

SIMUREX : Micro climats urbains

Bertrand Carissimo, CEREAA



Modélisation détaillée de l'environnement atmosphérique
à l'échelle du quartier :
(du point de vue de l'atmosphère urbaine)



Prise en compte de :

- vent et turbulence
- dispersion des polluants
- échanges énergétiques
(en particulier avec les bât.)

Options :

- chimie, particules...
- cycle eau
(brouillards, panaches...)

Outline

- Background on global climate
- Urban climate
- Processes
- Air quality
- The challenges of adaptation
- Numerical tools
- Examples of studies by CEREIA and others (CAPITOU, EUREQUA, EM2PAU)

Cities are not resolved in GCMs!

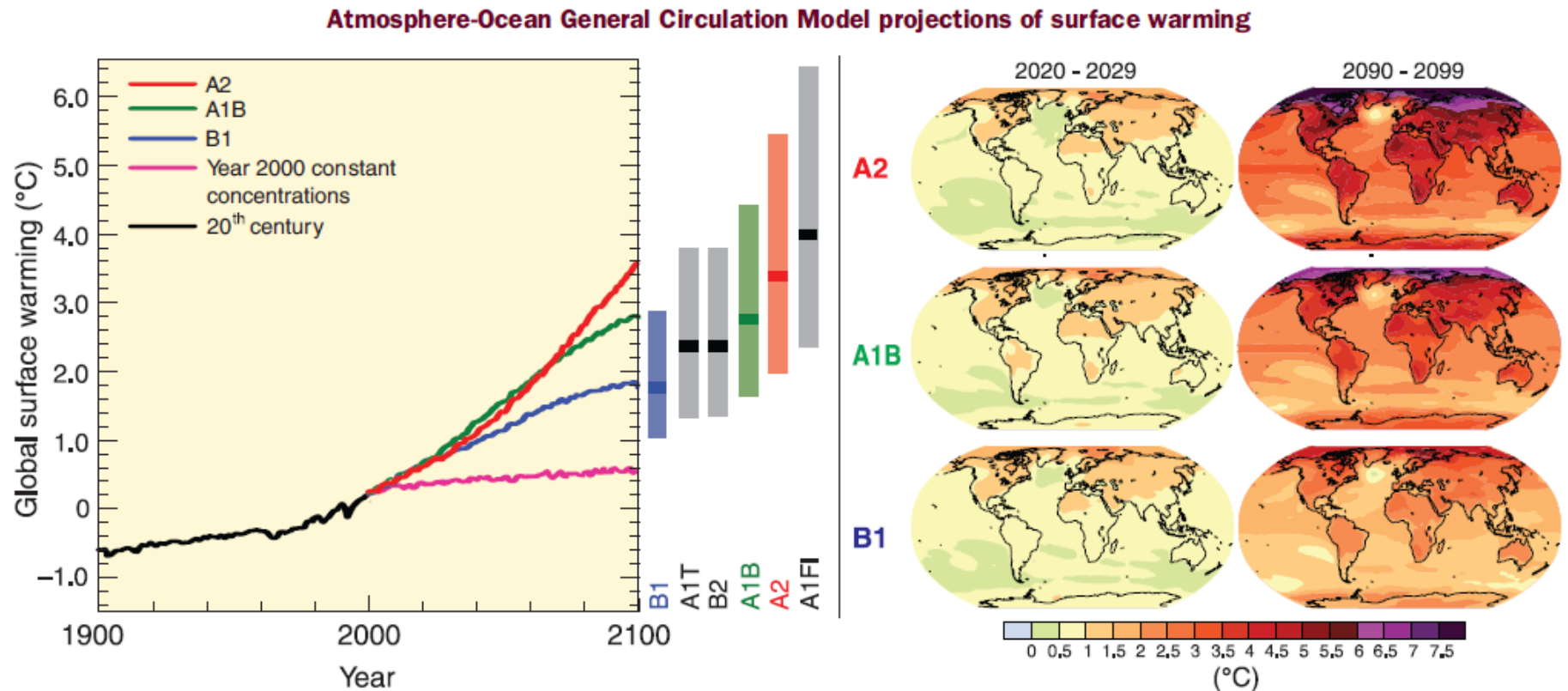
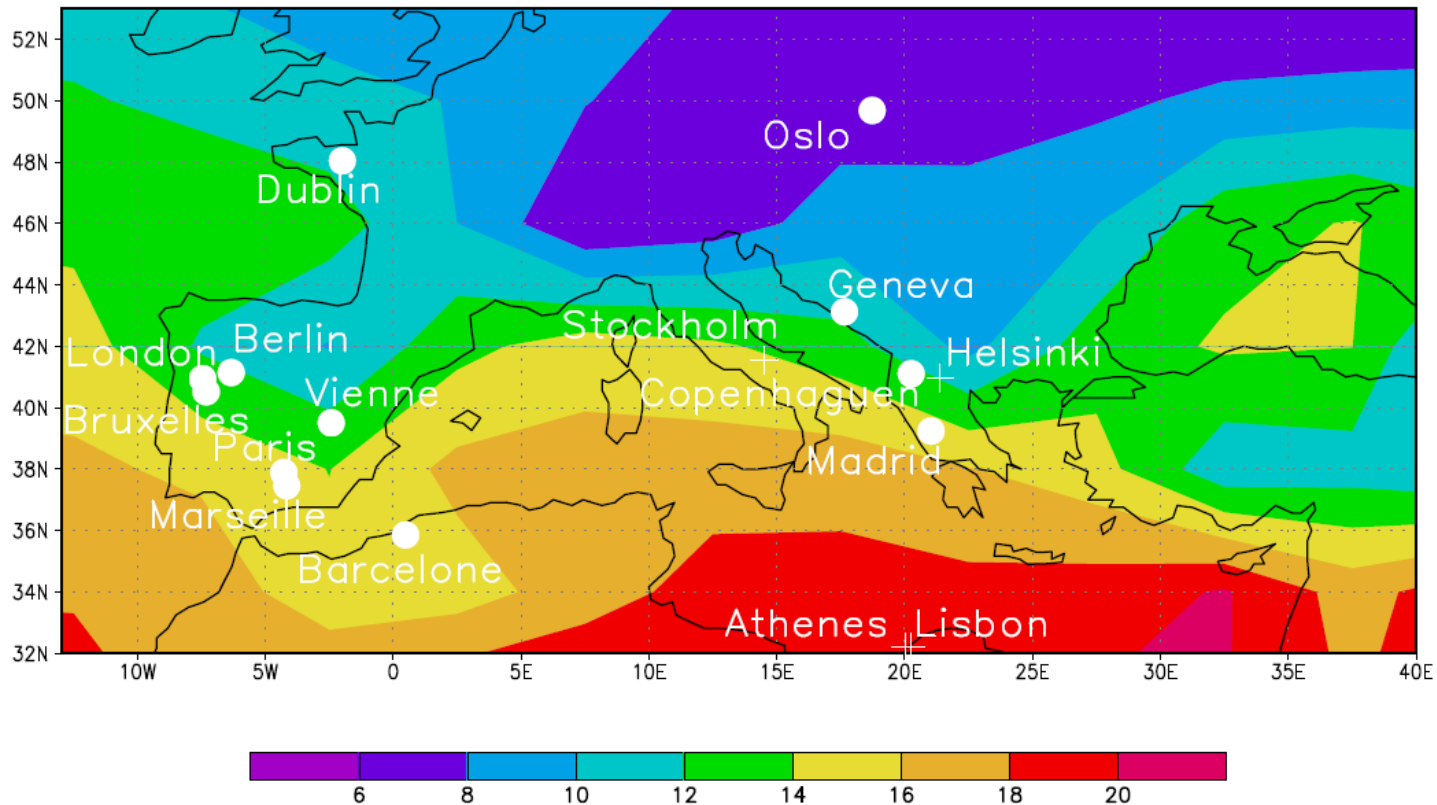


Figure 3.2. Left panel: Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099 relative to 1980-1999. The assessment of the best estimate and likely ranges in the bars includes the Atmosphere-Ocean General Circulation Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. Right panels: Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020-2029 (left) and 2090-2099 (right). {WGI 10.4, 10.8, Figures 10.28, 10.29, SPM}

Urban climate modeling (for 2100, A2) (Hallegate et al. 2004)

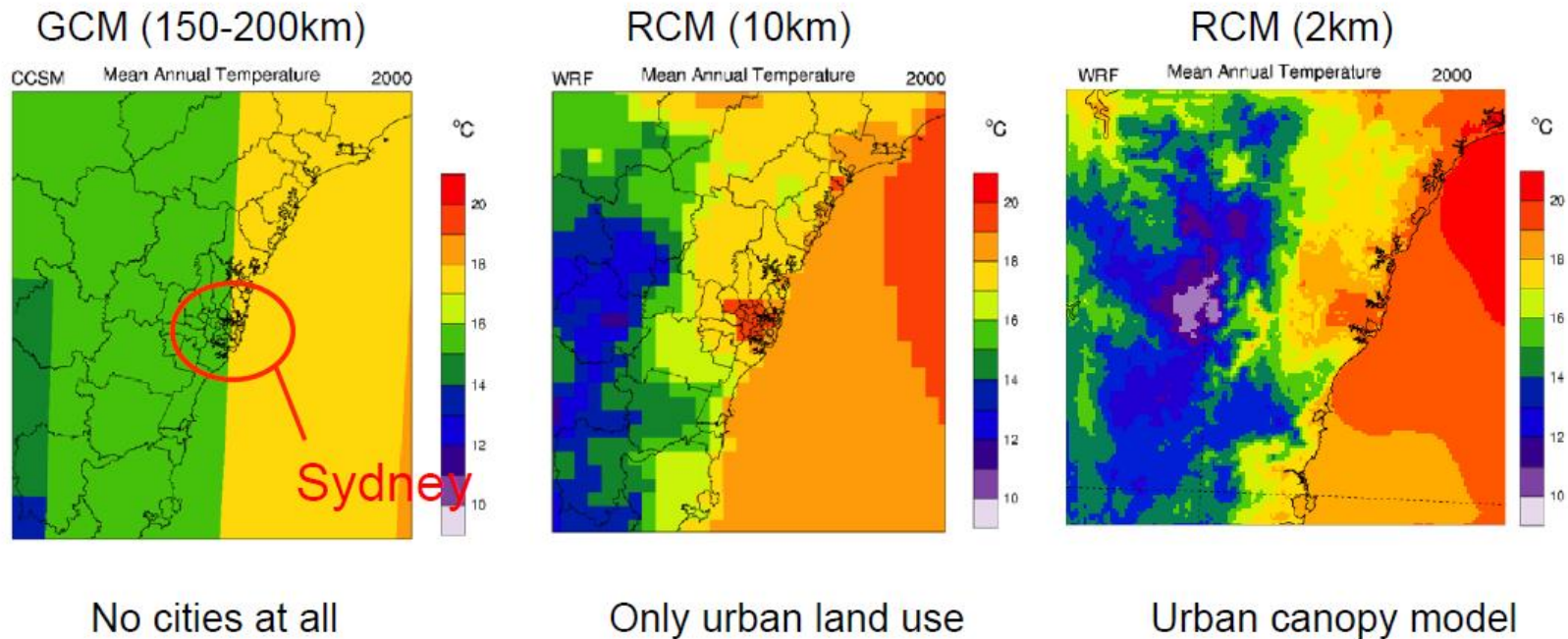


GrADS: COLA/IGES

2004-10-26-20:43

Figure 1. Map of Europe and the Mediterranean basin, with a few cities represented by circles, at the location of their acceptable analogue, *i.e.* a location that presently enjoys a climate close to their future climate. When no acceptable analogue is found, a cross denotes the location of the best temperature analogue, neglecting precipitations. The background shows the mean annual temperature in the present climate. The upper panel is for the CNRM ARPEGE-Climat model, bottom panel for the Hadley Centre HadRM3H model.

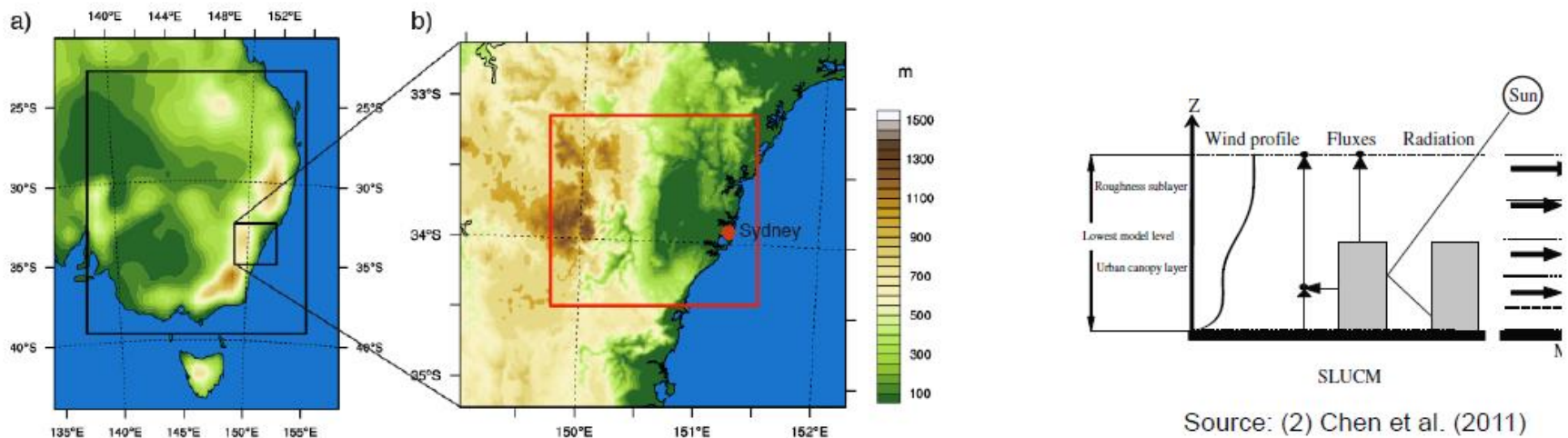
Future climate at urban scales → « downscaling »



→ Accompanying reduction of simulation time scale

Experiment design

- Weather Research and Forecasting (WRF) system
- 2-km spatial resolution (nested in 10k and 50k)
 - CSIRO-MK3.5
- No cumulus parameterization in inner domain (explicit)
- Using Urban Canopy Model (SLUCM)¹

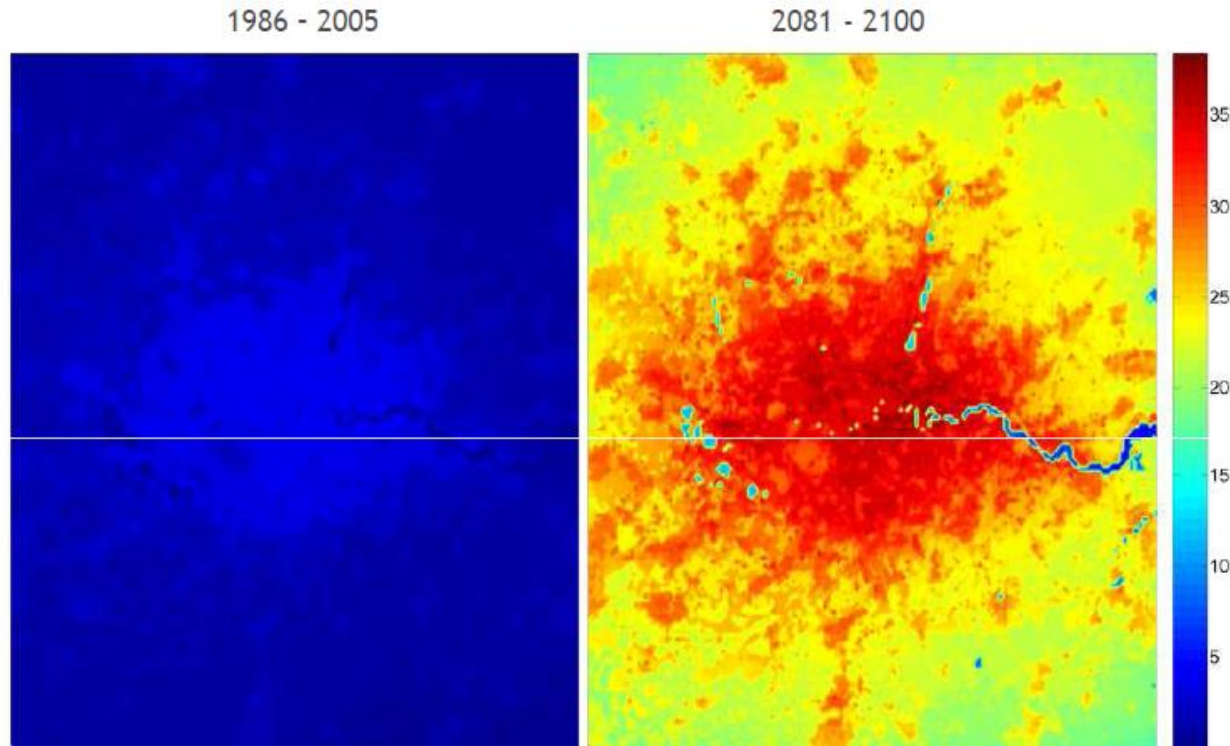


Source: (2) Chen et al. (2011)

(1) Kusaka et al. (2001) Boundary-Layer Meteorology

Future urban climate

Heat-wave days



Number of heat wave days in London for 11 global climate models
Scenario: RCP8.5

Number of heat wave days
increases by a factor ~ 10, both
in urban and rural areas

Assessing climate change in cities using UrbClim

Hooyberghs, H.



Deux effets distincts mais

Réchauffement climatique

- Phénomène sur l'ensemble de notre **planète**
- +2°C à +6°C d'ici 2100
- Lié au activités humaines

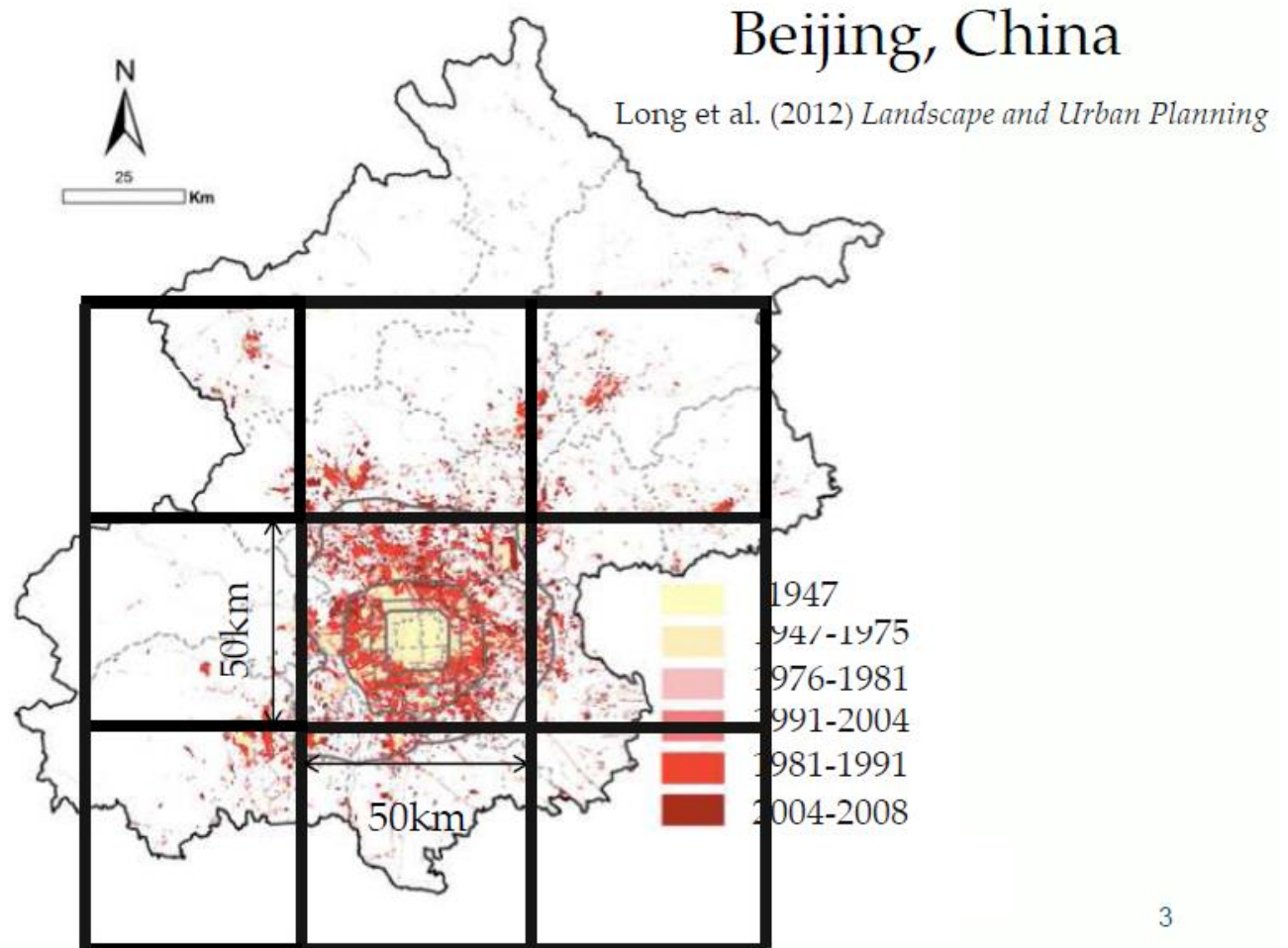


L'îlot de chaleur urbain

- Une **ville** comme Toulouse est parfois la nuit plus chaude de **6°C** que la campagne alentours
- Phénomène actuel

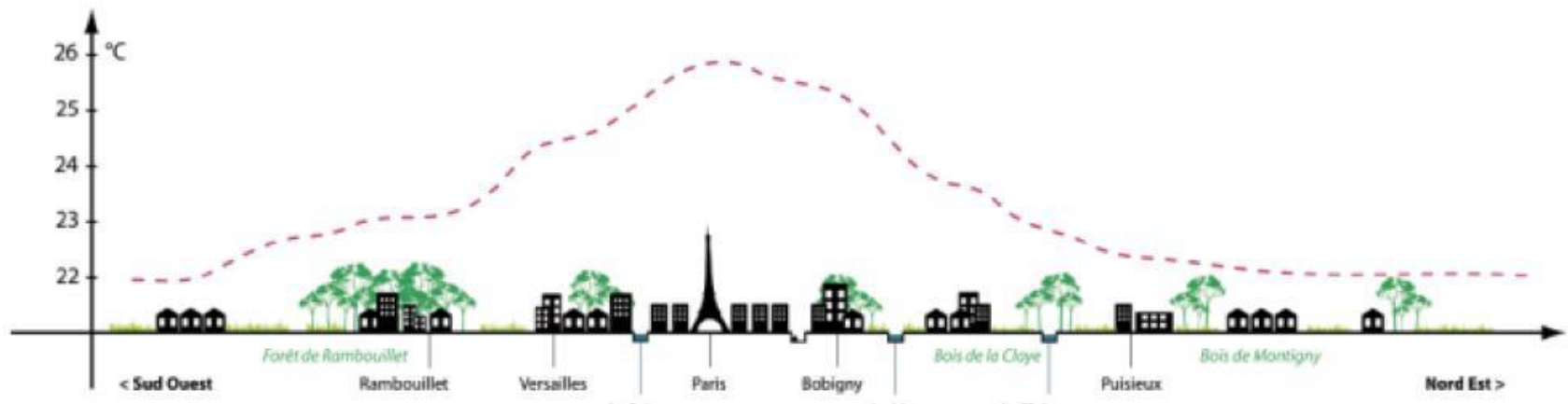


Cities are also expanding



Example : the Paris Heat Island

(measured along a transect by vehicle)



<http://www.iau-idf.fr/>

Urban warming in Japanese cities and its relation to climate change monitoring

Fumiaki Fujibe

Meteorological Research Institute, Tsukuba
305-0052, Japan

*The seventh International
Conference on Urban Climate,
29 June - 3 July 2009, Yokohama,
Japan*

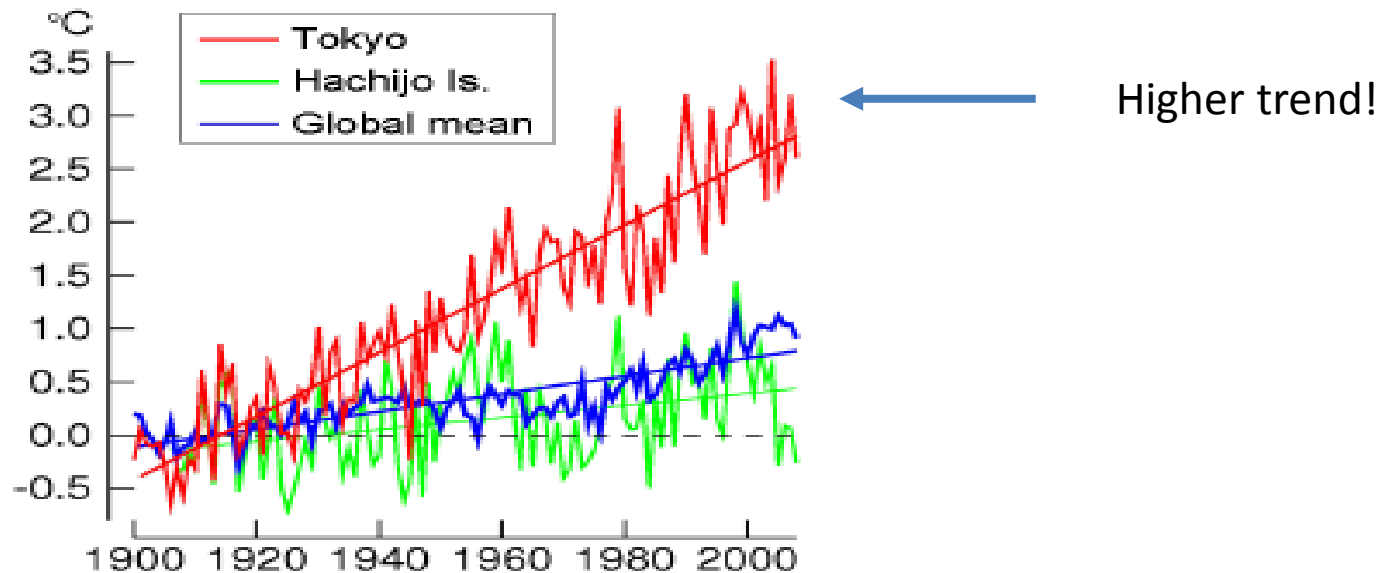


Fig.2 Time series of annual mean temperature for 1901 to 2008 (departure from the average for 1901-1920).

Urban and Regional Temperature Trends in Las Vegas and Southern Nevada (Miller, 2011)

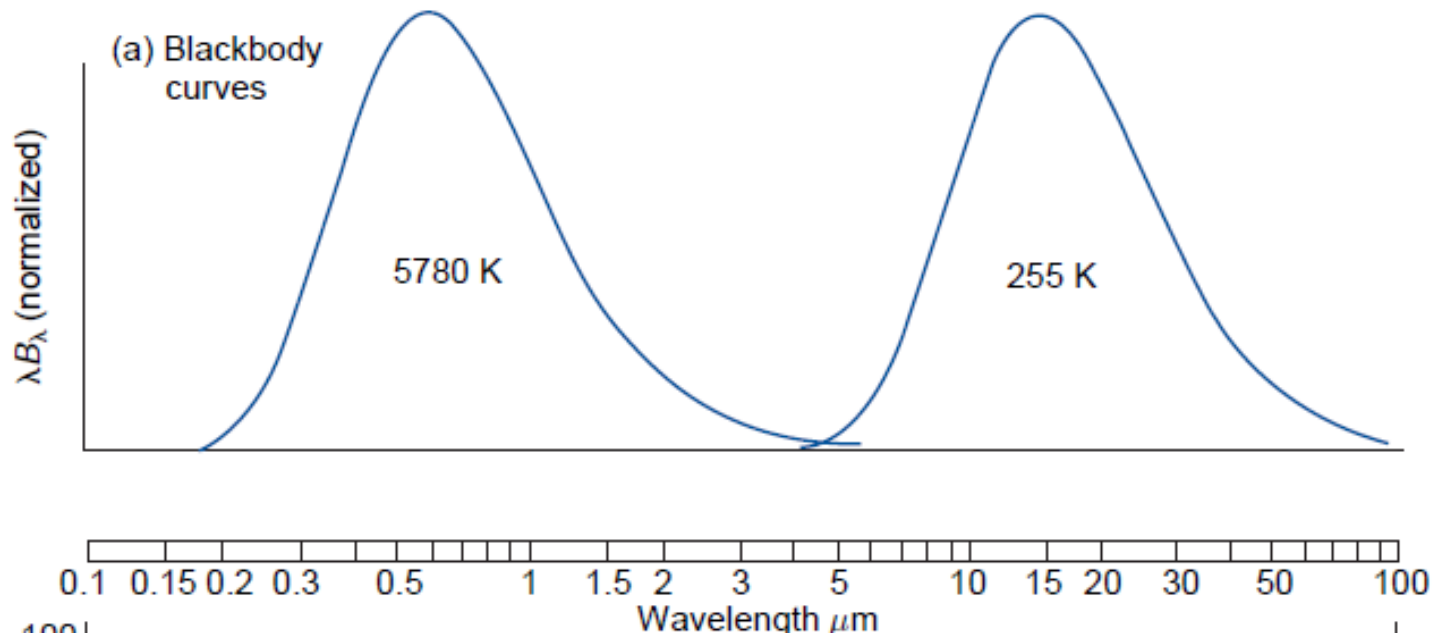
Table 2. The magnitude of seasonal and annual temperature trends ($^{\circ}\text{C}$) for the period (a) 1940-2009 and (b) 1977-2009. All listed trends were significant at the 95% level or higher.

(a)	Temperature Change since 1940 ($^{\circ}\text{C}$)				
	Winter	Spring	Summer	Fall	Annual
Las Vegas					
Tmax	--	--	--	-1.0 $^{\circ}$	--
Tmin	+4.5 $^{\circ}$	+5.1 $^{\circ}$	+5.4 $^{\circ}$	+5.4 $^{\circ}$	+5.1 $^{\circ}$
Tavg	+2.1 $^{\circ}$	+2.7 $^{\circ}$	+2.8 $^{\circ}$	+2.2 $^{\circ}$	+2.5 $^{\circ}$
Tdrnl	-4.8 $^{\circ}$	-4.7 $^{\circ}$	-5.4 $^{\circ}$	-6.1 $^{\circ}$	-5.2 $^{\circ}$
DGR					
Tmax	--	--	+1.8 $^{\circ}$	--	+0.6 $^{\circ}$
Tmin	--	+1.6 $^{\circ}$	+1.3 $^{\circ}$	--	+1.1 $^{\circ}$
Tavg	--	+1.3 $^{\circ}$	+1.4 $^{\circ}$	--	+1.0 $^{\circ}$
Tdrnl	--	--	--	--	--
T _{u-r}					
Tmax	--	--	-1.2 $^{\circ}$	--	--
Tmin	+4.0 $^{\circ}$	+3.5 $^{\circ}$	+4.2 $^{\circ}$	+4.7 $^{\circ}$	+4.0 $^{\circ}$
Tavg	+2.0 $^{\circ}$	+1.7 $^{\circ}$	+1.6 $^{\circ}$	+1.9 $^{\circ}$	+1.8 $^{\circ}$
Tdrnl	-3.7 $^{\circ}$	-4.0 $^{\circ}$	-5.9 $^{\circ}$	-5.2 $^{\circ}$	-4.7 $^{\circ}$

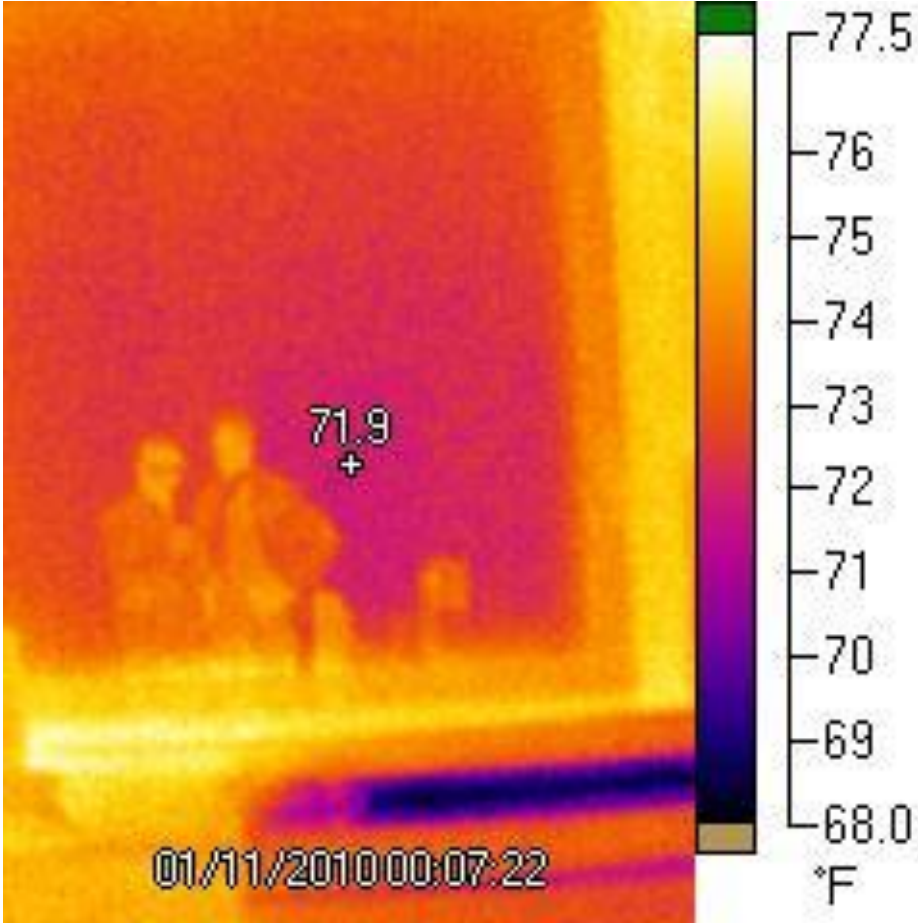
Outline

- Background on global climate
- Urban climate
- **Processes**
- Air quality
- The challenges of adaptation
- Numerical tools
- Examples of studies by CEREIA and others (CAPITOU, EUREQUA, EM2PAU)

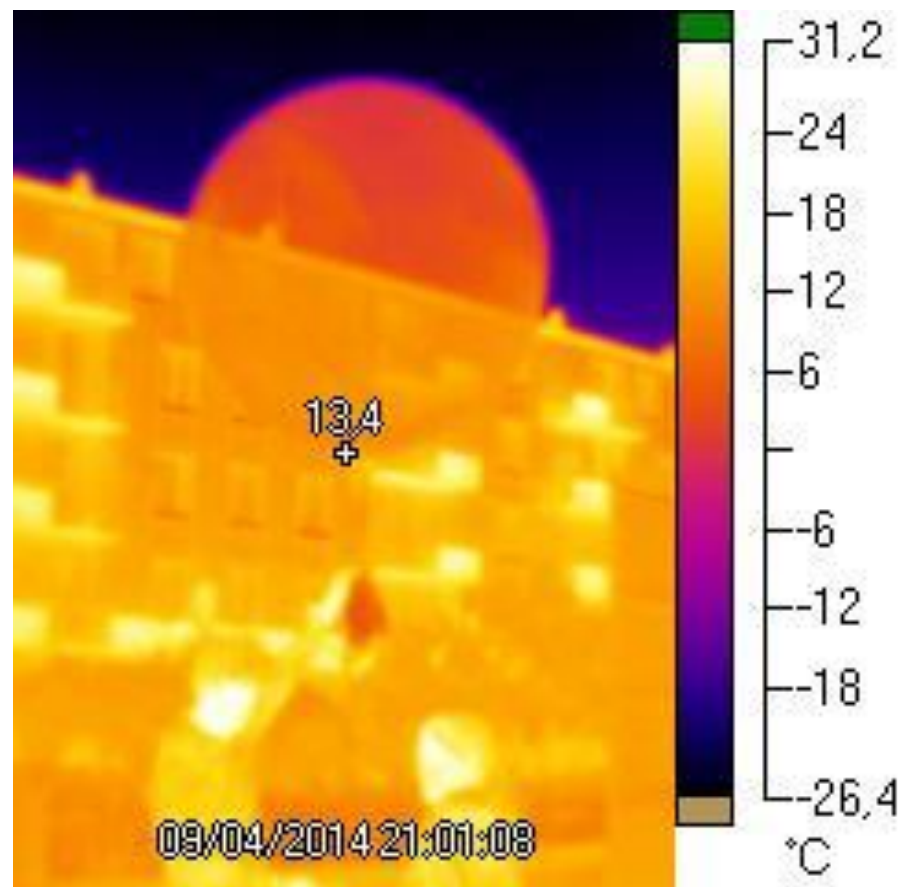
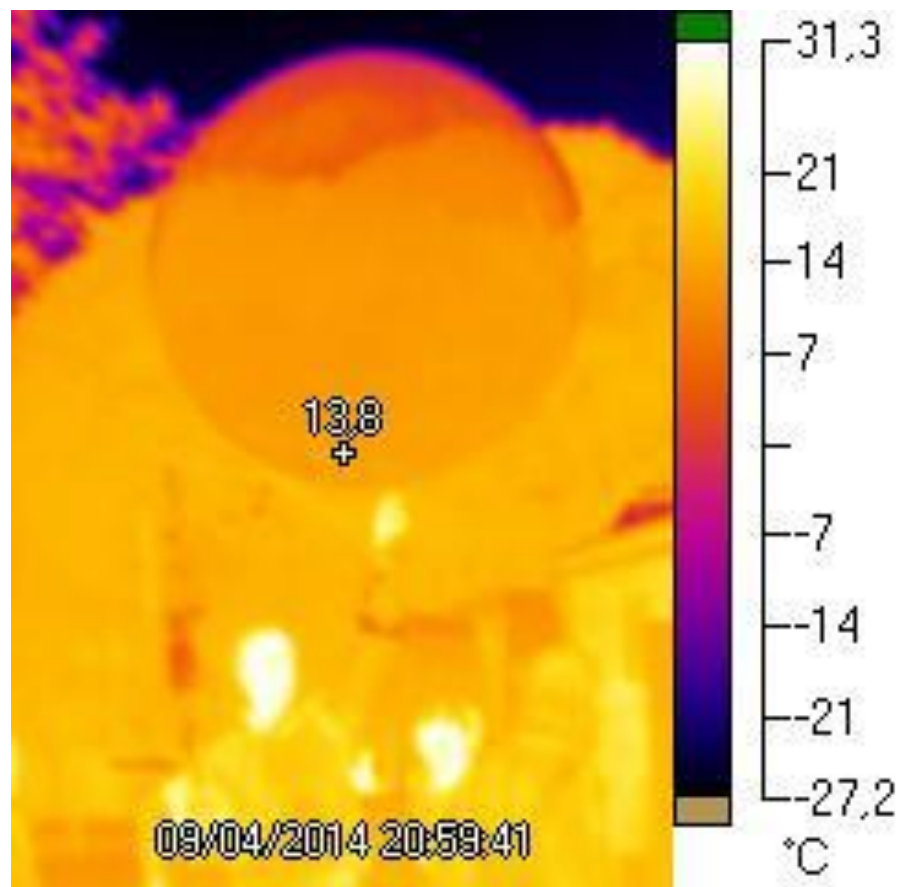
Solar (visible) & terrestrial (IR) separation :



