Numerical simulations of pollutant dispersion in the centre of a European city for different thermal transfer conditions

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Outline

Introduction (I)

❖ **Context and objectives:**

- To model the atmosphere in non neutral stratification for dispersion, risk assessment and urban climate studies (to take into account radiation budget in simulation of flow in built up areas).

- Radiative scheme for atmospheric mesoscale models (1D) are not suited for urban scale Computational Fluid Dynamics (CFD) studies (3D).

- We have developped a radiative and thermal scheme adapted to urban CFD modeling (Milliez, 2006).

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Introduction (II)

- **Previous work:**

- Validation based on thermal data from Mock Urban Setting Test (MUST) experiment (Qu et al., 2011).
- Comparison of two radiation models: *Code_Saturne* and SOLENE (Qu, 2011).
- Numerical study of the thermal effects of buildings with low speed airflow (Qu et al., 2012).
- Validation based on field campaign: Canopy and Aerosol Particle Interactions in Toulouse Urban Layer (CAPITOUL) (Qu, 2011).

- **This work:**
- Modeling the effects of diurnal radiation heating on pollutant dispersion in the center of a European city (Toulouse, south-west of France).

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Outline

1. Introduction
2. **Model design**
3. Simulation Results
4. Conclusions and Perspectives

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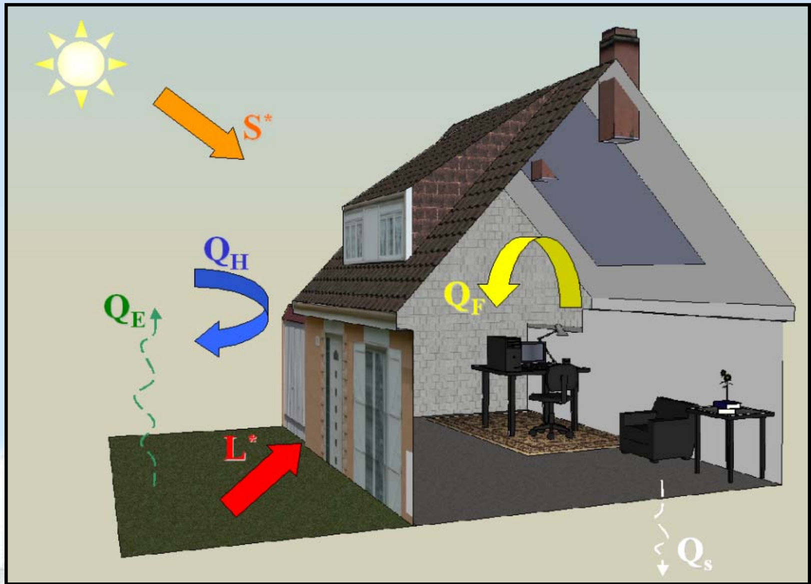
Model design (I)

Computational Fluid Dynamics (CFD) model

- Simulations are performed with the 3D open-source CFD code *Code_Saturne* which can handle complex geometry and physics (www.code-saturne.org).
- The atmospheric module takes into account the larger scale meteorological and the stratification of the atmosphere (Milliez and Carissimo, 2007).

Thermo-Radiative model

- Discrete Ordinate Method (DOM) (Fiveland, 1984)
- Short and long-wave radiation budget at each boundary facet
- Ground temperature: Force-restore model (Deardorff, 1978)
- Buildings walls temperature: Wall thermal model



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Model design (II)

Algorithm outline

1. Input Conditions

Meteo conditions
- Date, location
- Incoming Solar radiation
- Wind Velocity
- Air temperature, etc

Geometry properties
- Shape
- Resolution
- Wall thickness
- Roughness, etc

Thermal properties
- Albedo
- Emissivity
- Heat conductivity, etc

2. Coupled simulation of CFD and Radiation

Thermo-Radiative calculation

- Radiation flux
- Surface temperature
- Sensible heat

CFD calculation

Feedback

3. Post-processing

- Wind Velocity
- Air temperature
- Turbulence
- Surface temperature
- Heat Flux
- Mean value
- Profiles
- Temporel variation
- 3D visualisation
- Etc.

