constant" should depend on wind field around the obstacle, temperature gradient between inside and outside, and obstacle characteristics
  - More precise data about the buildings to evaluate their airtightness

Concentrations due to the traffic emissions in the streets network and inside the buildings in a district of Paris



Micro-SPRAY GENERALIZED DEPOSITION PROCESSES – 1/3

- Dry or wet depositions result in plume depletion and contamination spots on all accessible surfaces (especially important in the case of radionuclides releases)

- Depositions can be evaluated on the ground, and also on complex surfaces like façades, roofs, and ceilings of covered structures (tunnels, walkways, arches...)

- Ground deposition Boughton and Delaurentis (1987) model has been extended
  - *Seven particles deposition probabilities are defined, functions of distance to the obstacle, local turbulence and species deposition velocity*
  - *If a particle is surrounded by obstacles together east, west, north, and south, it can settle on the four surfaces, also on a ceiling or roof, or on the ground*
  - *Random drawing methods have been tested in Micro-SPRAY to determine the order of deposition on the different surfaces (all methods converge to a unique solution)*

- The chosen method is adapted both to gases and aerosols
  - *At each time step, a particle can settle only on one surface*
  - *The seven deposition probabilities are distributed proportionally between 0 and 1*
  - *A random number is drawn and determines on which surface the deposition occurs*

Micro-SPRAY GENERALIZED DEPOSITION PROCESSES – 2/3

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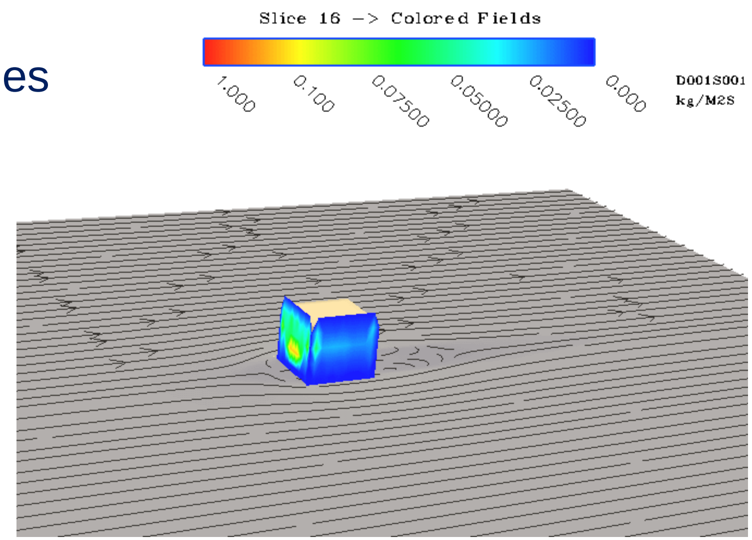
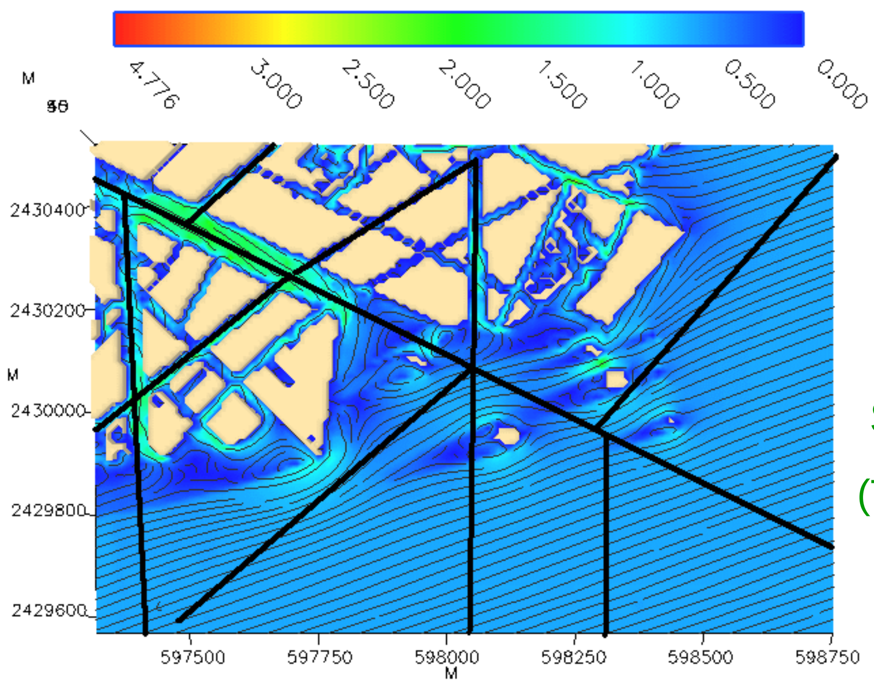
DRY DEPOSITION COMPUTATIONS FOR SIMPLE GEOMETRIES AND REALISTIC CONFIGURATIONS INCLUDING NUMEROUS BUILDINGS

Dry depositions on cube sides
Streamlines are shown as depositions on the façades