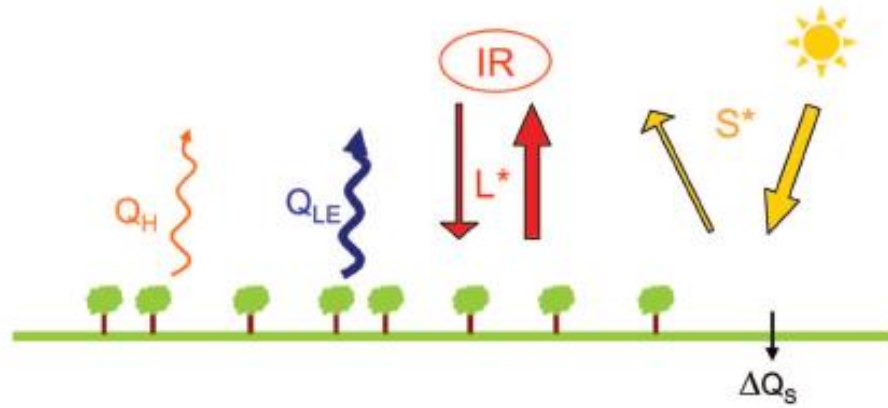
Solar and IR



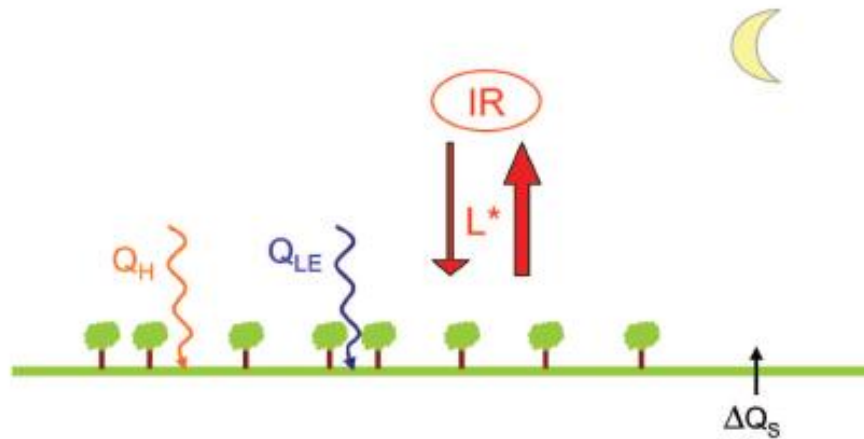
Images IR du ballon de Radio-sondage de Meteo France : (latex + talc, opaque dans le visible)



Bilan radiatif en milieu rural

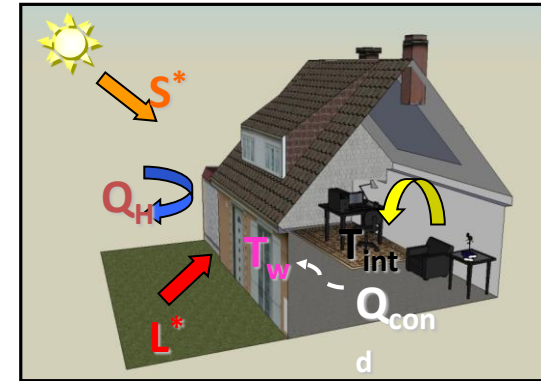
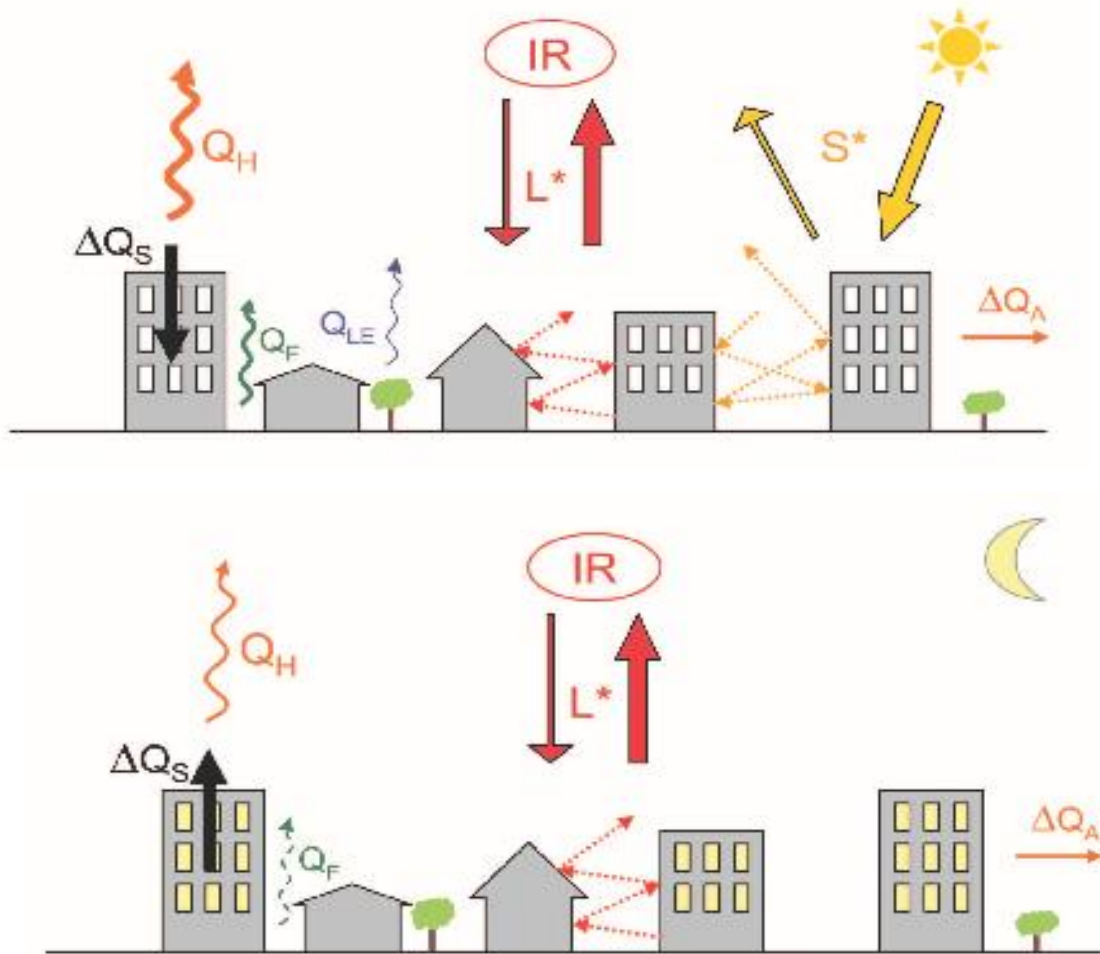


(a)

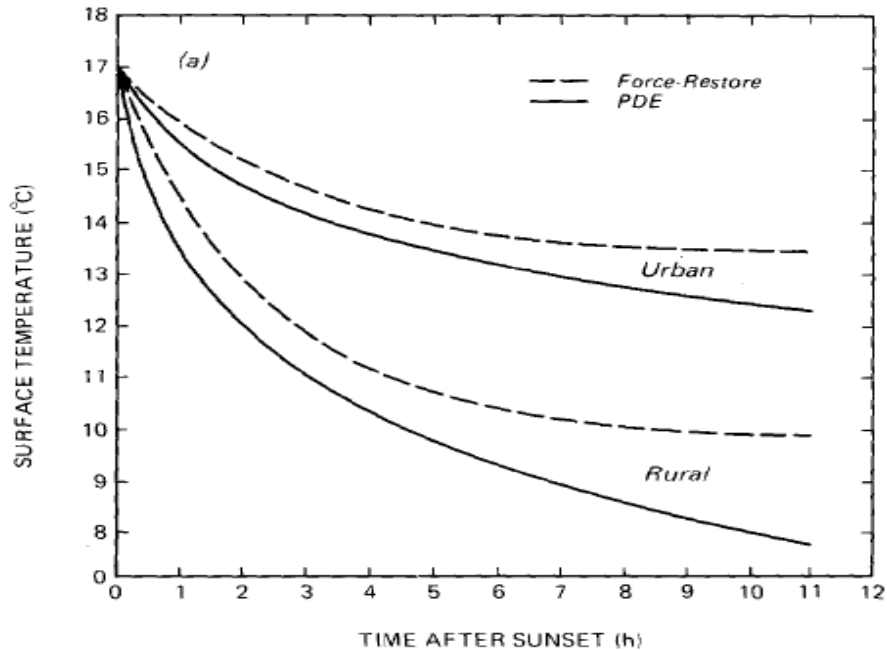
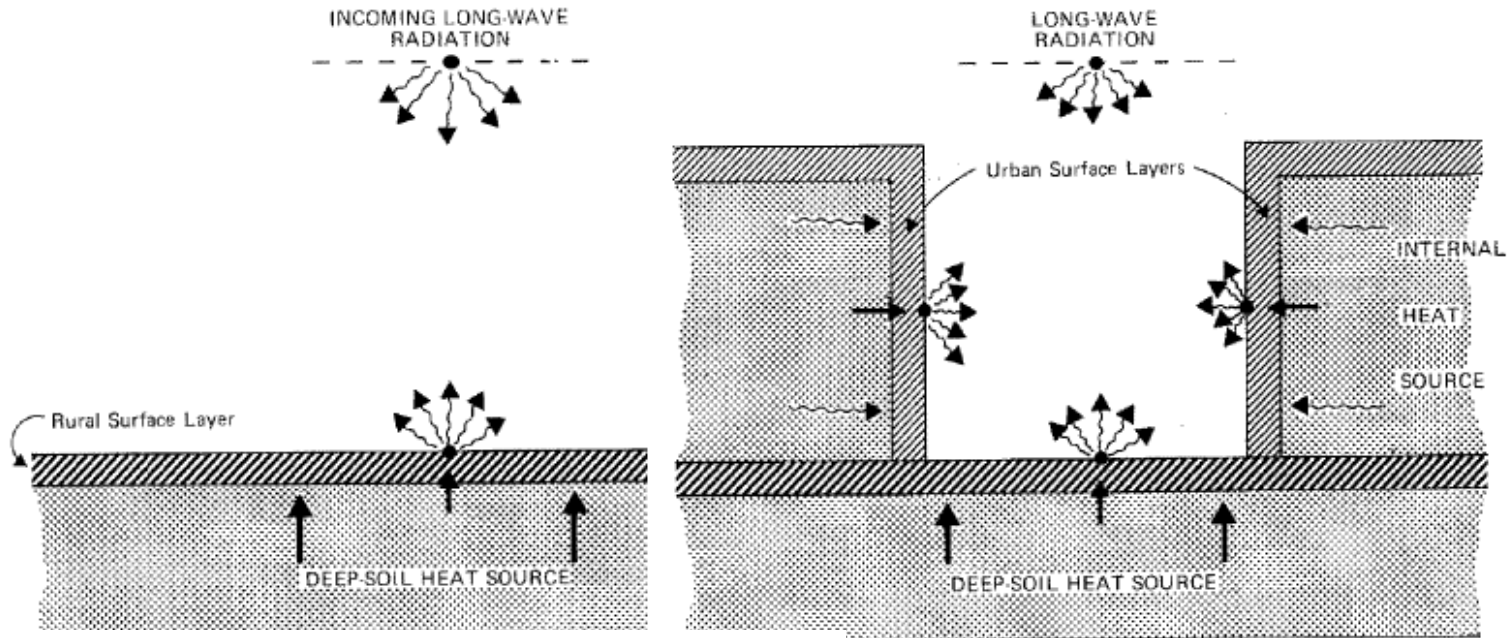


(b)

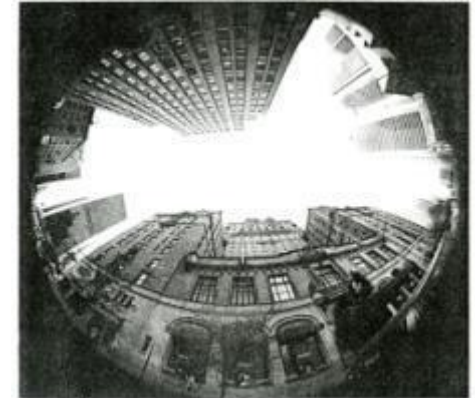
Bilan radiatif en milieu urbain



Rural / Urban cooling at night (Johnson, 1991)



Sky view factor



(Ratti et al. 2003)

Outline

- Background on global climate
- Urban climate
- Processes
- **Air quality**
- The challenges of adaptation
- Experimental and numerical tools
- Examples of studies by CEREIA and others (CAPITOU, EUREQUA, EM2PAU)

Air Quality



À Pekin



2013-08-12_07:19:22
@声闻于天@邹毅的邹



2013-08-11_07:06:14
@声闻于天@邹毅的邹



2013-08-10_07:00:57
@声闻于天@邹毅的邹



2013-08-09_06:53:18
@声闻于天@邹毅的邹



2013-08-08_06:52:36
@声闻于天@邹毅的邹



2013-08-07_07:19:05
@声闻于天@邹毅的邹



2013-08-06_07:02:03
@声闻于天@邹毅的邹



2013-08-05_07:26:56
@声闻于天@邹毅的邹



2013-08-04_07:07:38
@声闻于天@邹毅的邹

weibo.com/u/1000481815

@邹毅的邹

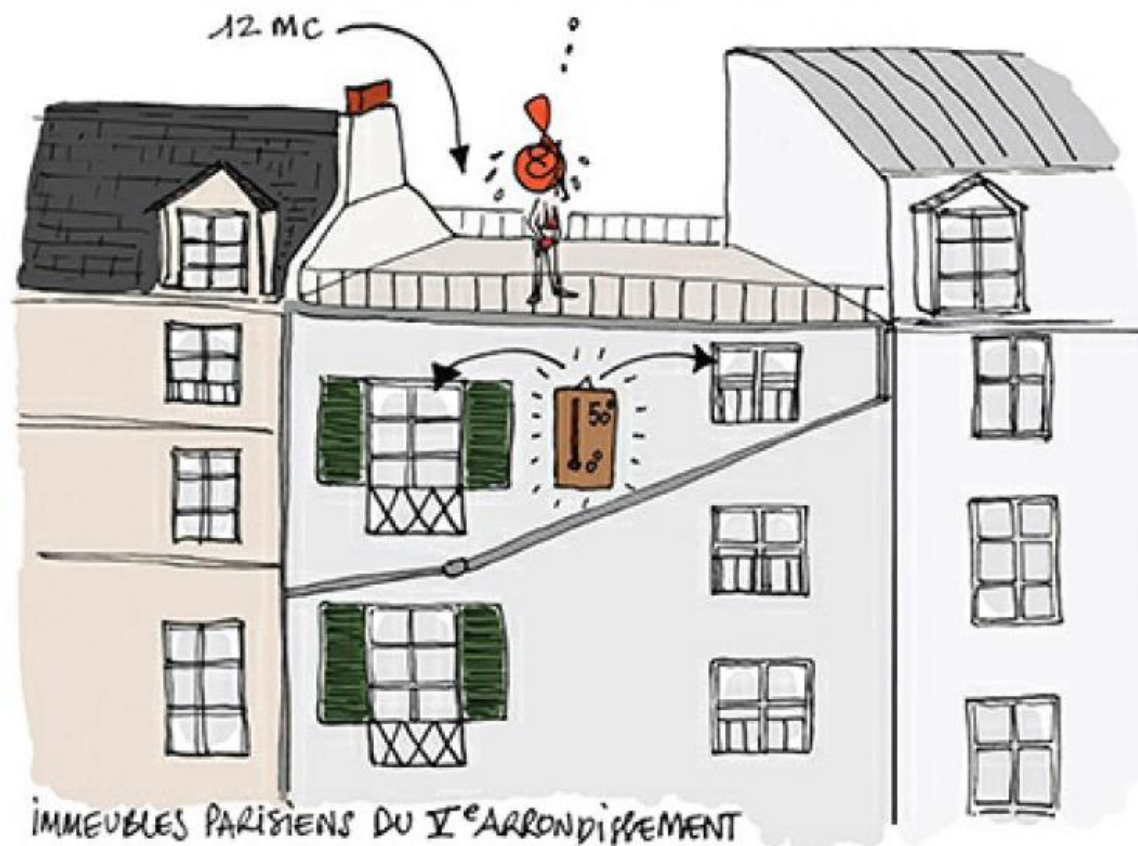
weibo.com/u/1000481815

Outline

- Background on global climate
- Urban climate
- Processes
- Air quality
- **The challenges of adaptation**
- Numerical tools
- Examples of studies by CEREIA and others (CAPITOU, EUREQUA, EM2PAU)

DE RETOUR CHEZ MOI, J'AI PRIS UNE DÉCISION.

IL FAUT LUTTER CONTRE LE RÉCHAUFFEMENT
URBAIN... JE VAIS FAIRE UN TOIT VÉGÉTAL.





Damon Winter NYT



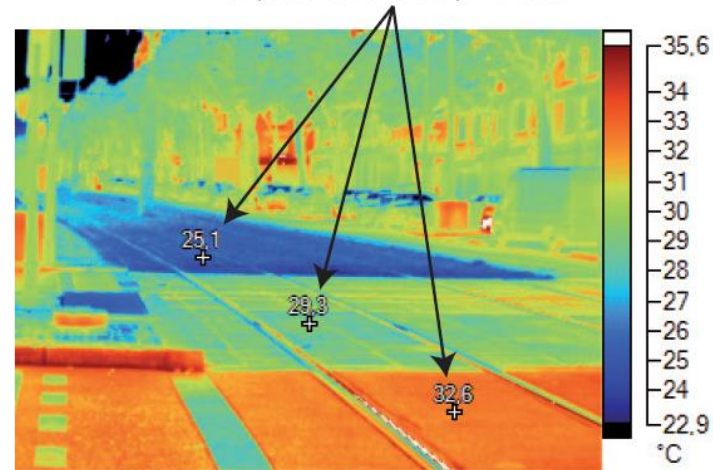
Damon Winter NYT

FIGURE 2 – EXEMPLES DE CLICHÉS PRIS SUR L'AMÉNAGEMENT DU TRAMWAY T3, BOULEVARD MORTIER



Photo « réelle »

Température en différents points du sol



Thermographie infra-rouge

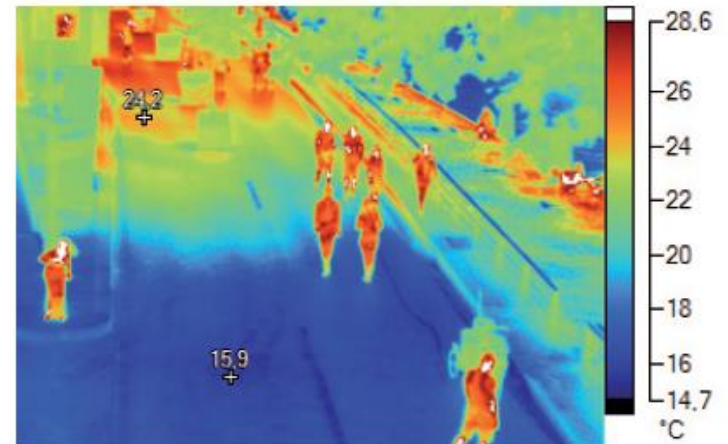
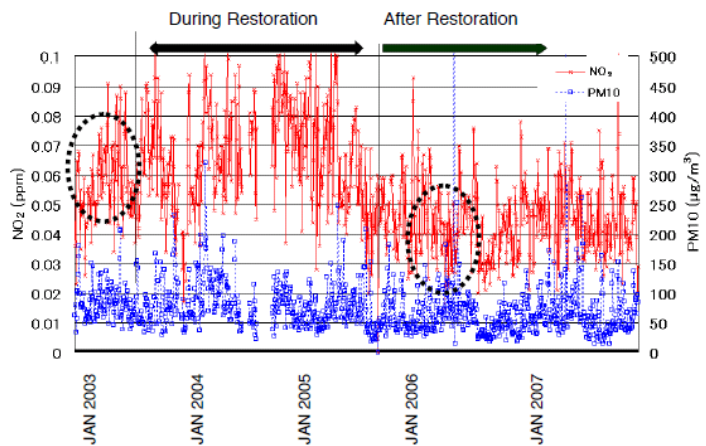


Figure 12 – Port des Célestins le 31 juillet 2011 à 21h30 : effet de refroidissement après aspersion de la chaussée. La température de la chaussée chute d'une dizaine de degrés.

Effets de la restauration d'une rivière à Séoul



The Cheong-Gye Stream before and after the restoration (left: June 2003, right: August 2005) (Ichinose, 2009)



The interannual change in NO₂ (red line) and PM10 (blue line) concentrations beside the stream (in "Cheong-Gye 4-ga" monitored by Seoul Metropolitan Government)

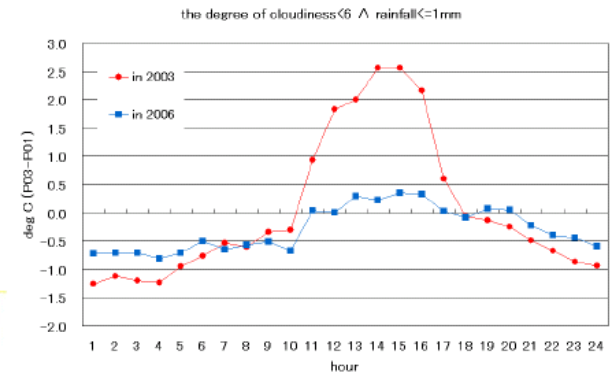
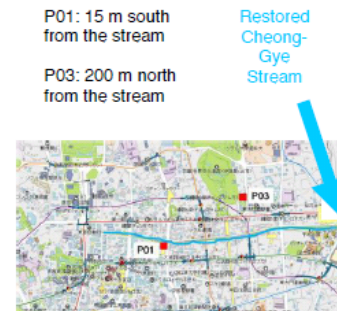
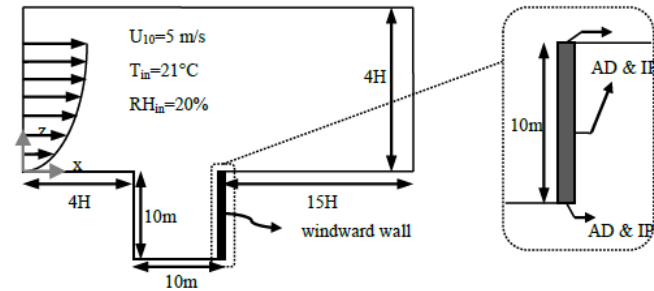


Fig. 3 The difference in temperature by hour on typical fine days in August in 2003 and 2006
Observation in 2003 was performed as collaboration with METRI/KMA etc.

Influence d'une paroi végétalisée



Credit : Atelier International du Grand Paris



(Saneinejad, et al. 2011)

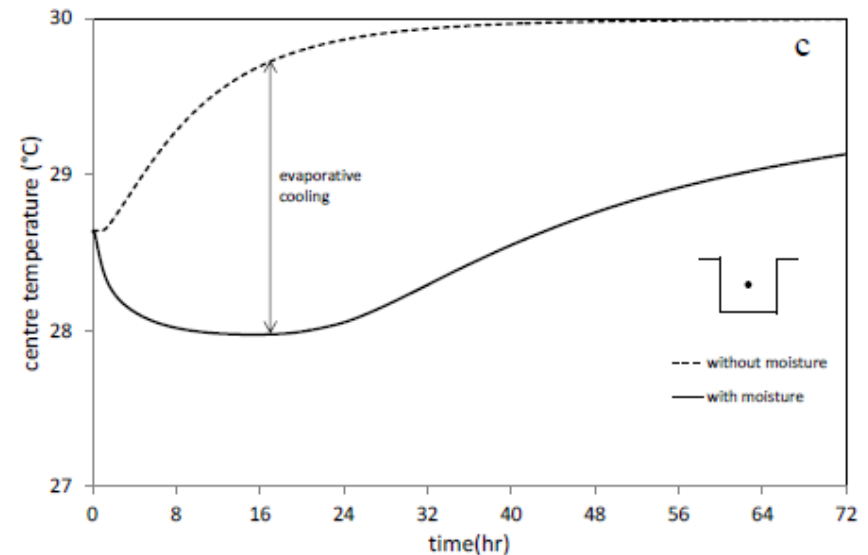
Evolution de la température au centre de la rue avec et sans végétation :



Les toits comme vecteurs de la nature en ville

Le réaménagement des toits permettrait de créer de nouveaux espaces de détente mais également d'apporter la nature en ville. Végétalisé les toits est par ailleurs un moyen efficace d'isolation pour une meilleure performance énergétique.

DOCUMENT PRÉSENTÉ PAR L'ÉQUIPE RICHARD ROGERS / ROGERS STIRH HARBOUR + PARTNERS, LES, ARUP



Phoenix adaptation

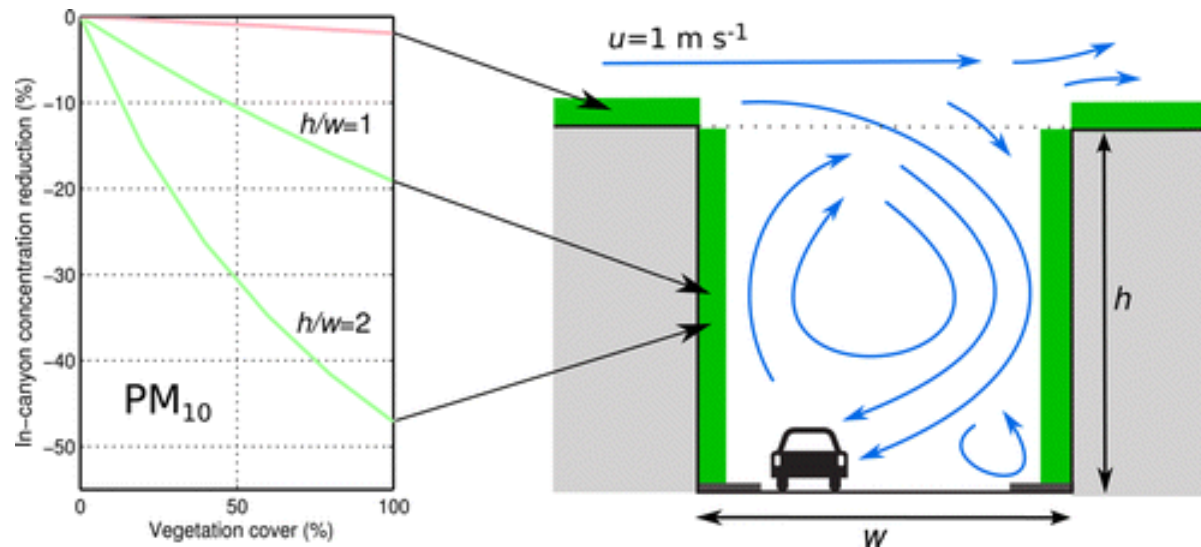


FIG. 7. Typical (a) mesic to (b) xeric residential landscaping in the PMA. The “xeriscaping” policy promoted by several PMA cities involves landscape conversion of water-intensive plants to low-water-demand, drought-resistant vegetation (Source: CAP-LTER).

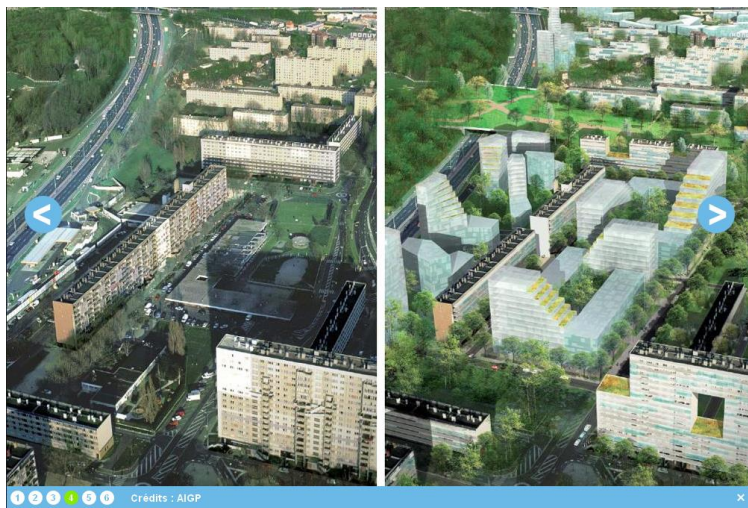


FIG. S1. Present-day streetscape (2nd Ave.) in downtown Phoenix, illustrating the influence of sustainable street-level shading. Previously, a single strip of palm trees provided little pedestrian shade. To increase thermal comfort and reduce daytime urban ambient temperatures, the Downtown Phoenix Plan recommended planting 1) a double row of broad canopy, low-water-demand trees to increase shading and 2) low shrubs or screens to reduce pedestrian exposure to longwave radiation emitted from the adjacent asphalt road (Source: City of Phoenix 2008).

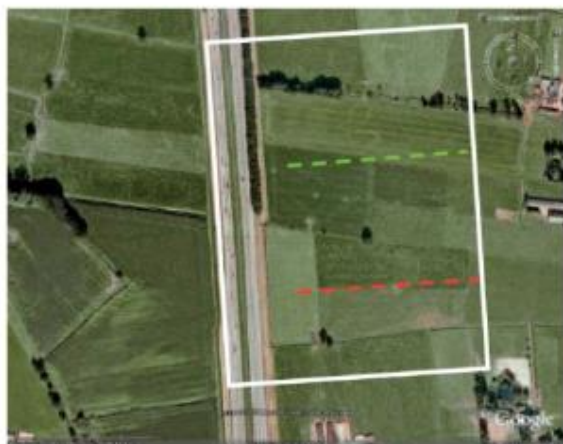
Effect of green walls in an urban canyon on pollution by particles (PM_{10} , Pugh et al. 2012)



Influence des arbres



- Effets barrière + dépôts
- Emissions biogéniques



Différences de pollution avec et sans les arbres

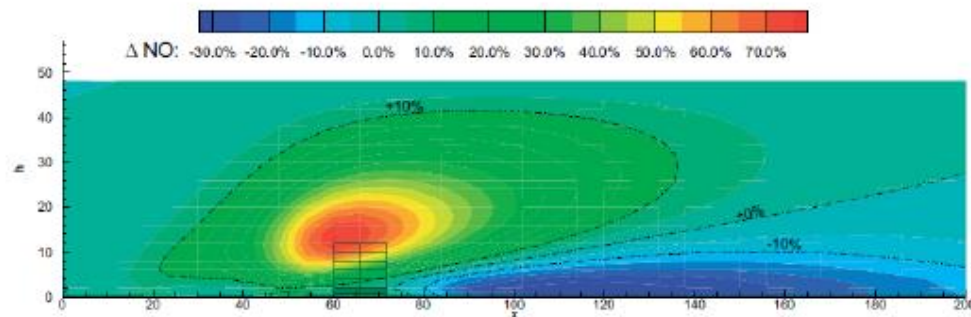
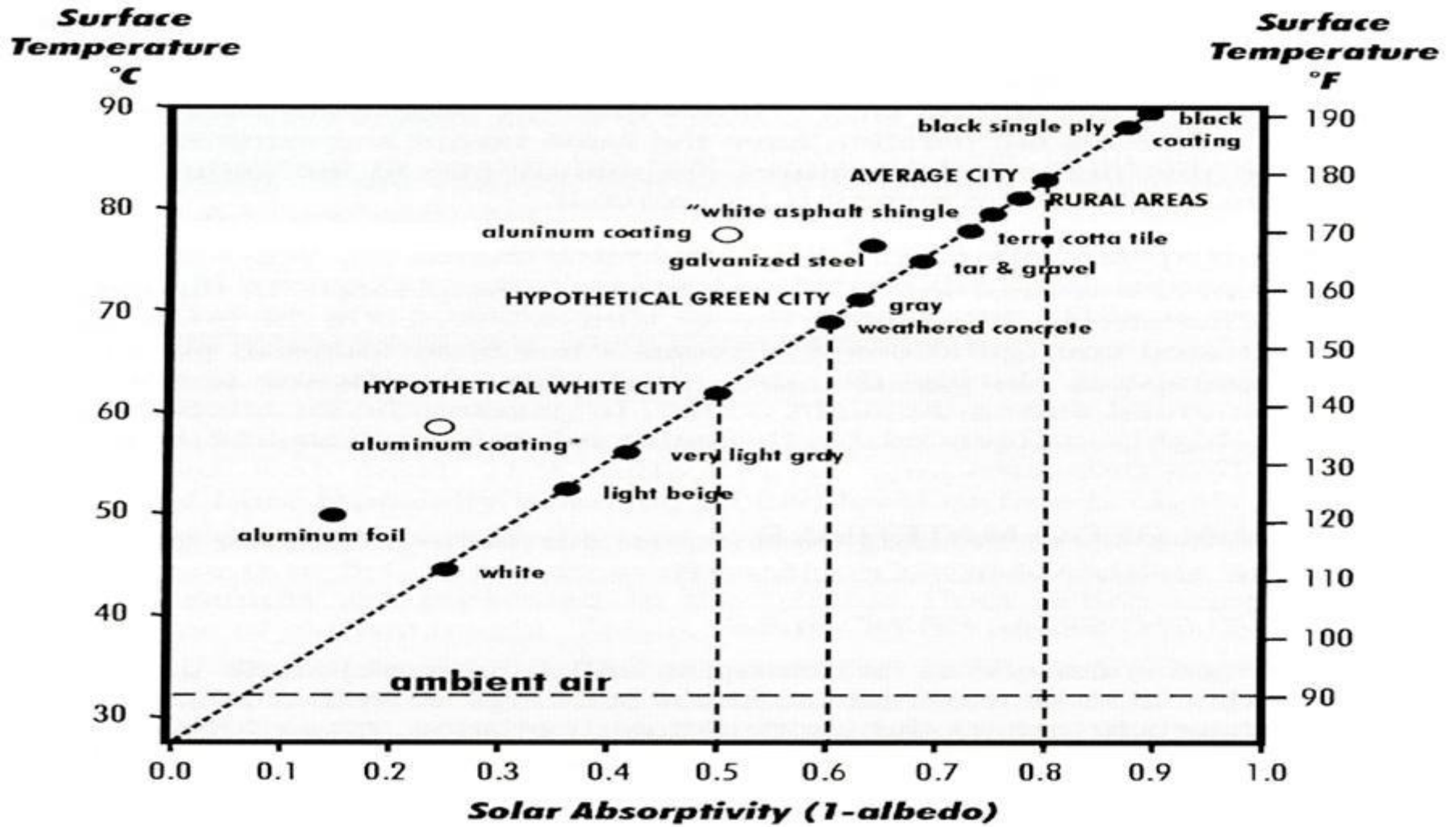


Figure 1: Left: Measurement location in Vaassen, 2006. Dashed lines indicate the line along which the measurements were taken (green: with vegetation, red: reference line). The white box indicates the model domain for the simulations. (Source: Google Earth). Right: Mean relative difference in NO concentrations with and without a vegetation barrier (from De Maerschack et al., 2009).



