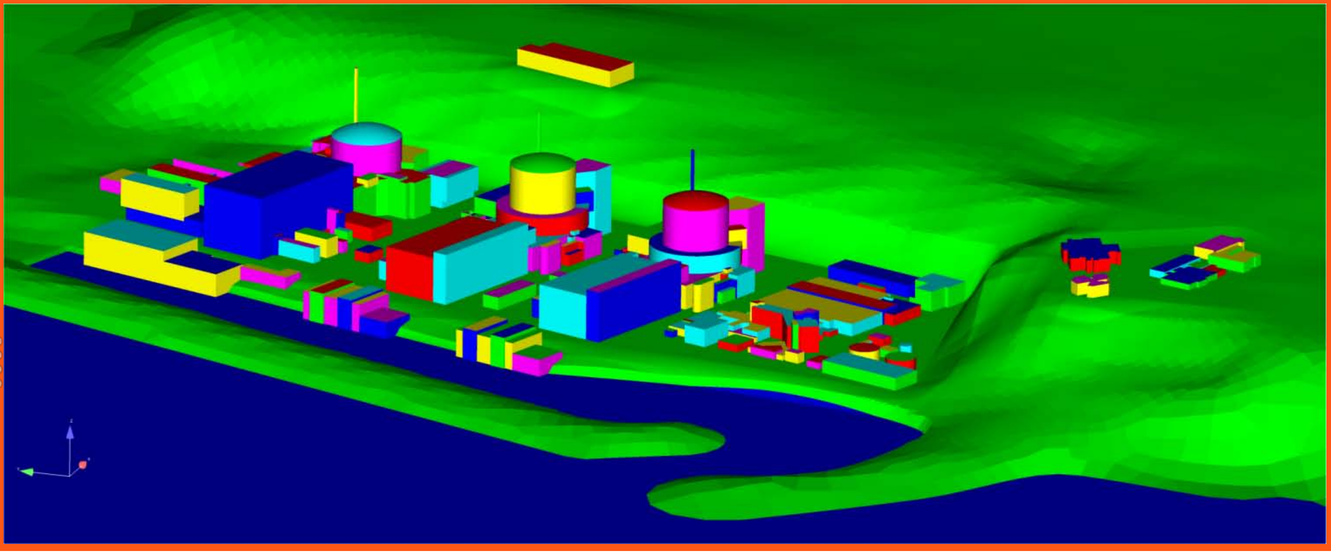
An overview of existing and future atmospheric simulations with Code_Saturne



EDF R&D

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Atmosphérique

ECOLE NATIONALE DES PONTS ET CHAUSSEES
ParisTech
INSTITUT DES SCIENCES ET TECHNOLOGIES
PARIS INSTITUTE OF TECHNOLOGY
UNIVERSITÉ PARIS-EST

B. Carissimo et col.

Outline

- Why an atmospheric option in *Code_Saturne* ?
- Boundary conditions
- Equations
- Additional models (chemistry, nano-particles …)
- Validations
- Futur plans

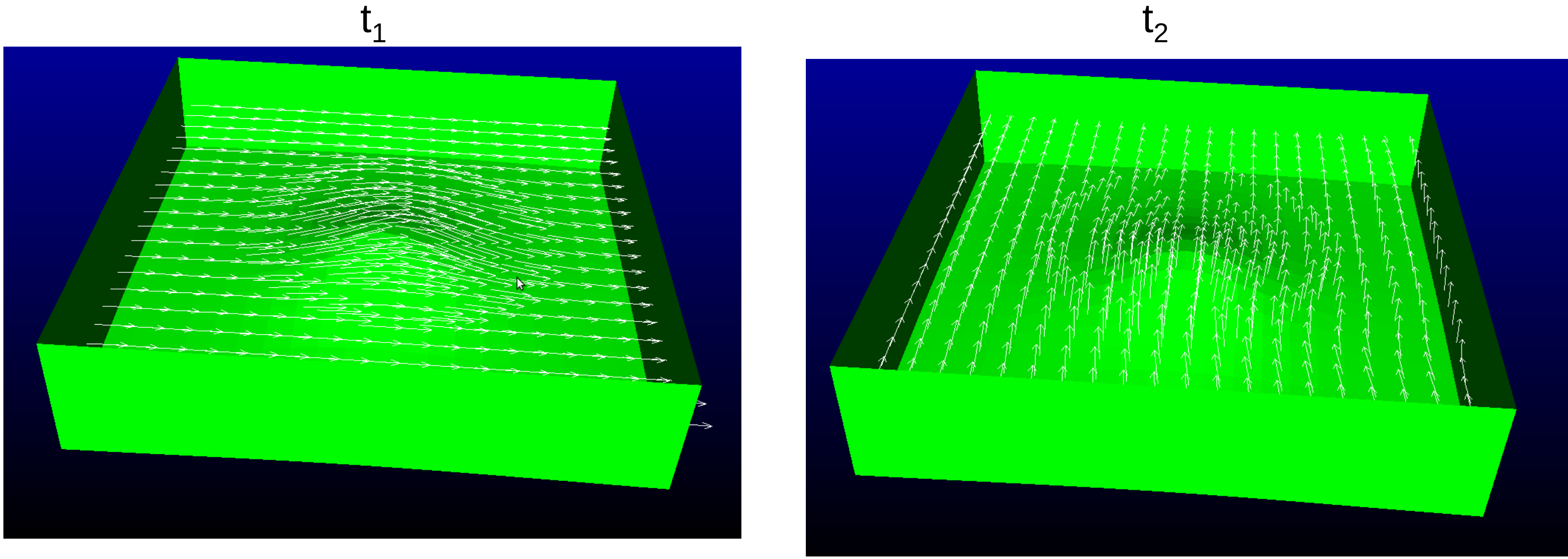
Why an atmospheric option in *Code_Saturne* ?

Atmospheric environment :

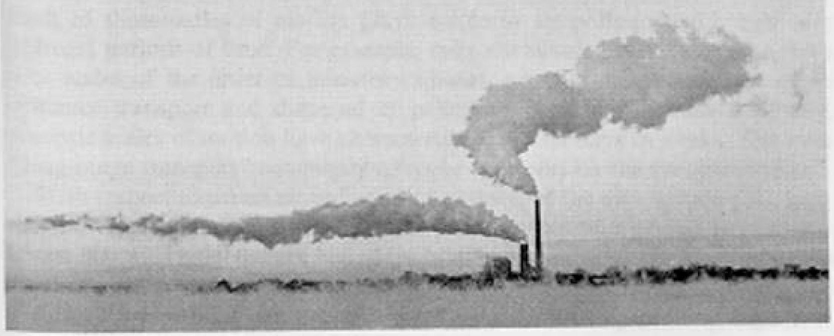
Pollutant dispersal, wind energy (cf. poster), building and city neighboorhood studies …

Example : flow over a 3D hill

Boundary conditions:
1 rough wall : ground
5 inlet-outlet faces : free atmosphere

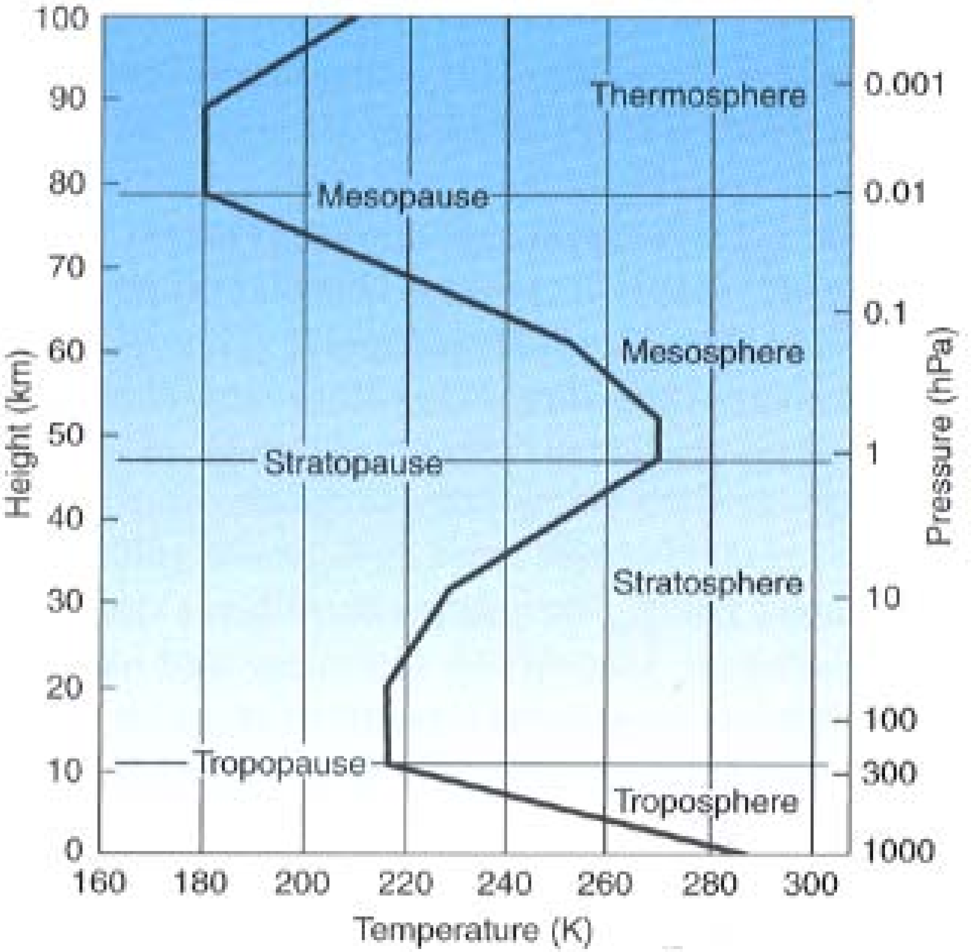


Stratification Influence on dispersion :



Condensation plumes for a 500 ft. and three 250 ft. stacks in Salem, Massachusetts. The picture, taken on a cold February morning, shows the complex thermal structure and large wind shear in the lower atmosphere. Steaming fog in the foreground is over the Beverly-Salem Harbor. The original photograph was taken by Ralph Turcotte, a staff photographer for the Beverly (MA) Times.