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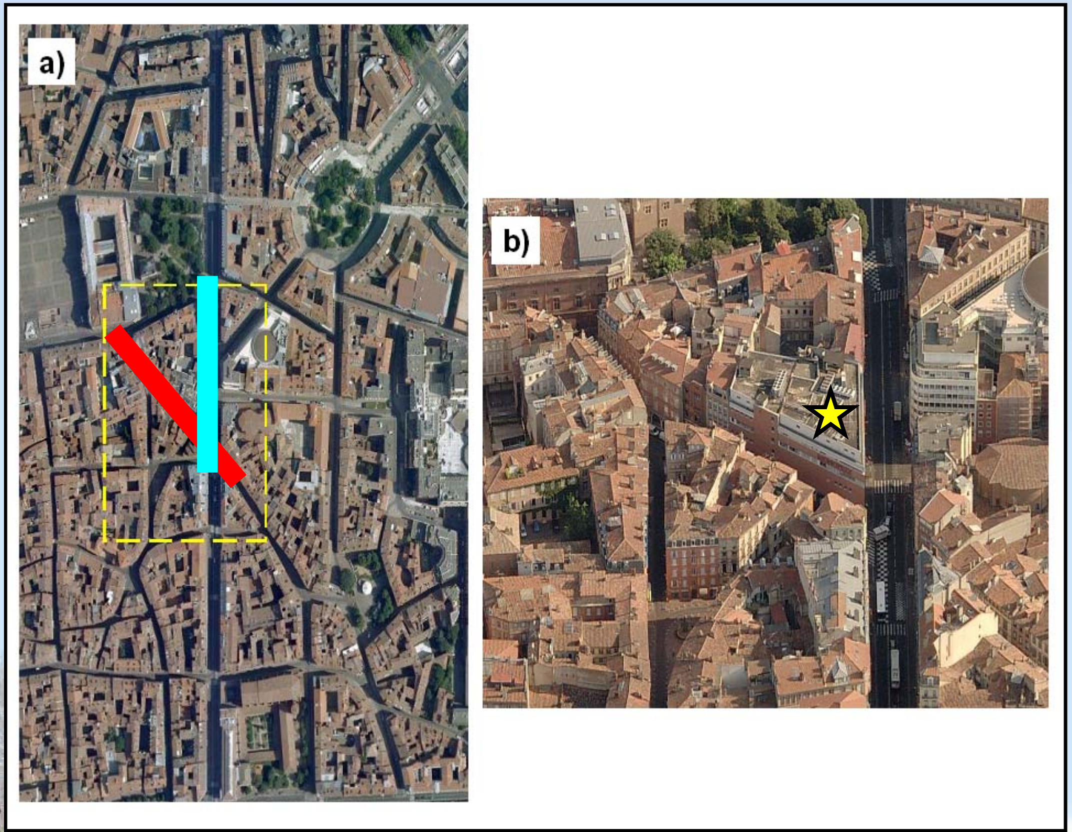
Outline

Results: validation with CAPITOUL dataset (I)

❖ CAPITOUL project summary

- Canopy and Aerosol Particles Interactions in Toulouse Urban Layer (CAPITOUL) field took place from February 2004 to February 2005 (Masson et al., 2008).



Aerial view of downtown Toulouse, France:

a) Main study area, from Google Maps;

b) Zoom in the selected area a) (yellow contour), from Bing Maps

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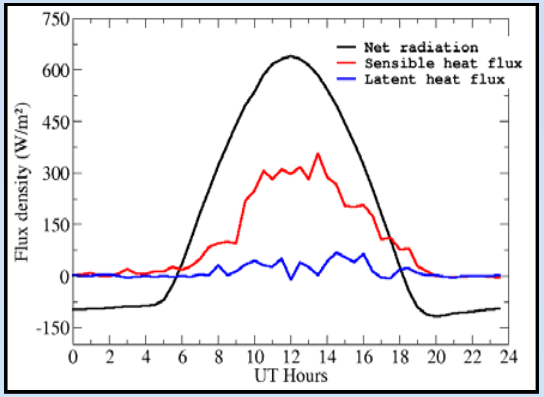
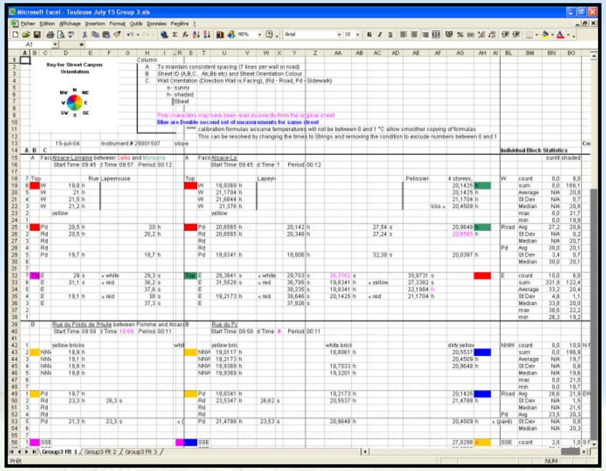
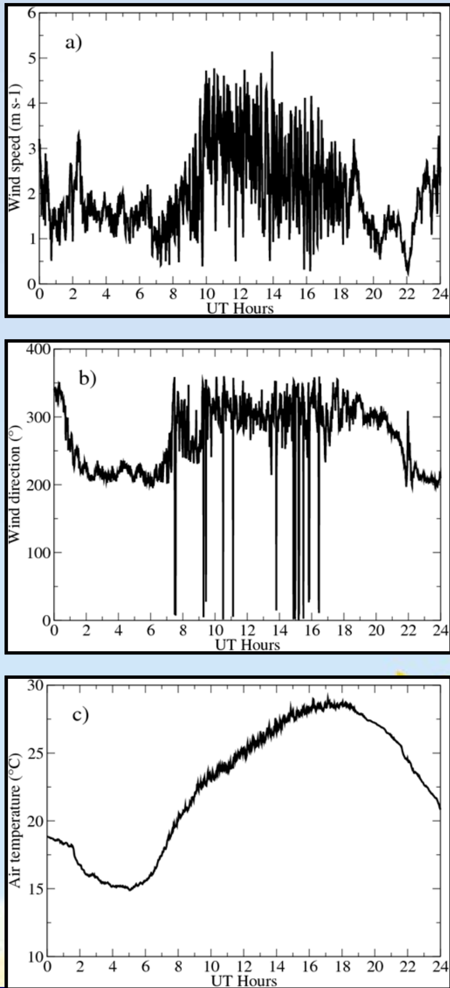
Results: validation with CAPITOUL dataset (II)