(Taha et al. 1999)

NYC °CoolRoofs by the Numbers

2010

1,596 volunteers
135 buildings + 1,168,369 square feet

2012

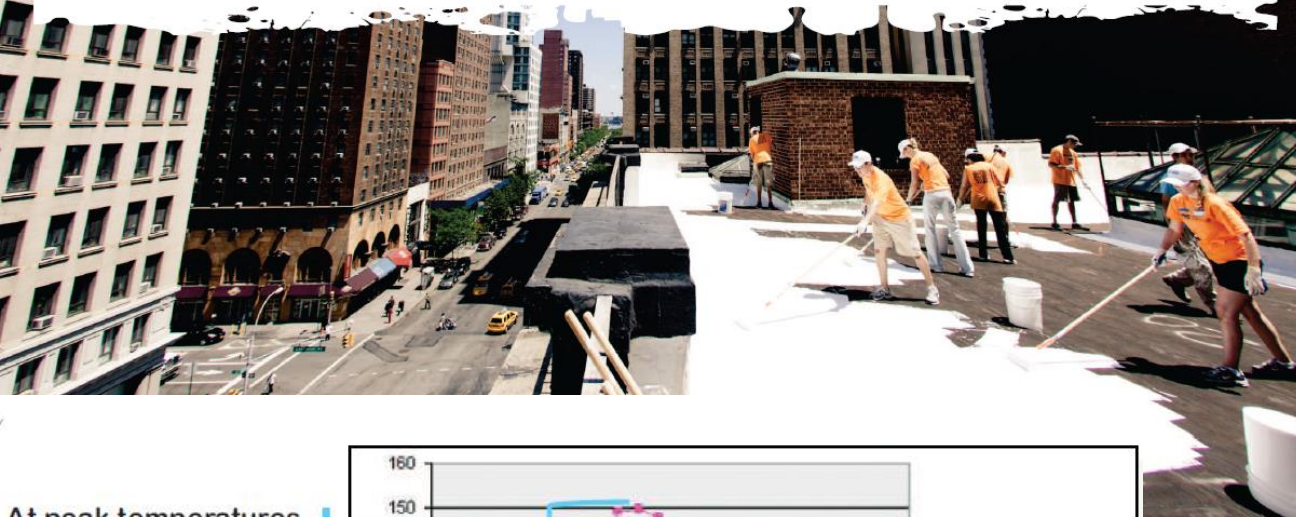
1,417 volunteers
128 buildings + 1,195,091 square feet

2011

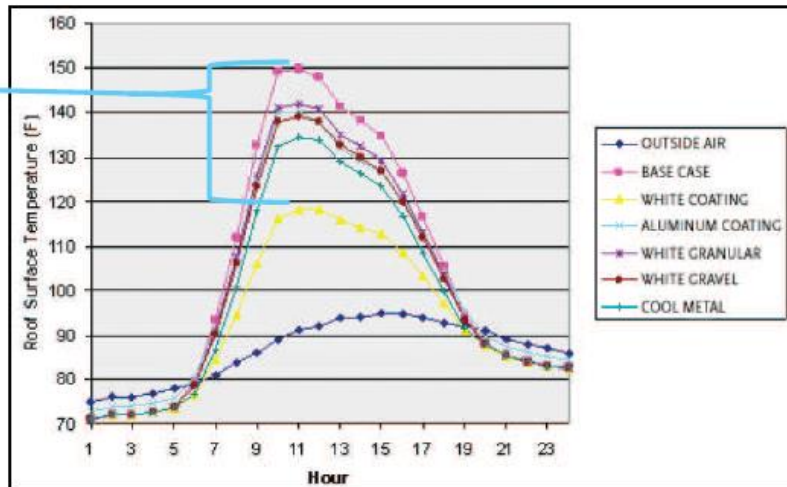
1,239 volunteers
153 buildings + 1,307,572 square feet

Program Total

4,252 volunteers
416 buildings + 3,671,032 square feet



At peak temperatures, a white roof is 20°F cooler than a roof with aluminum coating and 30°F cooler than a dark roof.



Morphologie des quartiers

- Modifier un square pour le confort (vents forts)

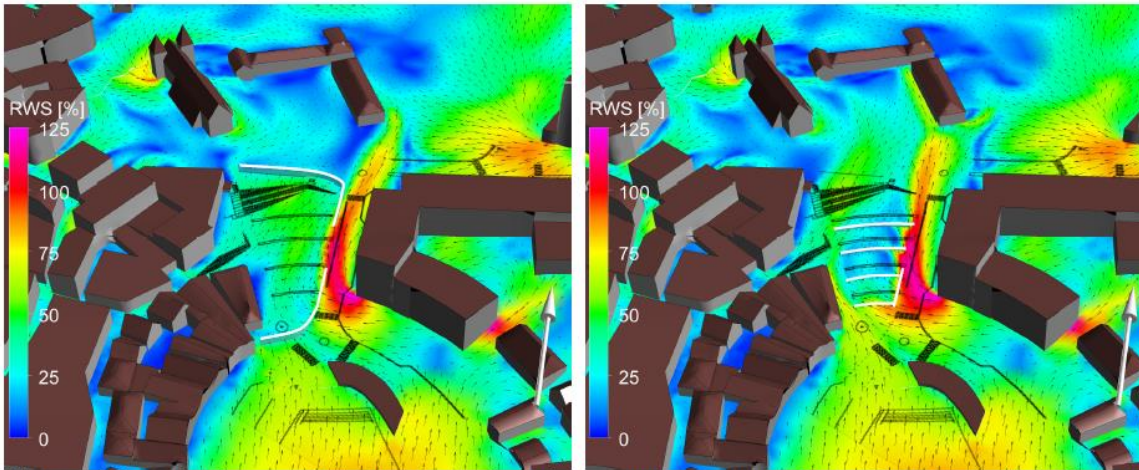


Figure 6. Wind shielding concepts, respectively, 5 m height around the square (left) and 3 meter height "distributed".

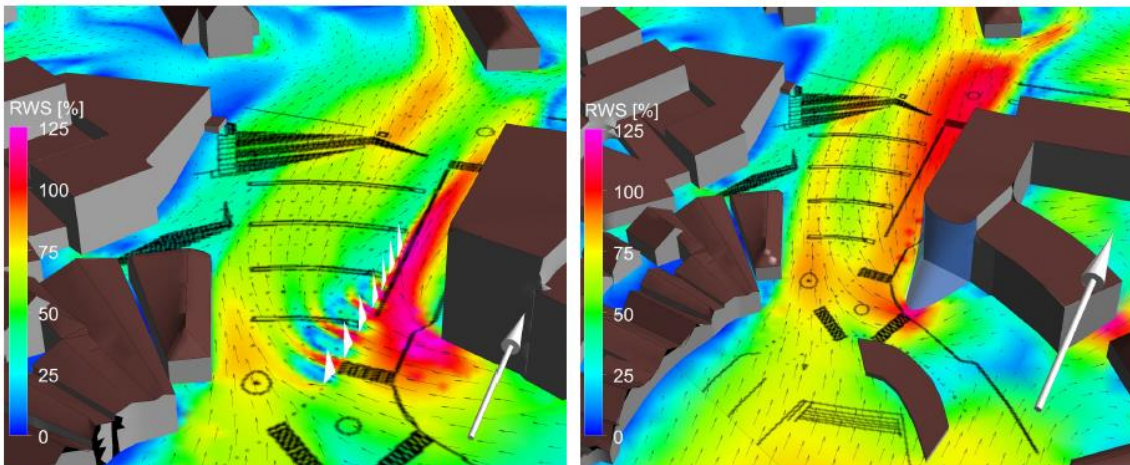
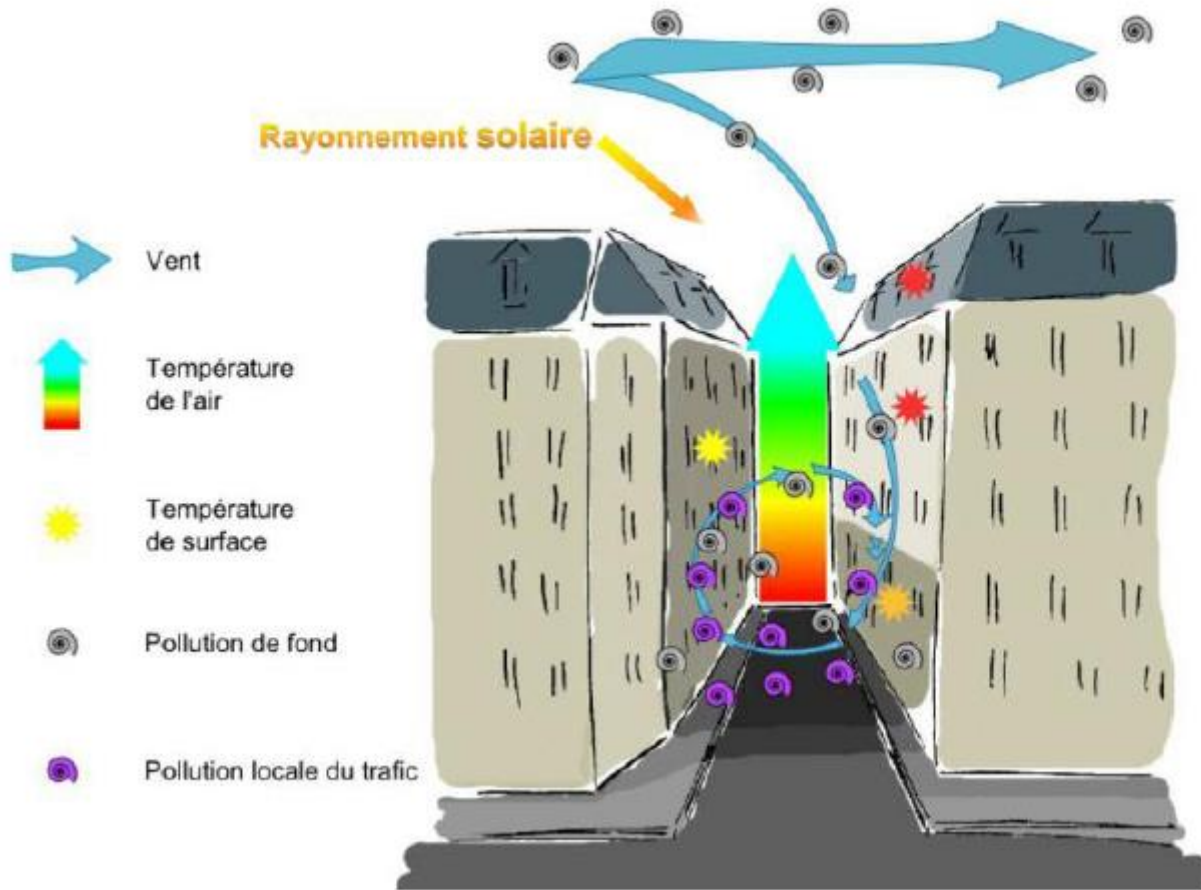


Figure 7. New ideas: distributed row of "sails" (left) and a new façade construction.

- Différentes options de pare vent
- Modification de façades

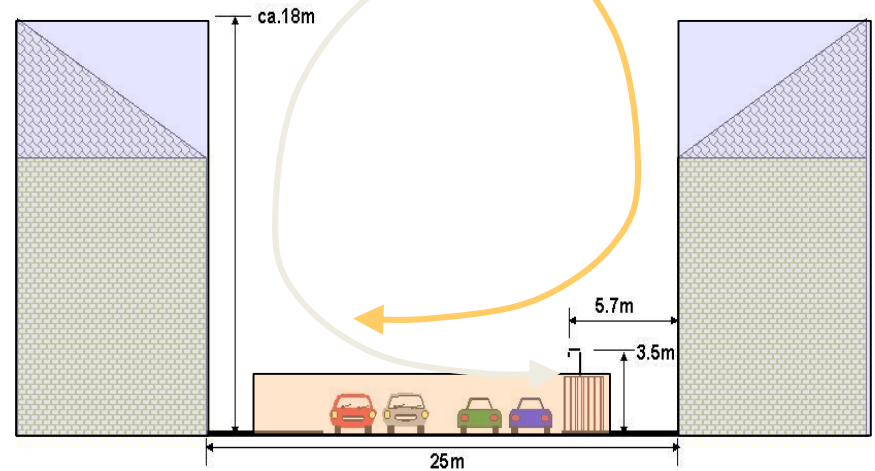
(Venas & Borresen, 2010)

Pollution in a street canyon

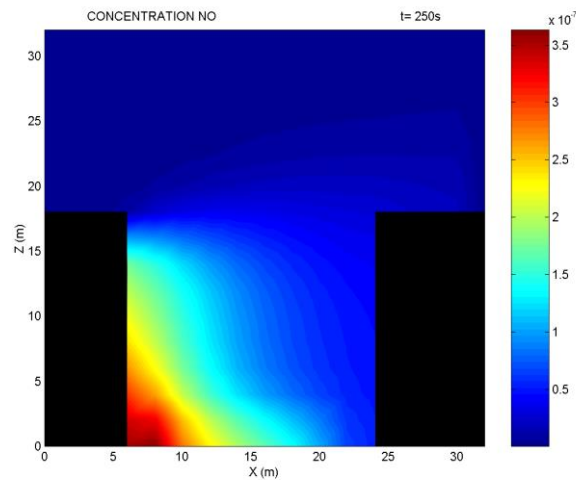


Trafic

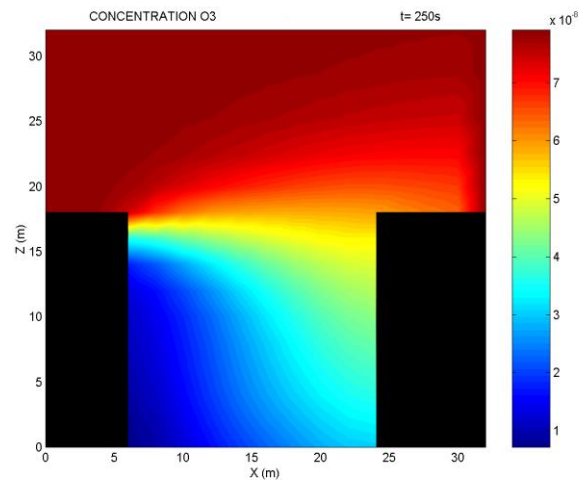
- Ventilation des rues
- Réactions chimiques



Oxyde d'Azote



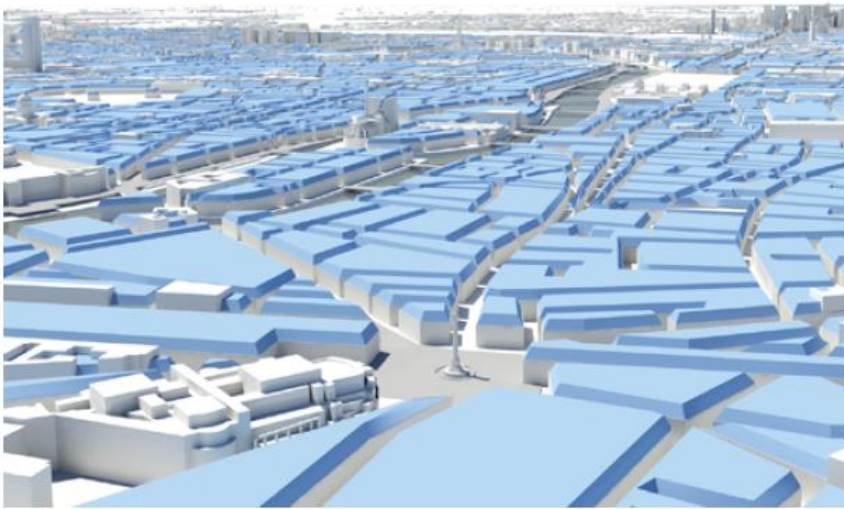
Ozone



(Lacour et al. 2003)

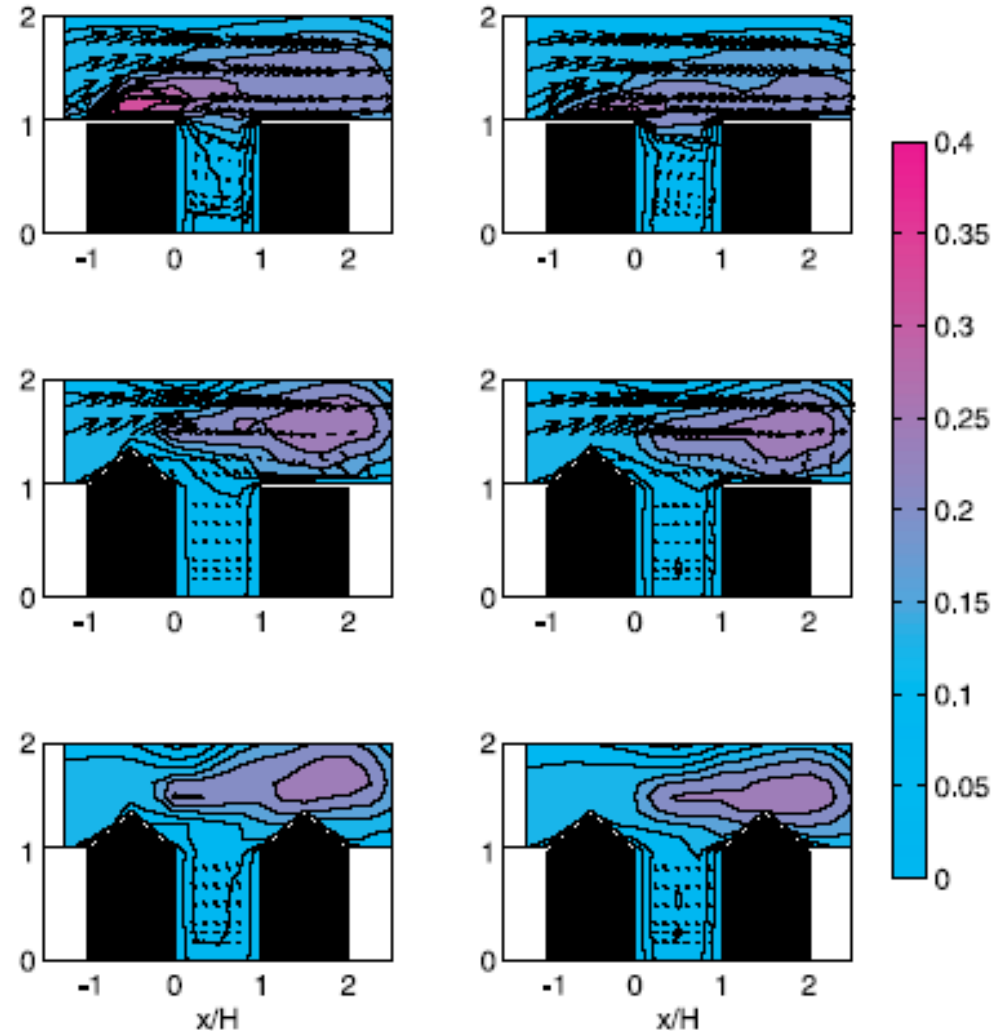
Morphologie des bâtiments

- Influence de la forme des toits



Principe d'extension sur les toits de Paris

DOCUMENT PRÉSENTÉ PAR L'ÉQUIPE WINY MAAS / MVRDV



Kastner-Klein et al 2004

Impacts des couvertures

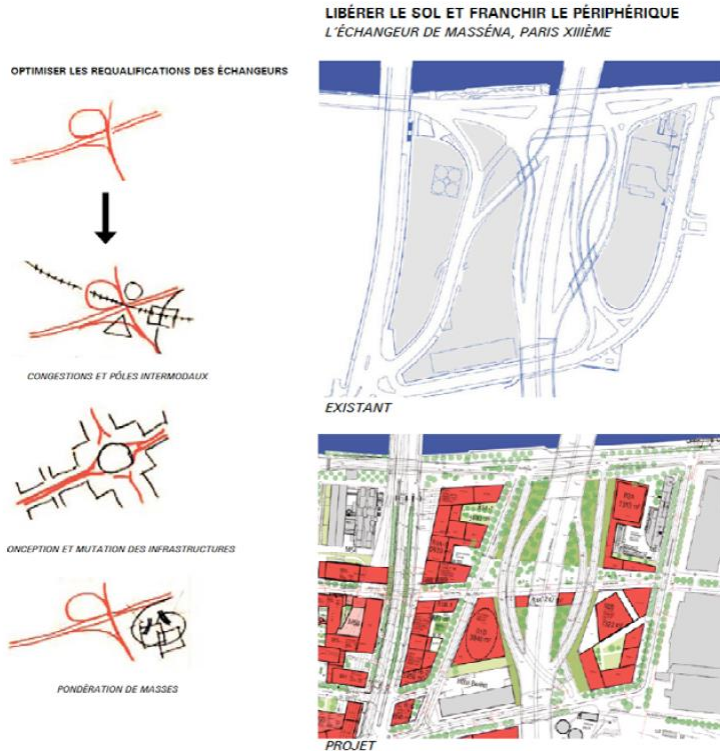
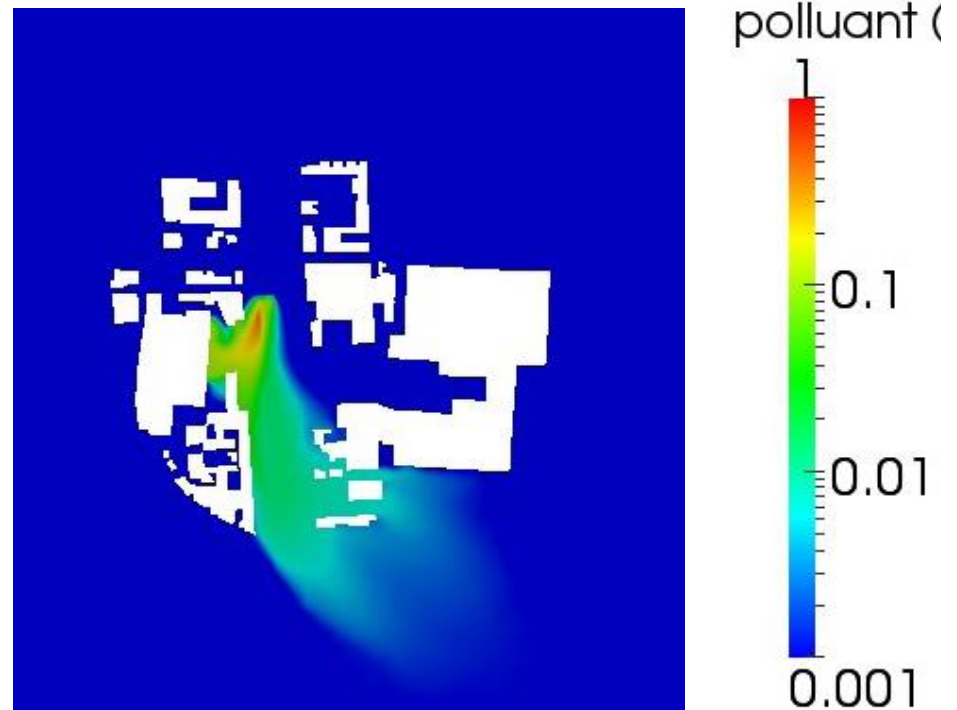


Schéma de requalification de l'échangeur Masséna, Paris 13ème

DOCUMENTS PRÉSENTÉS PAR L'ÉQUIPE YVES LION / GROUPE DESCARTES

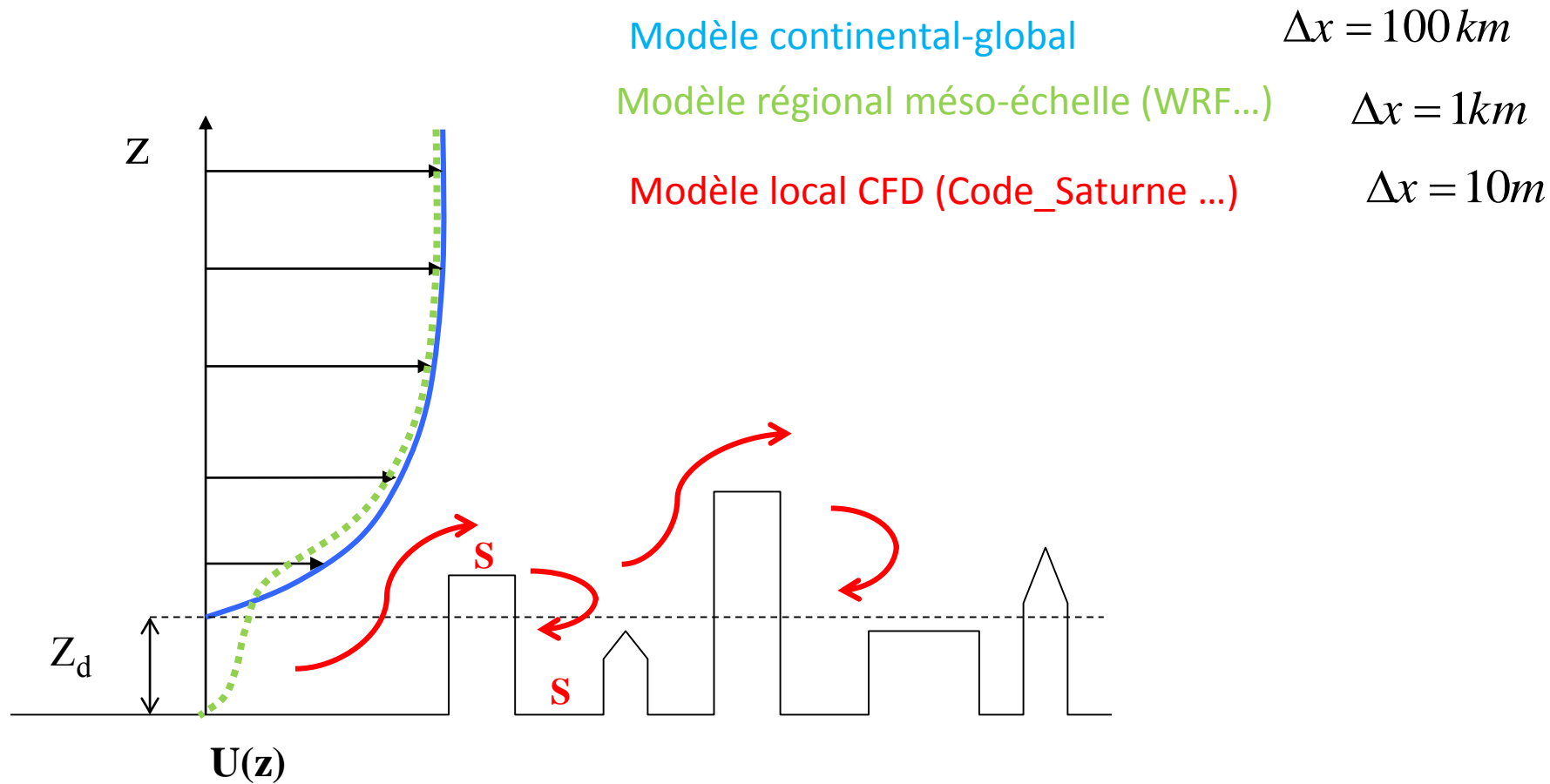


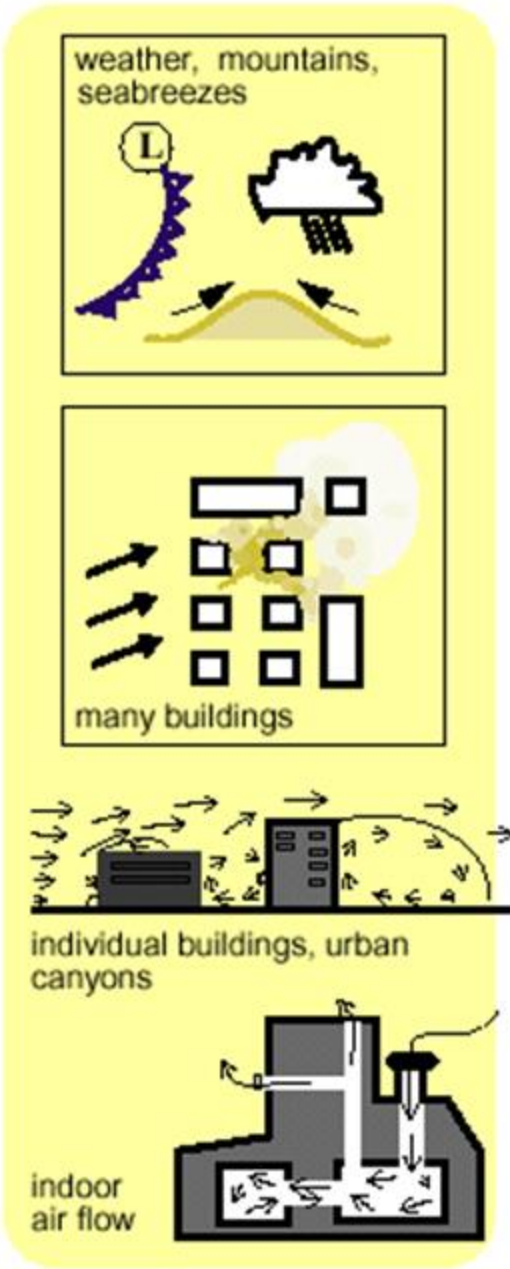
Couverture du Landy (A1) :
Thierry Kubwimana, CETU
Laëtitia Girault, CEREAA

Outline

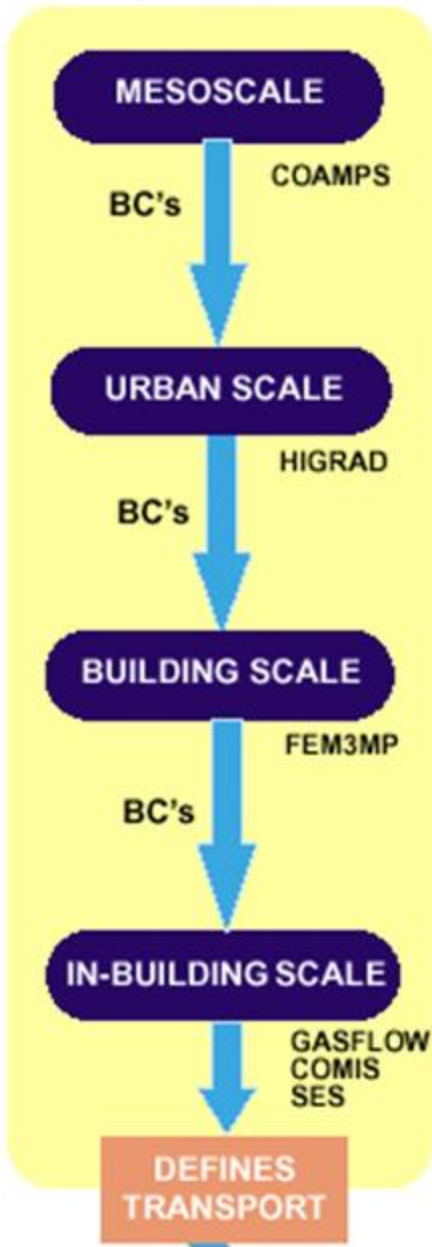
- Background on climate change
- Effects on urban climate
- Air quality
- The challenges of adaptation
- Numerical tools
- Examples of studies by CEREIA and others

La couche limite atmosphérique : une question d'échelle d'étude

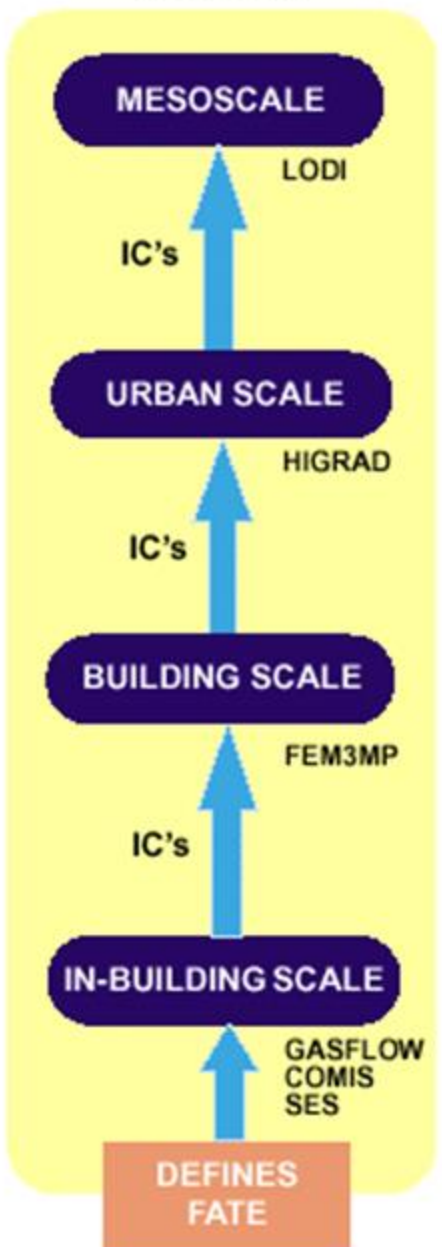




FLUID DYNAMICS MODELS



PLUME DISPERSION MODELS



CFD with *Code_Saturne*

Example of a family of models

LLNL
LANL

Description générale

Code_Saturne: modèle 3D de mécanique des fluides dont le noyau est développé par EDF-R&D et dont le CEREA développe une version physique particulière dédiée aux écoulements atmosphériques

➤ **Maillages non structurés:**

- possibilité de traiter des géométries complexes (milieu bâti) par une prise en compte directe dans le maillage
- accepte tout type de polyèdre: hexaèdres, tétraèdres, prismes ...

➤ **Méthodes numériques:** volumes finis, variables colocalisées, méthode “prédicteur-correcteur”

➤ **Code:** 500 000 lignes, 49% FORTRAN 90, 41% C, 10% Python

➤ **Parallèle** sur machine à mémoire distribuée (MPI)

➤ 2 versions par an, 1 version de production tous les 2 ans

➤ **Open source** (licence GPL) (www.code-saturne.org)

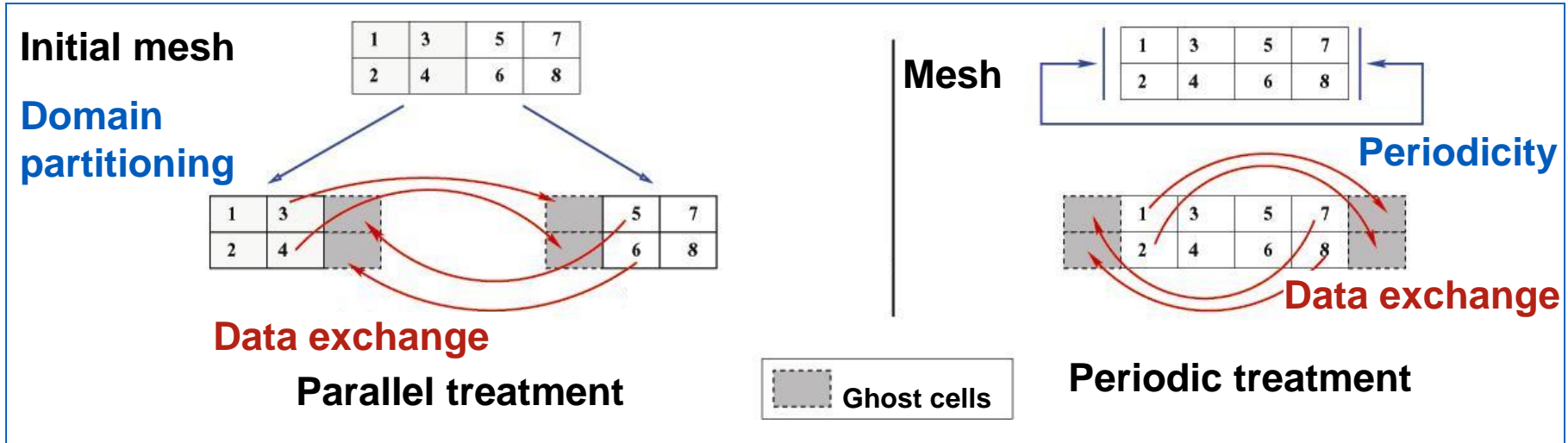
➤ Développé sous **Assurance qualité**

➤ Club utilisateurs

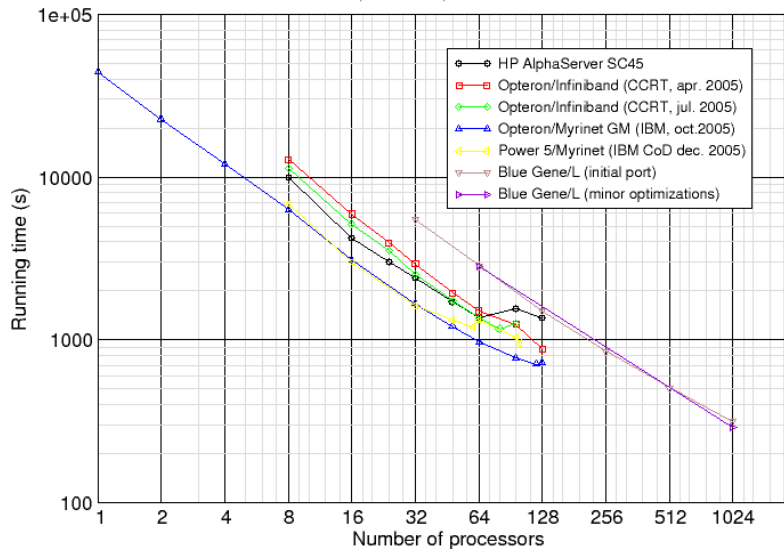
➤ **Version atmosphérique utilisée par:** Aria-Technologies, Numtech, Apsys, INERIS, CEA, ECL, CSTB, INSA ...