Vertical structure of the atmosphere



Vertical profile of temperature

(standard atmosphere USA 1976)

Free atmosphere

Atmospheric Boundary Layer

(0.1 – 2 km)

- Use compressible equations ?
  - Low Mach number, very little energy in sound part of the spectrum
  - Adding complexity (ByC) (already in with internal gravity waves)
  - Rarely used in mesoscale meteorological models

- Prefer anelastic approximation already in *Code_Saturne*, but using <u>potential temperature</u>

Adiabatic transformation and potential temperature

- **First law of thermodynamics + perfect gas law :**

$$dq = C_p dT - \alpha dp \qquad p\alpha = rT$$

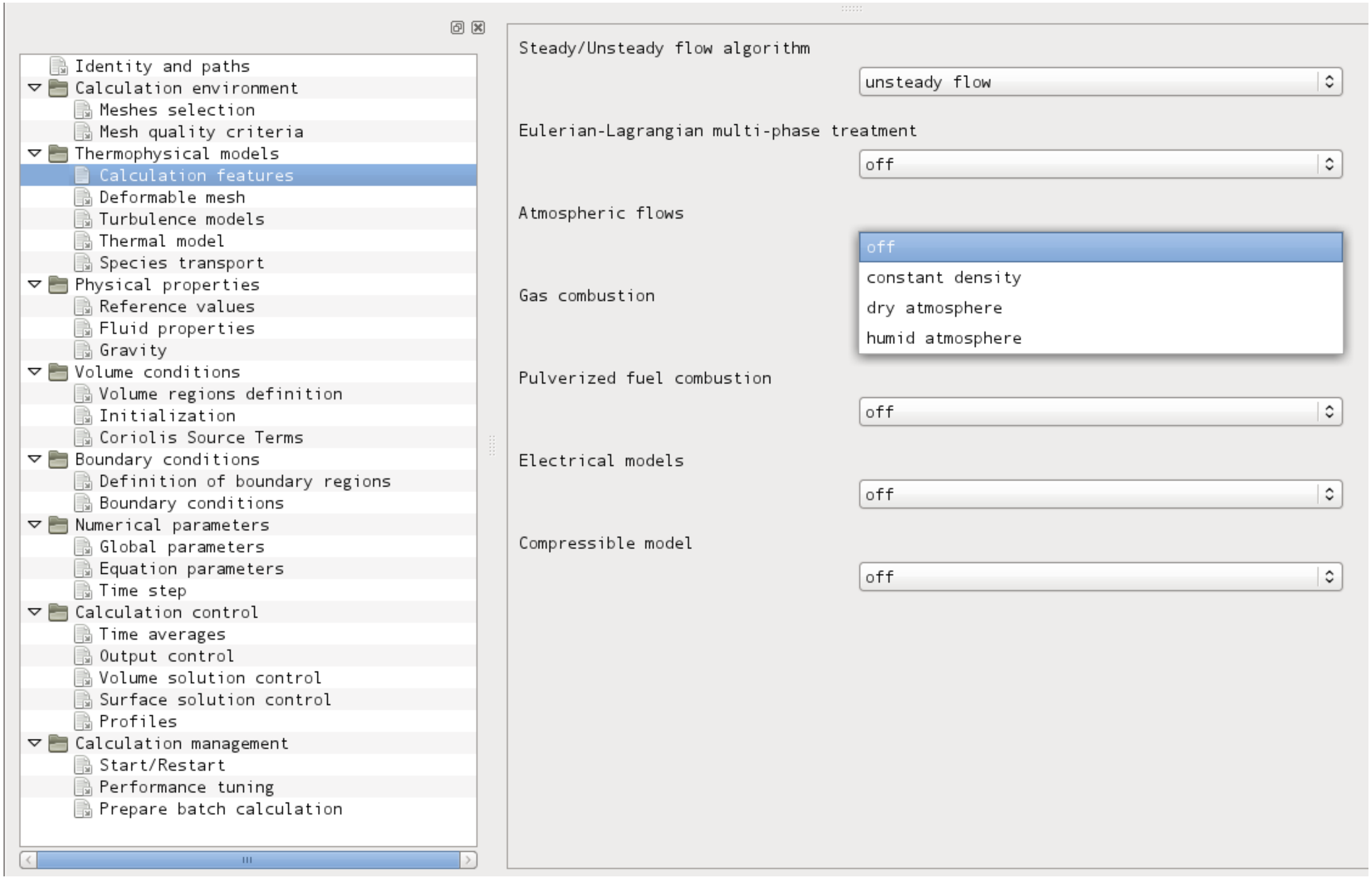
- **Adiabatic process** : no heat exchange

$$0 = C_p dT - \frac{rT}{p} dp \quad \Rightarrow \quad 0 = \frac{dT}{T} - \frac{r}{C_p}\frac{dp}{p}$$

- **Potential temperature** : temperature that an air parcel would have if it was expanded or compressed adiabatically from its existing pressure and temperature to a standard pressure p_0 (1000hPa)

$$\theta = T\left(\frac{p_0}{p}\right)^{\frac{r}{C_p}}$$

Code_Saturne 3.0: atmospheric options



Steady/Unsteady flow algorithm: unsteady flow

Eulerian-Lagrangian multi-phase treatment: off

Atmospheric flows: off

- off
- constant density
- dry atmosphere
- humid atmosphere

Gas combustion

Pulverized fuel combustion: off

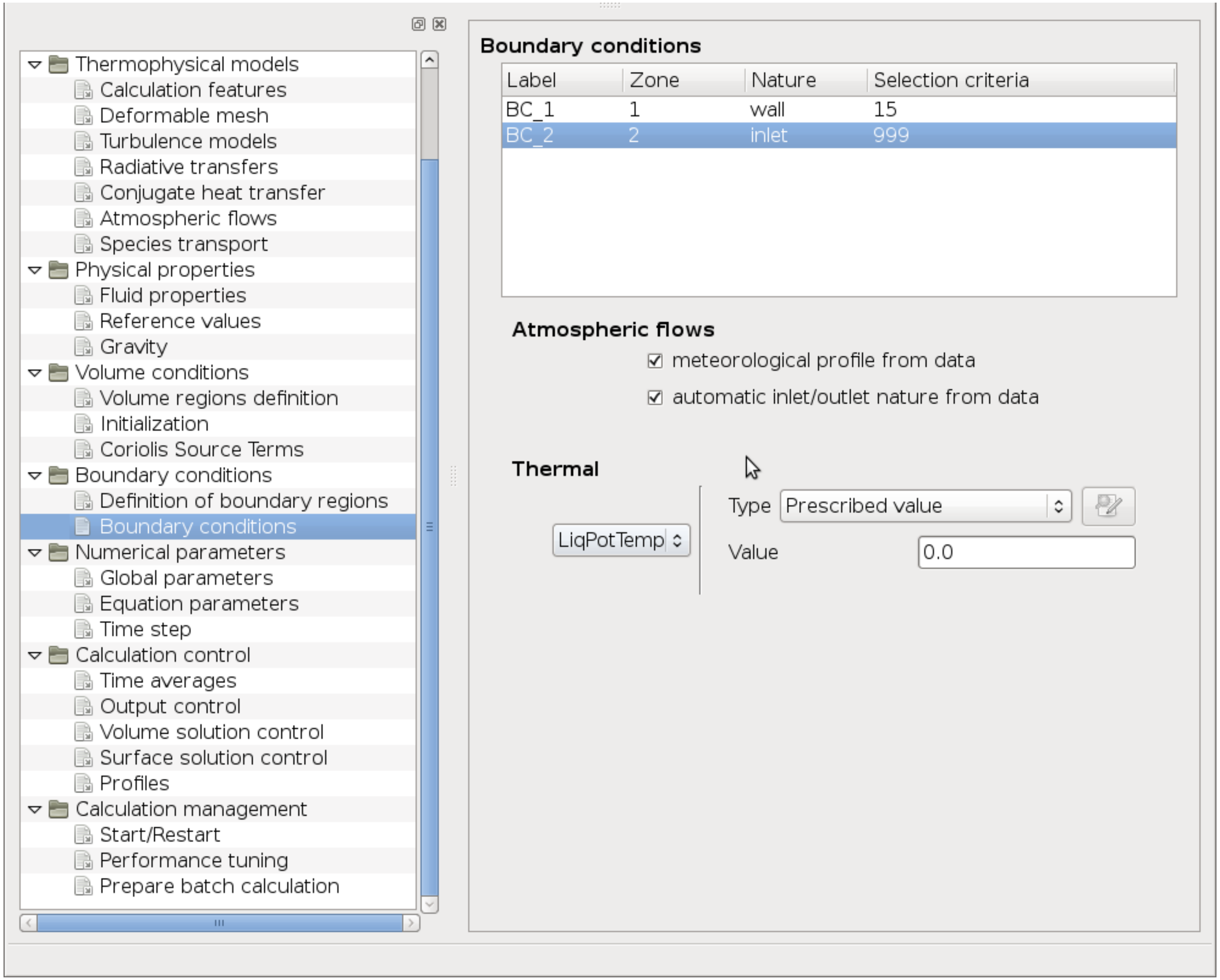
Electrical models: off

Compressible model: off

$$\text{dry atmosphere}: \ \theta$$

$$\text{humid atmosphere}: \theta_l, q_w, N_c$$

Code_Saturne 3.0: atmospheric boundary conditions



Boundary conditions

Label	Zone	Nature	Selection criteria
BC_1	1	wall	15
BC_2	2	inlet	999

Atmospheric flows

☑ meteorological profile from data

☑ automatic inlet/outlet nature from data

Thermal

LiqPotTemp

Type: Prescribed value

Value: 0.0

« meteo »
file (text)
in DATA

Equations in *Code_Saturne 3.0*, atmospheric option

- Momentum : unchanged
- Continuity : unchanged
- Energy for « dry atmosphere » : $\frac{\partial \theta}{\partial t} = \dots$
- « humid atmosphere » : $\theta_l \quad q_w \quad N_c$

(Moments of droplet distribution)