CAPITOUL project summary

- Study of the energy exchanges between the surface and the atmosphere was one of the objectives.
- Meteorological data
- Infrared surface temperature measurement
- Hand-held IRT data
- Aircraft data
- Traffic count data
- Energy consumption data







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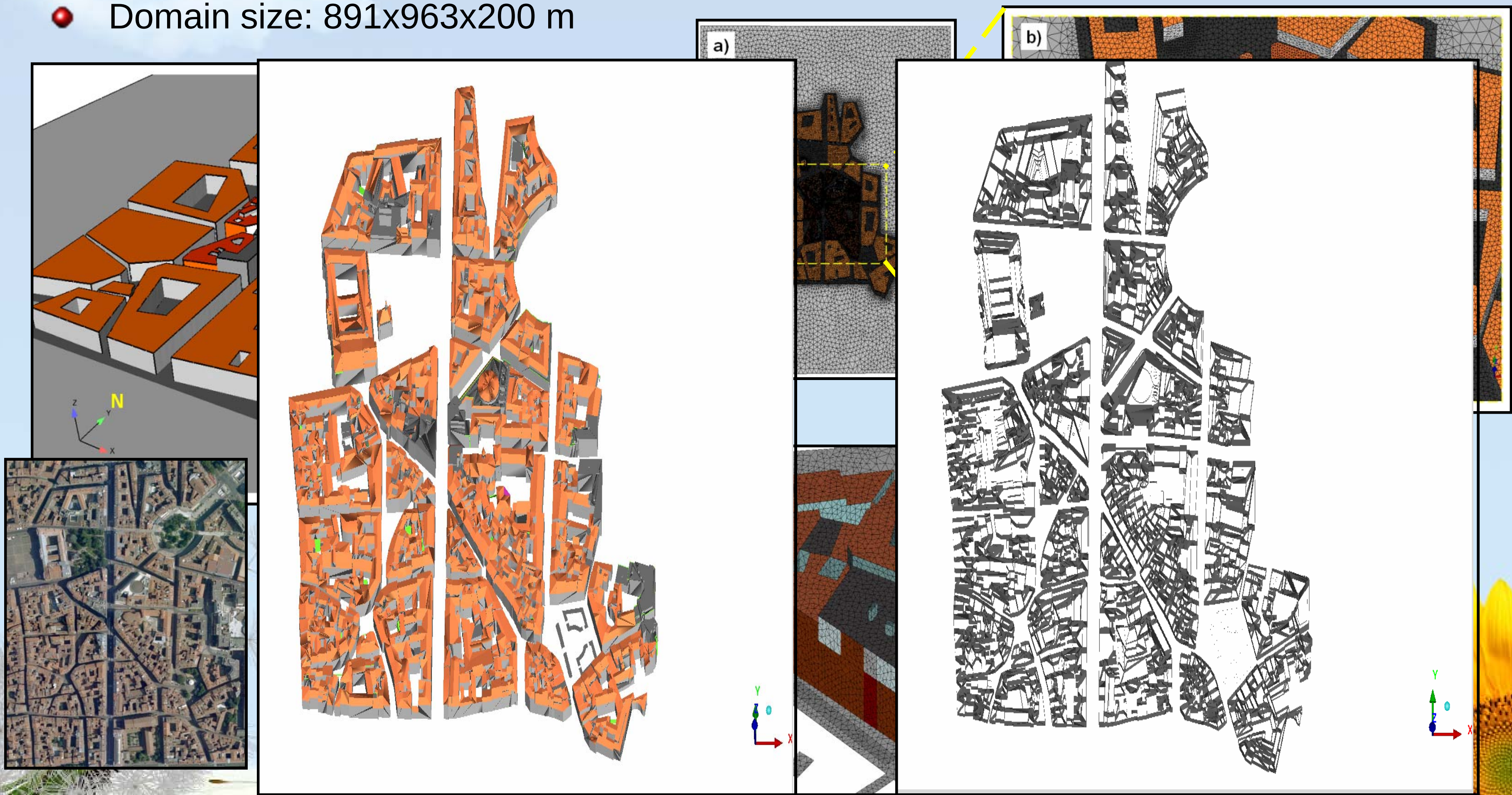
Results: validation with CAPITOUL dataset (III)