Parallelism - periodicity

➤ Parallelism and translation periodicity: data exchange



FATHER LES Case
961,920 cells; 200 iterations



Record actuel :
10 milliards de mailles
1 million de processeurs

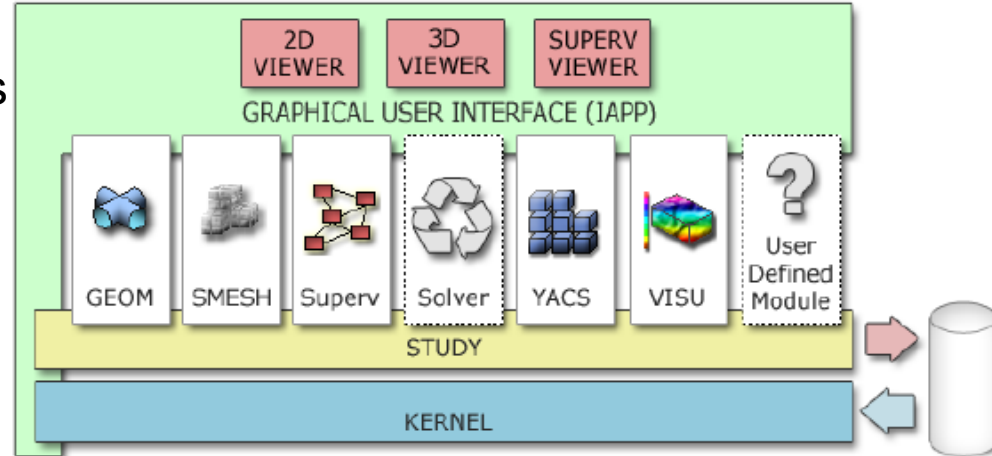
Prise en compte des processus atmosphériques

- Loi de paroi rugueuse
- Stabilité verticale
 - Variable thermodynamique: température potentielle
 - Prise en compte dans le modèle de couche de surface
 - Prise en compte dans modèle de turbulence
- Modèles de transfert radiatif 1D et 3D solaire et infra-rouge
- Interface sol-atmosphère (modèle à 2 couches)
- Microphysique de l'eau (schéma semi-spectral)
 - 3 grandeurs prognostiques: température potentielle liquide, contenu en eau total, nombre de gouttes
- Chimie gazeuse (3 schémas de complexité croissante)
- Chimie particulaire (chaînage avec SIREAM)
- Modèle de canopée forestière
- Résolution:
 - RANS: modèles de turbulence: $k-\varepsilon$ (jusqu'à présent), $Rij-\varepsilon$ (à venir)
 - Simulation des grandes échelles (LES)

Isotherme=stable (très)
Iso-temp.pot.=neutre

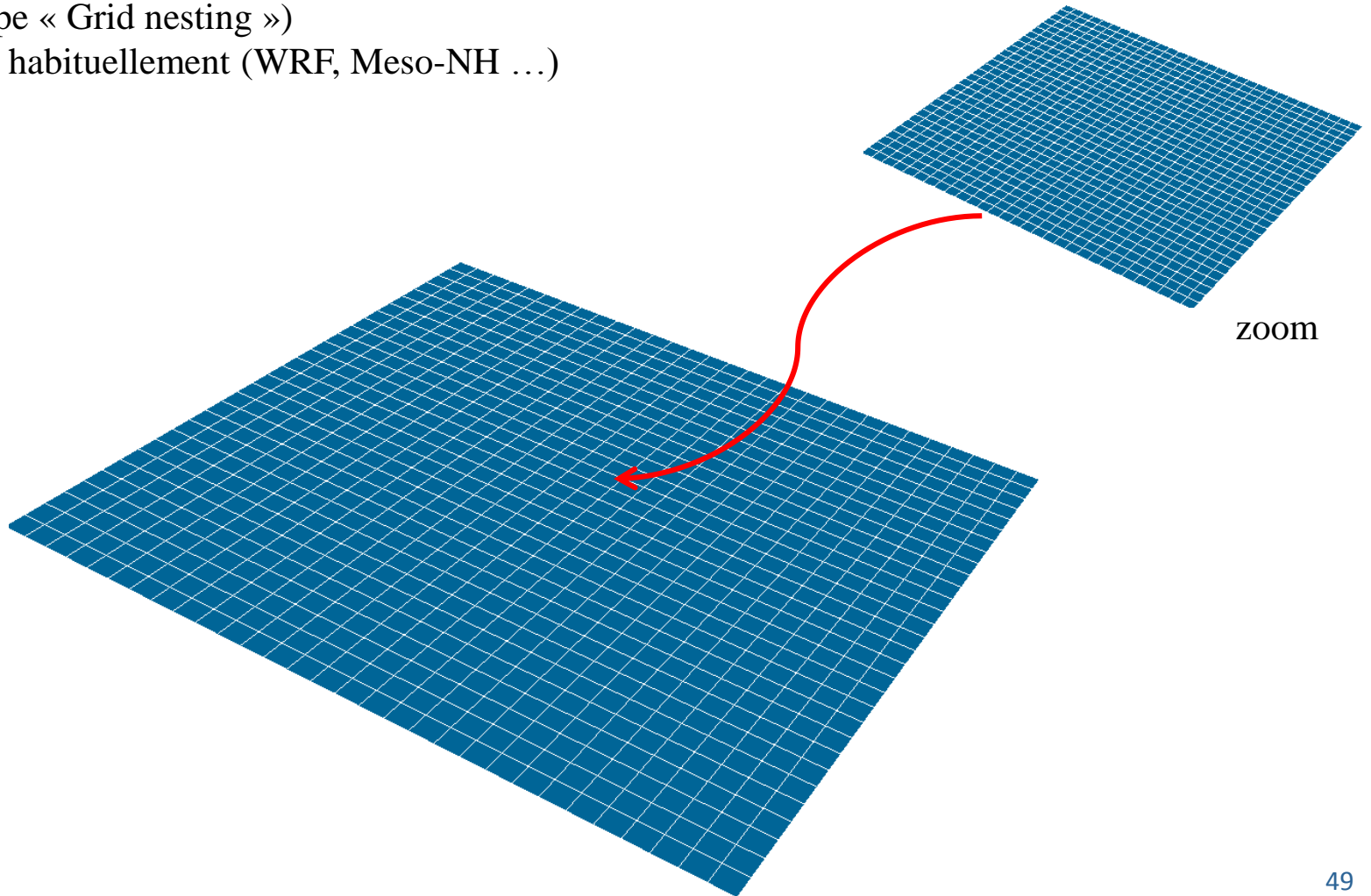
Plateforme SALOME

- Plateforme logicielle open-source pour le pre- et post-processing de simulations numériques (www.salome-platform.org)
CEA, EDF, OpenCascade
- GEOM: pour créer, éditer, importer et exporter des modèles de CAO
- SMESH: pour mailler un modèle de CAO
- YACS: pour coupler différents solveurs
- VISU/ParaVis: pour analyser les résultats des simulations
- ADAO : Data assimilation
- Possibilité de construire une version “métier” de Code_Saturne spécifiquement adaptée à certaines applications (dispersion autour d’un site, estimation du productible éolien ...)



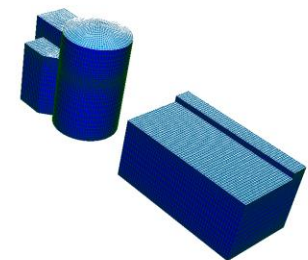
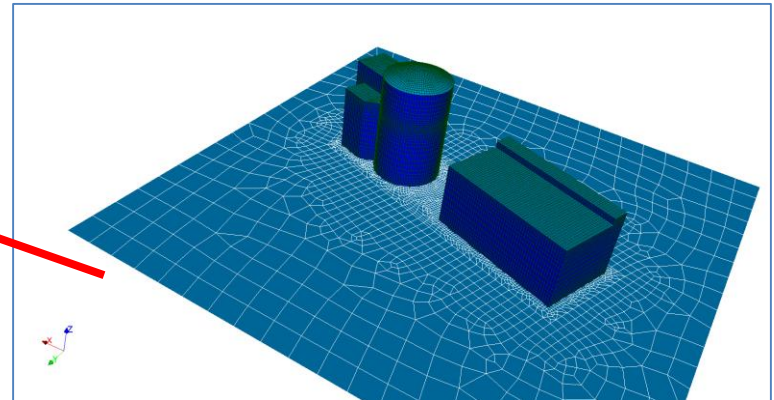
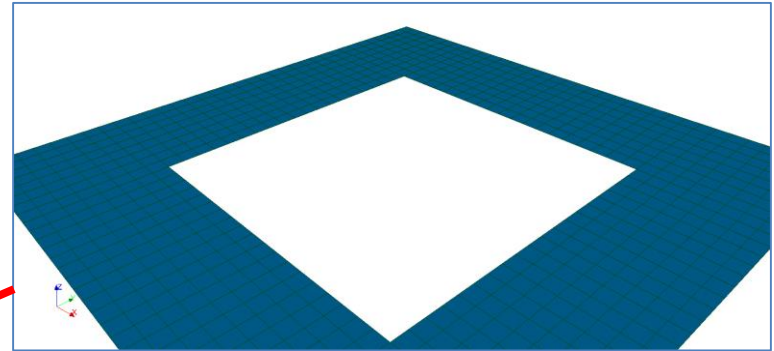
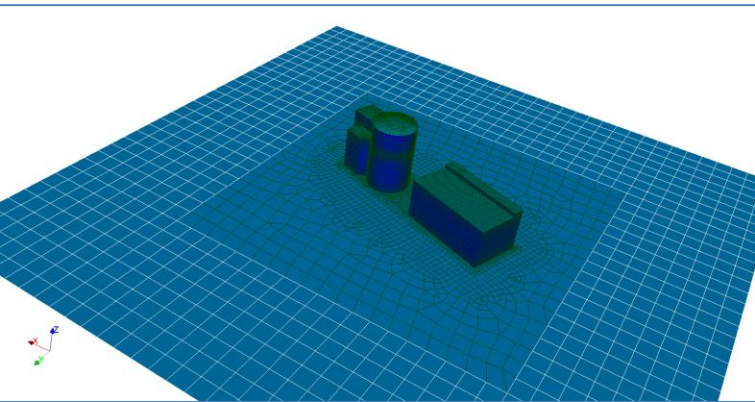
Domaine de calcul - I

Approche classique avec maillages emboîtés
(de type « Grid nesting »)
utilisé habituellement (WRF, Meso-NH ...)



Domaine de calcul - II

Approche de type CFD avec maillage non-structurés recollés
utilisé avec Code_Saturne :



3D radiative model design

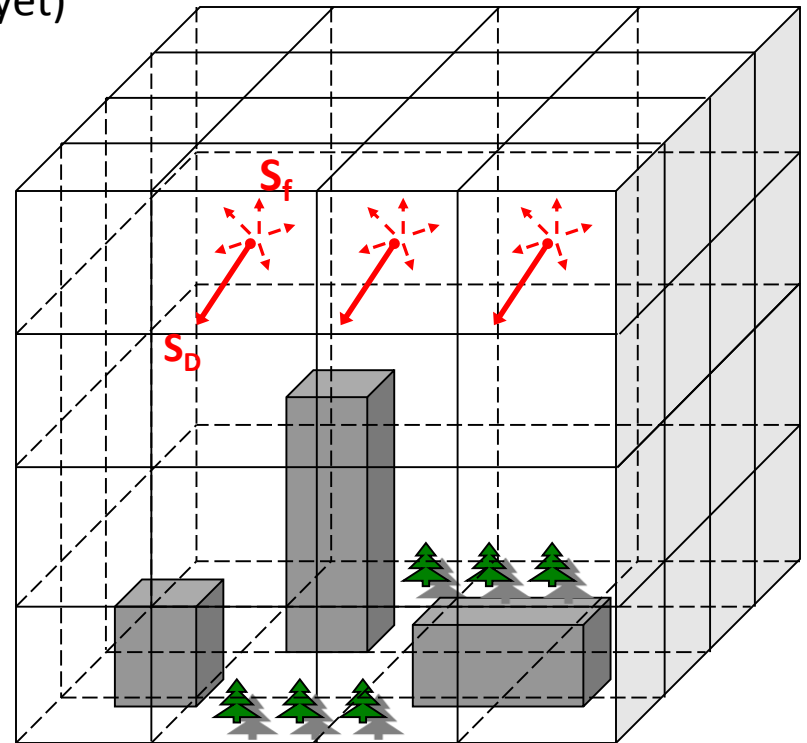
- ❑ Discrete Ordinate Method (DOM) (Fiveland, 1984)
- ❑ Spatial discretization uses the same mesh as the CFD model
- ❑ Absorption (Makke, 2015) and diffusion (not yet)
- ❑ Short and long-wave radiation

$$S^\downarrow = S_D + S_f + S_e$$

$$S^\uparrow = \alpha S^\downarrow$$

$$L^\downarrow = L_a + L_e$$

$$L^\uparrow = \varepsilon \sigma T_w^4 + (1 - \varepsilon)(L_a + L_e)$$

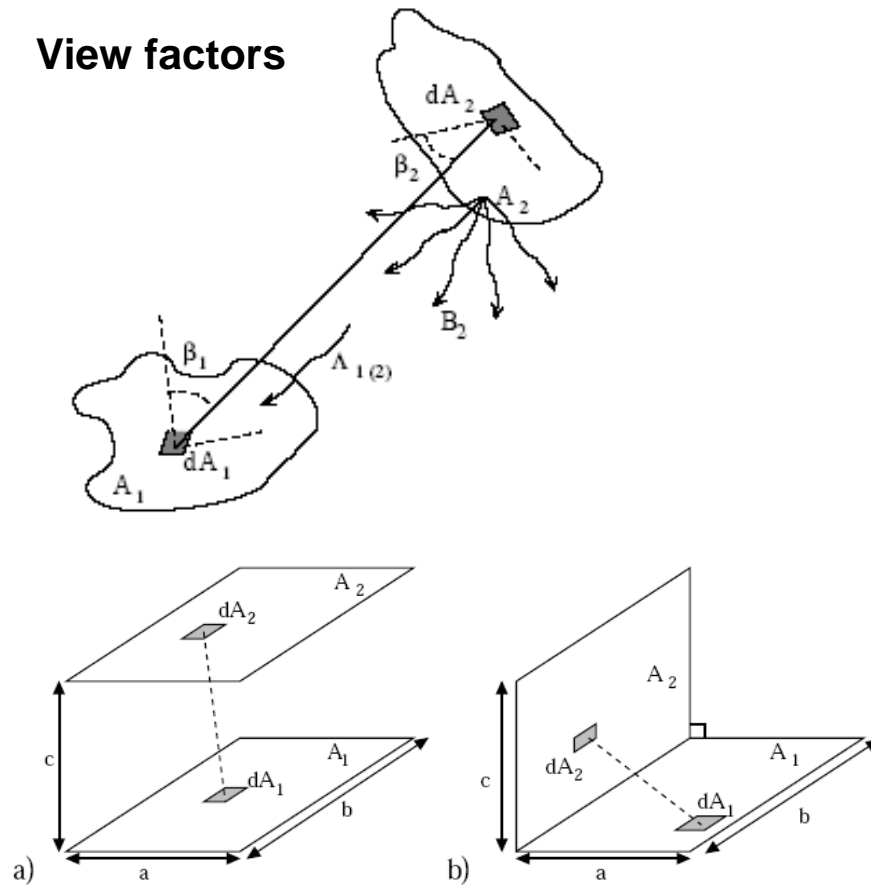


(Milliez 2006, Qu 2012, Makke 2015)

... different from the view factor approach:

- Used for example for SOLENE (Miguet and Groleau, 2002...), CitySim?...

View factors



Outline

- Background on global climate
- Urban climate
- Processes
- Air quality
- The challenges of adaptation
- Experimental and numerical tools
- Examples of studies by CEREIA and others (CAPITOU, EUREQUA, EM2PAU)

- Examples of studies by CERECA and others :
 - CAPITOUL : Toulouse City Center
 - EUREQUA : Environmental Evaluation and requalification of neighborhood
 - EM2PAU : coupling of CFD with a building model (derived from BuilSysPro)
 - + previous analytical and experimental validation

Validation with CAPITOUL dataset (Qu, 2012)

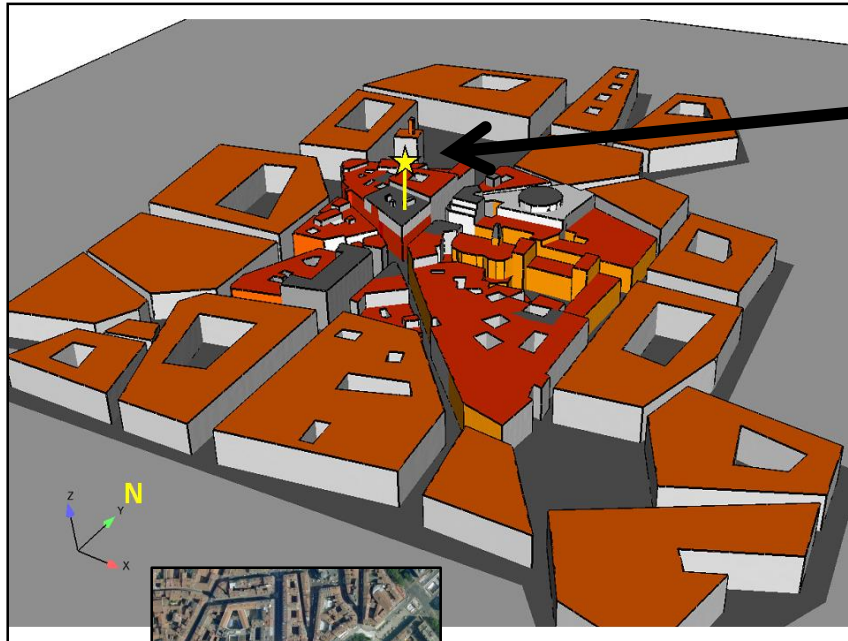
- Canopy and Aerosol Particle Interactions in Toulouse Urban Layer (CAPITOUL) field campaign took place from February 2004 to February 2005. (Masson et al., 2008)



- Aerial view of downtown Toulouse, France: a) Main study area; b) Zoom in the selected area (a) : yellow contour)

Validation with CAPITOUL dataset (Qu, 2012)

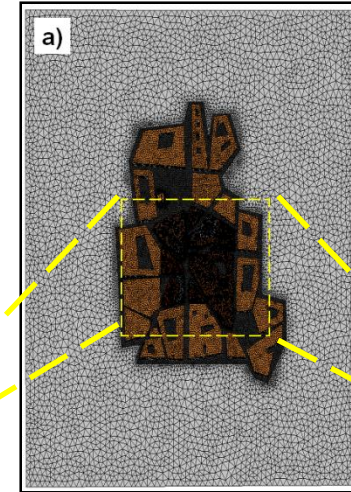
- Simulation set-up for July 15th 2004
- ❑ Central site area geometry processed by ICEM CFD
- ❑ From city of Toulouse 3D database (DXF)
- ❑ Domain size: 891x963x200 m



Meteo mast



- ❑ Mesh strategy



- ❑ Simulation mesh, total mesh ~1,8 M

Results: validation with CAPITOUL dataset

Simulation for July 15th 2004

Initial and boundary conditions

	Surface albedo α	Surface emissivity ε	Layer	Depth (m)	Material	Heat capacity ($10^6 \text{ J m}^{-3} \text{ K}^{-1}$)	Thermal conductivity ($\text{W m}^{-1} \text{ K}^{-1}$)
Wall	0.25	0.92	1	0.01	Red bricks	1.58	1.15
			2	0.05			
			3	0.18			
			4	0.05			
			5	0.01			
Roof	0.15	0.90	1	0.01	Red tiles	1.58	1.15
			2	0.05			
			3	0.02	Wood	2.20	0.20
			4	0.01			
Road	0.08	0.95	1	0.01	Asphalt	1.74	0.82
			2	0.04			
			3	0.20	Stone aggregate	2.00	2.1
			4	1.00	Gravel and soil	1.40	0.4

Source: Pigeon et al. (2008)

Classification of 4 colors for the buildings surfaces



Source: Google street

Sensitivity with several levels for heat transfer:

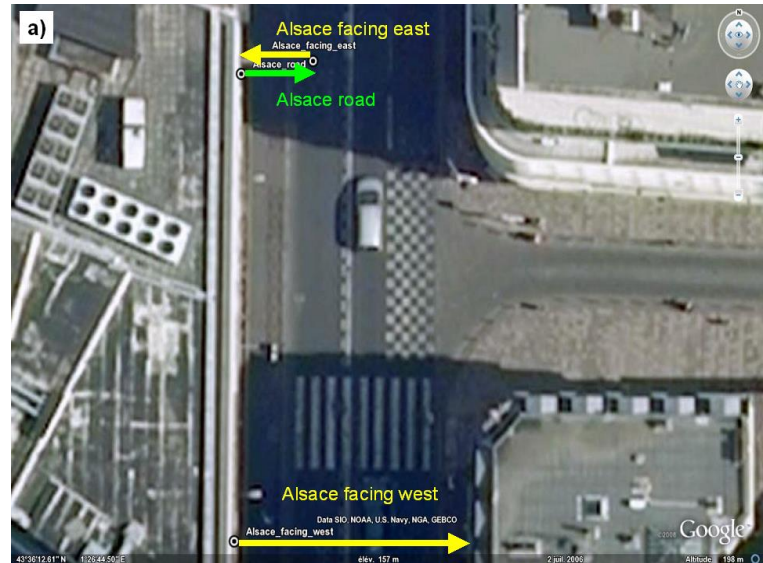
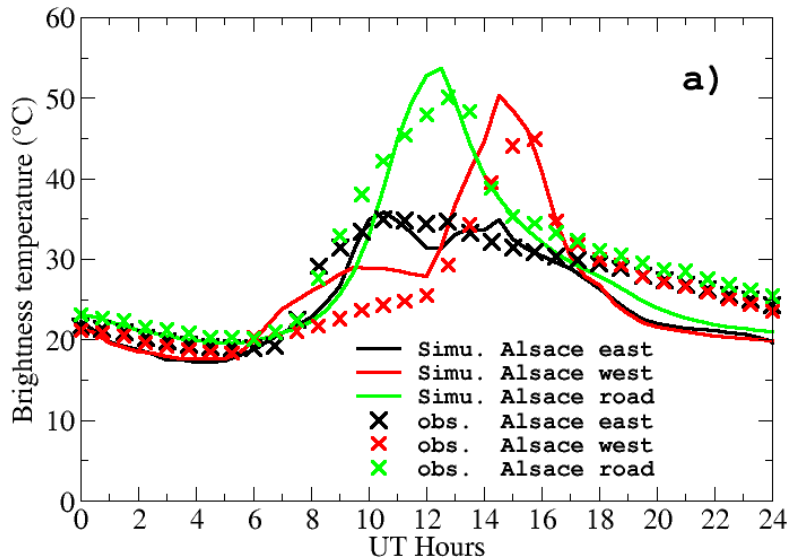
- 1) no wind
- 2) h_f constant
- 3) full radiative-dynamical coupling

Paint color	albedo
White	0.6
Whitewash	0.5
Rose	0.3
Gray	0.15

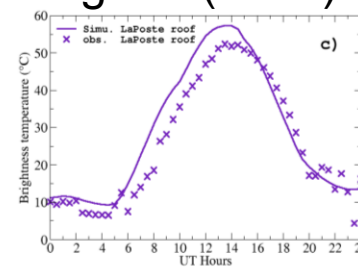
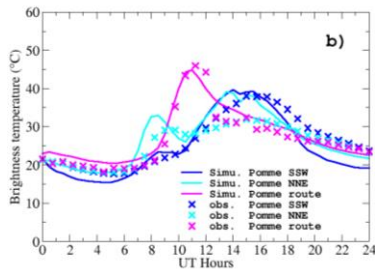
Results: validation with CAPITOUL dataset

► Simulation of July 15th 2004

□ Measurement-simulation comparison for diurnal evolution for brightness temperature of different positions of the infrared thermometers



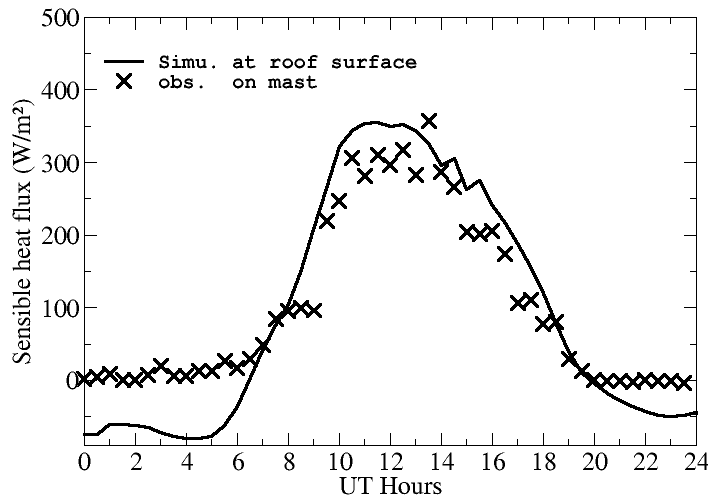
Source: Pigeon (2004)



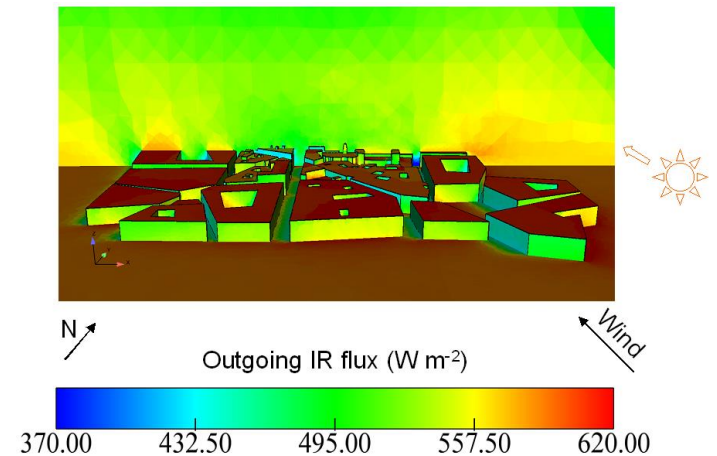
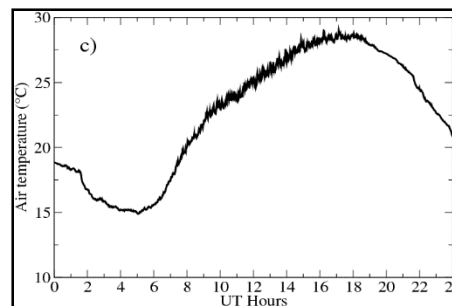
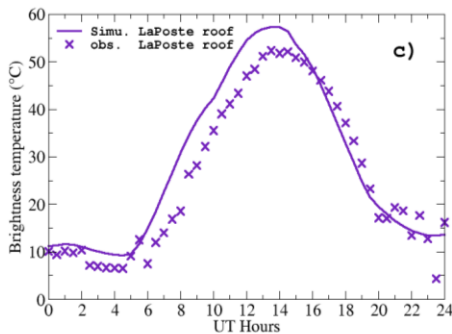
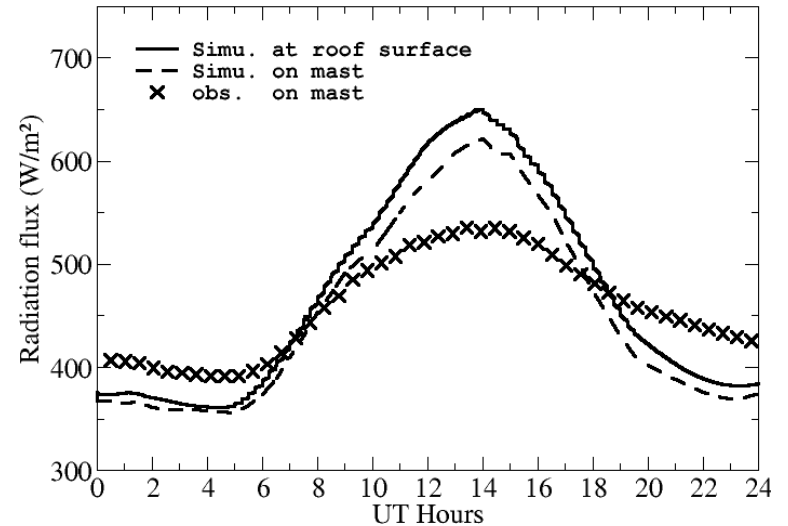
Results: validation with CAPITOUL dataset

► Simulation of July 15th 2004

□ Comparison of sensible heat flux



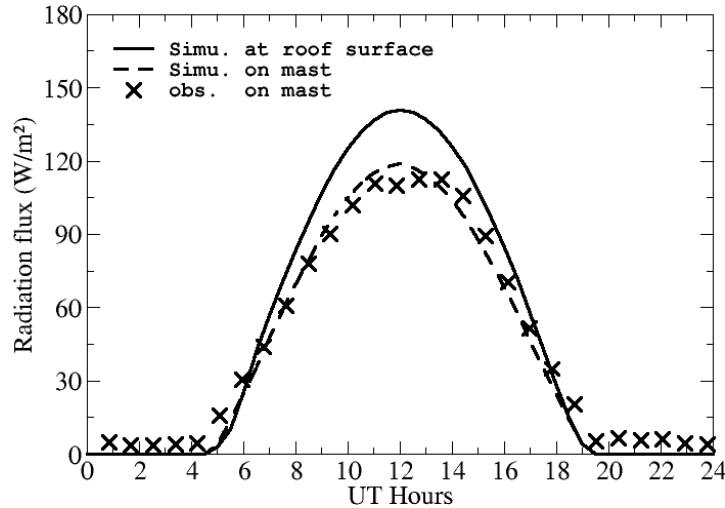
□ Comparison of outward IR flux



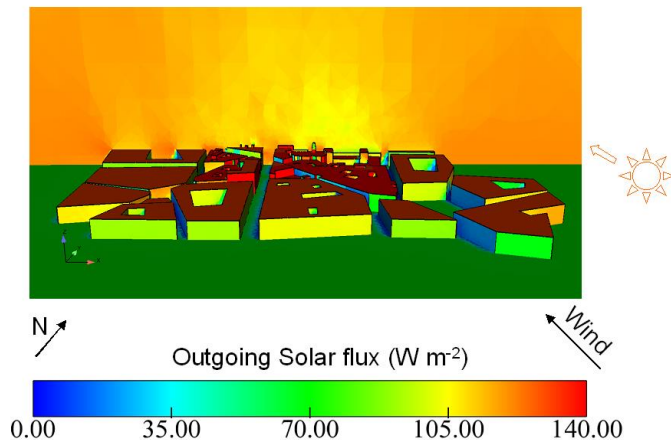
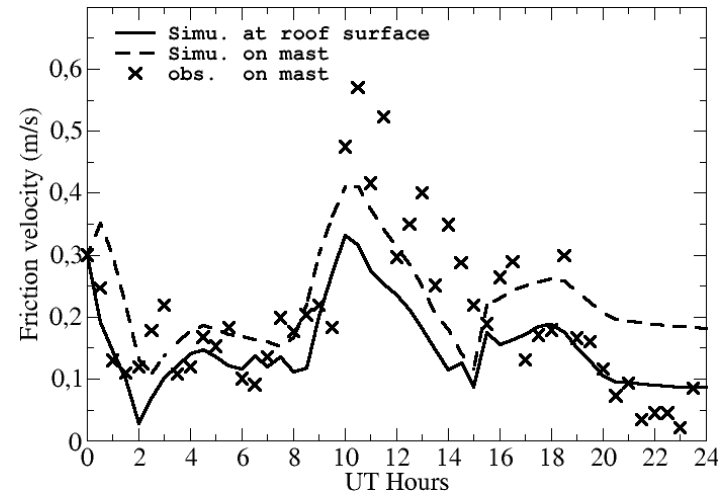
Results: validation with CAPITOUL dataset

Simulation of July 15th 2004

Comparison of outward solar flux



Comparison of friction velocity



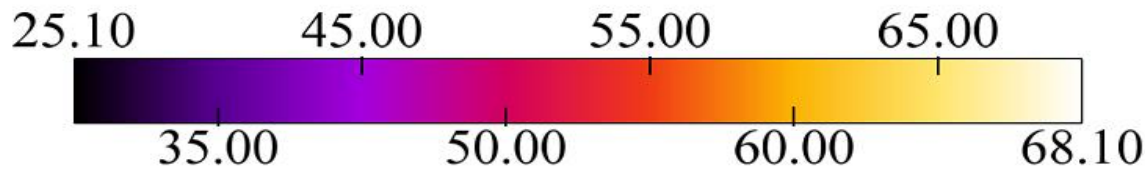
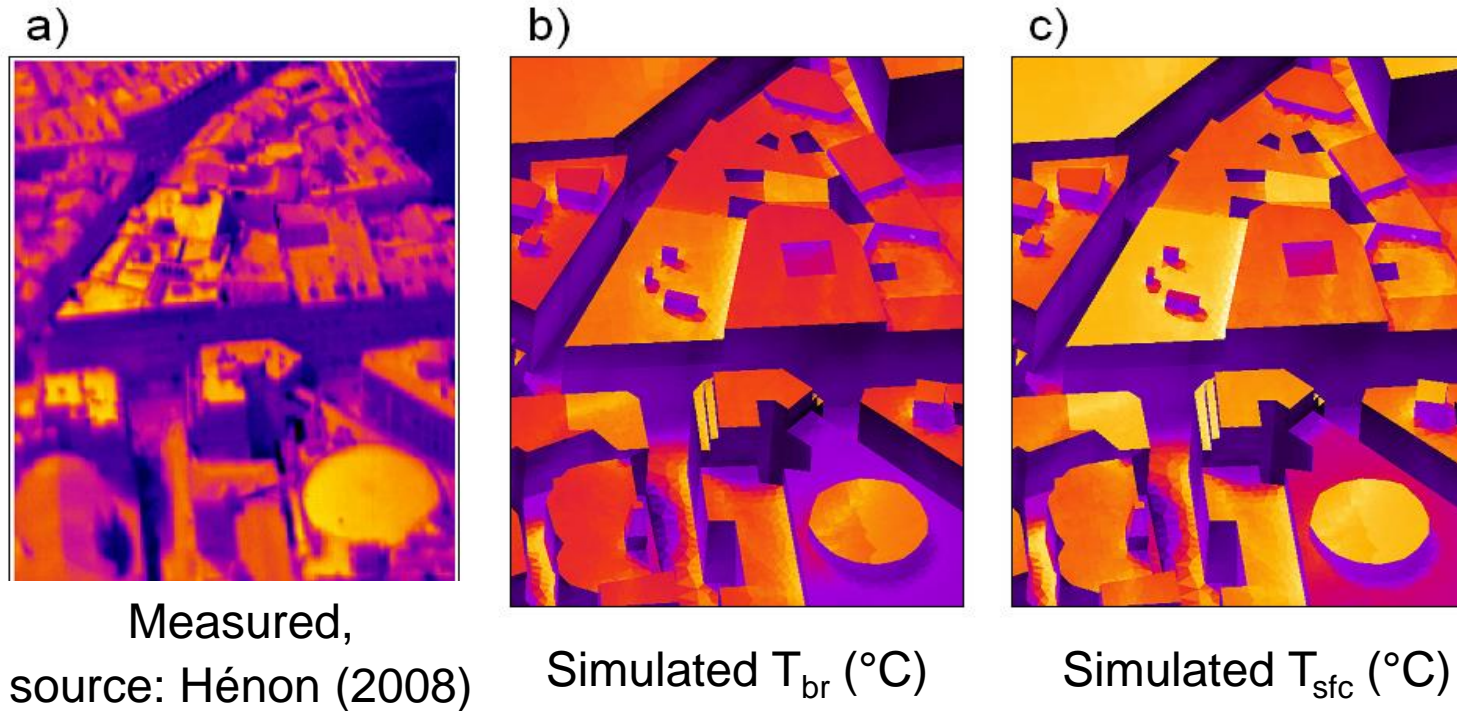
$$\text{At roof surface: } u^* = (|\tau_w / \rho|)^{1/2}$$

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

Results: validation with CAPITOUL dataset

Simulation of July 15th 2004

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



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

Results: effect of variable exchange coefficient

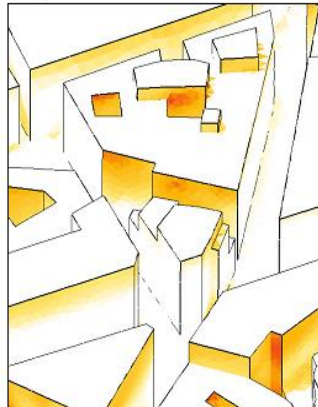
Simulation of July 15th 2004

Thermal infrared (TIR) airborne images 11:38 during flight 431 (Lagouarde et al. 2010):

a)



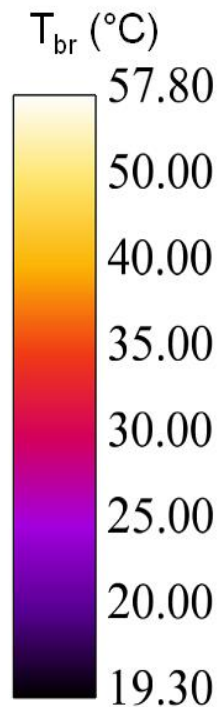
b)



c)



d)



a) Measured,
source from Hénon (2008)