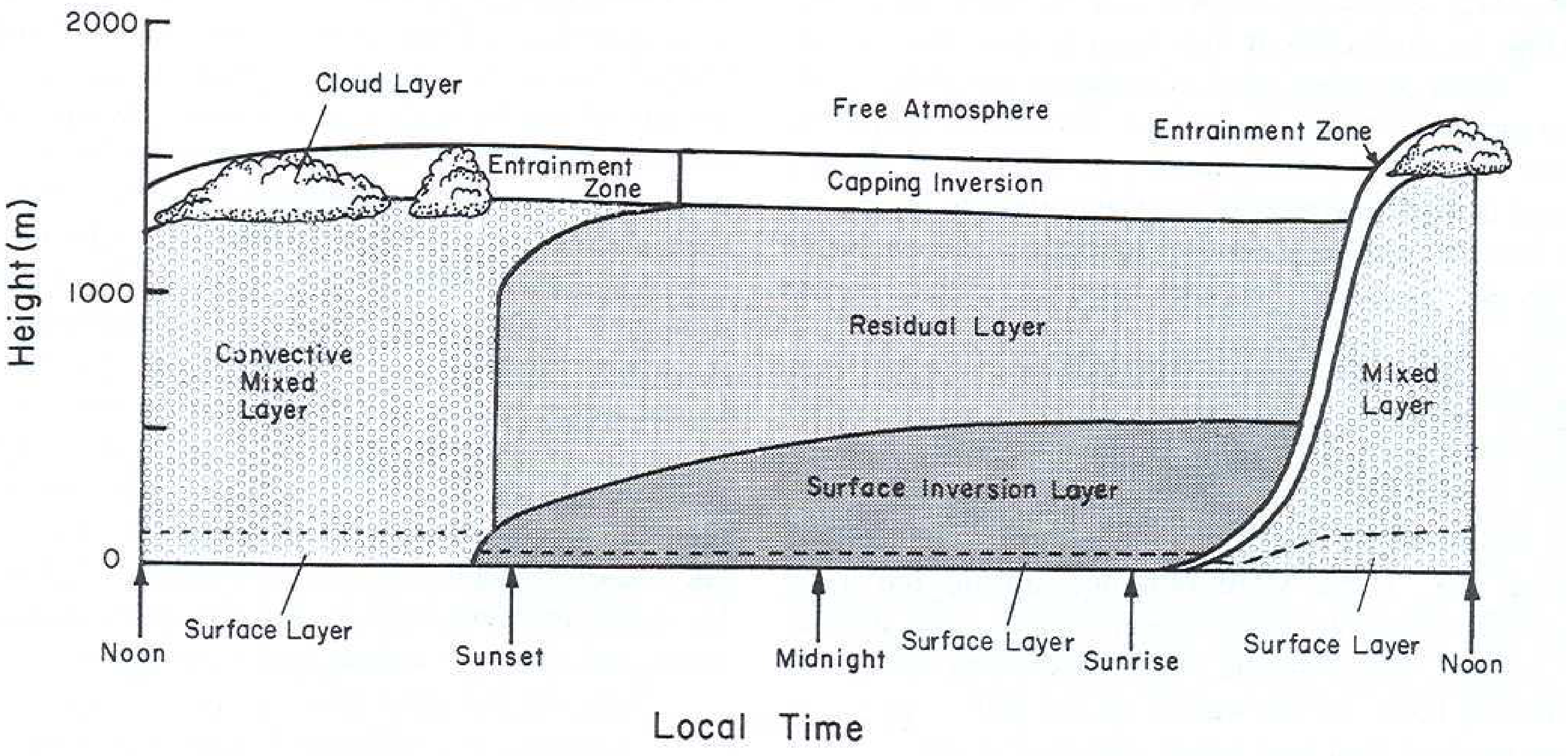
- \+ modified turbulence buoyancy production (k-eps) and rough wall laws (Monin-Obukhov similarity)

Validation for *Code_Saturne* 3.0, atmospheric option

- Standard Validation :
  - Roughness transition, comparison with data (Bradley)
  - Boundary layer diurnal cycle (Wangara)

- Additional atmospheric validations (cf. poster):
  - Land-sea breeze (analytical)
  - Mountain waves (analytical)
  - Dispersion of heavy gas (including aerosols)
  - Cooling tower plume
  - ….

Structure of the ABL



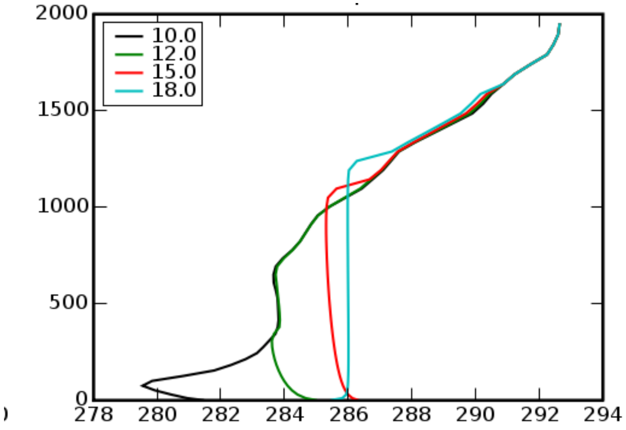
Stull (1988)

Code_Saturne: validation on Wangara experiment - I

- **Experiment often used to test the ability of models to reproduce the diurnal cycle**
- **Vertical profiles of potential temperature**

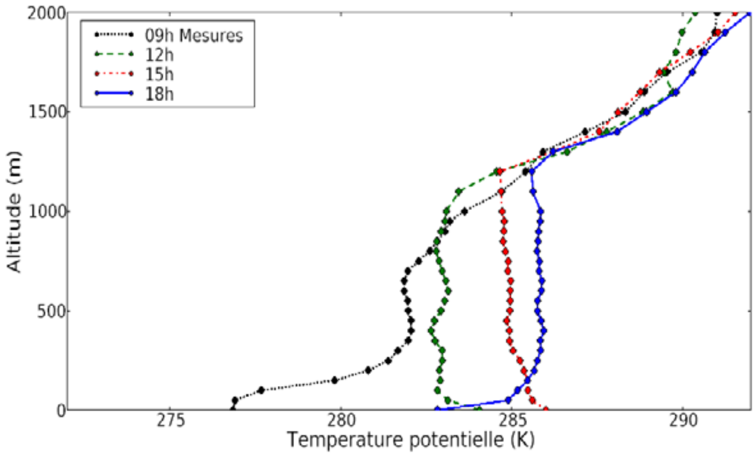
Unstable
(day)

Potential temperature (K)

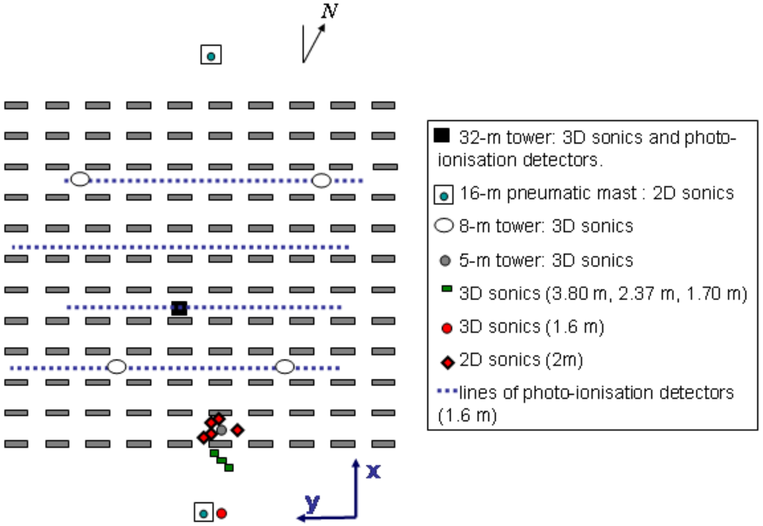


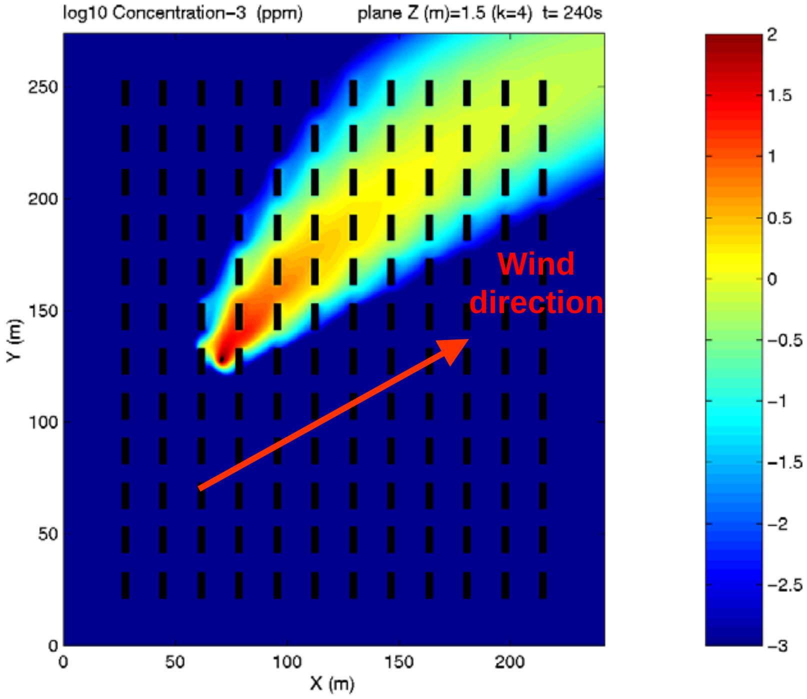
calculated

measured



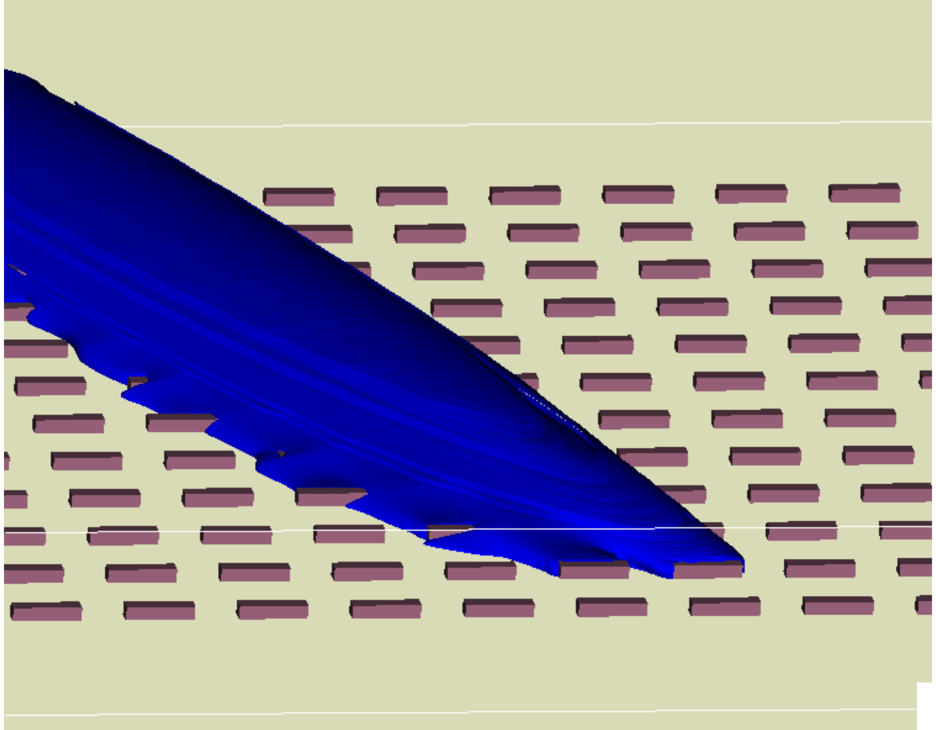
Dispersion modeling in built up environment
MUST experiment (Mock Urban Setting Test)