❖ Simulation set-up for July 15th 2004

- Central site area geometry processed by ICEM CFD
- Domain size: 891x963x200 m



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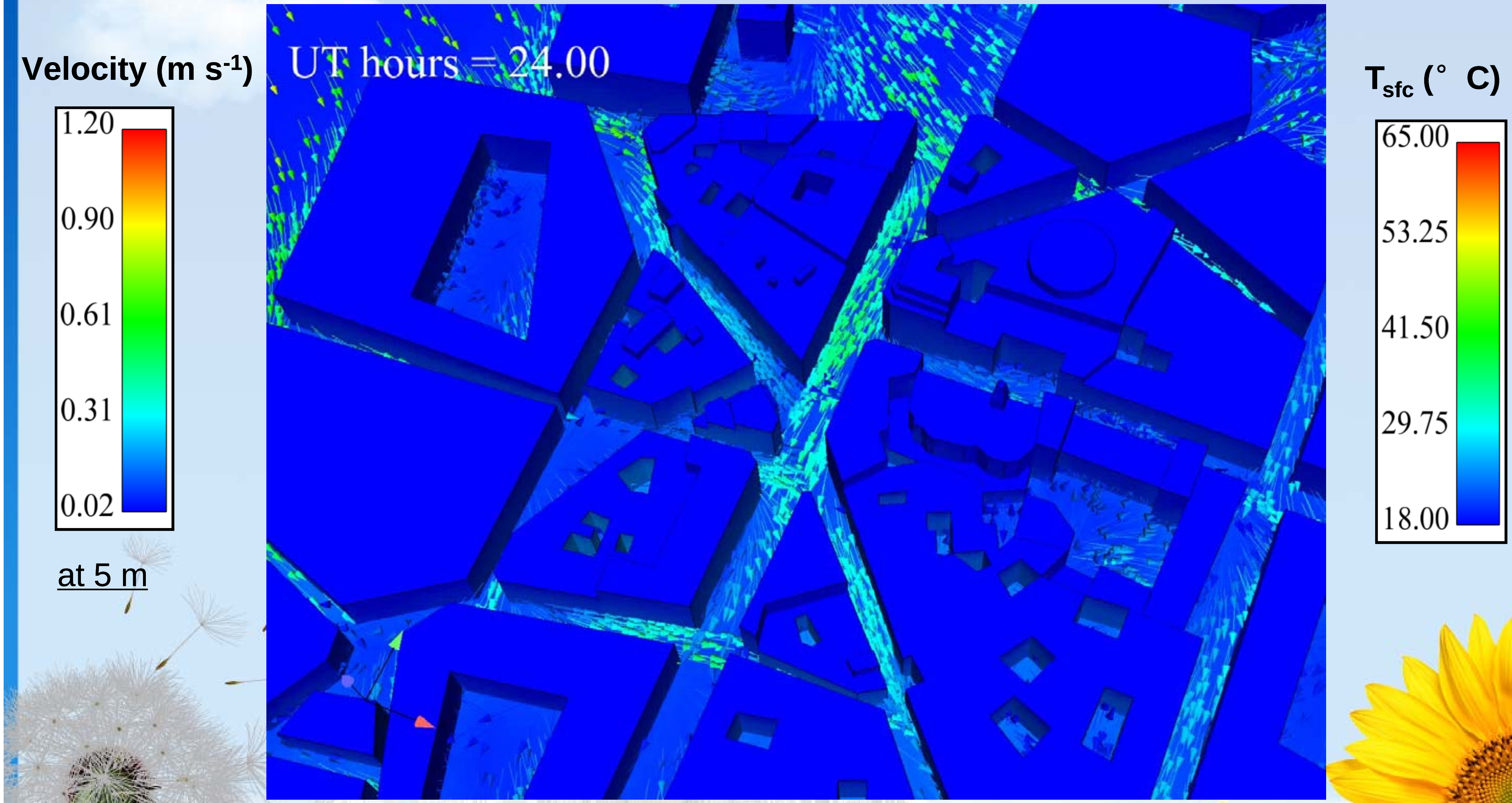
CAPITOUL simulation film