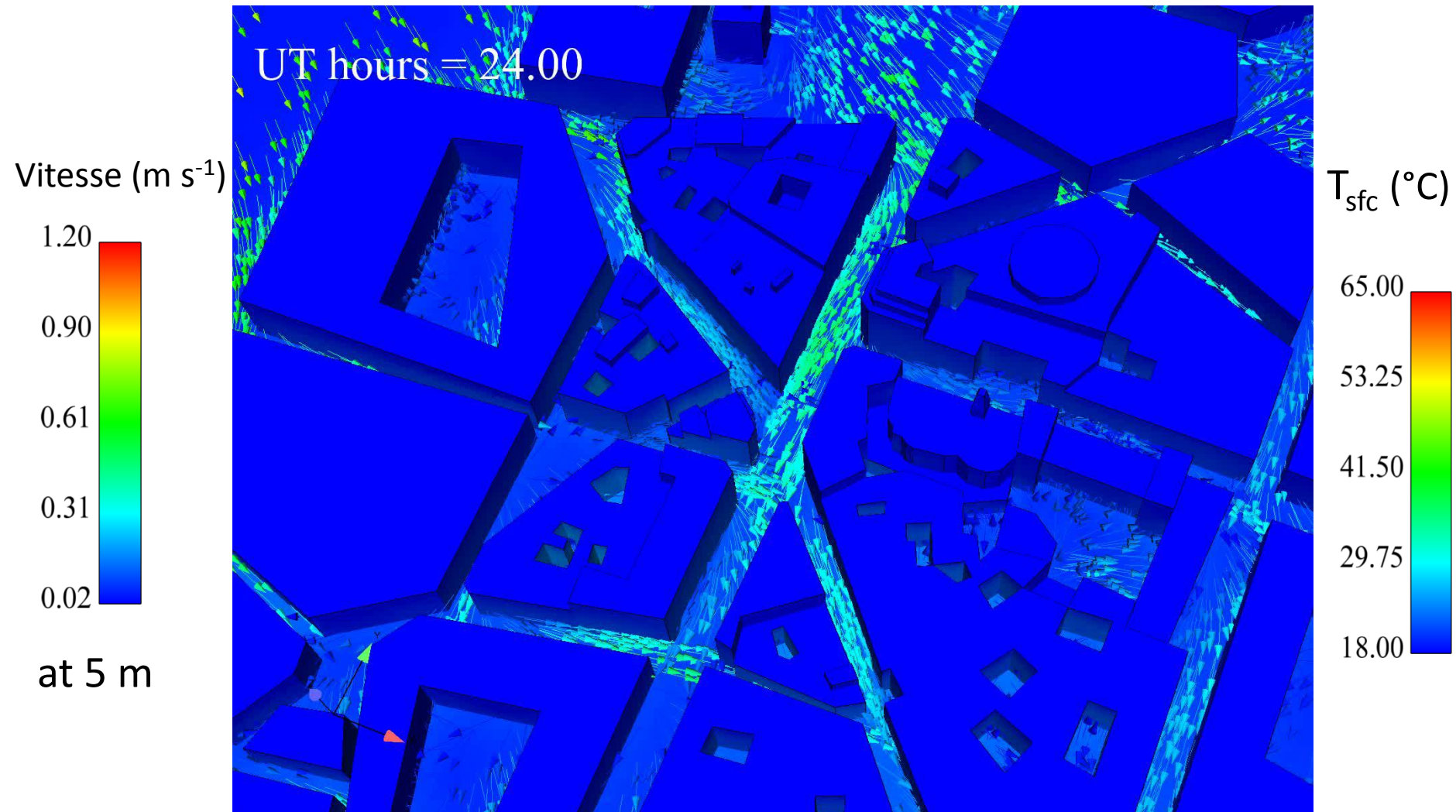
b) Simulated T_{br} without wind

c) Simulated T_{br} with h_f constant

d) Simulated T_{br} with full coupling

Toulouse, simulation de la campagne CAPITOUL (15 Juillet 2004)

(Qu, 2012)



Projet ANR EUREQUA

- **Evaluation mUltidisciplinaire et Requalification Environnementale des QUArtiers**

SHS
LISST-Cieu (*Toulouse*)
LAVUE (*Paris*)
LPED (*Marseille*)

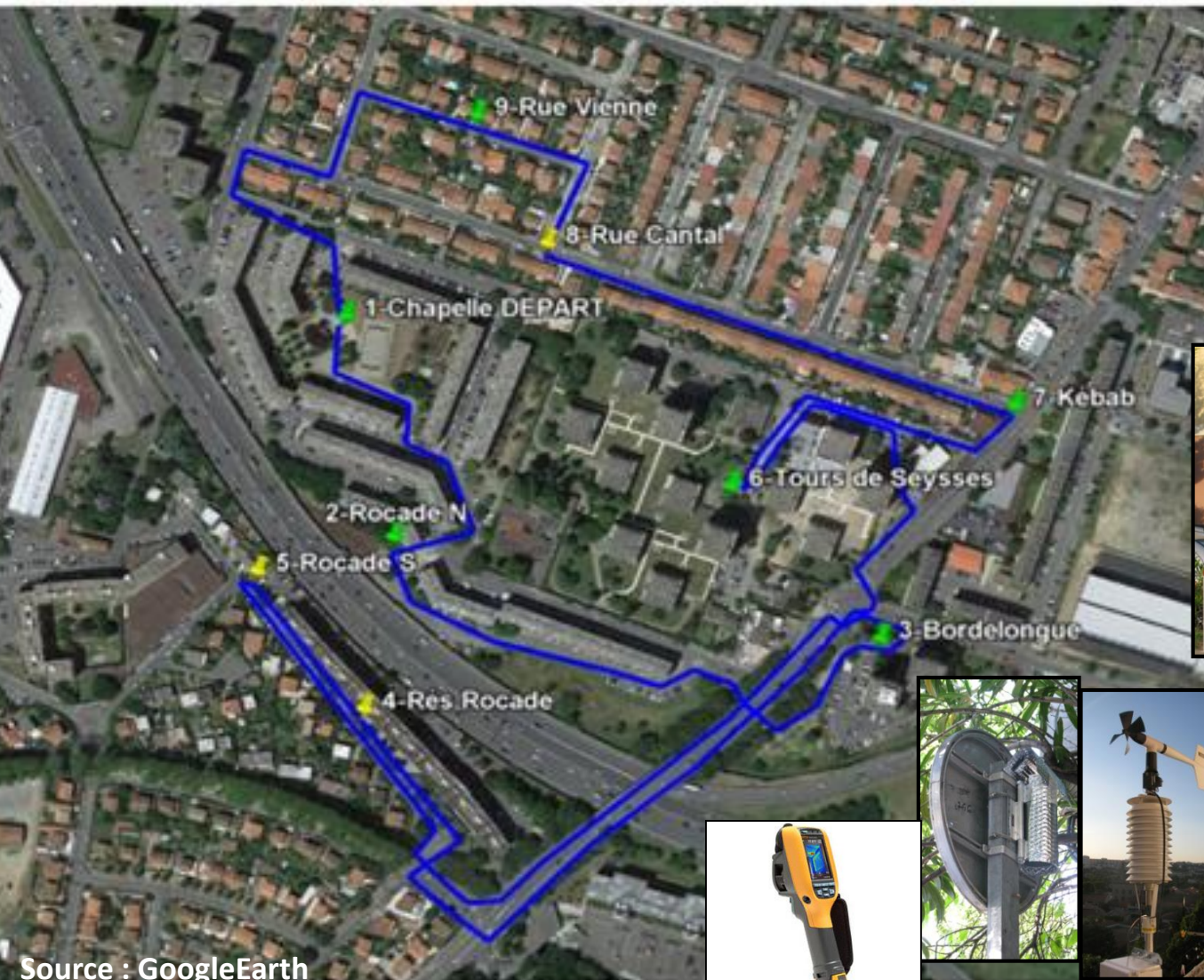
Professionnels
IAU-IdF
Ateliers Lion



SPI
GAME - *climatologie urbaine*
IFSTTAR – *acoustique*
CEREA – *qualité de l'air*

Acteurs institutionnels
Toulouse Métropole
Ville de Marseille

Toulouse 2014 field campaigns (3) (also 1 in Paris and 1 in Marseille)



Fixed and mobile network:

- Meteo
- AQ
- Sound

+ traffic counts

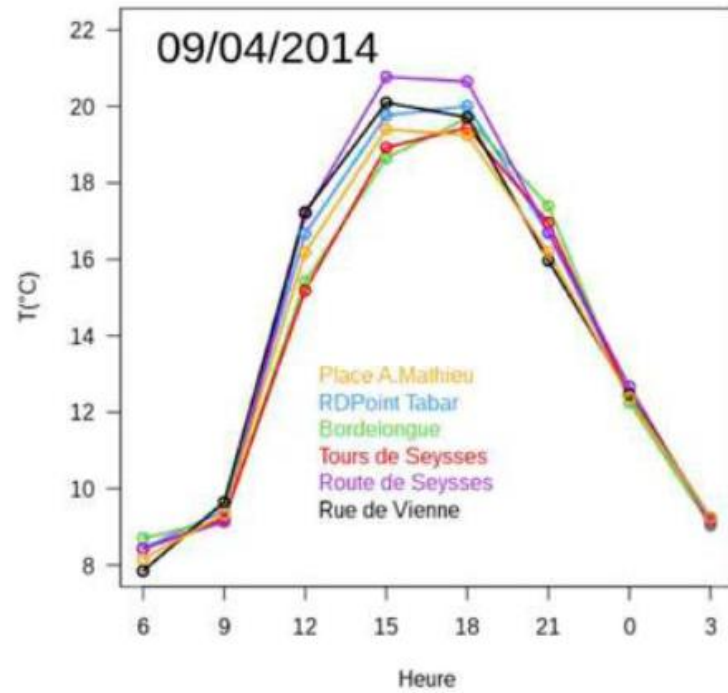
+ questionnaires (10,16,19h)



09/04/2014



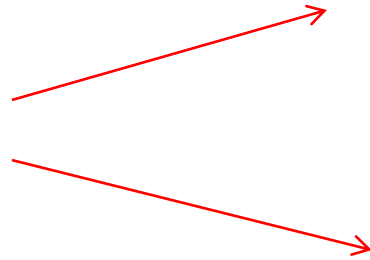
18h



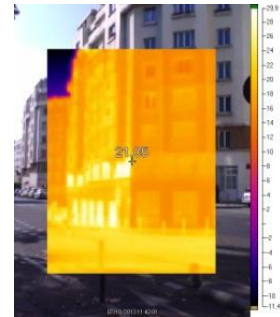
Infrared camera



File « xxx.is2 »
(Fluke format)



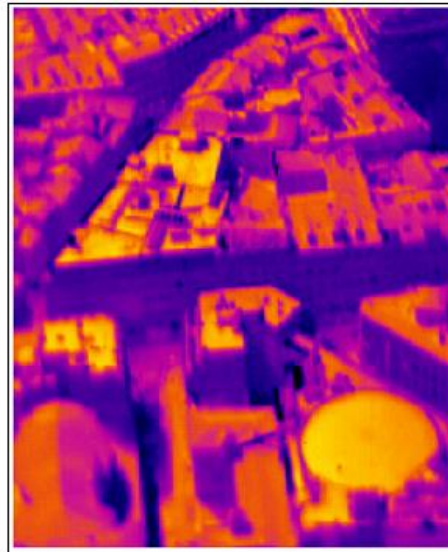
Visible image



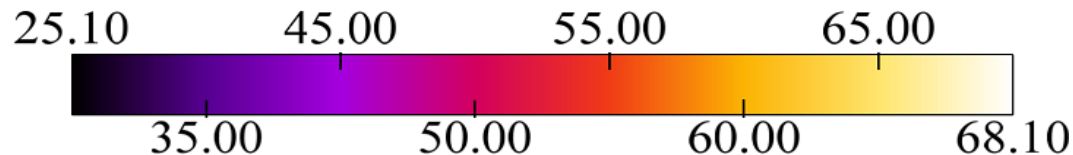
+ IR image

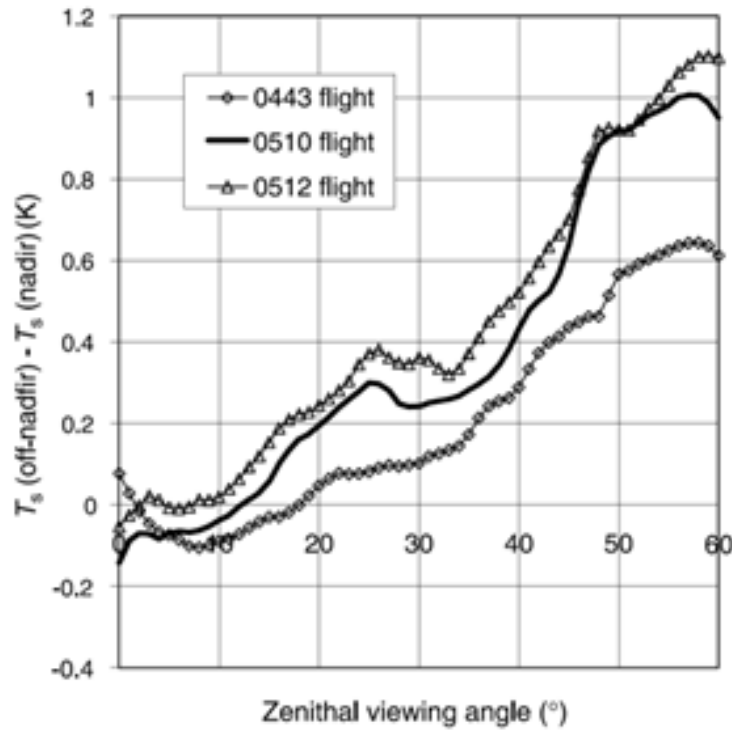
Context / Motivation

- ❑ CAPITOUL (Masson et al., 2008)
- ❑ Thermal infrared (TIR) airborne images 1412 UT during flight 432 (Henon, 2008; Lagouarde et al., 2010):

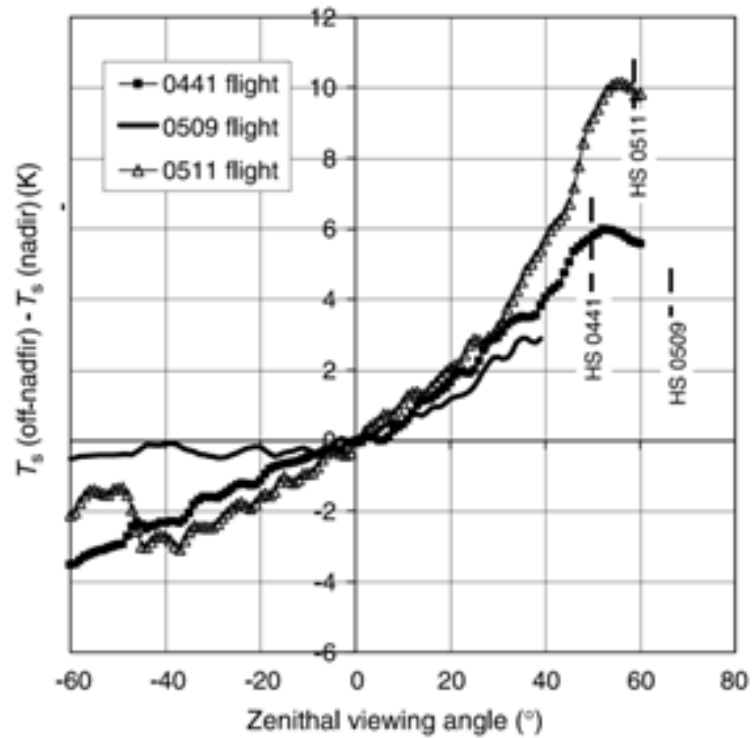


Measured T_{br} ($^{\circ}\text{C}$)





Night flights



Day flights

?
90

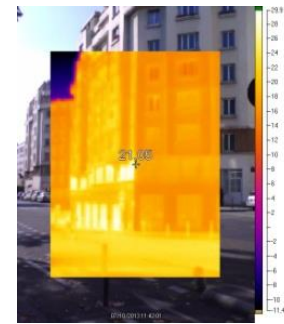
Infrared camera



File « xxx.is2 »
(Fluke format)



Visible image



+ IR image

9 stop points
8 horizontal dir. + 3vert.
~Every 3h, 3days (20)
January, April, June
~6000 IR pictures
+ visible

Toutes les températures dans °C.

Z:\D\100FLUKE\IR003434.IS2

	1	2	3	4	5	6	7	8	9	10	11
1	~-11,13	~-11,17	~-11,23	~-11,23	~-11,33	~-11,17	~-11,17	~-11,08	~-10,98	~-11,17	~-11,17
2	~-11,08	~-11,03	~-11,23	~-11,42	~-11,23	~-11,08	~-11,13	~-11,23	~-10,78	~-10,98	~-11,17
3	~-10,38	~-11,03	~-10,88	~-11,03	~-10,48	~-11,03	~-11,03	~-10,73	~-10,83	~-10,53	~-10,53
4	~-10,94	~-10,73	~-10,83	~-10,64	~-10,53	~-10,69	~-10,64	~-10,69	~-10,69	~-10,69	~-10,73
5	~-10,39	~-10,34	~-10,53	~-10,64	~-10,44	~-10,48	~-10,73	~-10,69	~-10,53	~-10,53	~-10,23
6	~-10,34	~-10,44	~-10,48	~-10,64	~-10,30	~-10,34	~-10,34	~-10,34	~-10,39	~-10,39	~-10,39
7	~-10,44	~-10,14	~-10,48	~-10,05	~-10,05	~-10,14	~-10,00	~-10,44	~-10,00	~-10,14	~-10,14
8	~-9,84	~-10,05	~-10,09	~-9,95	~-9,80	~-9,95	~-9,95	10,00	~-9,61	~-10,09	~-9,95
9	~-9,84	~-9,80	~-9,80	~-10,05	~-9,75	~-9,84	~-9,75	~-9,84	~-9,75	~-9,84	~-9,70
10	~-9,41	~-9,61	~-9,52	~-9,75	~-9,66	~-9,61	~-9,56	~-9,13	~-9,84	~-9,70	~-9,95
11	~-9,36	~-9,41	~-9,47	~-9,61	~-9,47	~-9,31	~-9,31	~-9,47	~-9,31	~-9,47	~-9,13
12	~-9,31	~-9,36	~-9,56	~-9,27	~-9,36	~-9,41	~-9,03	~-9,27	~-9,31	~-9,08	~-9,08
13	~-9,08	~-9,27	~-9,08	~-9,08	~-9,03	~-8,88	~-9,13	~-9,31	~-9,08	~-8,88	~-8,88
14	~-9,17	~-8,83	~-8,98	~-8,83	~-8,69	~-8,78	~-8,78	~-8,73	~-8,83	~-8,88	~-8,88
15	~-8,69	~-8,88	~-8,59	~-8,73	~-8,59	~-8,55	~-8,64	~-8,59	~-8,55	~-8,88	~-8,88
16	~-8,41	~-8,25	~-8,41	~-8,45	~-8,64	~-8,59	~-8,50	~-8,59	~-8,31	~-8,70	~-8,88
17	~-8,11	~-8,31	~-8,45	~-8,36	~-8,36	~-8,45	~-8,16	~-8,36	~-8,31	~-8,06	~-8,88
18	~-7,83	~-7,97	~-7,97	~-8,16	~-8,11	~-8,36	~-7,88	~-8,02	~-7,97	~-7,97	~-7,97
19	~-7,92	~-7,73	~-7,97	~-7,64	~-8,02	~-7,92	~-7,78	~-7,78	~-7,83	~-7,73	~-7,73
20	~-7,88	~-7,73	~-7,69	~-7,59	~-7,69	~-7,69	~-7,69	~-7,69	~-7,69	~-7,50	~-7,50
21	~-7,27	~-7,59	~-7,55	~-7,50	~-7,41	~-7,31	~-7,41	~-7,17	~-7,41	~-7,13	~-7,13
22	~-7,36	~-7,13	~-7,03	~-7,13	~-7,36	~-7,36	~-7,17	~-6,98	~-7,27	~-7,13	~-7,13
23	~-6,78	~-7,03	~-6,69	~-6,64	~-6,69	~-6,88	~-6,59	~-7,03	~-7,08	~-6,78	~-6,78
24	~-6,50	~-6,69	~-6,69	~-6,78	~-6,73	~-6,64	~-6,45	~-6,94	~-6,73	~-6,83	~-6,83
25	~-6,14	~-6,50	~-6,64	~-6,69	~-6,64	~-6,55	~-6,64	~-6,33	~-6,55	~-6,38	~-6,38
26	~-5,81	~-6,38	~-6,14	~-6,14	~-6,50	~-6,38	~-6,09	~-6,14	~-6,28	~-6,09	~-6,09
27	~-5,48	~-5,95	~-6,14	~-6,14	~-5,86	~-6,19	~-6,09	~-5,91	~-6,05	~-5,95	~-5,95
28	~-5,44	~-5,72	~-5,81	~-6,00	~-5,63	~-5,77	~-5,77	~-5,86	~-5,48	~-6,00	~-6,00

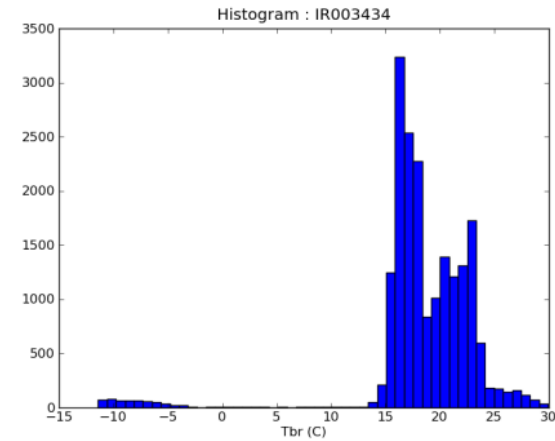
IR data

➔ Manual classification (time consuming team work!)

Filière de traitement (python):

- Relecture des fichiers .txt
- figures
- statistiques

```
toutes les températures dans °C.
Z:\D\100FLUKE\IR003434.IS2
1  --11,13 --11,17 --11,23 --11,23 --11,33 --11,17 --11,17 --11,08 --10,98 --11,17 --
2  --11,08 --11,03 --11,23 --11,42 --11,23 --11,08 --11,13 --11,23 --10,78 --10,98 --
3  --10,58 --11,03 --10,88 --11,03 --10,48 --11,03 --11,03 --10,73 --10,83 --10,53 --
4  --10,94 --10,73 --10,83 --10,64 --10,53 --10,69 --10,64 --10,69 --10,69 --10,73 --
5  --10,39 --10,34 --10,53 --10,64 --10,44 --10,48 --10,73 --10,69 --10,53 --10,23 --
6  --10,34 --10,44 --10,48 --10,64 --10,30 --10,34 --10,34 --10,34 --10,39 --10,39 --
7  --10,44 --10,14 --10,48 --10,05 --10,05 --10,14 --10,00 --10,44 --10,14 --
8  -9,84 --10,05 --10,09 -9,95 -9,80 -9,95 -9,95 -10,00 -9,61 --10,09 -9
9  -9,84 -9,80 -9,80 --10,05 -9,75 -9,84 -9,75 -9,84 -9,75 -9,70 -9
10 -9,41 -9,61 -9,52 -9,75 -9,66 -9,61 -9,56 -9,13 -9,84 -9,70 -9
11 -9,36 -9,41 -9,47 -9,61 -9,47 -9,61 -9,31 -9,31 -9,47 -9,13 -9
12 -9,31 -9,36 -9,56 -9,27 -9,36 -9,41 -9,03 -9,27 -9,31 -9,08 -9
13 -9,08 -9,27 -9,08 -9,08 -9,03 -8,88 -9,13 -9,31 -9,08 -8,88 -8
14 -9,17 -8,83 -8,98 -8,83 -8,69 -8,78 -8,78 -8,73 -8,83 -8,88 -8
15 -8,69 -8,88 -8,59 -8,73 -8,59 -8,55 -8,64 -8,59 -8,55 -8,88 -8
16 -8,41 -8,25 -8,41 -8,45 -8,64 -8,59 -8,50 -8,59 -8,31 -8,20 -8
17 -8,11 -8,31 -8,45 -8,36 -8,36 -8,45 -8,16 -8,36 -8,31 -8,06 -8
18 -7,83 -7,97 -7,97 -8,16 -8,11 -8,36 -7,88 -8,02 -7,97 -7,97 -7
19 -7,92 -7,73 -7,97 -7,64 -8,02 -7,92 -7,78 -7,78 -7,83 -7,73 -7
20 -7,88 -7,73 -7,69 -7,59 -7,69 -7,69 -7,69 -7,69 -7,69 -7,50 -7
21 -7,27 -7,59 -7,55 -7,50 -7,41 -7,31 -7,41 -7,17 -7,41 -7,13 -7
22 -7,36 -7,13 -7,03 -7,13 -7,36 -7,36 -7,17 -6,98 -7,27 -7,13 -7
23 -6,78 -7,03 -6,69 -6,64 -6,69 -6,88 -6,59 -7,03 -7,08 -6,78 -6
24 -6,50 -6,69 -6,69 -6,78 -6,73 -6,64 -6,45 -6,94 -6,73 -6,83 -6
25 -6,14 -6,50 -6,64 -6,69 -6,64 -6,55 -6,64 -6,33 -6,55 -6,38 -6
26 -5,81 -6,38 -6,14 -6,14 -6,50 -6,38 -6,09 -6,14 -6,28 -6,09 -6
27 -5,48 -5,95 -6,14 -6,14 -5,86 -6,19 -6,09 -5,91 -6,05 -5,95 -6
28 -5,44 -5,72 -5,81 -6,00 -5,63 -5,77 -5,77 -5,86 -5,48 -6,00 -5
```



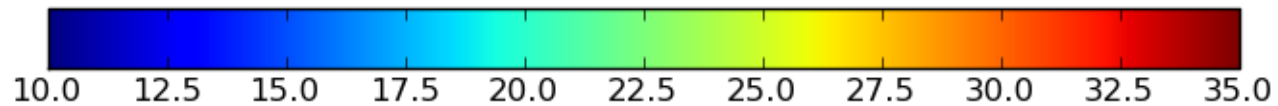
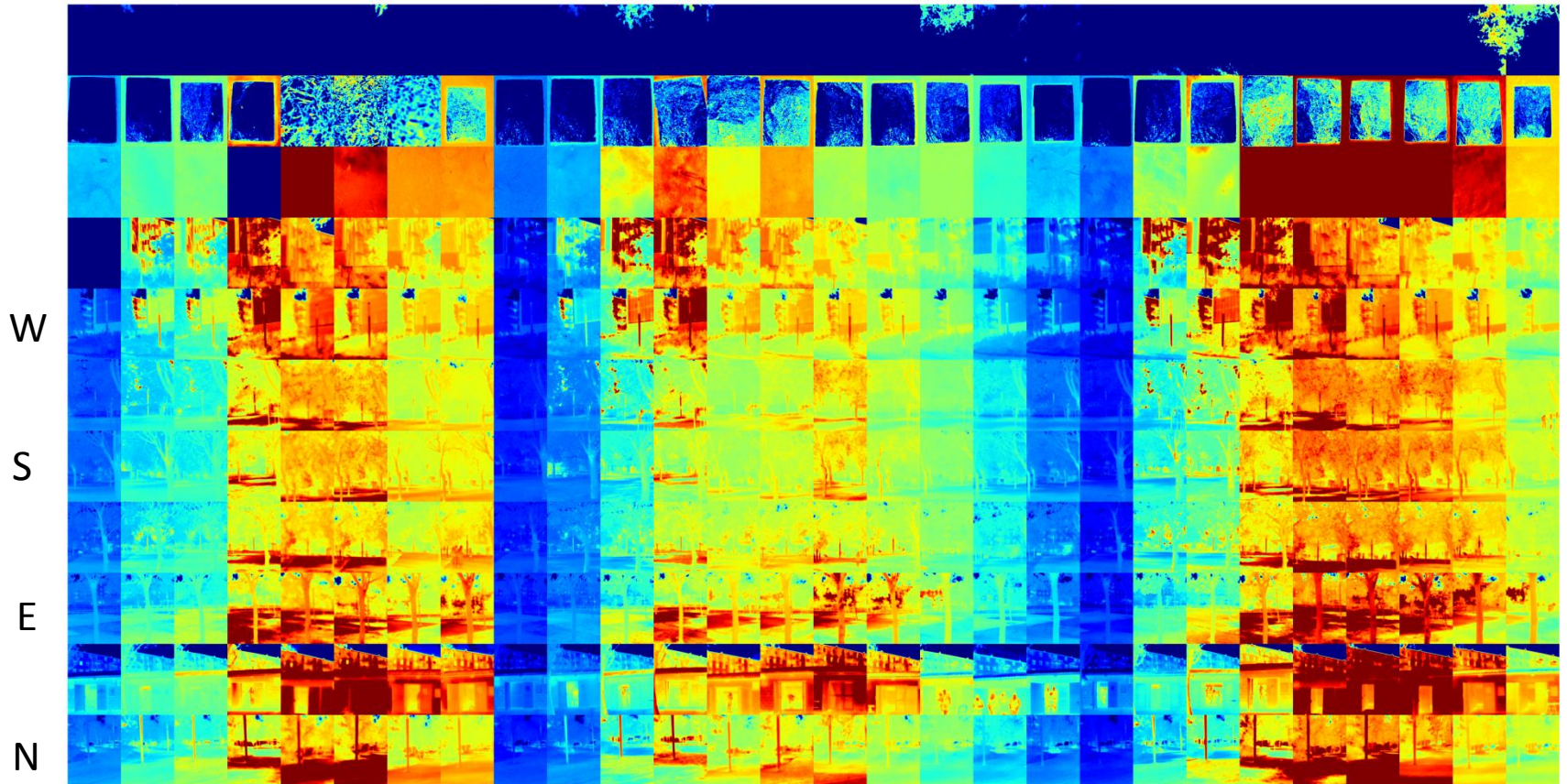
Base de données (format .xls) contenant les statistiques et les repères spatiaux temporels (entrées manuelles)

Filename	Day	Hour	Location	Direction	Choice	Tspot	Tmin	Tmax	Tmean	Tstd	Tp05	Tp10	Tp25	Tp50	Tp75	Tp90	Tp95	
IR003539	7	18	3	3	-1	1	20,83	20,36	22,06	21,09	0,31	20,66	20,72	20,83	21,02	21,34	21,56	21,63
IR003540	7	18	3	3	-2	1	16,77	4,95	22,78	18,93	2,26	14,97	15,69	17,02	20,55	20,77	20,88	20,98
IR003541	7	18	3	3	0	1	18	-1,33	24,44	18,08	1,86	16,56	17,02	17,55	18,14	19,16	19,59	19,73
IR003542	7	18	3	3	1	1	18,7	-17,58	20,91	17,66	3,18	15,47	17,22	17,7	18,38	18,59	18,81	18,97
IR003543	7	18	3	3	2	1	18,48	16,8	21,2	18,97	0,47	18,19	18,45	18,7	19	19,27	19,48	19,67
IR003544	7	18	3	3	3	1	19,27	-12,33	22,06	18,00	2,55	15,34	16,98	17,81	18,33	19,08	19,59	19,89
IR003545	7	18	3	3	4	1	19,67	-0,45	27,59	17,78	3,04	11,72	15,97	17,92	18,67	19,11	19,38	19,52
IR003546	7	18	3	3	5	1	18,97	3	26,83	17,71	2,11	15,63	16,98	17,55	18,08	18,52	19,08	19,38

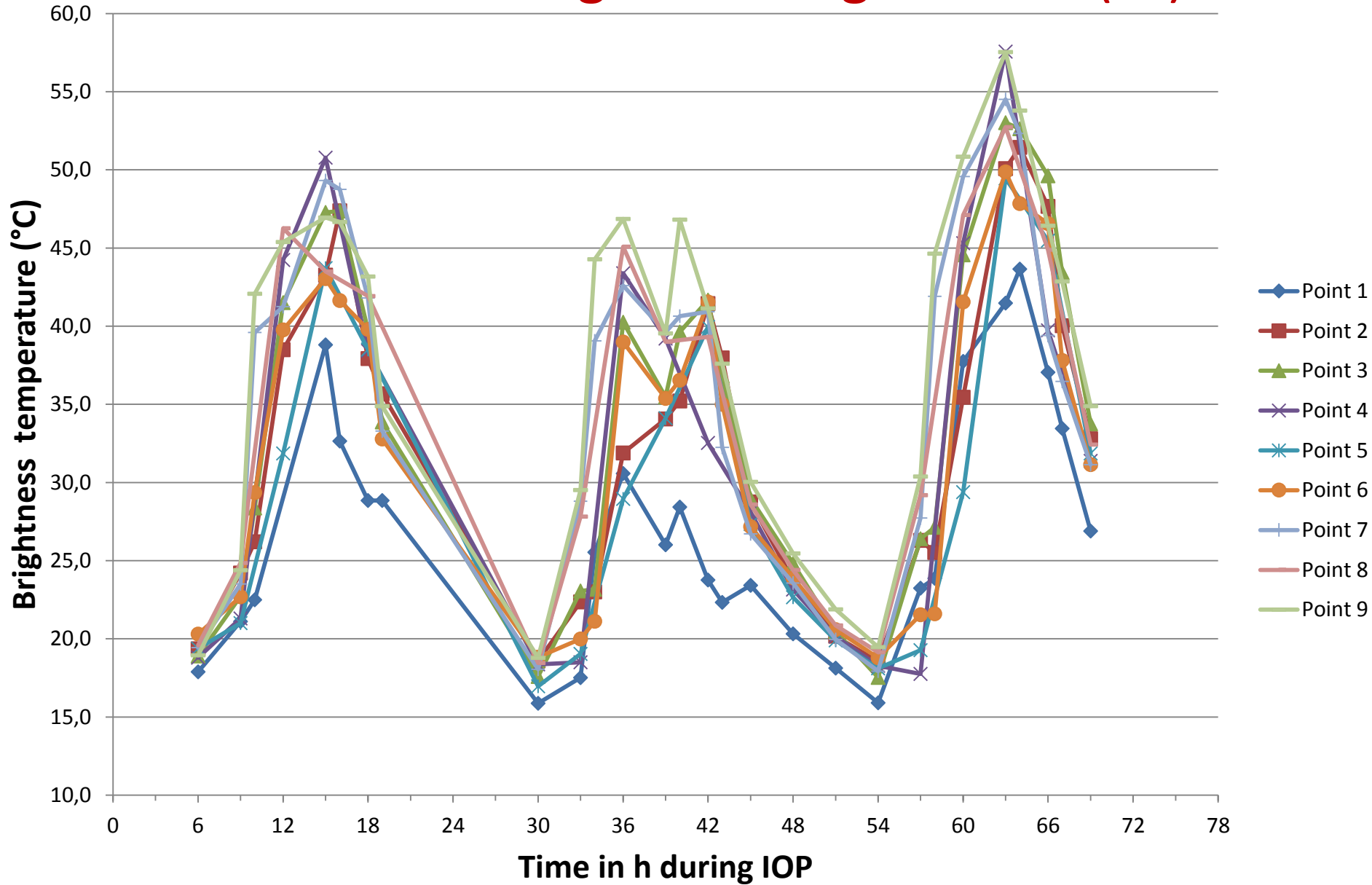
array of IR images, scaled and assembled

Ex : Toulouse POI 3 /Point 1

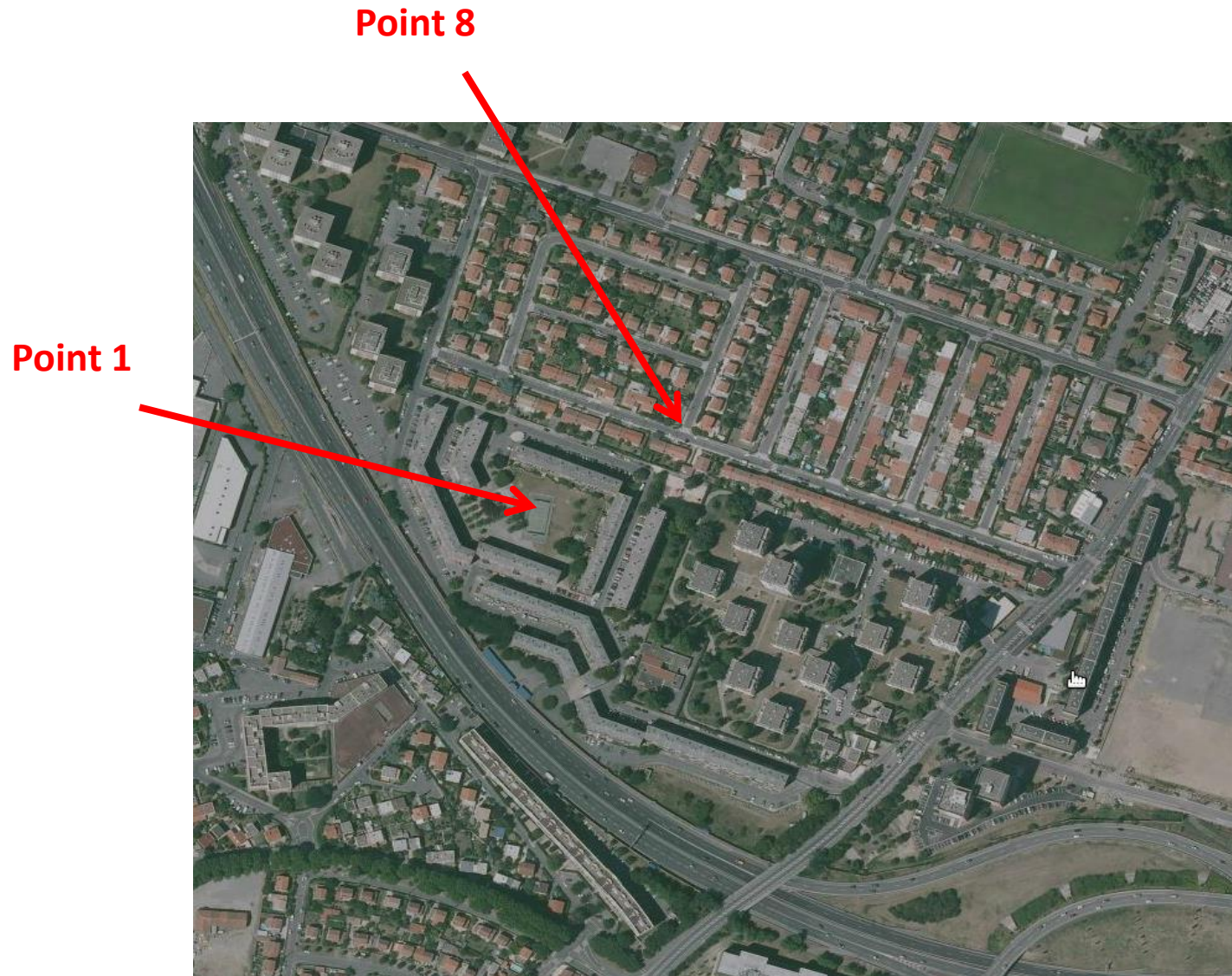
Time →



Time evolution of ground brightness T (°C)