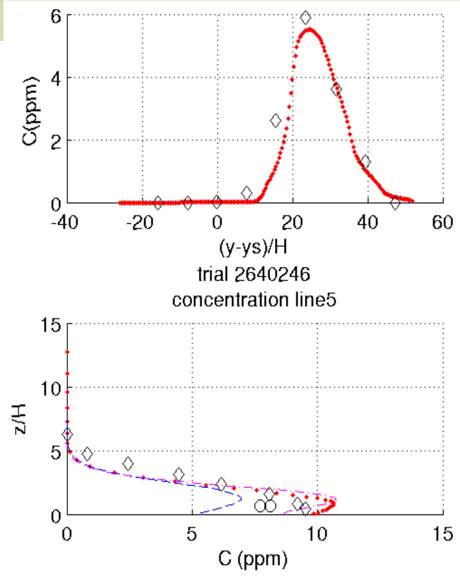


MUST = Mock Urban Setting Test

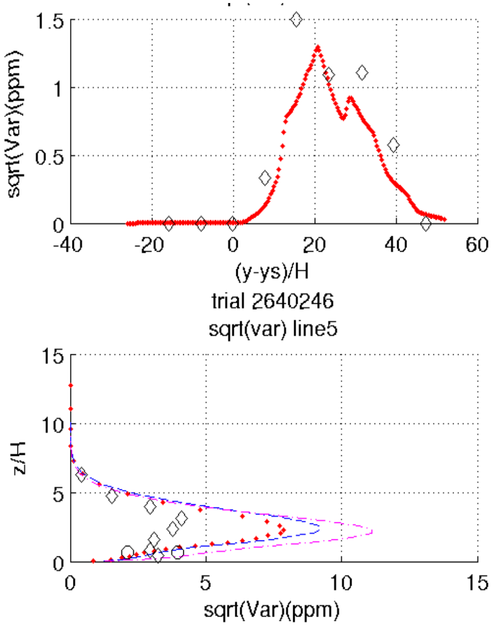
Milliez & Carissimo, 2007



$\overline{c}$



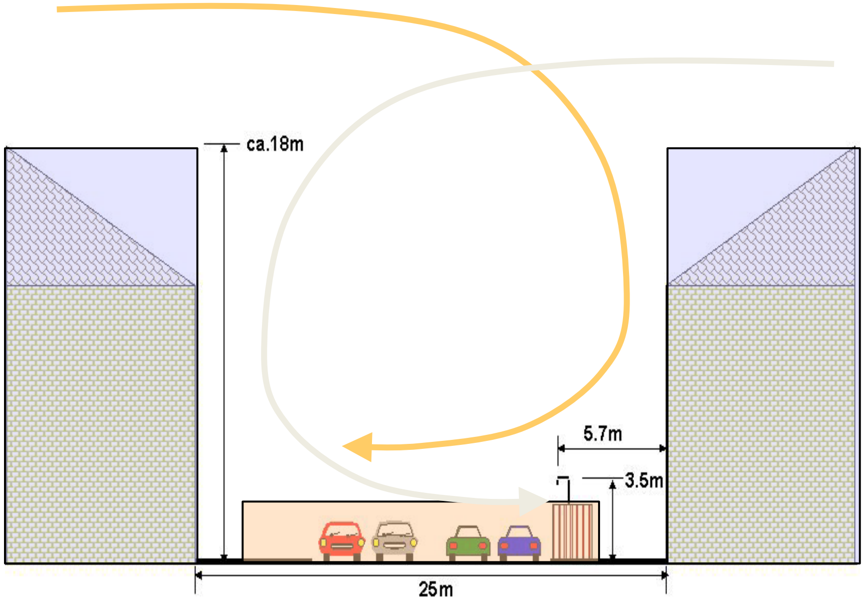
$\sqrt{\overline{c'^2}}$



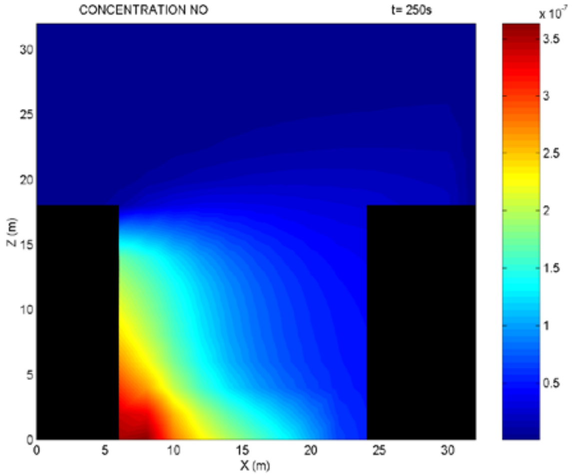
Chemistry submodel

Trafic

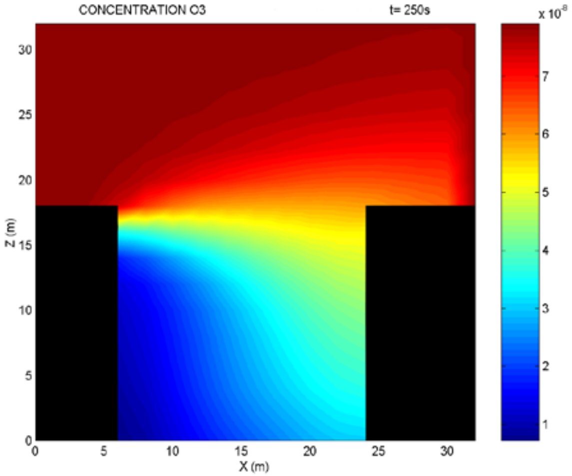
- **Canyon ventilation**
- **Chemical reactions**



Oxyde d'Azote



Ozone



Formation des nano-particules par le trafic routier (Albriet et al. 2009)

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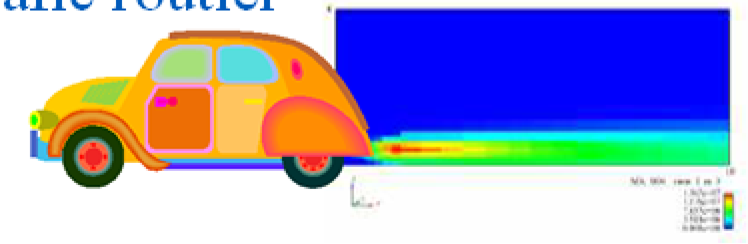
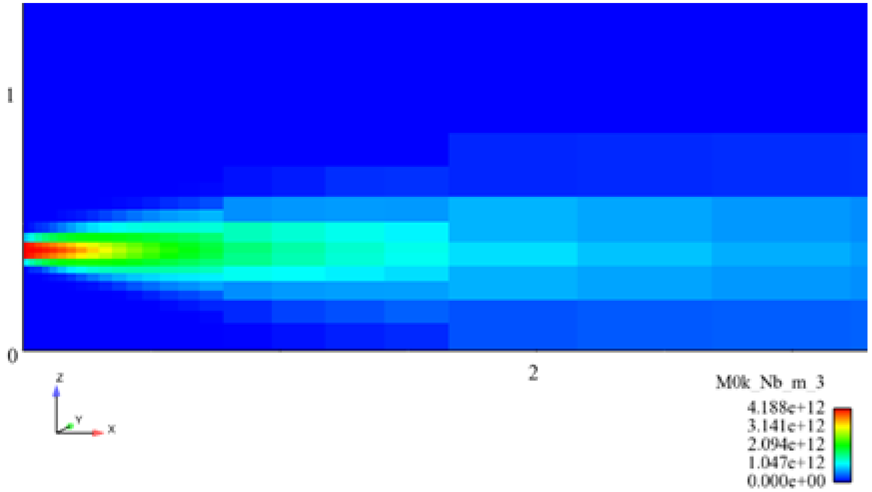
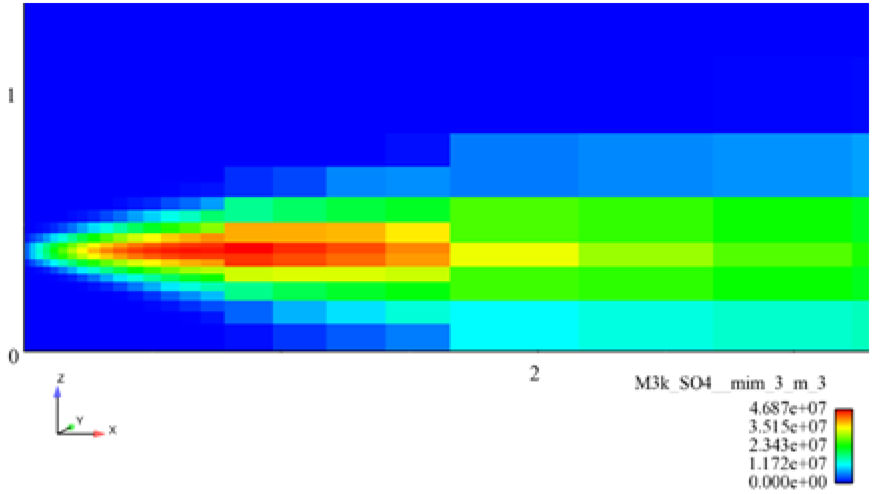
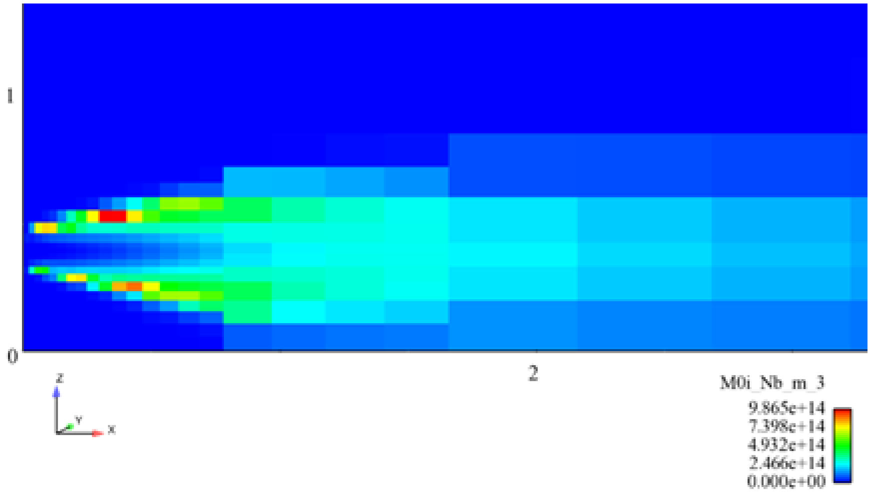
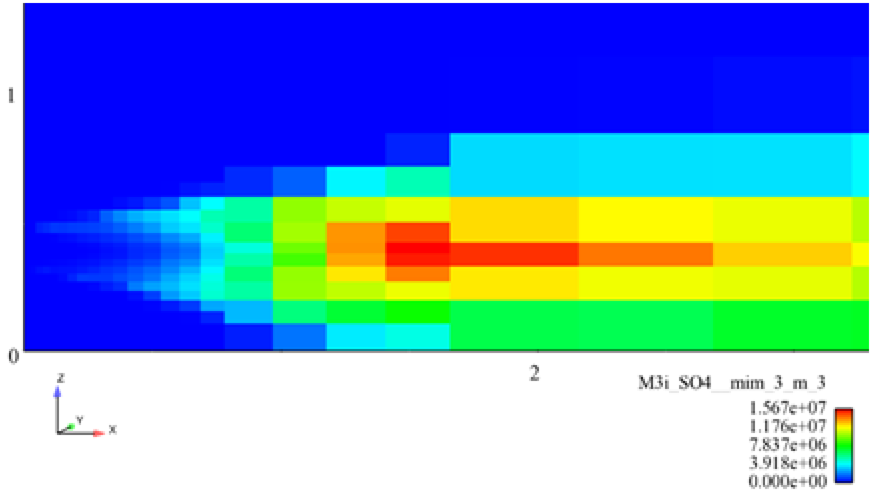