- **Simulation of July 15th 2004**



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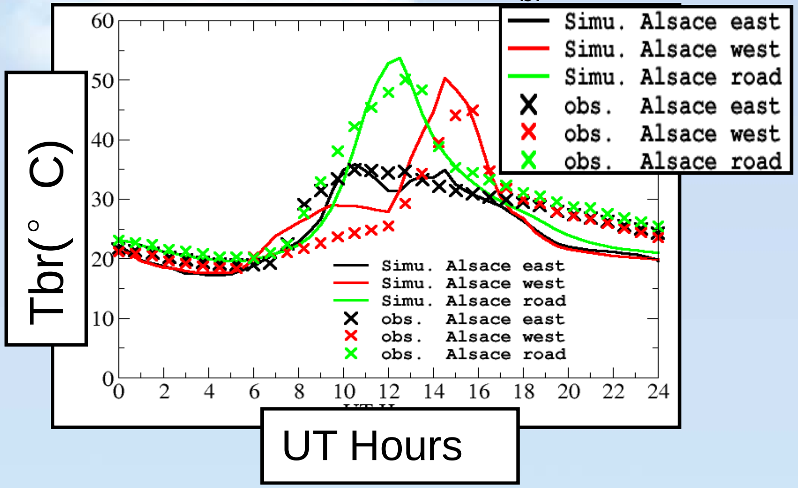
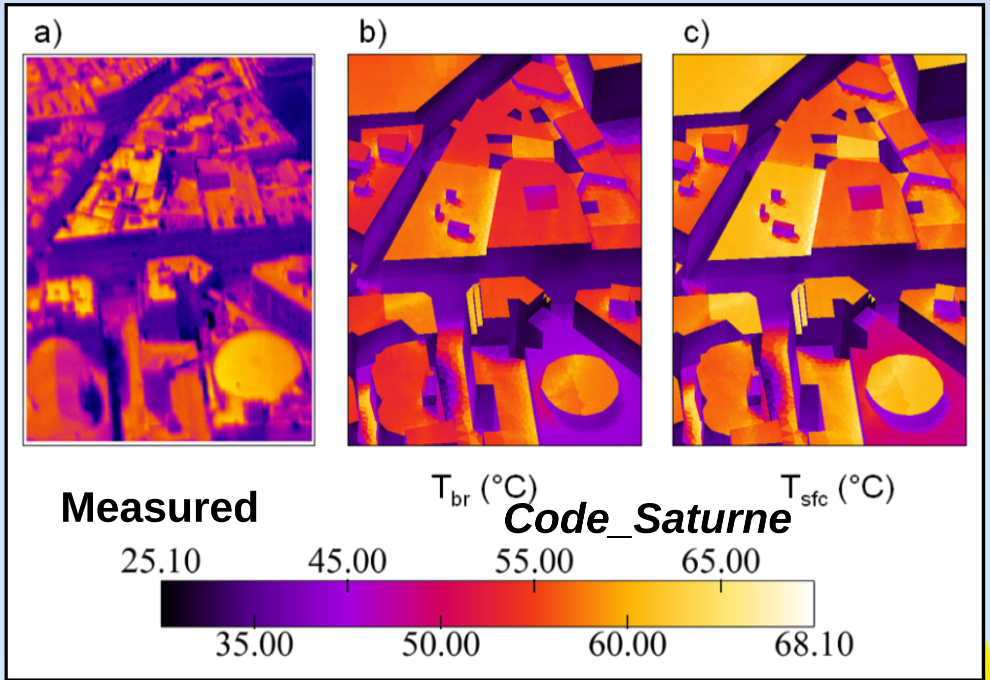
Results: validation with CAPITOUL dataset (IV)

Simulation of July 15th 2004

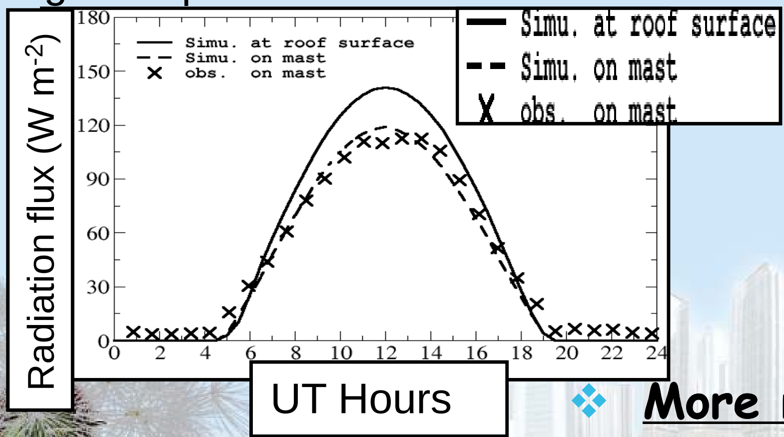
- e.g. Diurnal evolution for T_{br} of different positions of the infrared thermometers



- e.g. TIR airborne images



- e.g. Comparison of heat flux



More results and details

Qu, Y., 2011: Three-dimensional modeling of radiative and convective exchanges in the urban atmosphere, Ph.D. Thesis, Ecole des Ponts ParisTech/ Université Paris-Est, 168pp. available on line at [http://cerea.enpc.fr/fr/theses.html].

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Results: pollutant dispersion study (I)