Time evolution of local anisotropy : two locations selected



Visible images



N



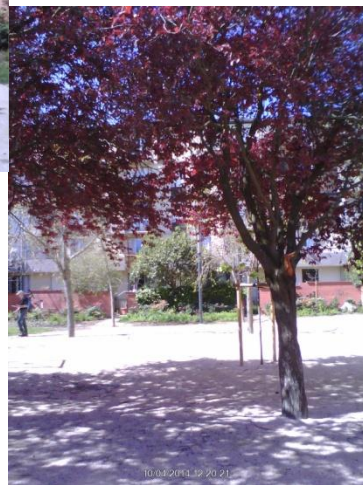
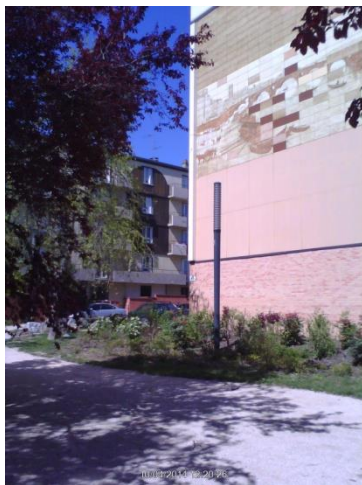
E



W

Point 1

S



Visible images



W

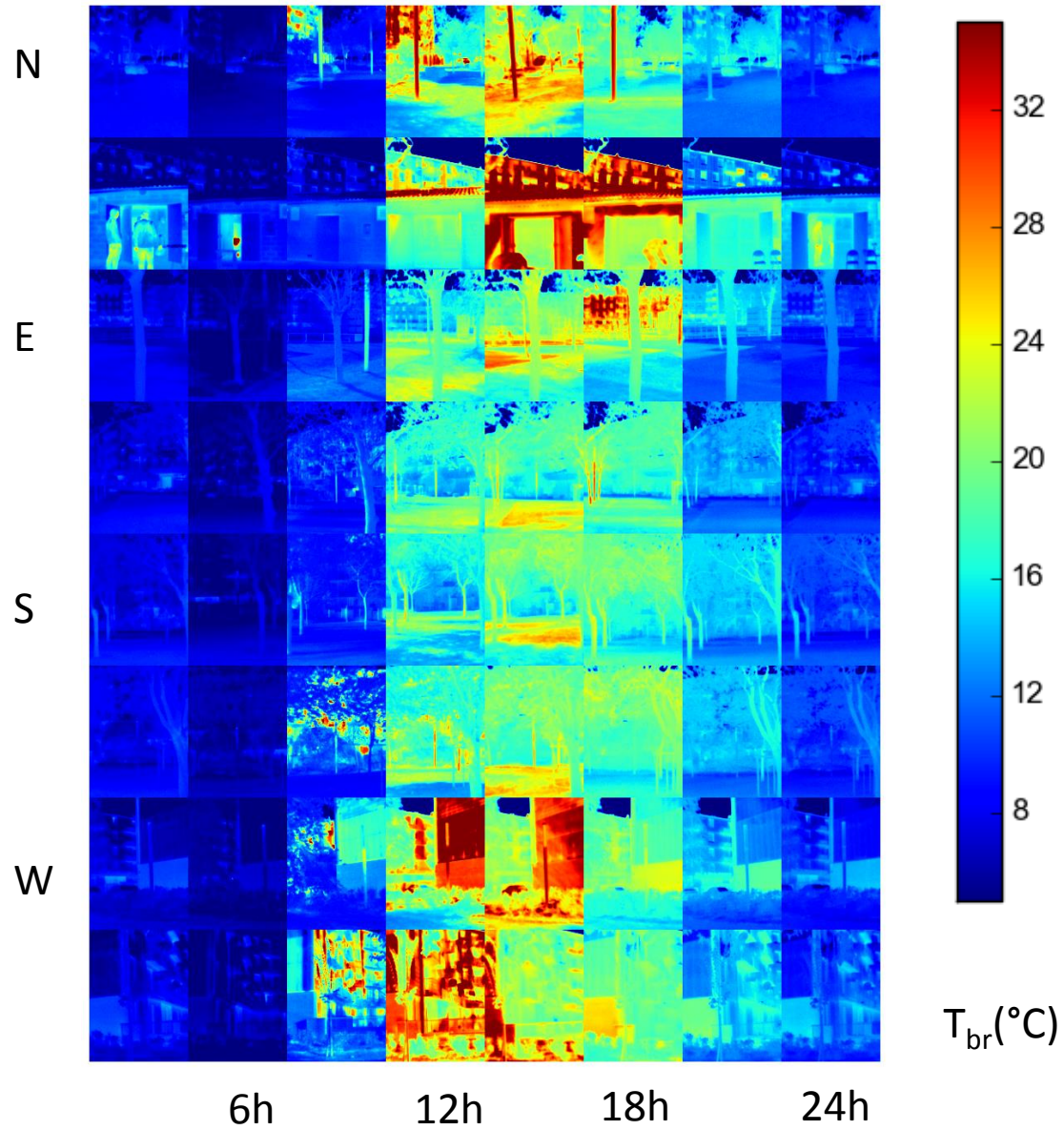
N

Point 8

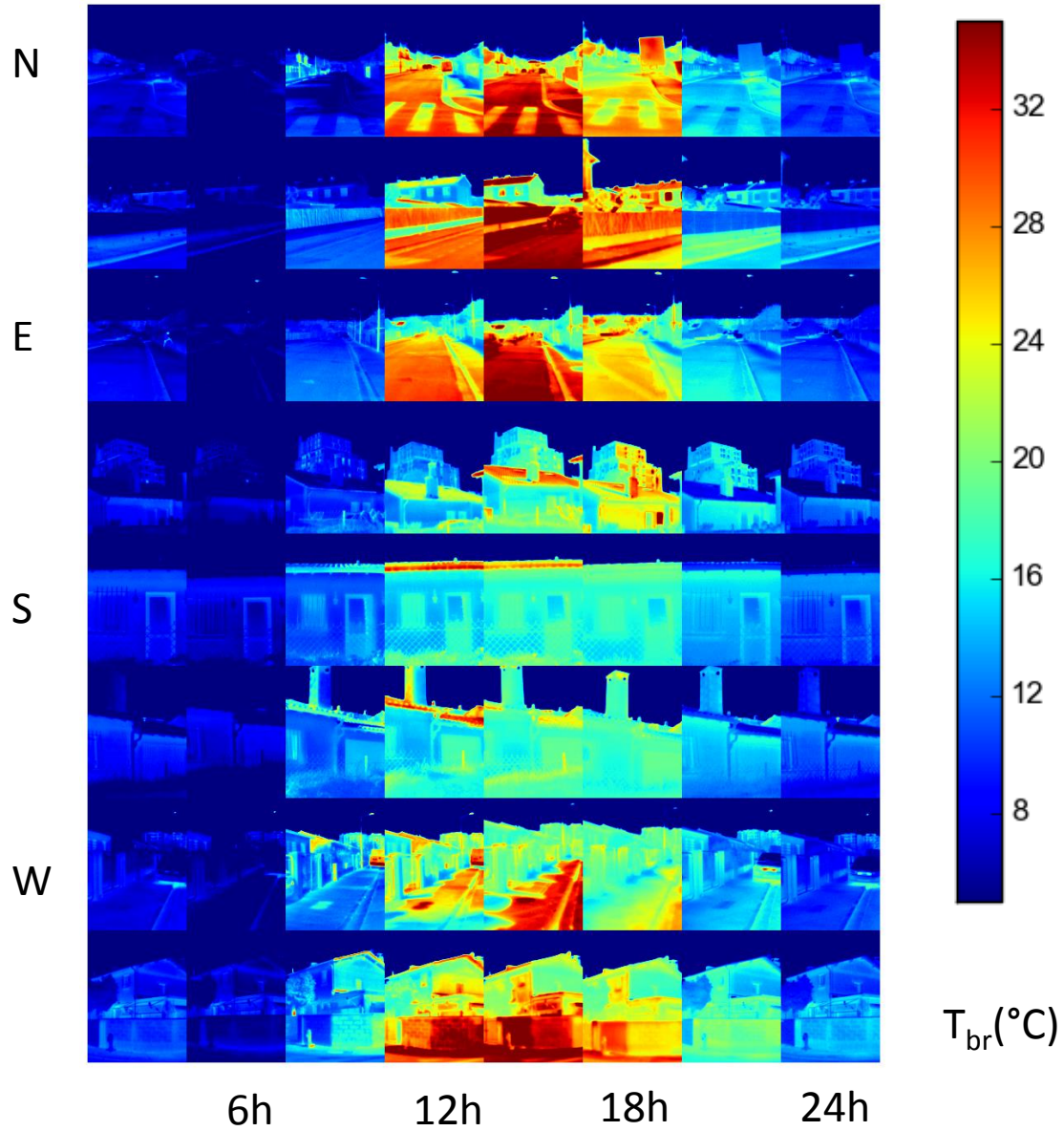
E

S

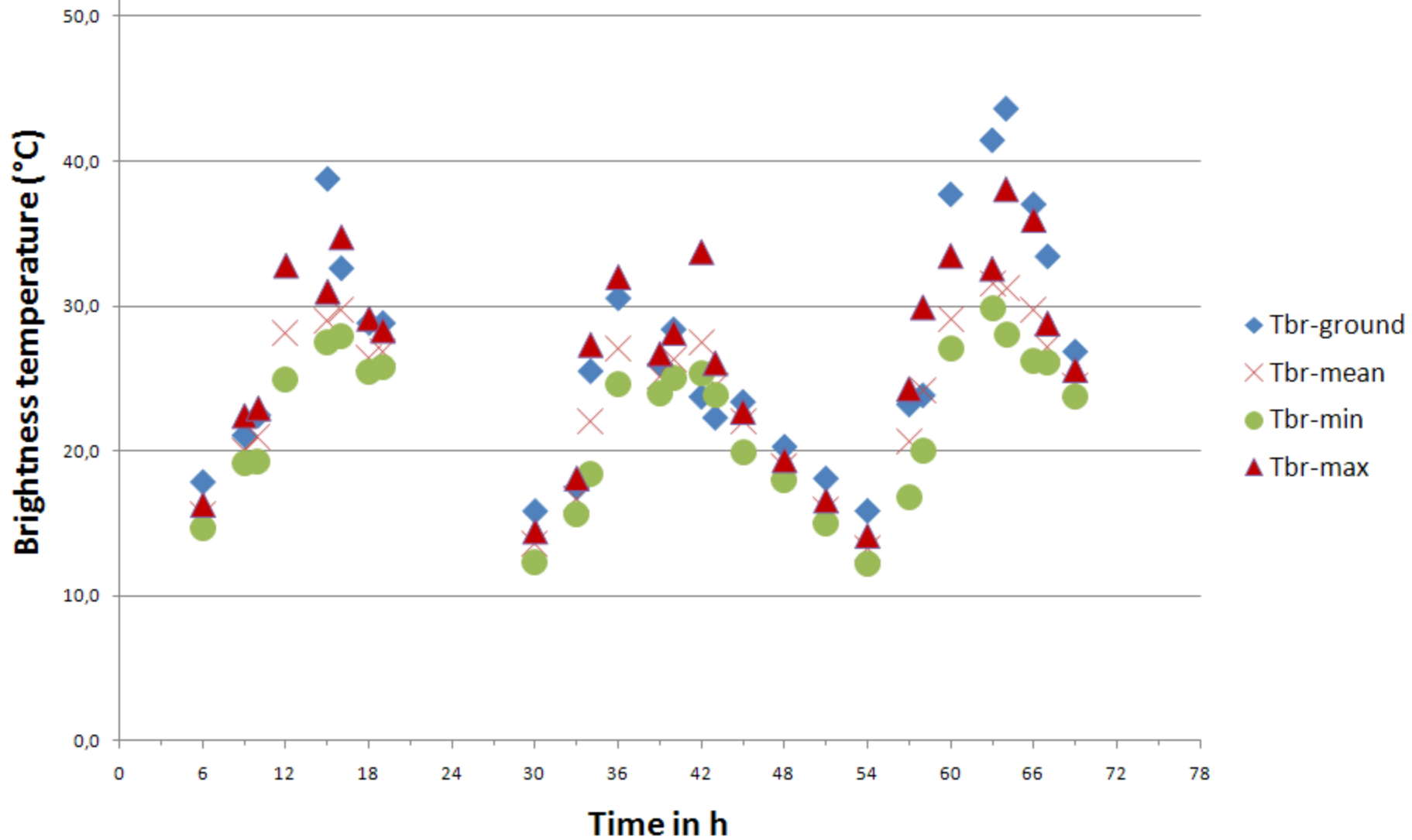
Point 1



Point 8

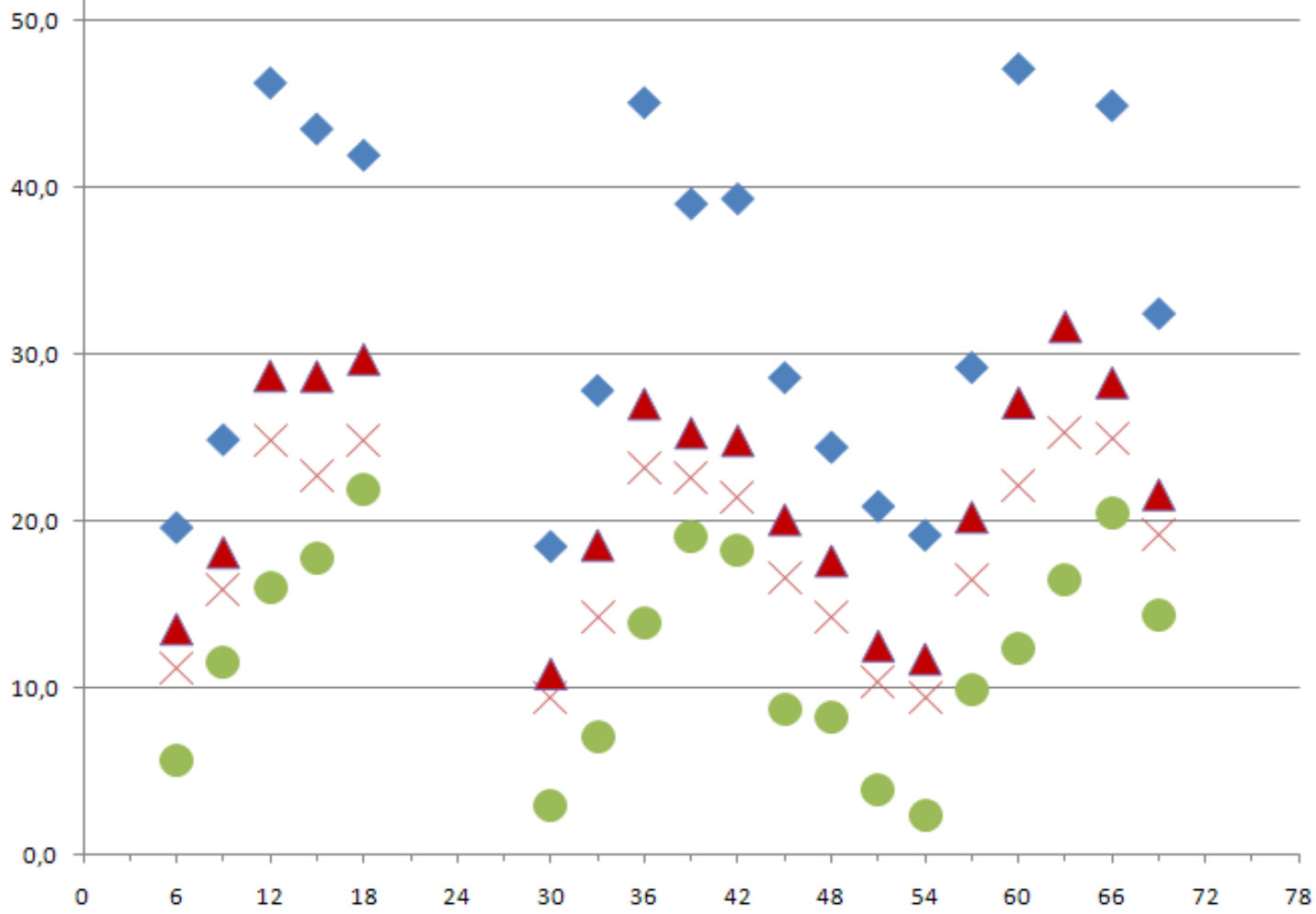


Point 1



Point 8

Brightness temperature (°C)



- ◆ Tbr-ground
- × Tbr-mean
- Tbr-min
- ▲ Tbr-max

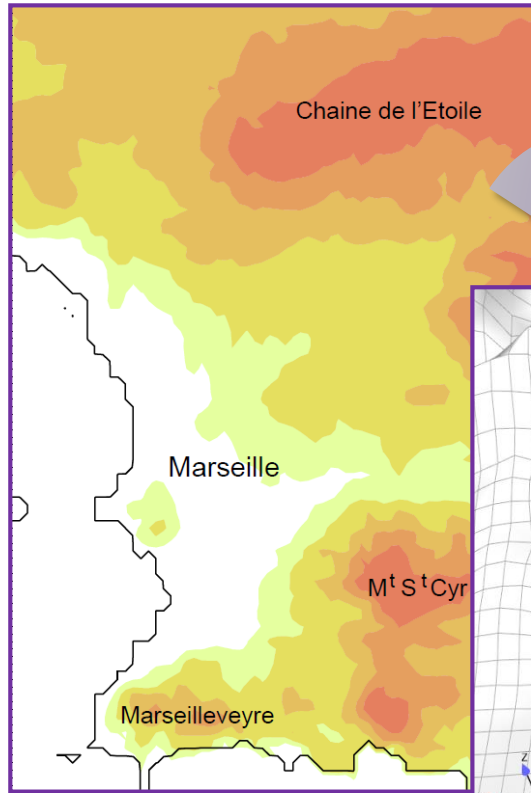
Numerical modeling :

3 - levels

Modèle dyn de trafic (ou comptage)

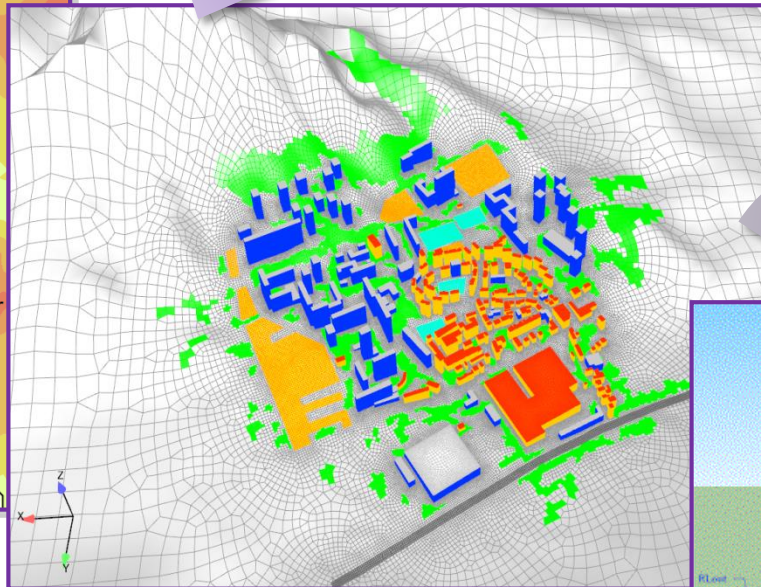


Modèle météo MESO-NH+TEB

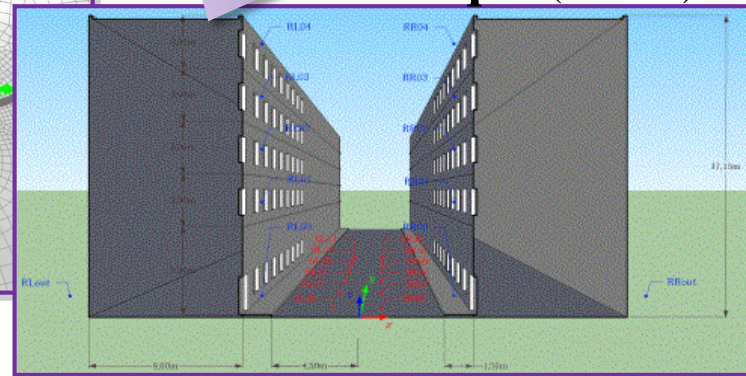


Boundary conditions

Modèle CFD+thermo-radiatif (800m x 500m)

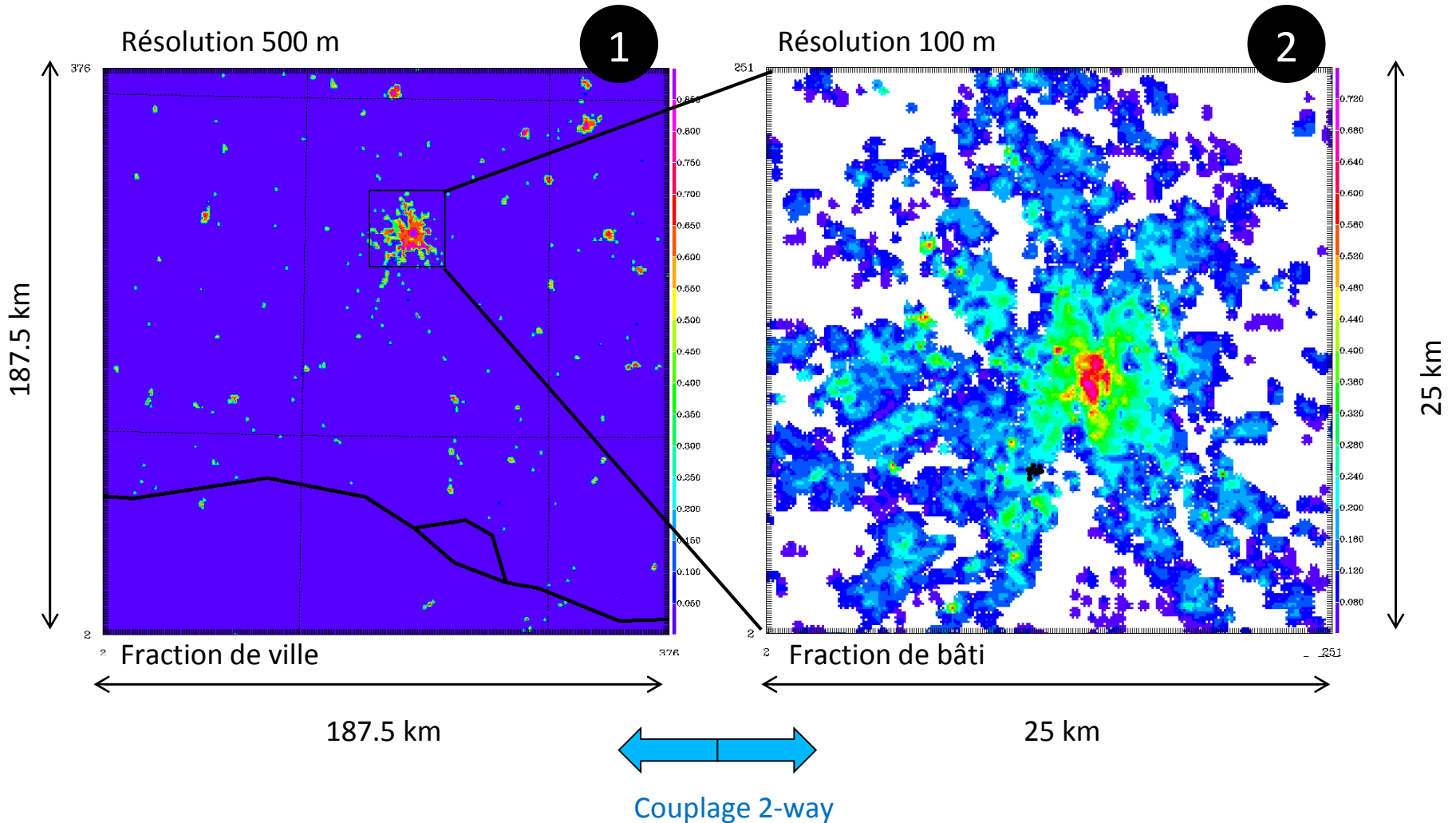


Modèle acoustique (~300m)

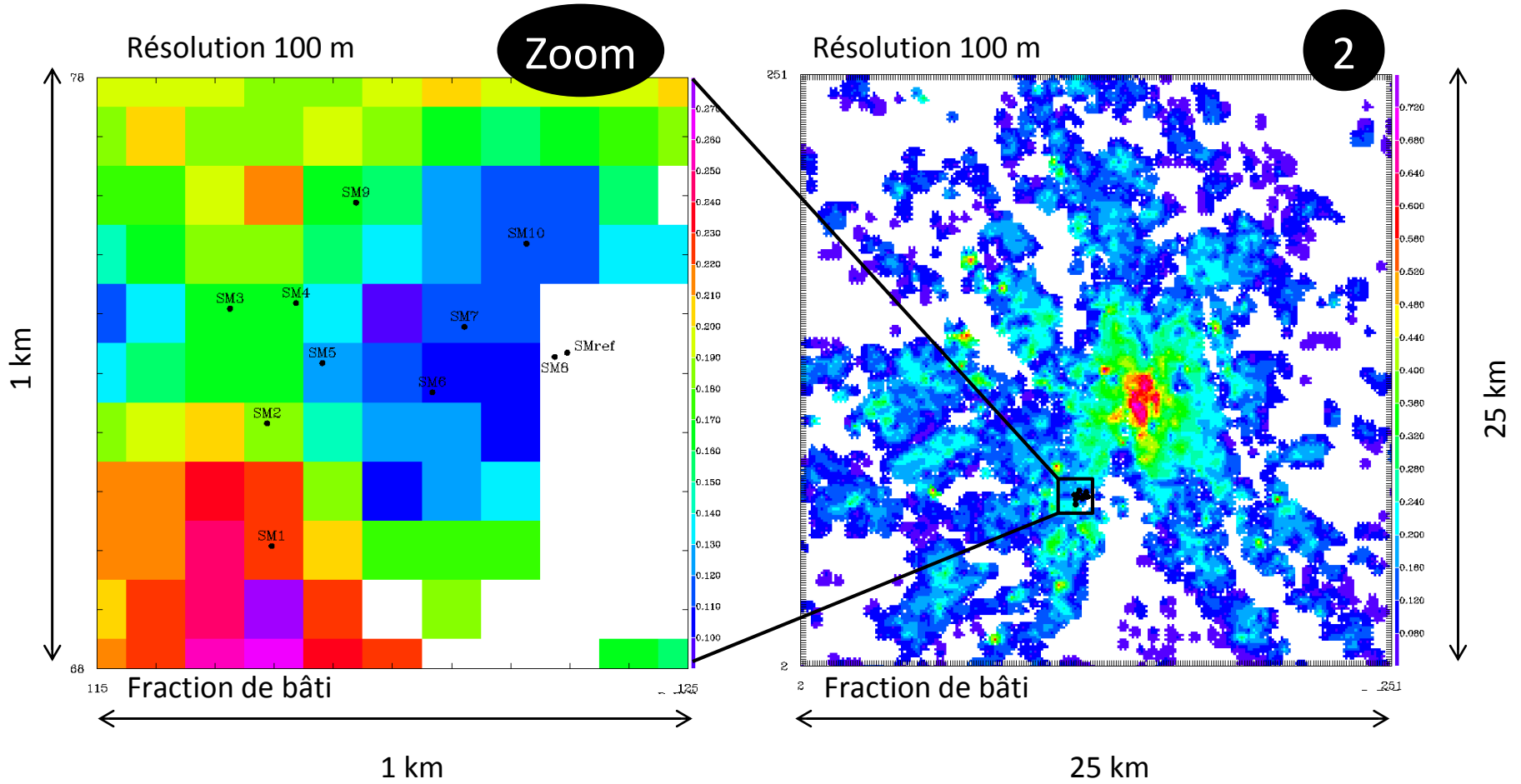


• Choix de la configuration de simulation Meso-NH (with TEB)

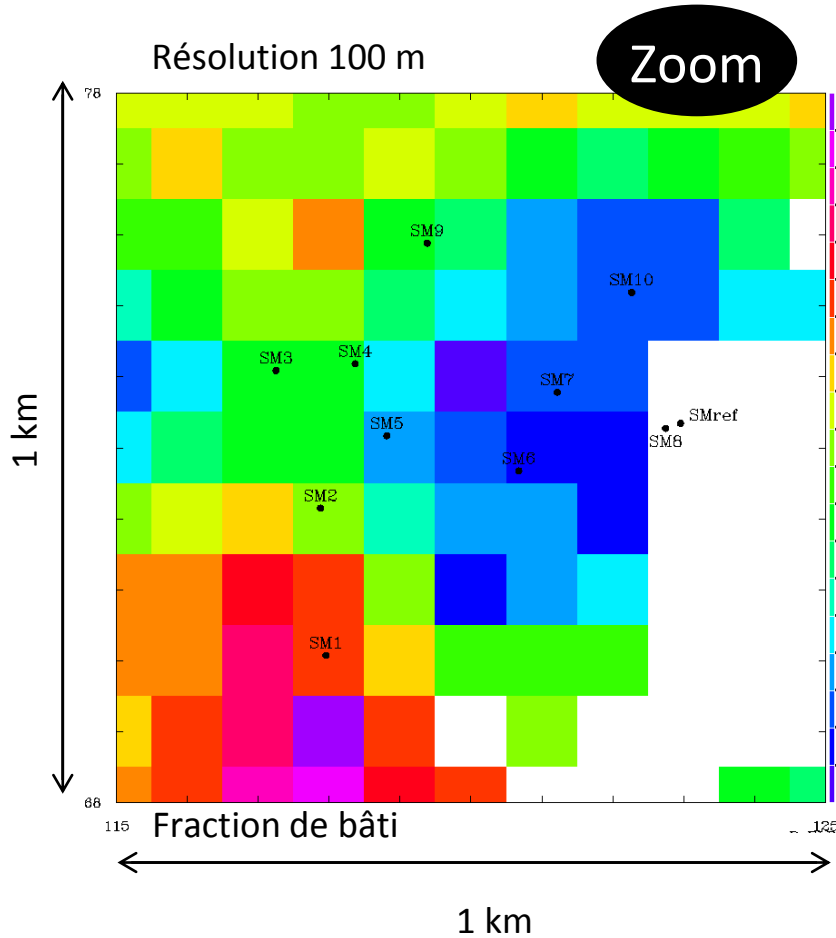
- 2 modèles → 2 domaines de simulation emboîtés



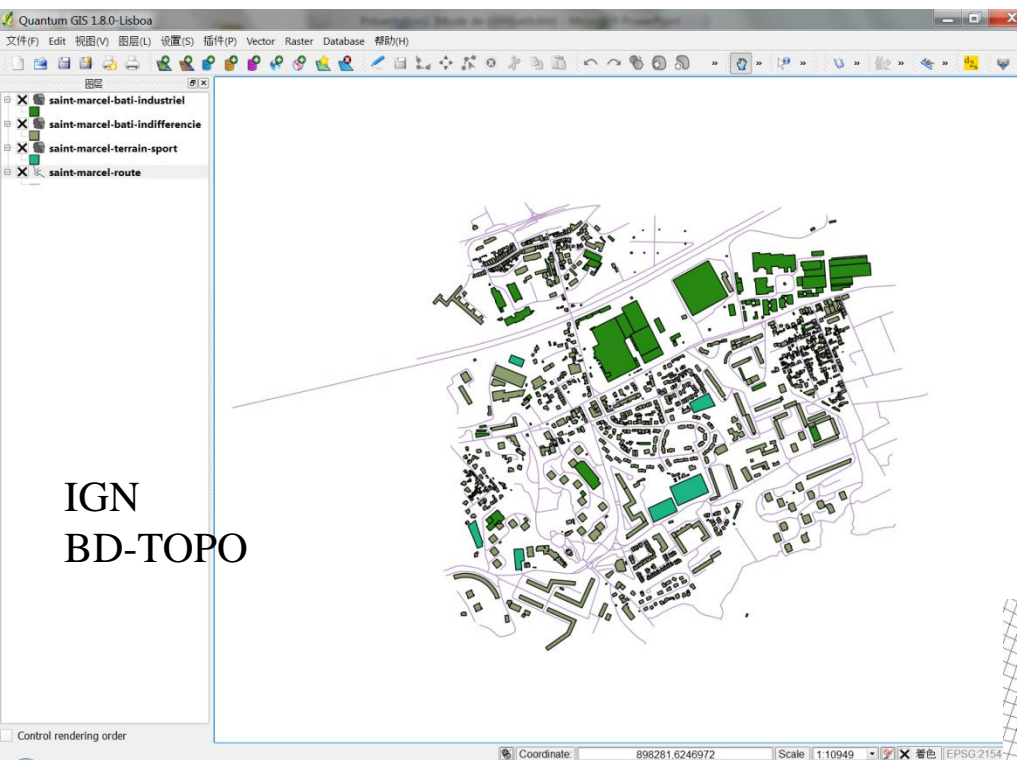
• Zoom sur la zone de la POI – réseau de stations fixes



• Zoom sur la zone de la POI – réseau de stations fixes



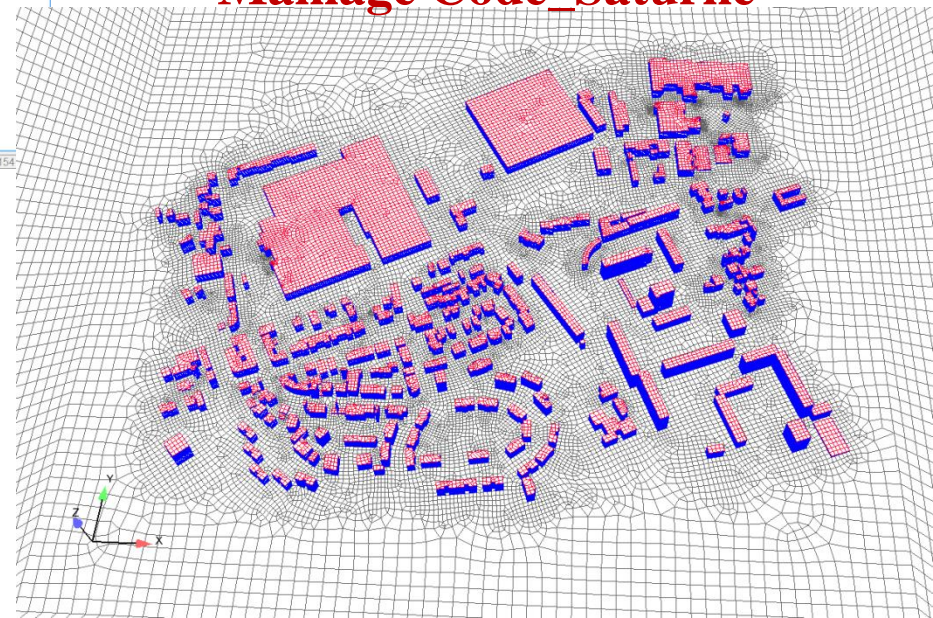
Maillage Marseille



IGN
BD-TOPO



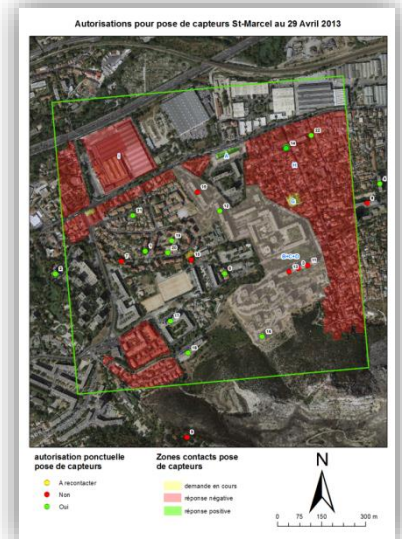
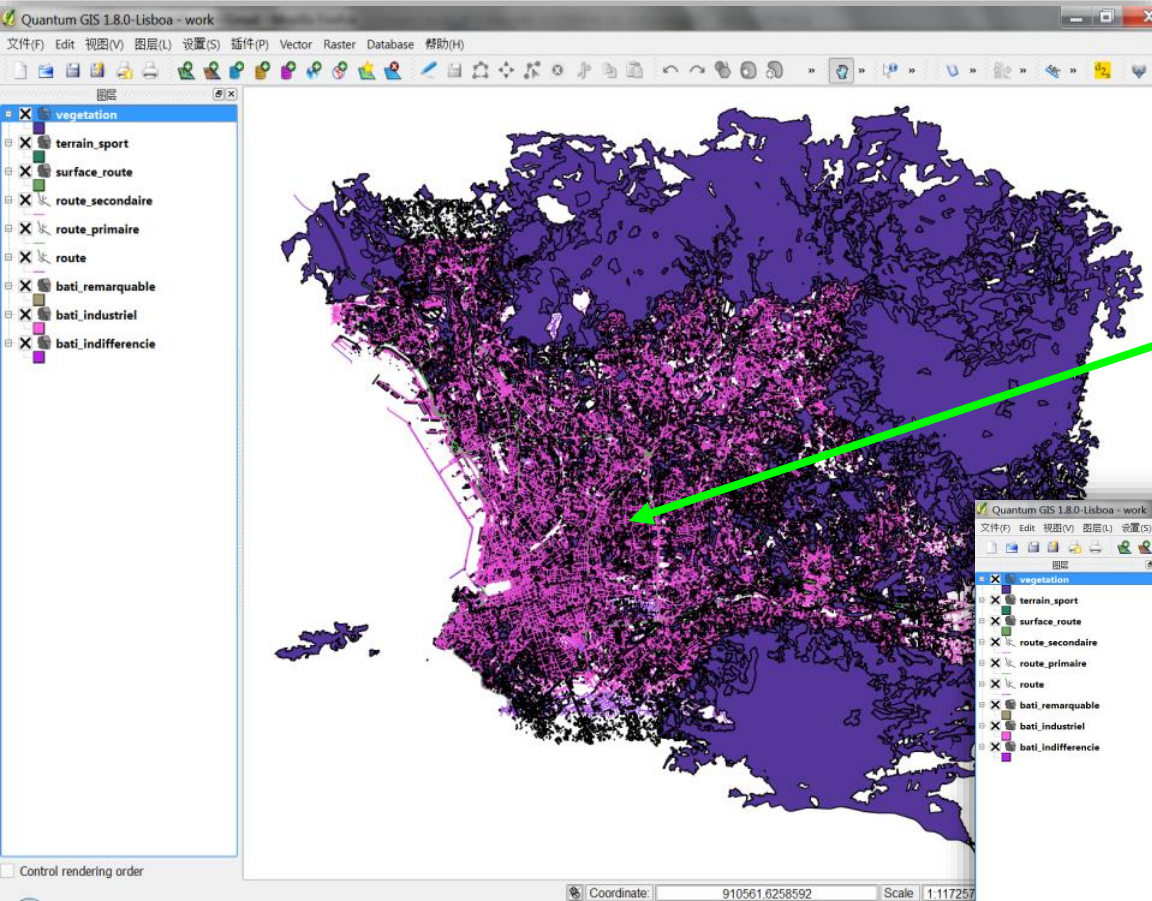
Maillage Code_Saturne