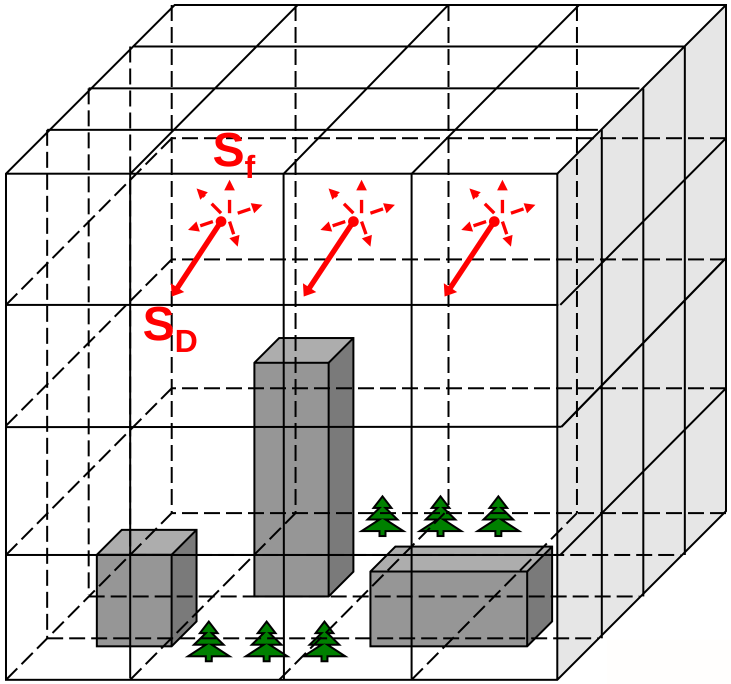


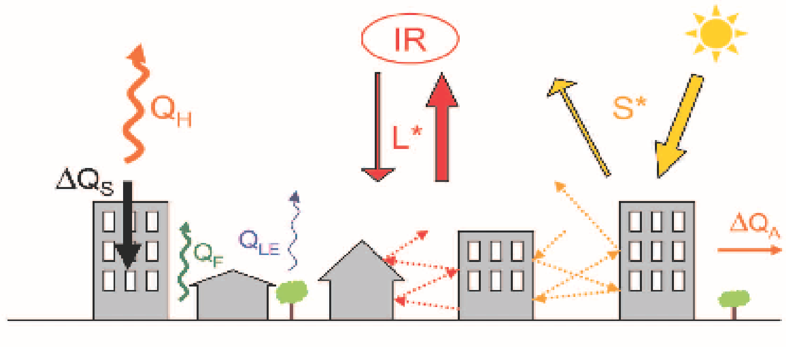


Futur plans :

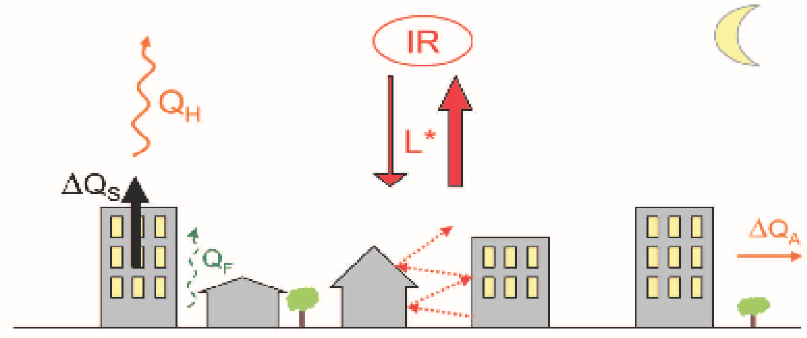
- non-uniform large scale meteo
  (nesting or « imbrication »)
- 3D atmospheric radiative scheme
- Rij atmospheric
- Lagrangian module for atmospheric dispersion
- Data assimilation