(The source is punctual, located upstream the obstacle deposition velocity is equal to zero on ground and roof)





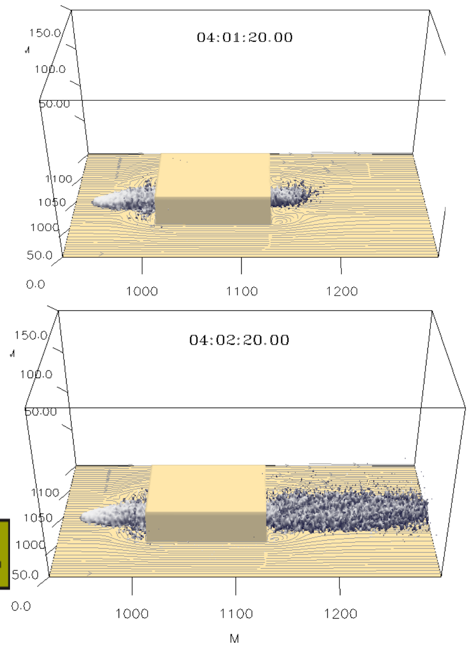
Urban district configuration
Streamlines and velocity field at 2 m

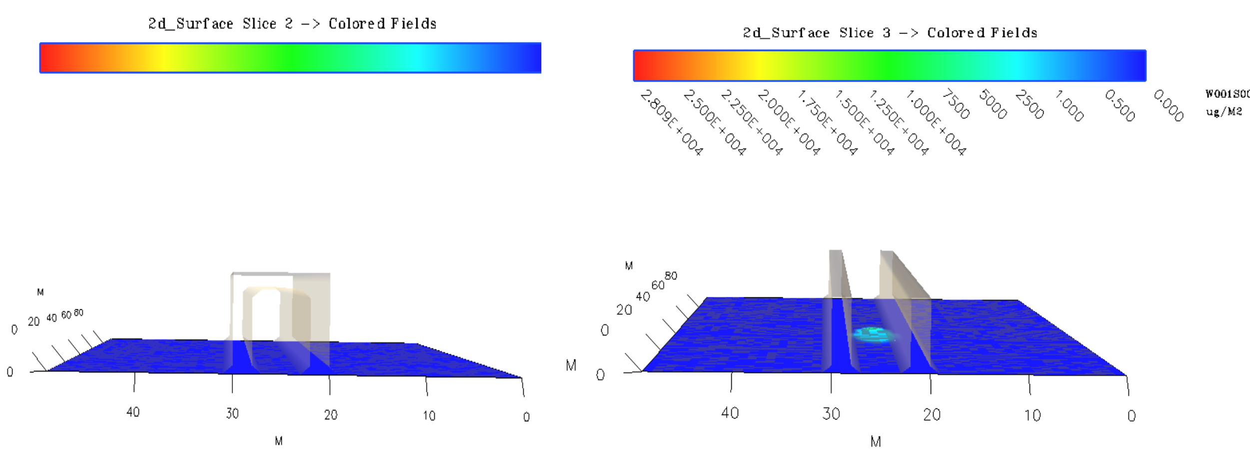
(The black lines figurate the linear sources of the traffic emissions)

Micro-SPRAY GENERALIZED DEPOSITION PROCESSES – 3/3

- Wet deposition was up-graded to take account of arches or bridges
  → *Particles protected against washout are not deposited*
- Shielding effect has been tested in a tunnel configuration
  - Particles are released and disperse in a tunnel when it's raining outside
  - If the tunnel vault is present, there is no deposition
  - If the tunnel vault is removed, there is wet deposition
- Wet deposition on buildings façades is not yet available in Micro-SPRAY

Example of hollow geometry





Evaluation of the wet deposition in the tunnel geometry energie atomique • energies alternatives

DISTRIBUTION OF DELETERIOUS SUBSTANCES IN THE VICINITY OF THE "PLACE DE L'ETOILE" DISTRICT – PARIS

- *3D concentration iso-surface*
- *2D concentration iso-surface*
- *3D deposition on ground and buildings frontages and roofs*
- *3D infiltration / exfiltration*

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CONCLUSION AND PERSPECTIVES

- Original functionalities have been recently implemented in MSS
  - *Interior concentrations can be computed using NSWIFT pressure field diagnostic*
  - *Micro-SPRAY was generalized to dry depositions on all accessible external surfaces*
  - *MSS was extended to hollow geometries and shielding effect against washout by rain*

- MSS has been conceived as the compromise of a simplified CFD solution (close to ‘‘full’’ Navier-Stokes CFD) and a quick response modeling system

- Next step in MSS development is to elaborate a system parallel architecture
  - *Called PMSS and performed by ARIA Technologies, MOKILI and CEA*
  - *Target configurations range from multi-core laptops to large Linux clusters*
  - *First tests show a dramatic decrease of the computation times*