Geométrie et maillage :
salome-platform.org

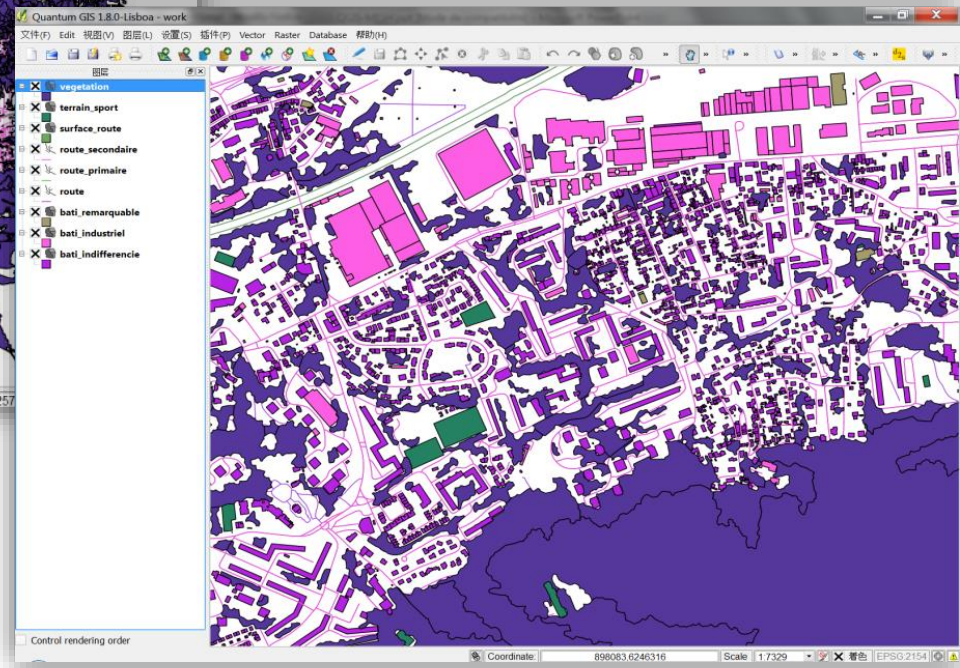
Sélection de données IGN sur le quartier (2,5D)

Vue globale de Marseille



Zone étudiée

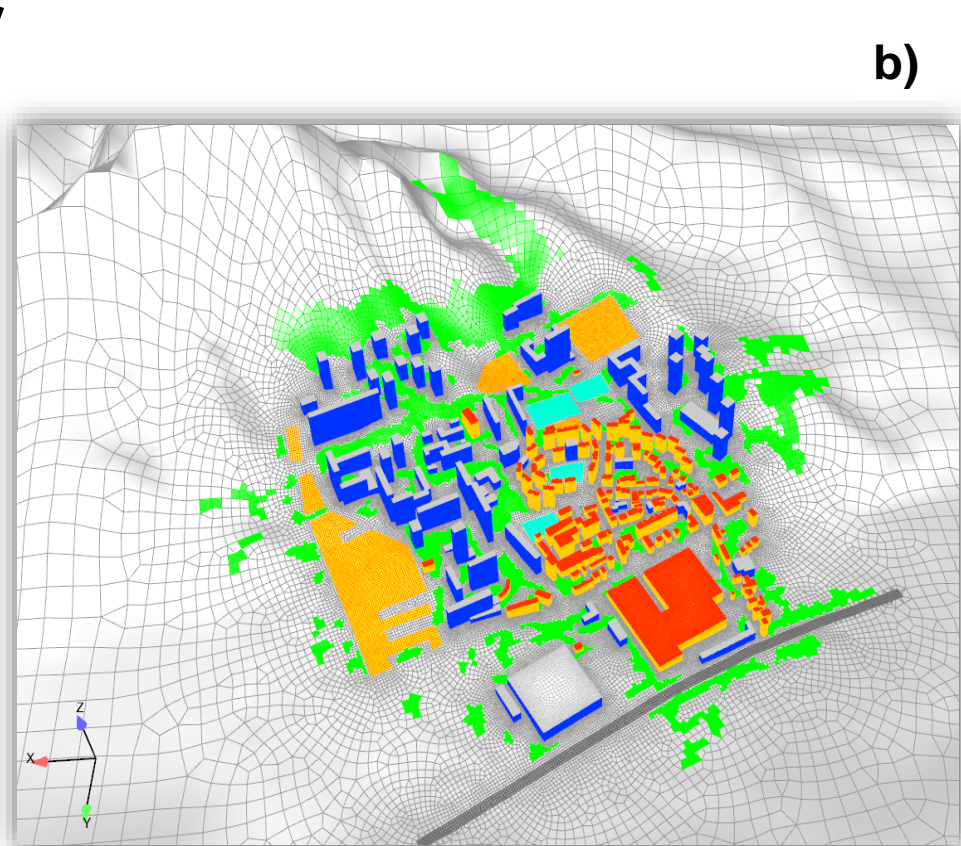
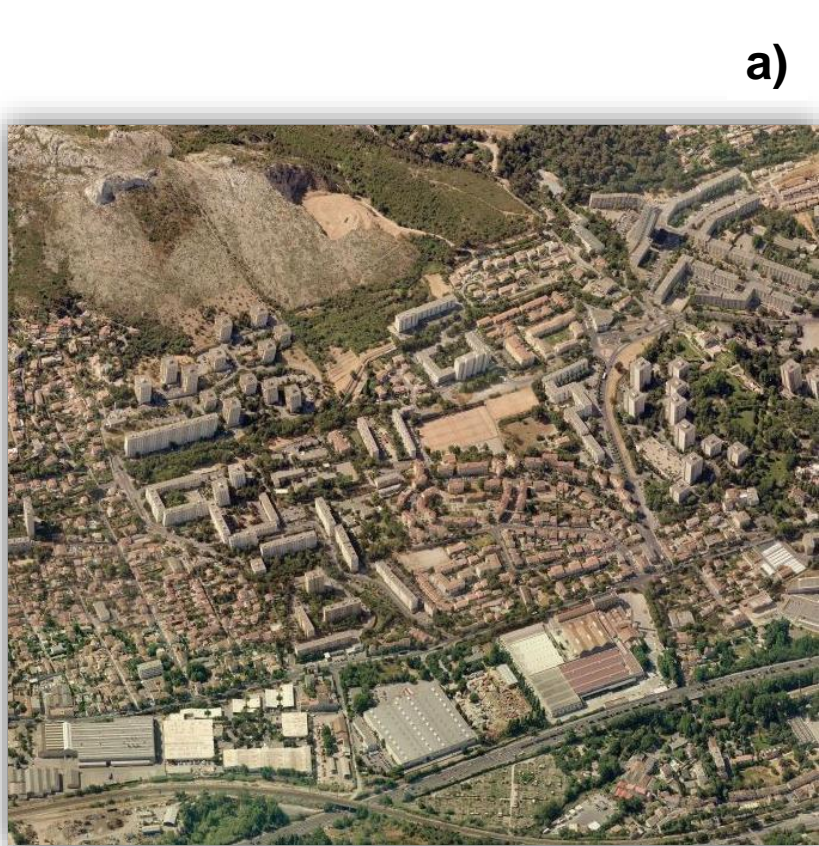
Données IGN disponibles sur toute la France



Relief

Fichier « *.asc »

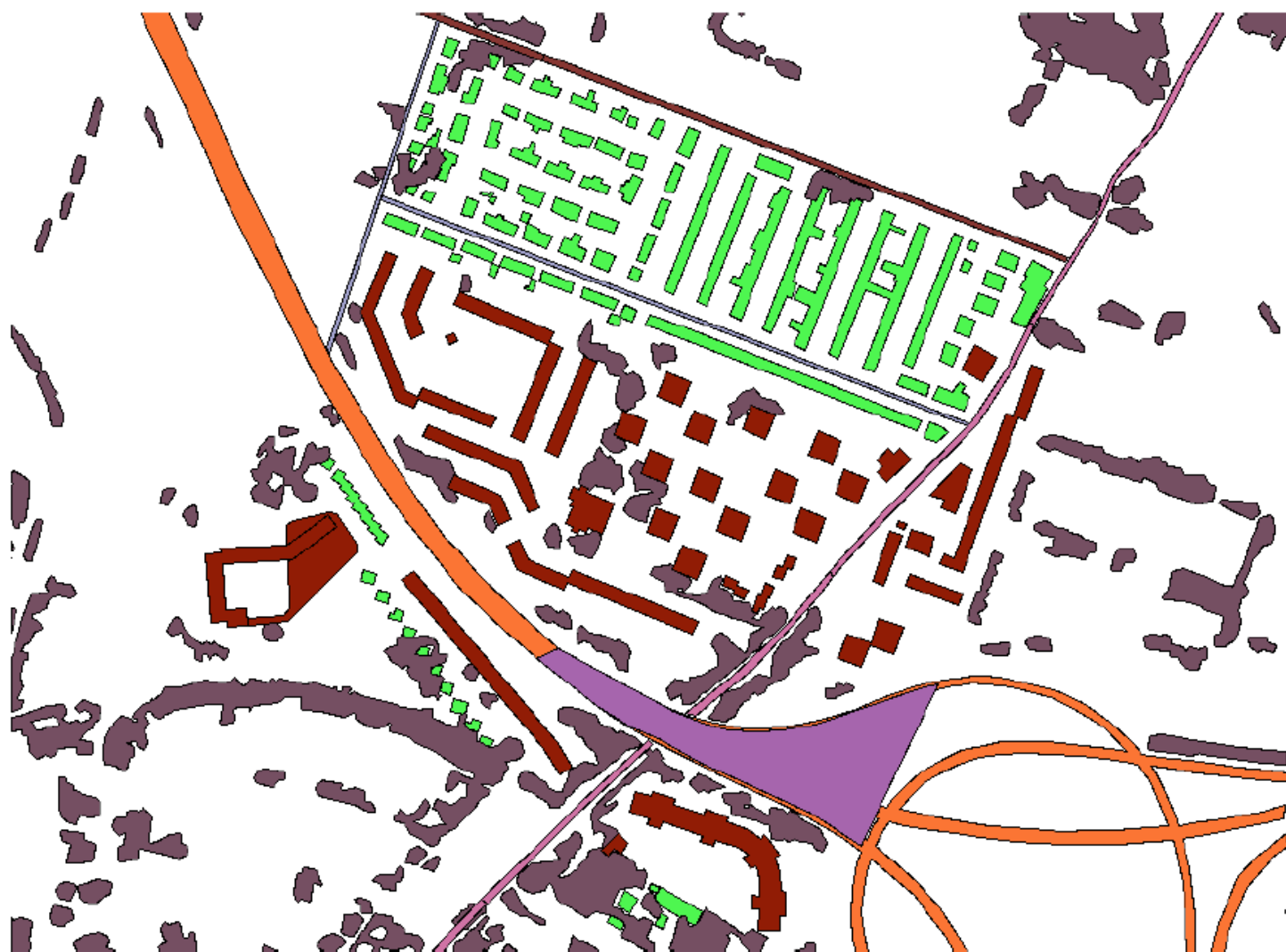
Résolution: 25 x 25 m



Mesh generation for zone 'Bordelongue'

- Geometry input: format *shapefile* of QGIS, *.shp*, *.shx*, *.dbf*
- Geometry simplification:
 - Selection of obstacles in the central zone: buildings, houses, autoroute, etc.
 - Simplification of geometrical forms:
 - python script: elimination of excessive points, convex envelop, Visvalingam-Whyatt algo., Ramer-Douglas-Peucker algo.
 - python script: fusion of nearby points
 - by hands
- Mesh generation with Salome script

Geometry simplification



Remove all the surrounding buildings

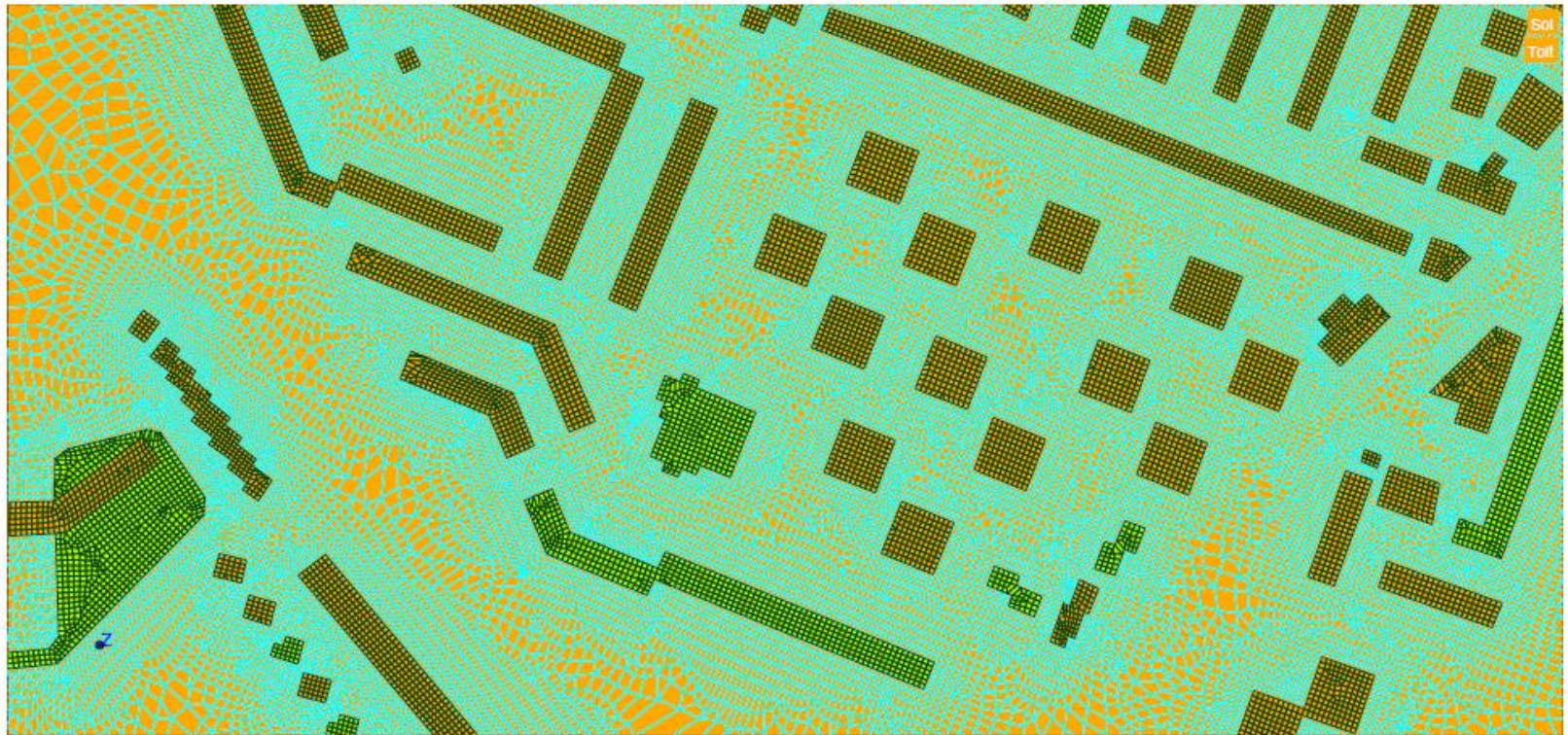
Geometry simplification

- Python script developed by CEREA
- By hands using QGIS

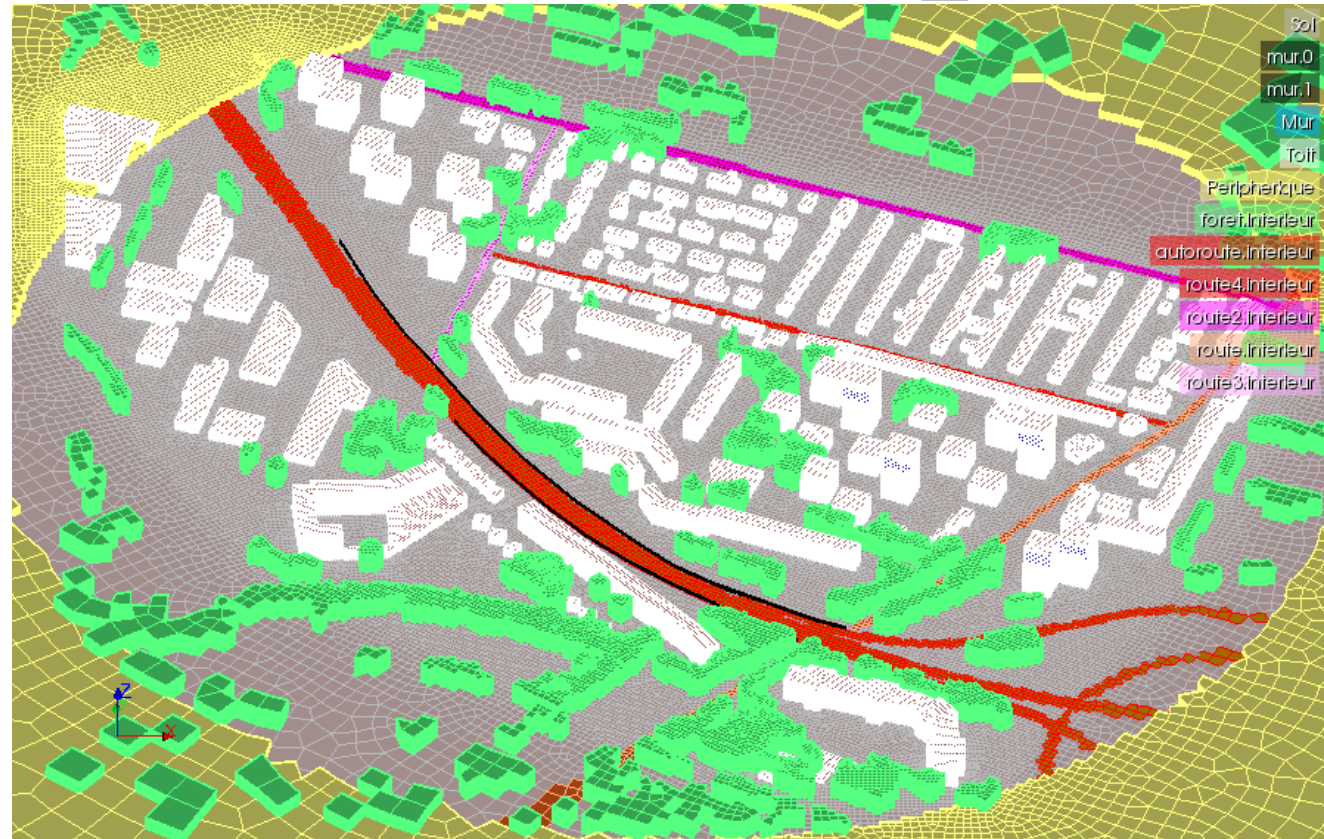
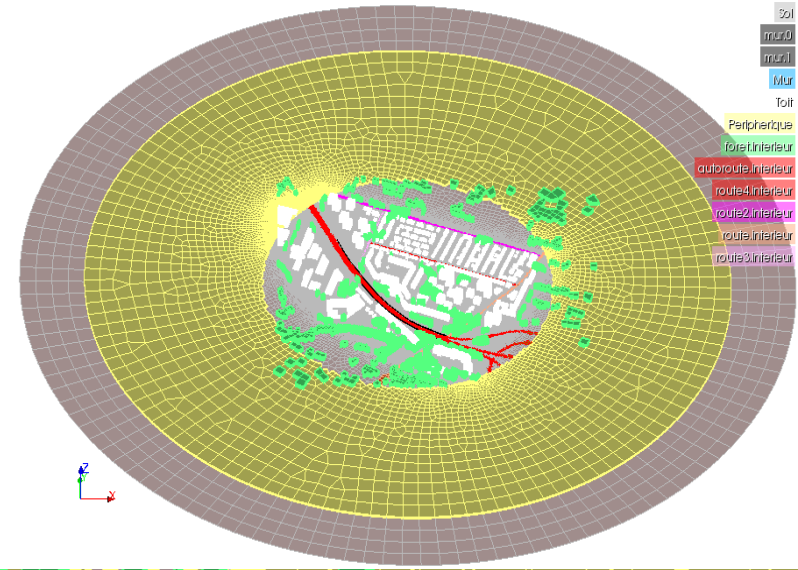


Mesh generation

- Logiciel SALOME
- Python script developed by CEREAs
- 2D Mesh generation

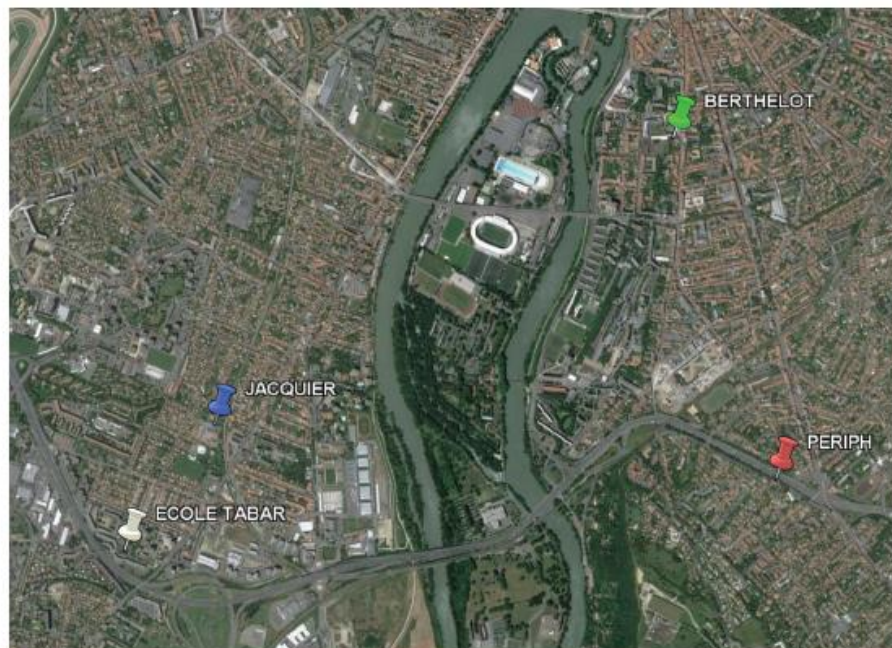


Simulation Code_Saturne
(micro-météo + qa, avec bâtiments)
(~2m minimum)
Imbriquée sur les résultats
de MesoNH (régional, 250m-100m)

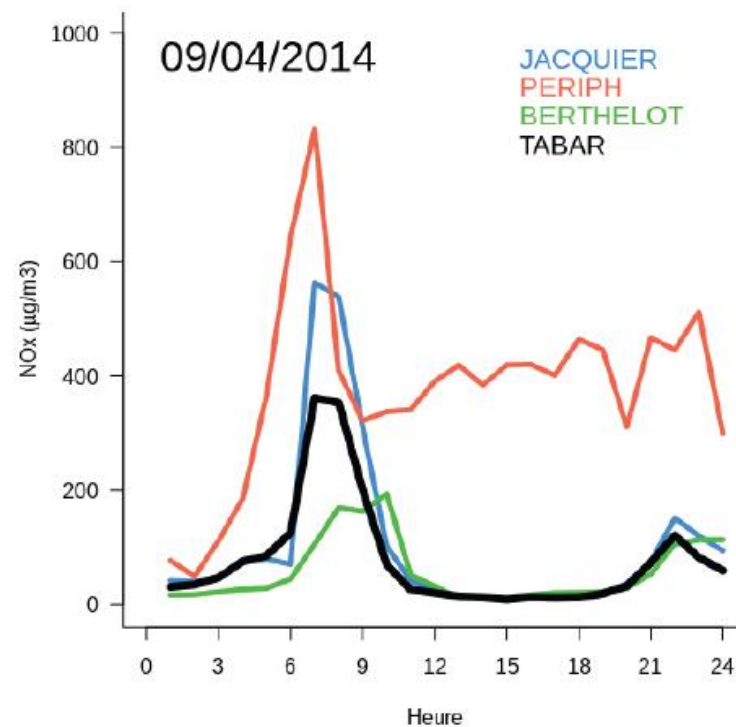


Scalars for pollutants

- Source terms: the first layer of cells next to surfaces of roads and highway
- Surrounding bords: Dirichlet condition for inlet flow (Jacquier)
- Data from measurements averaged for each hour during 72 hours

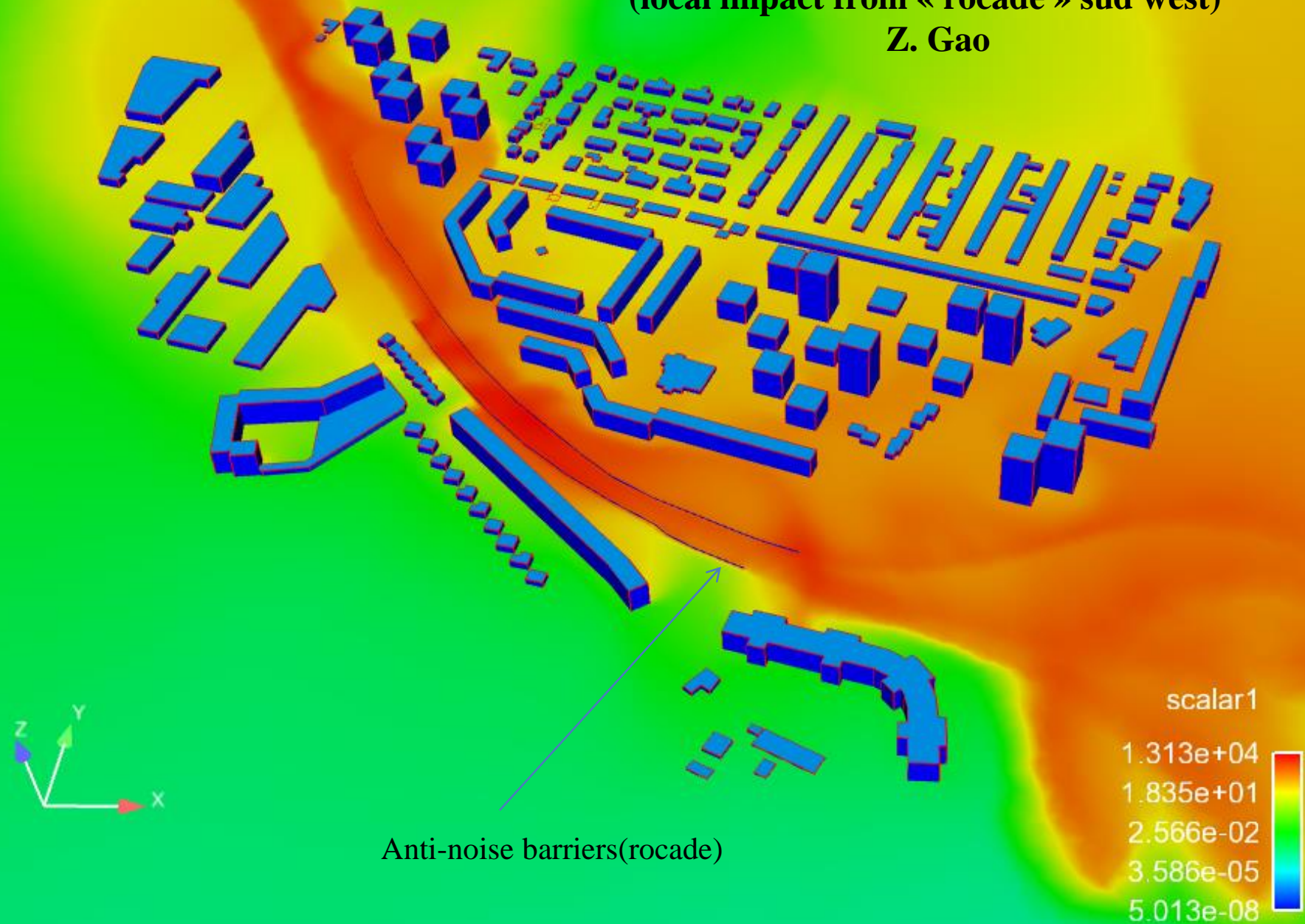


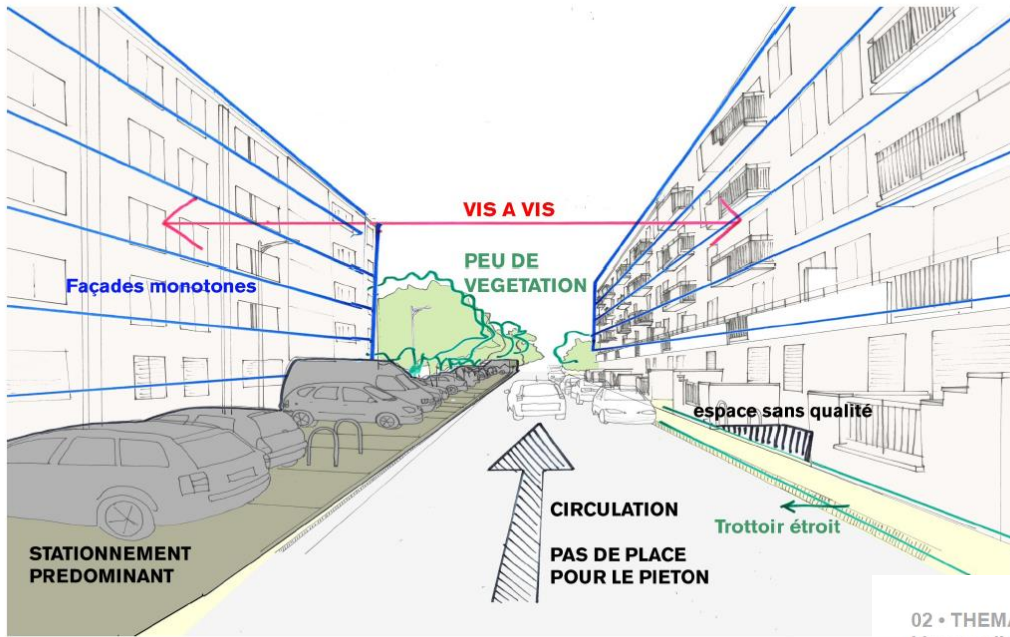
(a) Location of sensors



(b) 24 hour evolution

**Simulation Code_Saturne coupled with Meso-NH
(local impact from « rocade » sud west)
Z. Gao**





20/05/2015

Ateliers Lion associés, Architectes Urbanistes Paysagistes



20/05/2015

Ateliers Lion associés, Architectes Urbanistes Paysagistes

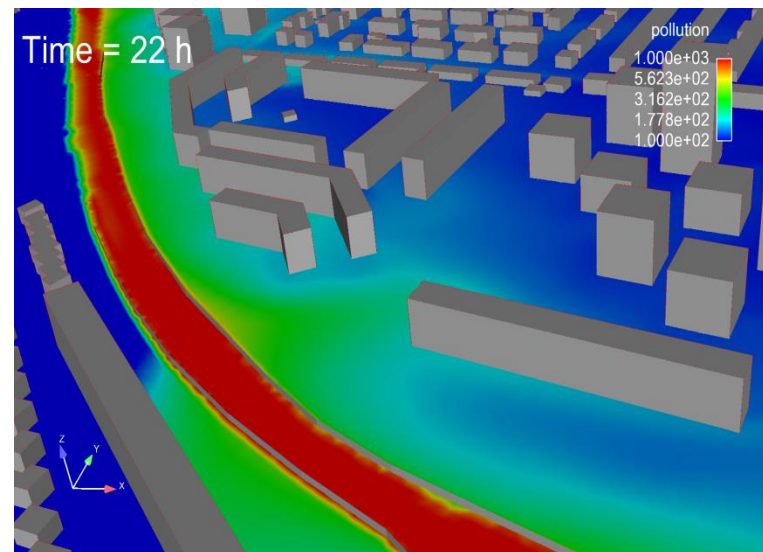
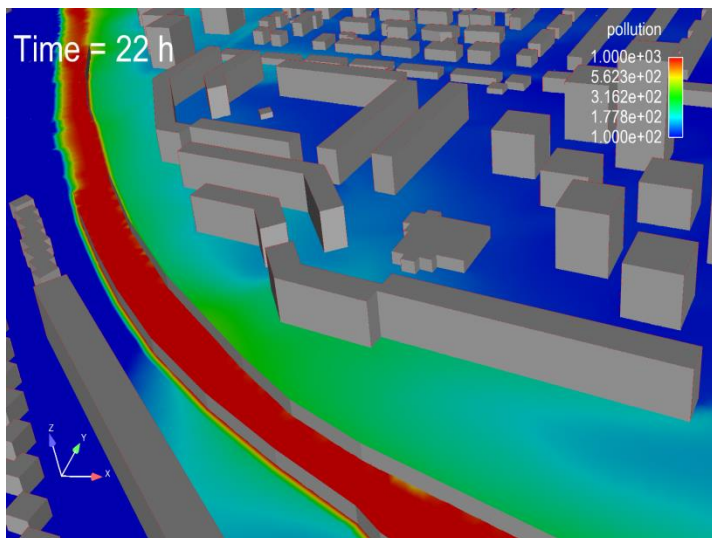
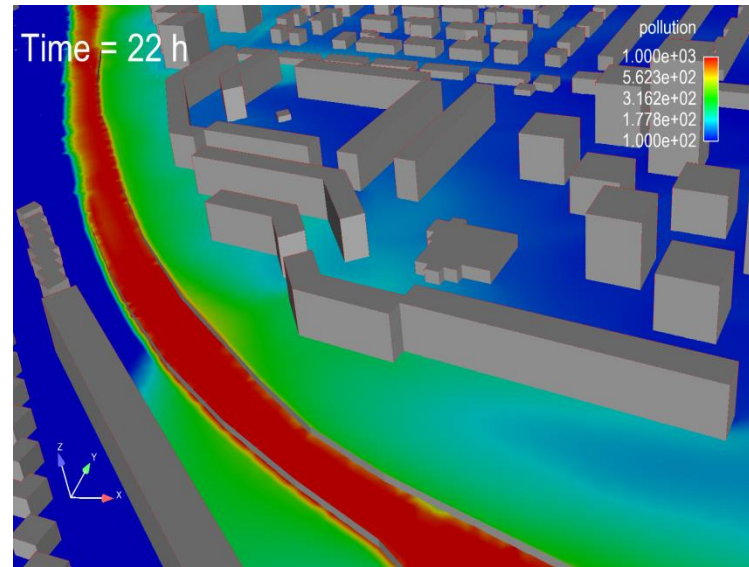
Architects provide scenario after meetings with locals

Trois scénarios

Mûr antibruit à la hauteur de 3m (right)

Mûr antibruit à la hauteur de 6m (bottom-left)

Mûr antibruit à la hauteur de 3m
avec deux bâtiments démolis (bottom-right)