3-D atmospheric radiative model under development

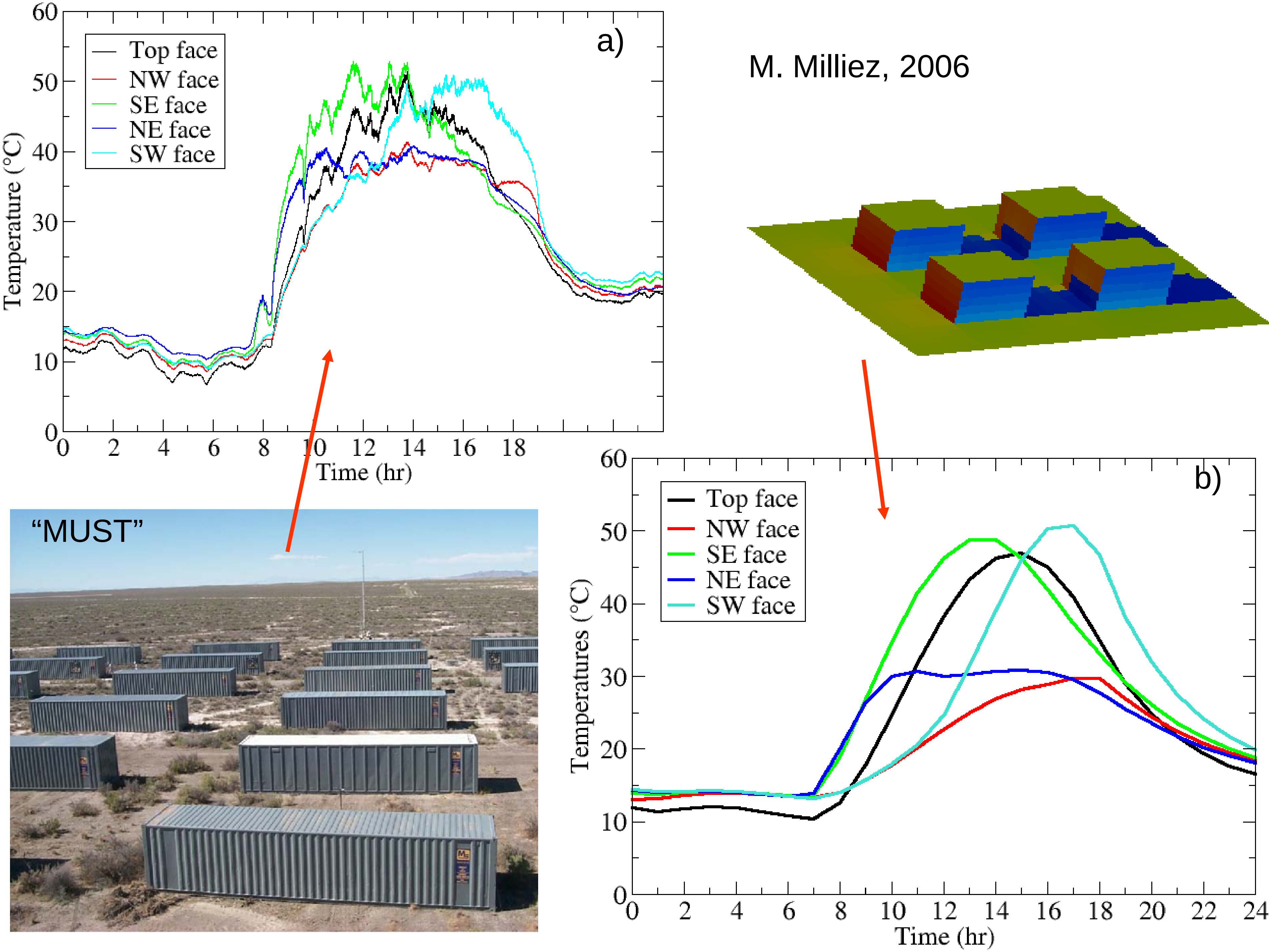




Jour



Nuit

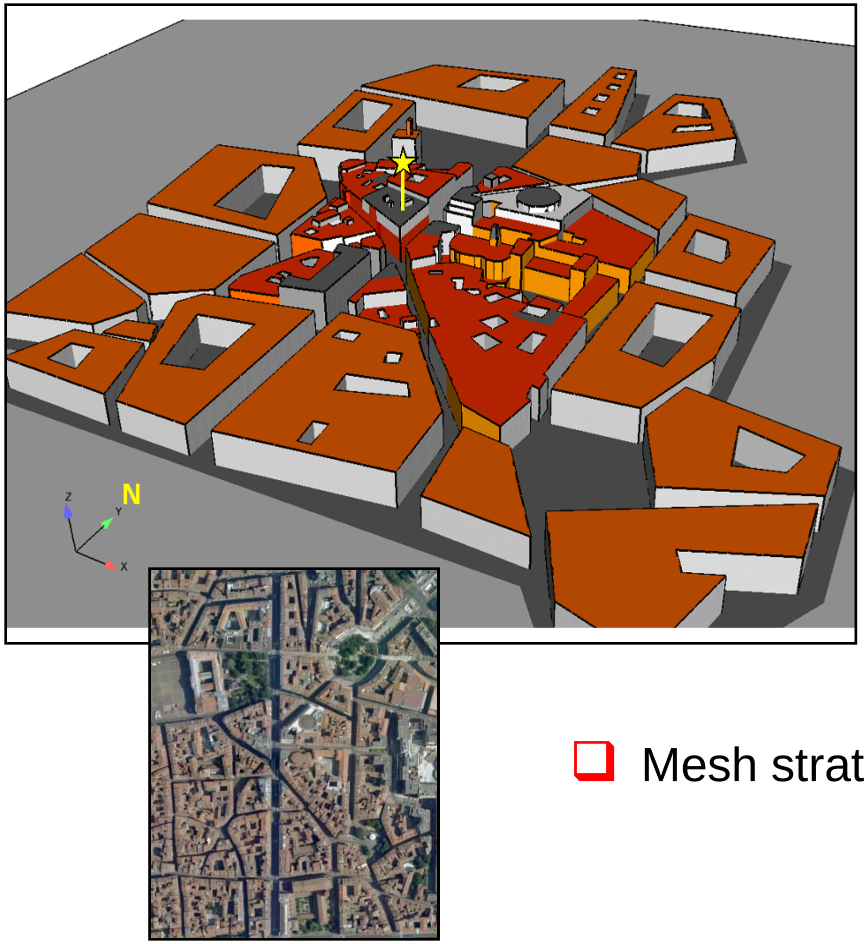


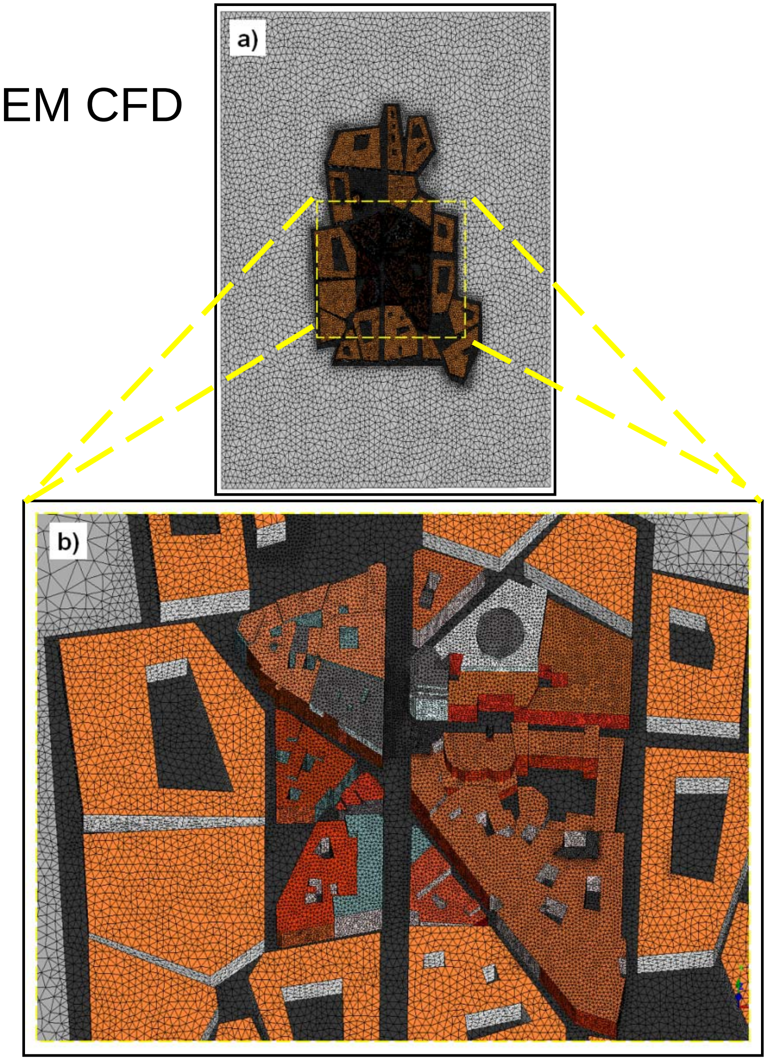
M. Milliez, 2006

“MUST”

Validation with CAPITOUL dataset (Qu, 2012)

- Simulation set-up for July 15th 2004
  - Central site area geometry processed by ICEM CFD
  - Domain size: 891x963x200 m





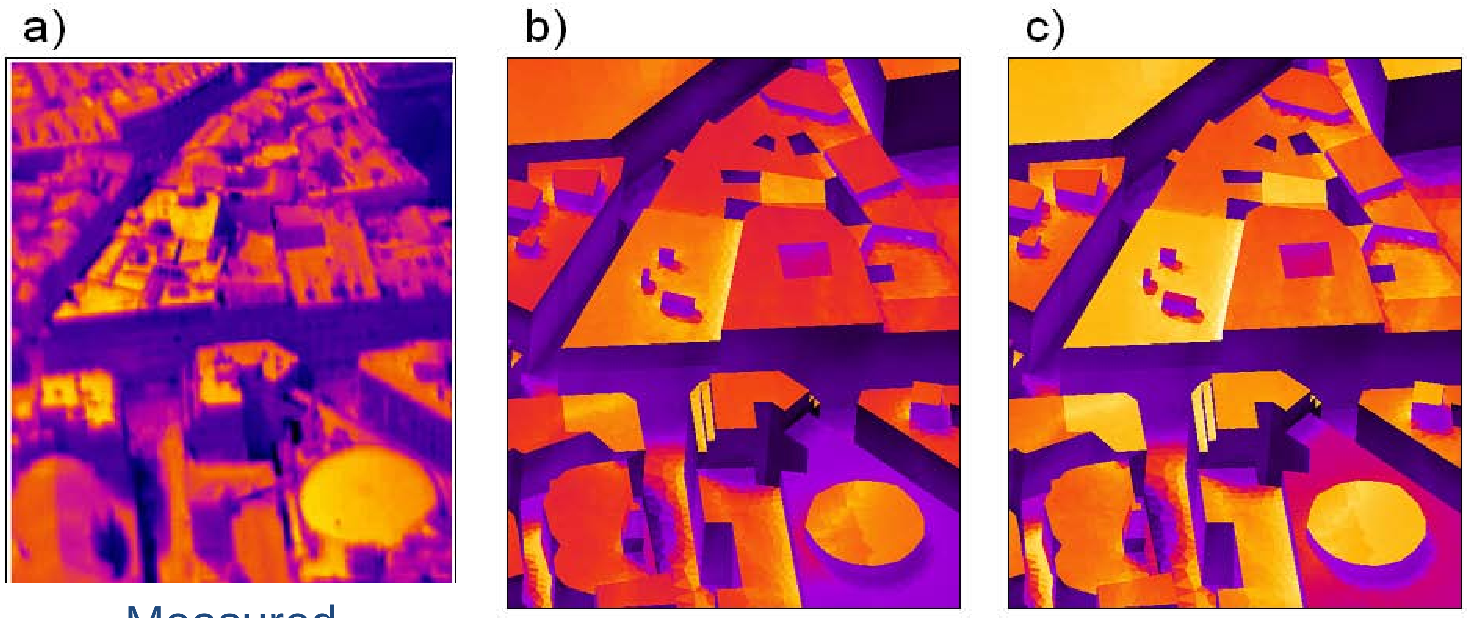
- Mesh strategy

- Simulation mesh, total mesh ~1,8 M

Validation with CAPITOUL dataset (Qu, 2012)

- Simulation of July 15th 2004

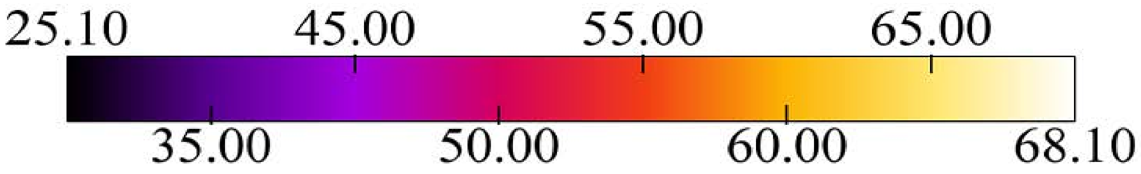
❑ Thermal infrared (TIR) airborne images 1412 UT during flight 432 (Lagouarde et al. 2010):



Measured,
source: Hénon (2008)

Simulated T_{br} (°C)

Simulated T_{sfc} (°C)

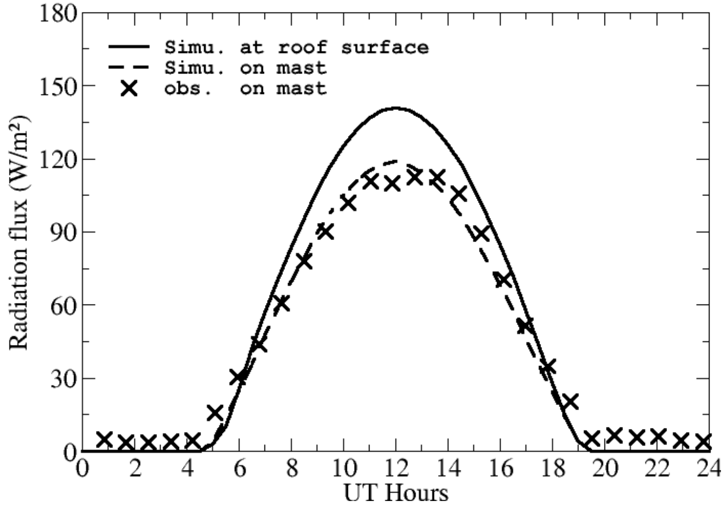


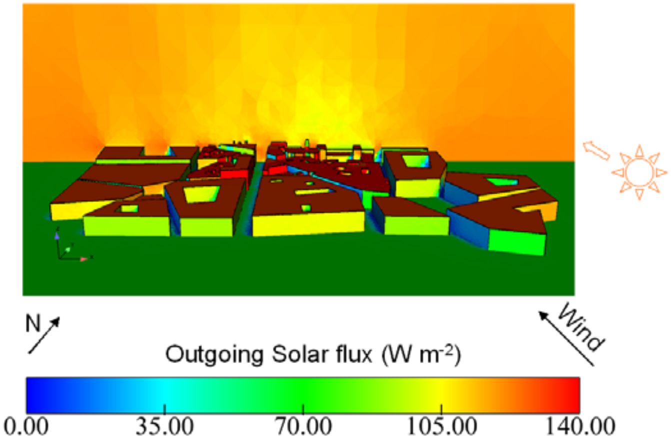
$$T_{br} \approx T_{sfc}\varepsilon^{1/4}$$

Validation with CAPITOUL dataset (Qu, 2012)