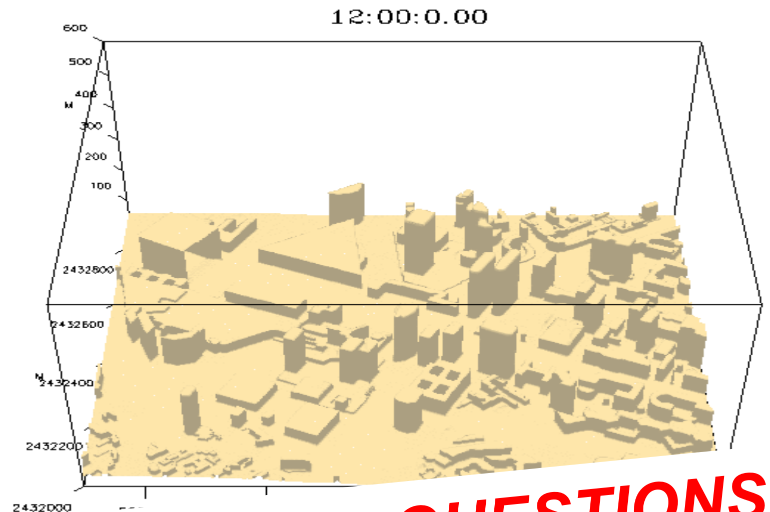
- Computing atmospheric dispersion with consideration for buildings effects and indoor / outdoor transfers, assessing the surface contamination and, later, the health impact, all of this in real or accelerated time, should make PMSS a modeling system adapted to the decision-support and emergency response

BRAND NEW PMSS RESULTS – THE BIG ARCH – PARIS!

Mesh data – DX = DY = 3 m

351 x 301 x 81 in 4 tiles

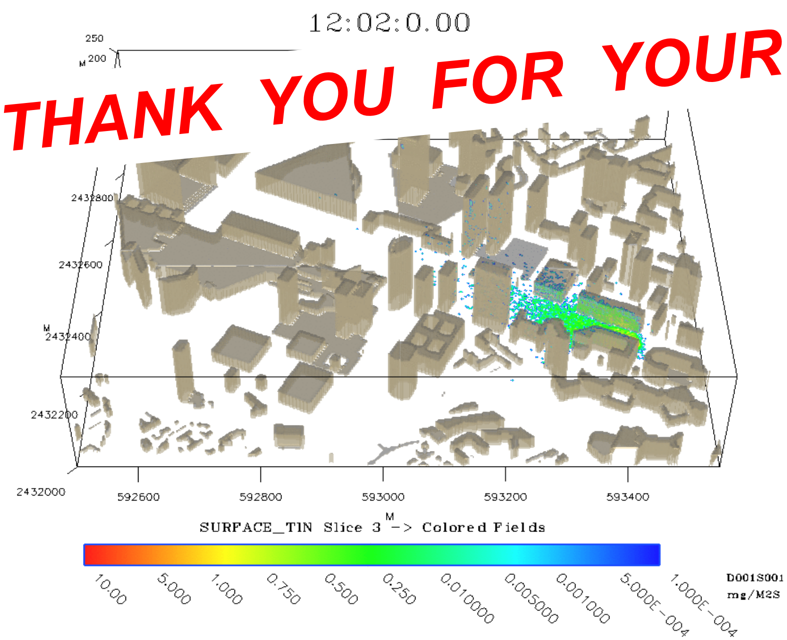
Promising speed-up!

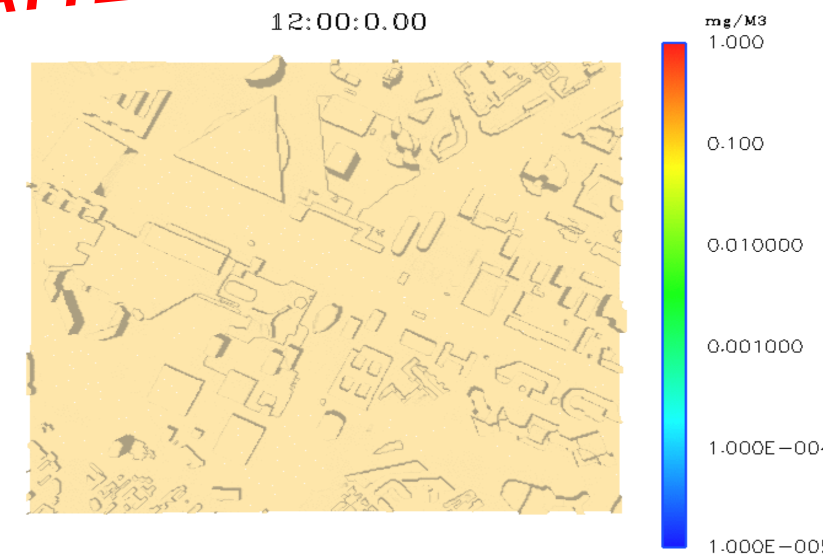


3D plume configuration

THANK YOU FOR YOUR ATTENTION – QUESTIONS?

3D deposition on ground and buildings frontages and roofs





2D concentration near the ground