- **Simulation set-up of July 15th 2004 from 1000 LST to 1300 LST**

N

Wind

$U_{ref} = 3 \text{ m s}^{-1}$

- Emission passive
  Release: 10h00-13h00

- **Two simulations:**
  - Neutral
  - Thermo-raditive transfer

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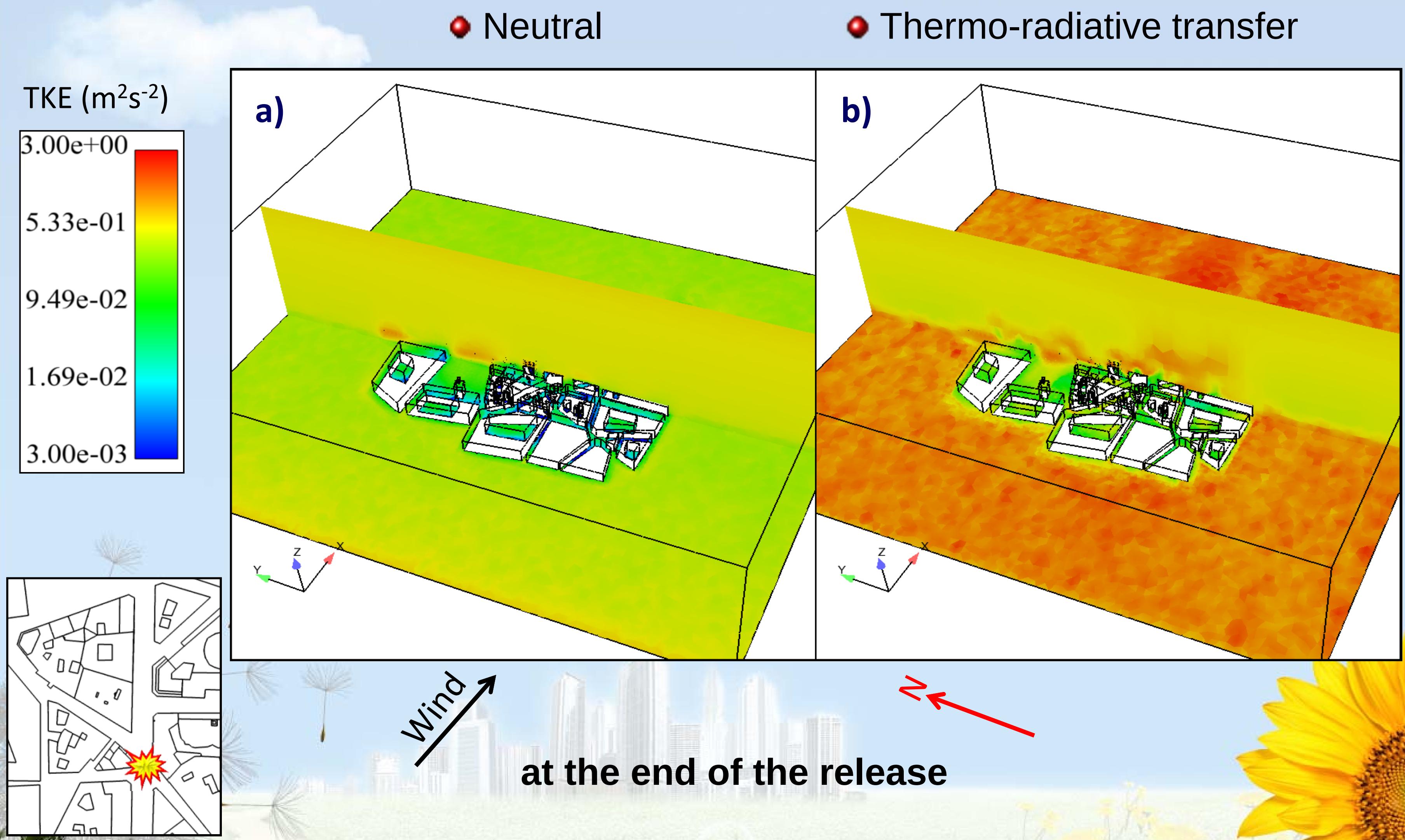
Results: pollutant dispersion study (III)

- **Comparison of the TKE distribution on the vertical- and horizontal sections**



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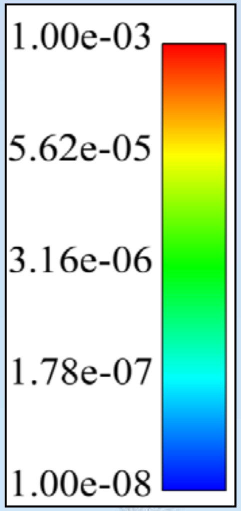
Results: pollutant dispersion study (IV)