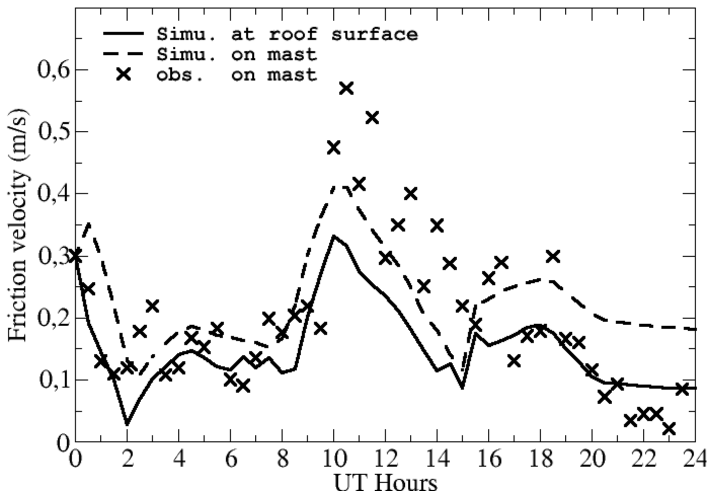
- Simulation of July 15th 2004

- Comparison of outward solar flux





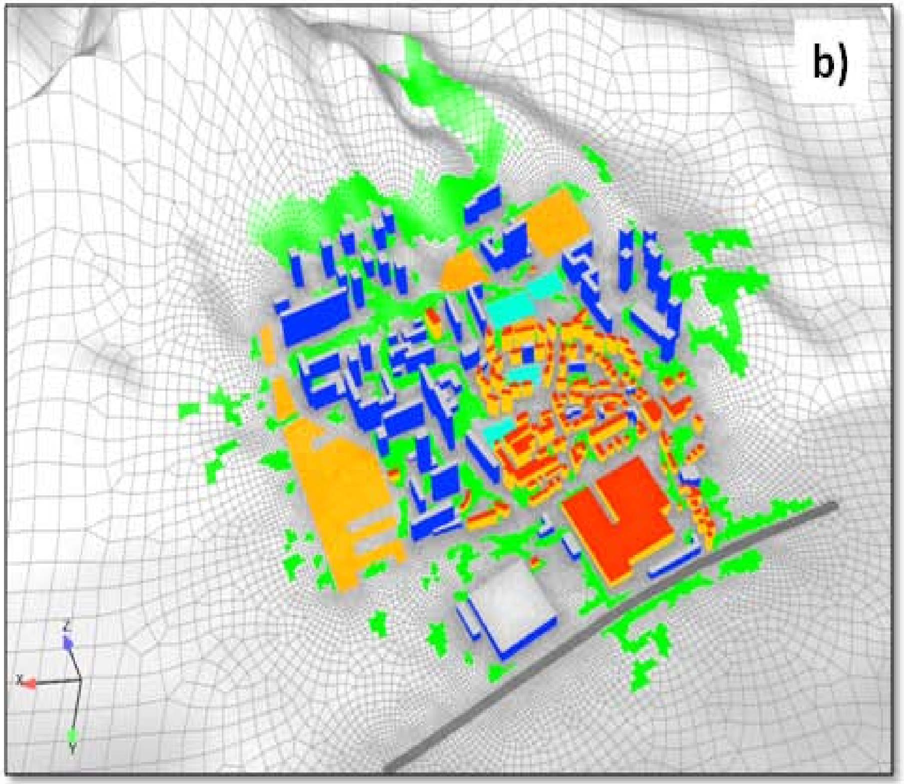
- Comparison of friction velocity



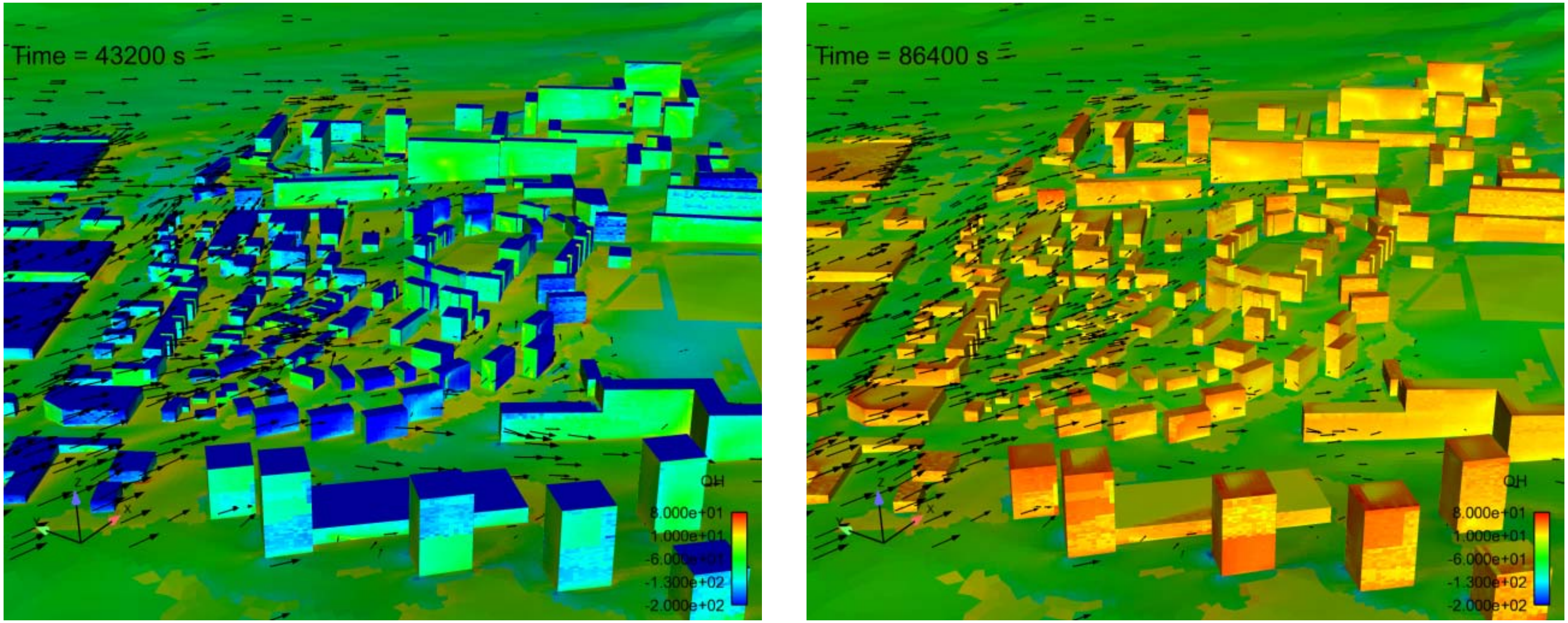
At roof surface: $u^*=(|\tau_w/\rho|)^{1/2}$

On the mast: $u^*=(\underline{u'w'}^2+\underline{u'w'}^2)^{1/4}$

Code_Saturne current simulations on Marseille / Saint Marcel - I



Code_Saturne current simulations on Marseille / Saint Marcel -II


12 h UTC

24 h UTC

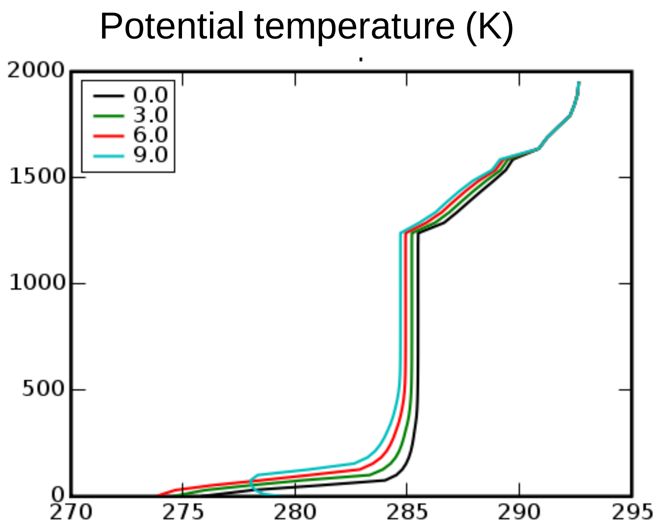
Heat flux from the wall
Wind at 55 m ASL

Thank you for your attention !

Code_Saturne: validation on Wangara experiment - II

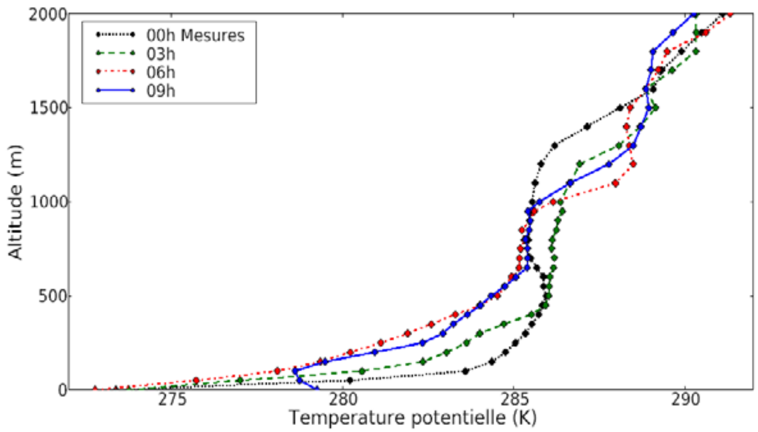
Vertical profiles of potential temperature

Stable
(night)



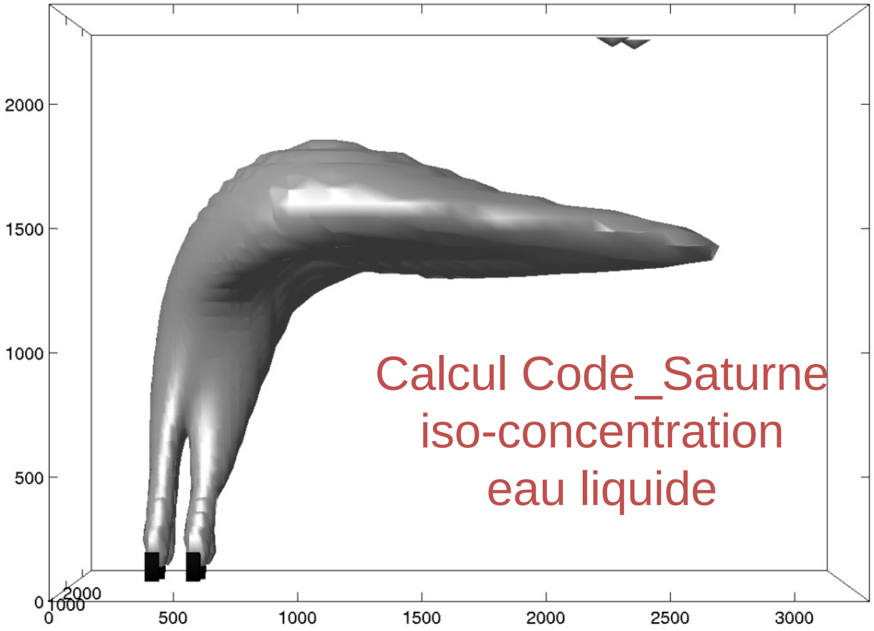
calculated

measured



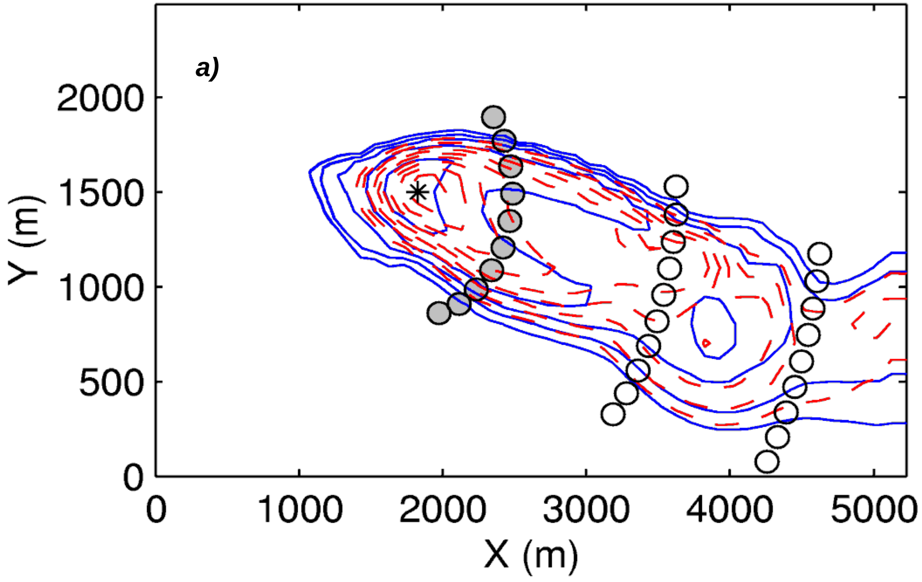
Bouzereau, 2004

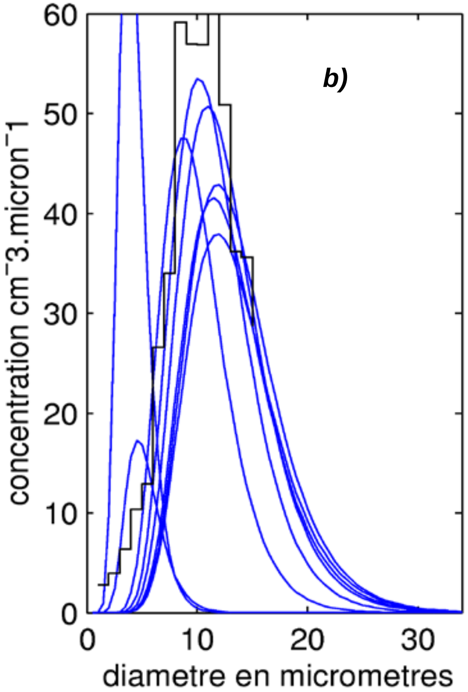
Panache Bugey
12 mars 1980



Calcul Code_Saturne
iso-concentration
eau liquide

Coupe horizontale du contenu en eau liquide



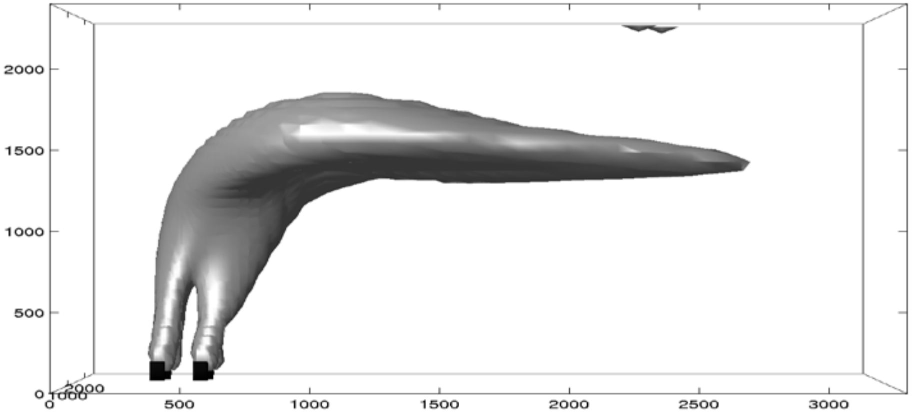


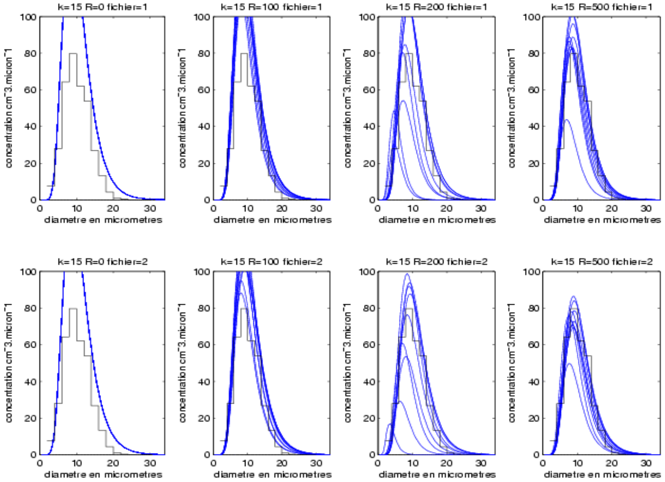
Spectres de goutte:
- calculé
- mesuré (noir)

La modélisation des panaches d’aéroréfrigérants avec Code_Saturne

<u>Paramétrisations physiques dans Code_Saturne</u>

- Turbulence RANS modèle k-ε
- Processus radiatifs dans le domaine solaire et IR
- Modélisation interface sol-Atmopshère
- Microphysique des nuages basée sur une représentation semi-spectrale (loi lognormale)
- Modélisation des précipitations
- Résolution explicite des bâtiments en maillage non-structuré





Adiabatic transformation and potential temperature - II

- **Adiabatic lapse rate :**

$$0 = \frac{1}{T}\frac{\partial T}{\partial z} - \frac{r}{C_p}\frac{1}{p}\frac{\partial p}{\partial z} \quad \Rightarrow \quad \Gamma_{ad} = -\left(\frac{\partial T}{\partial z}\right)_{ad} = -T\frac{r}{C_p}\frac{1}{p}\frac{\partial p}{\partial z}$$

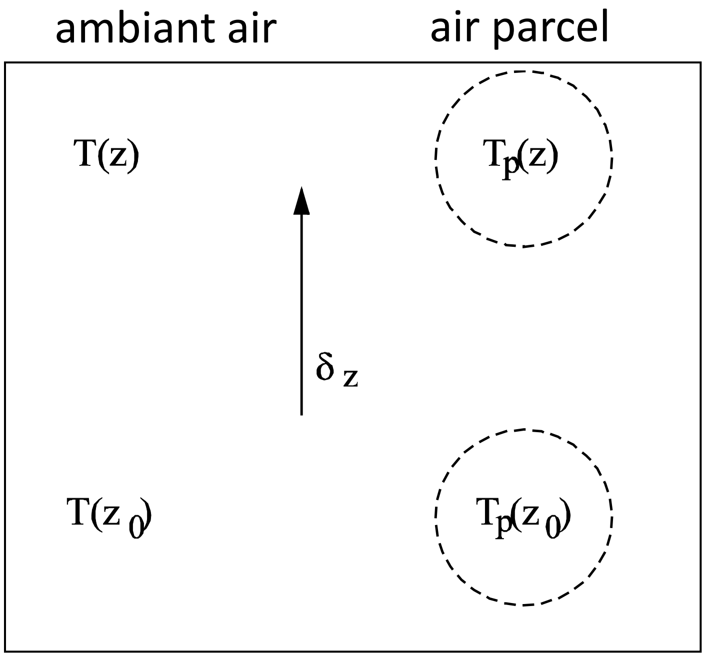
- **Adding hydrostatic relation :** $\left(\frac{\partial T}{\partial z}\right)_{ad} = -\frac{g}{C_p} = -9.8\,K/km$

- **Potential temperature gradient near the ground :** $\theta \approx T$

$$\frac{1}{\theta}\frac{\partial \theta}{\partial z} = \frac{1}{T}\frac{\partial T}{\partial z} - \frac{r}{C_p}\frac{1}{p}\frac{\partial p}{\partial z}$$

$$\frac{\partial \theta}{\partial z} \approx \frac{\partial T}{\partial z} - \left(\frac{\partial T}{\partial z}\right)_{ad}$$

Adiabatic transformation and potential temperature - III



- $$\frac{\partial T}{\partial z} = \left(\frac{\partial T}{\partial z}\right)_{ad} \Rightarrow T_p(z) = T(z)$$

neutral atmosphere

$$\frac{\partial \theta}{\partial z} = 0$$

- $$-\frac{\partial T}{\partial z} < -\left(\frac{\partial T}{\partial z}\right)_{ad} \Rightarrow T_p(z) < T(z)$$

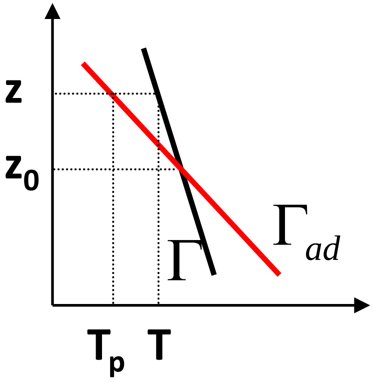
stable atmosphere

$$\frac{\partial \theta}{\partial z} > 0$$

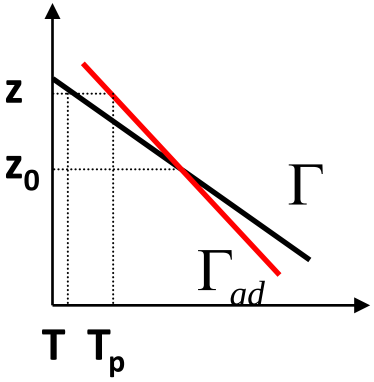
- $$-\frac{\partial T}{\partial z} > -\left(\frac{\partial T}{\partial z}\right)_{ad} \Rightarrow T_p(z) > T(z)$$

unstable atmosphere

$$\frac{\partial \theta}{\partial z} < 0$$



stability



instability