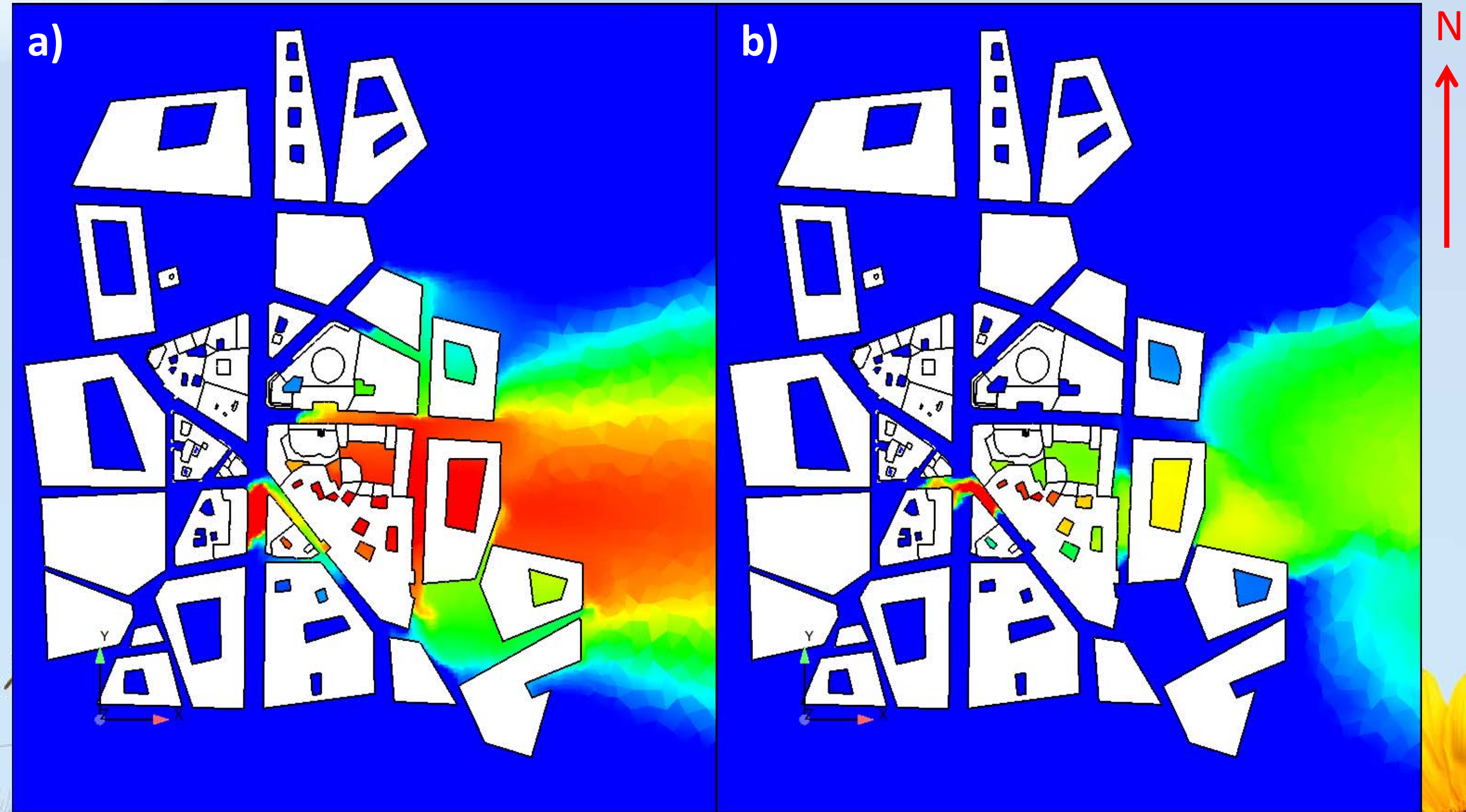
❖ **Comparison of the concentration distribution on the ground level**

Wind →

C (adim)



- Neutral
- Thermo-radiative transfer



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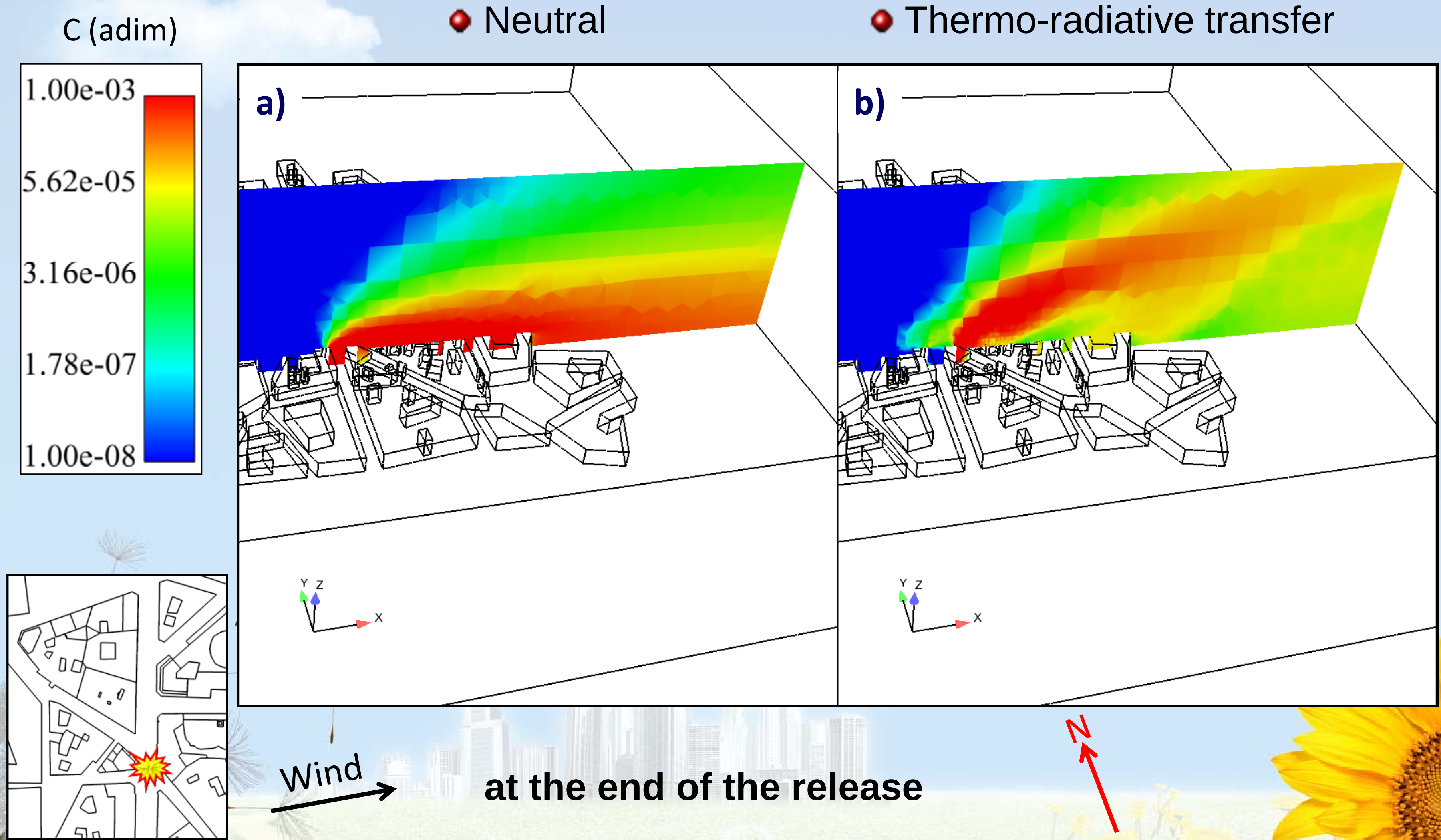
Results: pollutant dispersion study (V)

- Comparison of the concentration distribution on a vertical section



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Dispersion film

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Conclusions and Perspectives

- Investigating the energy exchanges in a real city with the atmosphere, using new atmospheric radiative and thermal schemes implemented in *Code_Saturne*.
- The simulation results show the importance of modeling in detail while doing local model-observation comparison, also show the thermal effects considerably alter the pollutant dispersion plume shape.
- This type of tools can be applied to detailed studies of local urban climate.
- To further assess the street canyon ventilation potential, the shading strategies, thermal comfort, the wind engineering in the urban environment.
- To the study of “hot spots” in the air quality of urban centers where the emissions are particularly concentrated and to evaluate the alternatives to mitigate them.
- The model results are encouraging and give insight into local surface-atmosphere processes, but further testing has to be performed with other datasets.
- Apply the model in other city centers, such as Paris and Marseille in France (Project EUREQUA) .

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Thank you!

❖ **References:**

Hénon, A., 2008: Températures mesurées, modélisées, et observées par télédétection infrarouge, dans la canopée urbaine: modélisation aéro-thermo-radiatif des flux de chaleur urbains. Ph.D. thesis, École Centrale de Nantes, 253 pp., [in French]

Lagouarde, J. P., A. Hénon, B. Kurz, P. Moreau, M. Irvine, J. Voogt, and P. Mestayer, 2010: Modelling daytime thermal infrared directional anisotropy over Toulouse city centre. *Remote Sens. Environ.*, 114, 87–105.

Masson, V., C. S. B. Grimmond, and T. R. Oke, 2002: Evaluation of the Town Energy Balance (TEB) Scheme with Direct Measurements from Dry Districts in Two cities. *J. Appl. Meteor.,* 41, 1011–1026.

Masson, V., et al., 2008: The Canopy and Aerosol Particles Interactions in TOulouse Urban Layer (CAPITOUL) experiment. *Meteor. Atmos. Phys.,* 102, 135–157.

Miguet, F. and D. Groleau, 2002: A daylight simulation tool for urban and architectural spaces - application to transmitted direct and diffuse light through glazing. *Build. Environ.*, 37, 833–843.

Milliez, M., 2006: Modélisation micro-météorologique en milieu urbain: dispersion des polluants et prise en compte des effets radiatifs. Ph.D. thesis, École des Ponts ParisTech, 228 pp. available on line at [http://cerea.enpc.fr/fr/theses.html].

Milliez, M. and B. Carissimo, 2007: Numerical simulations of pollutant dispersion in an idealized urban area, for different meteorological conditions. *Bound.-Layer Meteor.,* 122 (2), 321–342.

Musson-Genon, L., E. Dupont and D. Wendum, 2007: Reconstruction of the surface-layer vertical structure from measurements of wind, temperature and humidity at two levels. *Bound.-Layer Meteor.,* 124, 235–250.

Pigeon, G., M. A. Moscicki, J. A. Voogt, and V. Masson, 2008: Simulation of fall and winter surfac energy balance over a dense urban area using the TEB scheme. *Meteorol. Atmos. Phys.,* 102, 159–171.

Qu, Y., M. Milliez, L. Musson-Genon, B. Carissimo, 2011: Micrometeorological modeling of radiative and convective effects with a building resolving code, *J. Appl. Meteor. Climatol.,* 50 (8) 1713–1724.

Qu, Y., M. Milliez, L. Musson-Genon and B. Carissimo, 2012: Numerical study of the thermal effects of buildings on low-speed airflow taking into account 3D atmospheric radiation in urban canopy, *J. Wind Eng. Ind. Aerodyn.* (104–106), 474–483.

Qu, Y., 2011: Three-dimensional modeling of radiative and convective exchanges in the urban atmosphere, Ph.D. Thesis, Ecole des Ponts ParisTech/ Université Paris-Est, 168pp. available on line at [http://cerea.enpc.fr/fr/theses.html].

Yee, E., and C. A. Biltoft, 2004: Concentration fluctuations measurements in a plume dispersing through a regular array of obstacles. *Bound.-Layer Meteor.,* 111, 363–415.

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Questions?
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