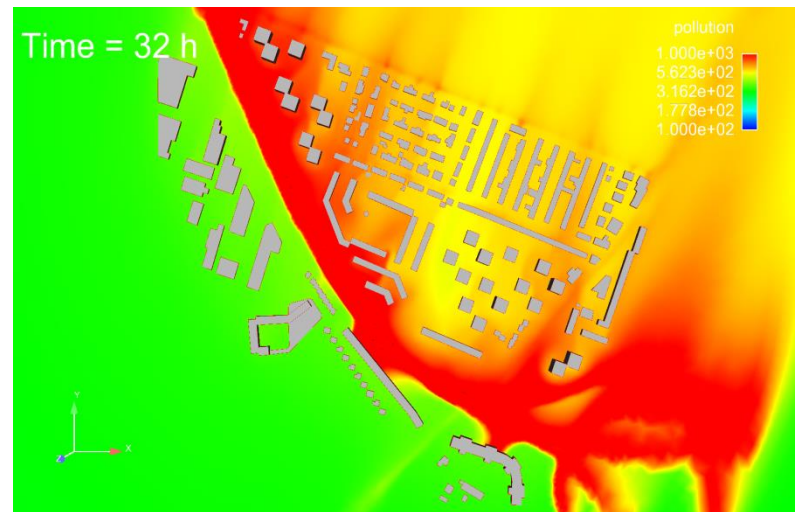
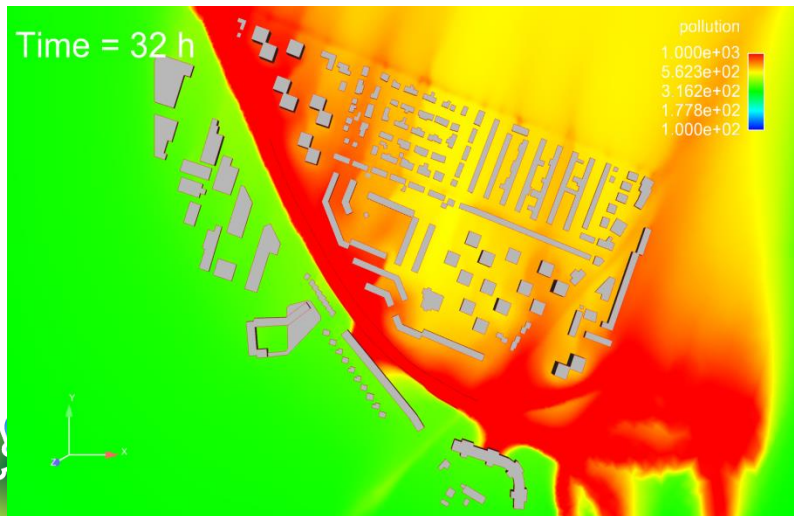
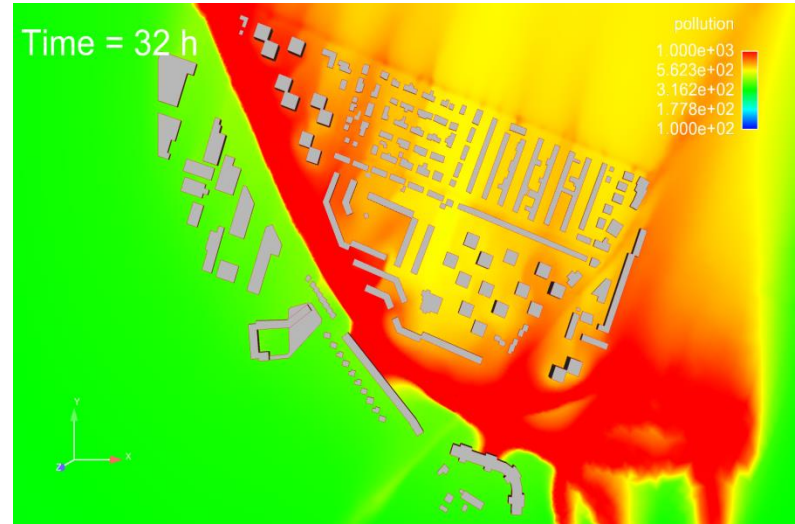


2m au dessus du sol (8h du matin, 9 avril 2014)

Mûr antibruit à la hauteur de 3m (right)

Mûr antibruit à la hauteur de 6m (bottom-left)

Mûr antibruit à la hauteur de 3m
avec deux bâtiments démolis (bottom-right)

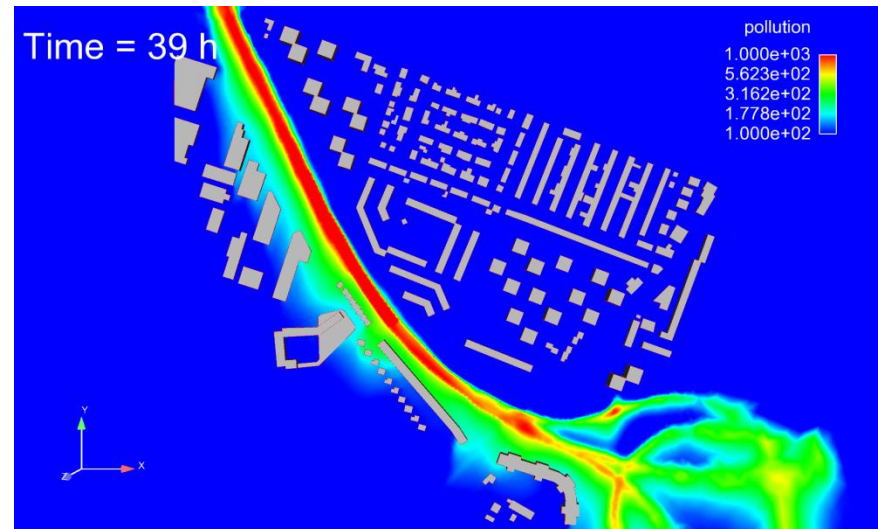
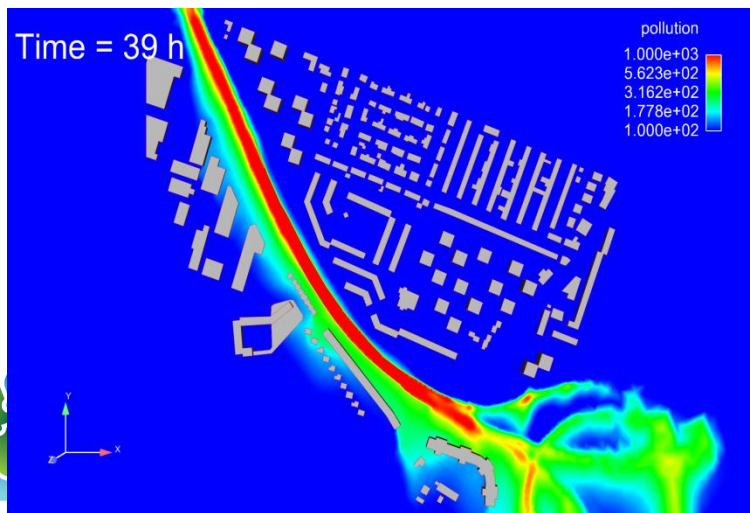
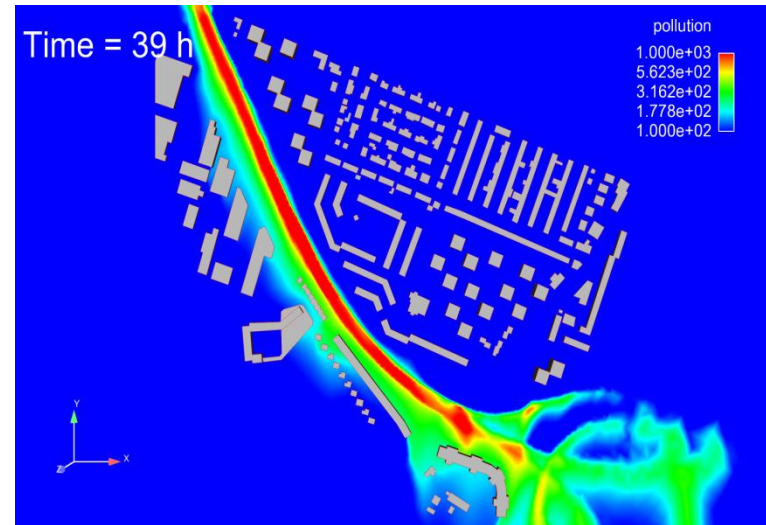


2m au dessus du sol (15h 9 avril 2015)

Mûr antibruit à la hauteur de 3m (right)

Mûr antibruit à la hauteur de 6m (bottom-left)

Mûr antibruit à la hauteur de 3m
avec deux bâtiments démolis (bottom-right)

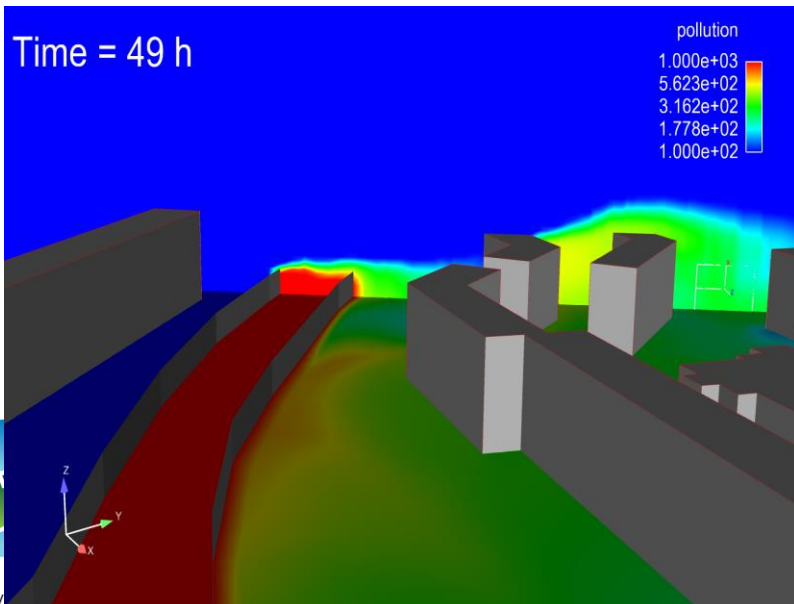
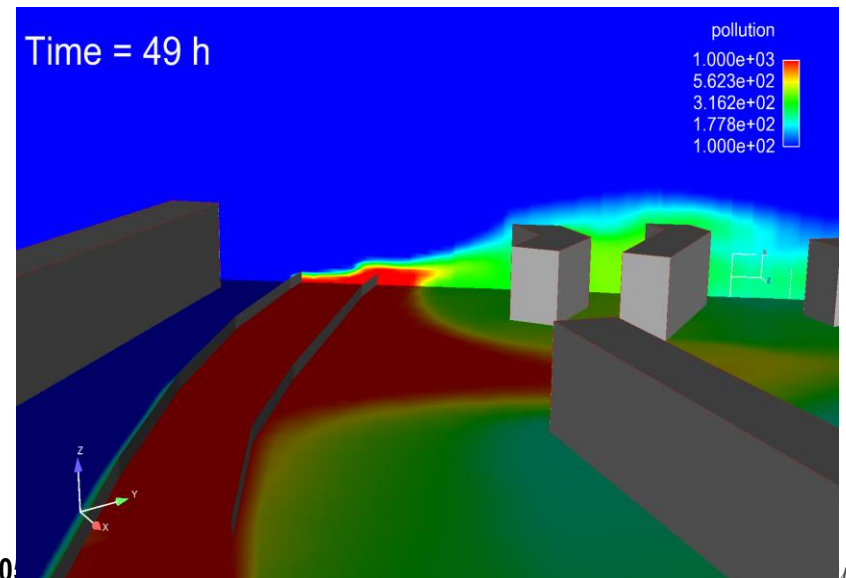
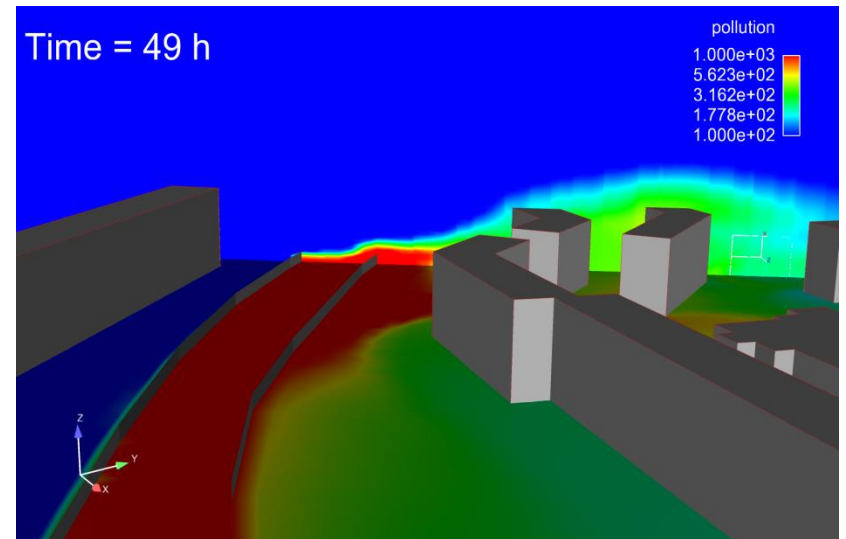


0,5m au dessus du sol et un plan vertical qui traverse le quartier

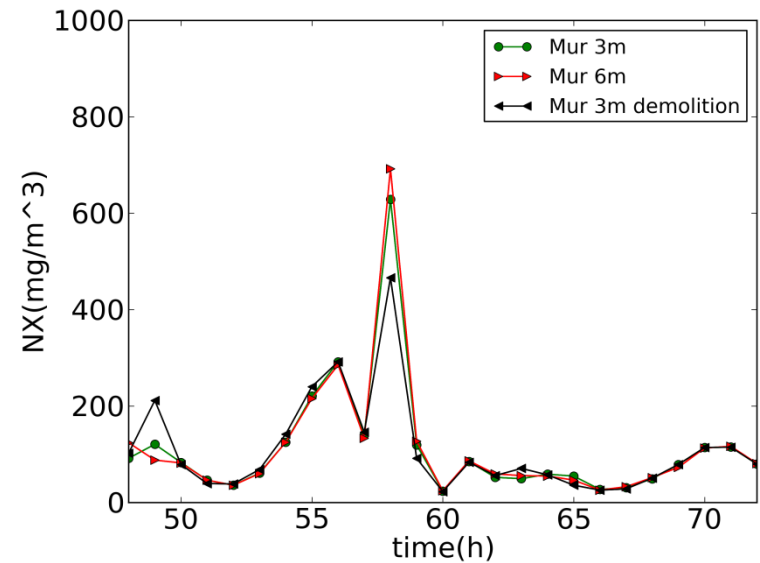
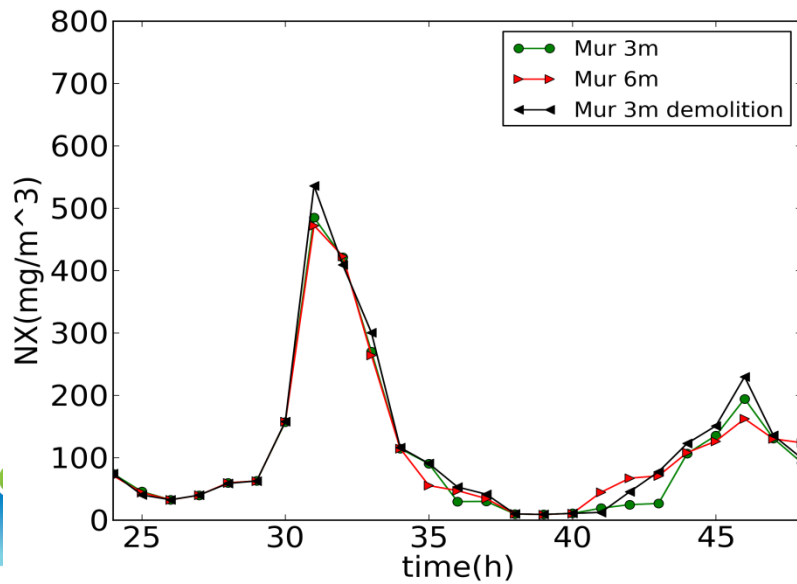
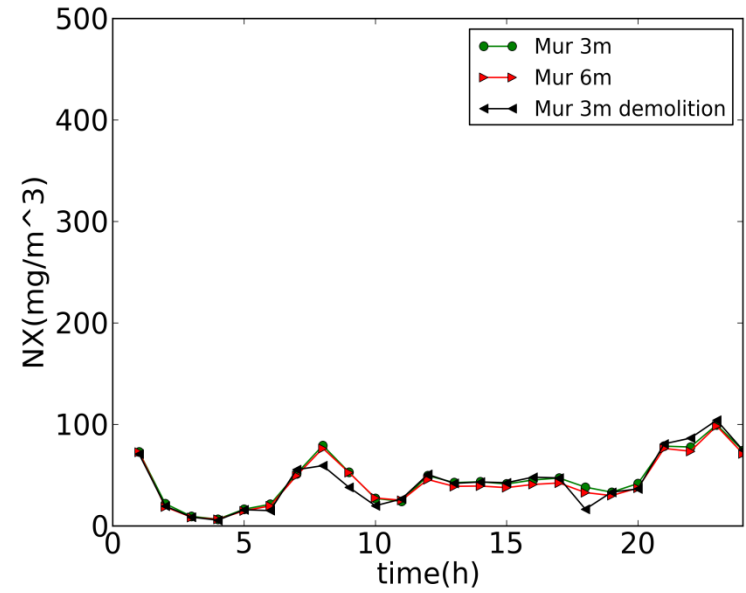
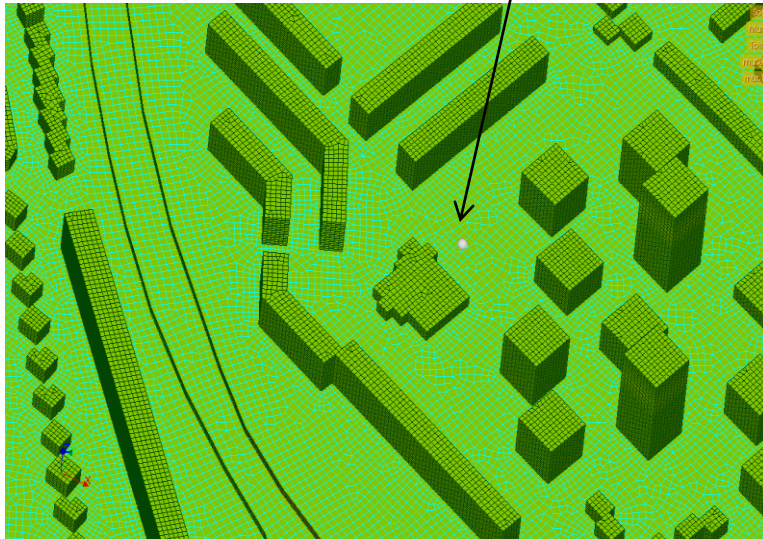
Mûr antibruit à la hauteur de 3m (right)

Mûr antibruit à la hauteur de 6m (bottom-left)

Mûr antibruit à la hauteur de 3m
avec deux bâtiments démolis (bottom-right)



Point dans la zone réaménagée



La campagne de mesures EM2PAU : présentation

Nantes, de mars à juin 2011

Documenter la circulation dans un canyon avec effets thermiques

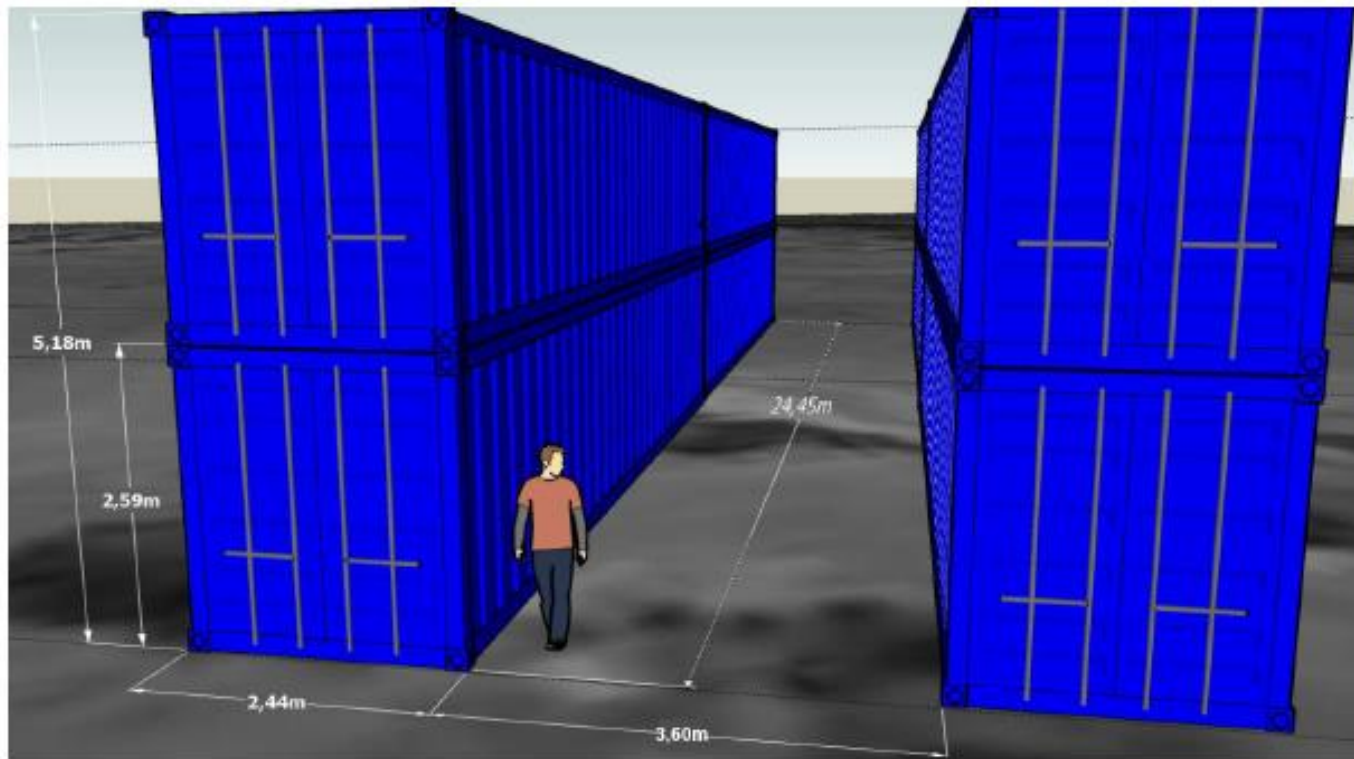
- IFSTTAR (Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux)
- LHEEA (Laboratoire de recherche en Hydrodynamique, Énergétique et Environnement Atmosphérique de l'École Centrale de Nantes)
- CSTB (Centre Scientifique et Technique du Bâtiment)
- Laboratoire d'Acoustique de l'Université du Maine



FIGURE: Vue aérienne du site de EM2PAU ;
Source : [Athamena(2012)]

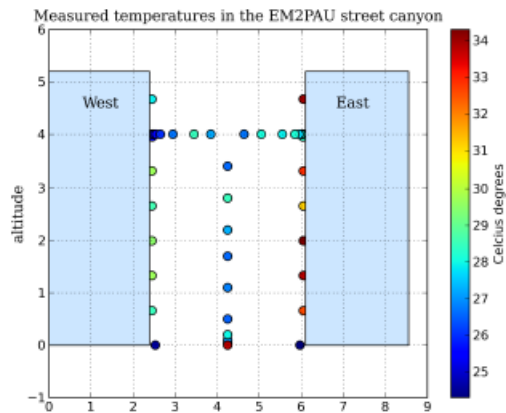


FIGURE: Radiomètre isolé ;
Source : [Athamena(2012)]

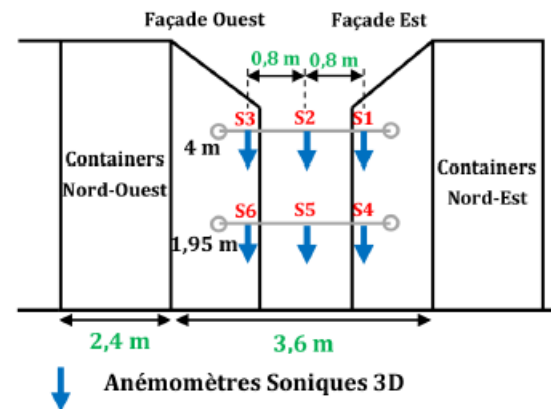


La campagne de mesures EM2PAU : l'installation

- 2 blocs de 4 conteneurs pour simuler un canyon urbain
- Mesures de températures (parois, sol, air)
- Mesures de vent
- Mesures de rayonnement (direct, diffus, global)



(a) Mesures de températures à 15h le 06/04/11

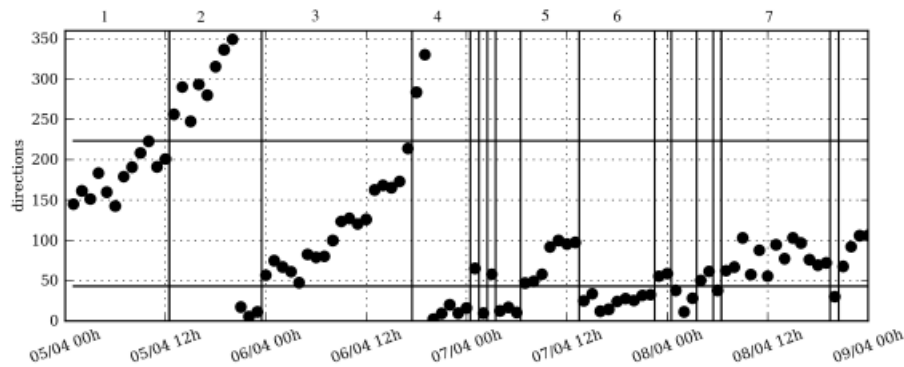


(b) Mesures de vent dans le canyon et à 10m d'altitude; *Source : [Athamena(2012)]*

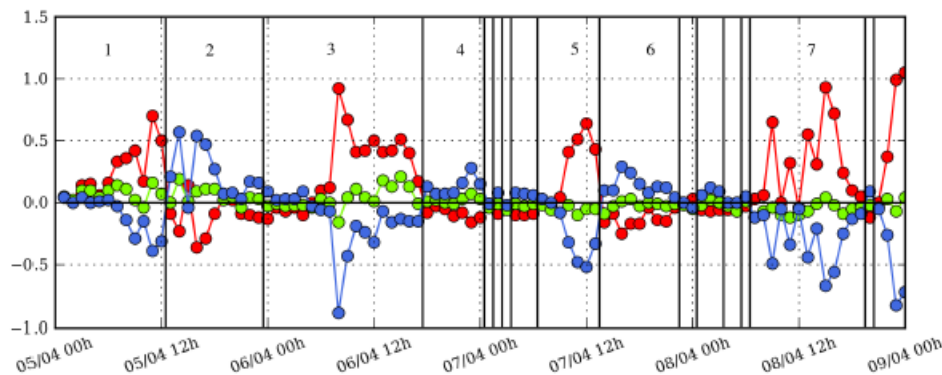
FIGURE:

Analyse des mesures de EM2PAU

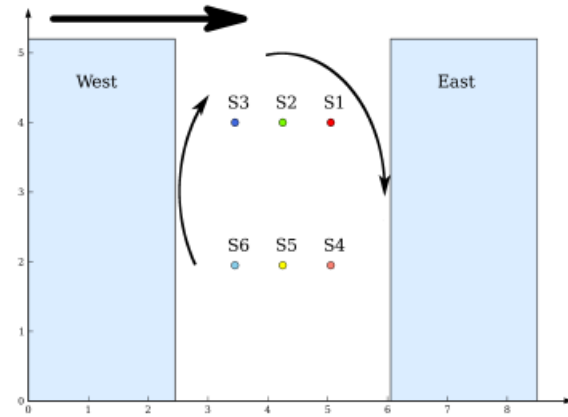
Effets dynamiques observés



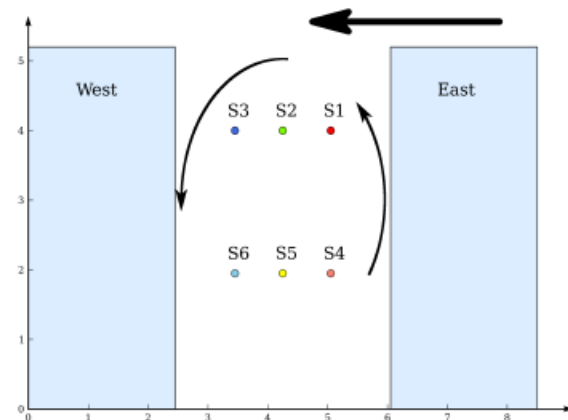
(a) Direction globale du vent.
1,3,5,7 : vents du SE ; 2,4,6 : vents du NO



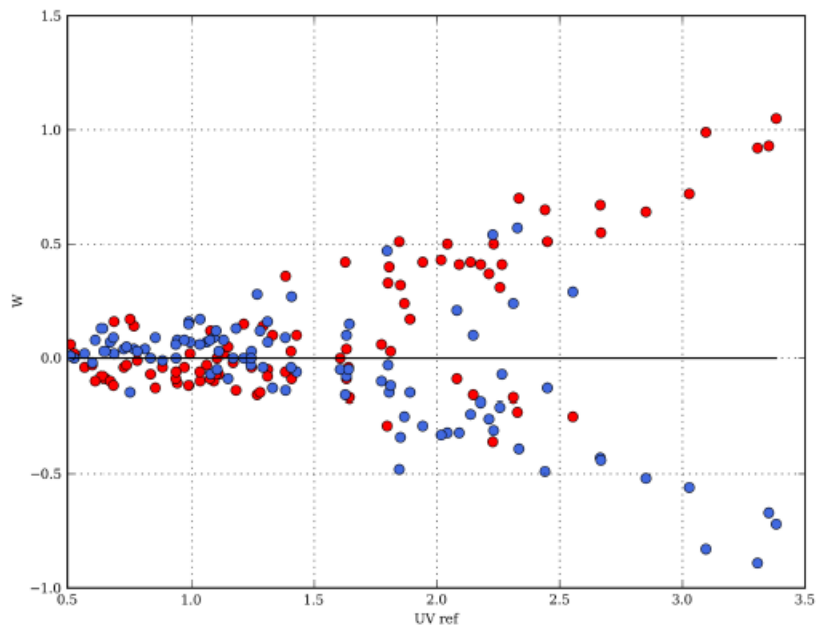
(b) Vitesse verticale aux soniques



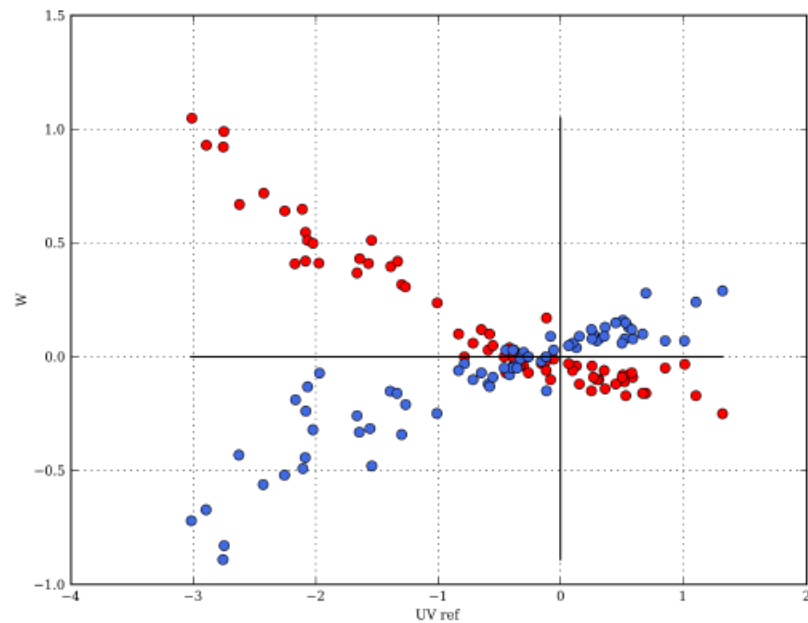
(c) Direction $\in [43, 223]$



(d) Direction $\in [0, 43]$ ou $[223, 360]$



(a) Vitesse verticale en fonction du module de la vitesse du vent de référence.



(b) Vitesse verticale en fonction de la composante perpendiculaire du vent de référence.

Un modèle de bâtiment à coupler avec Code_Saturne : BuildSysPro

- Logiciel développé par EnerBat de EDF
- Discrétisation des parois en plusieurs couches
- **Librairie permettant une modélisation 1D du bâtiment**

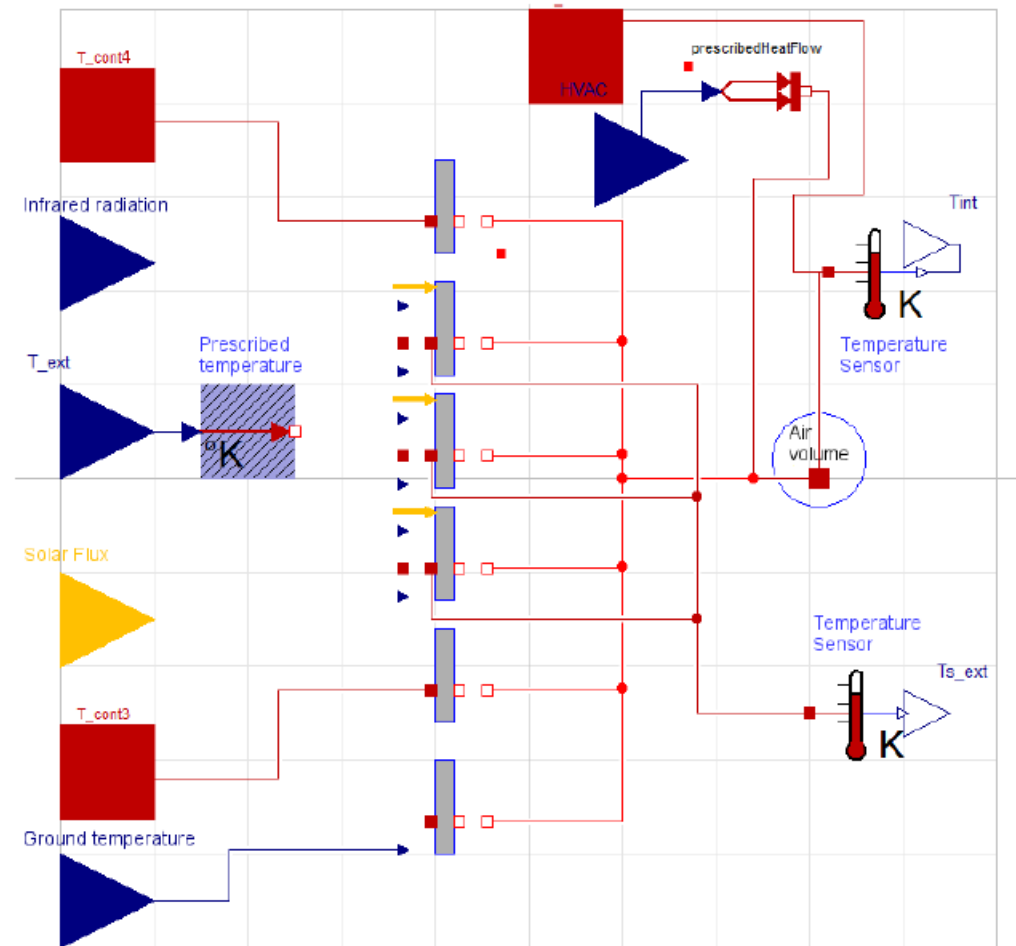
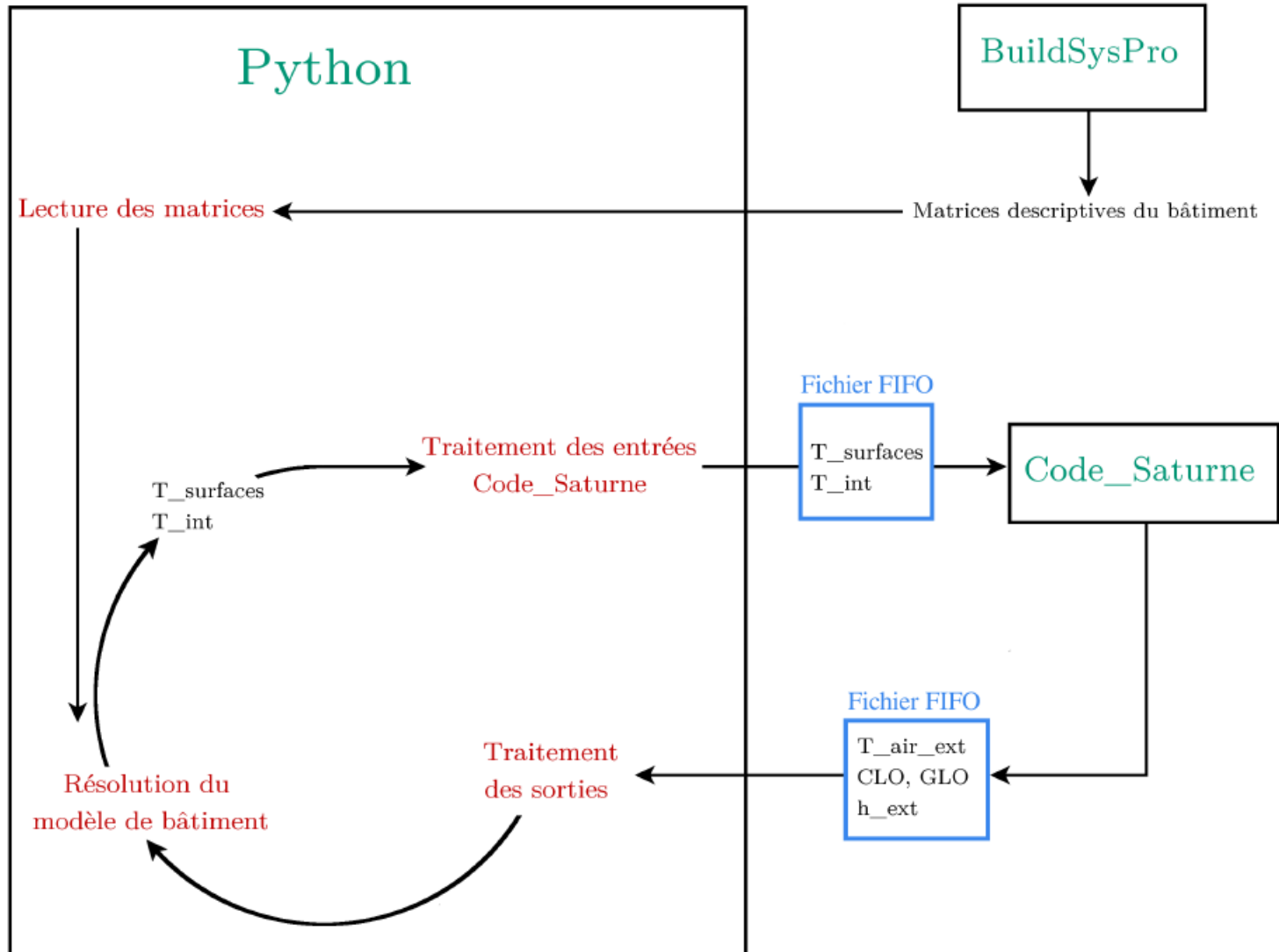


FIGURE: Représentation d'un conteneur avec HVAC

Couplage de Code_Saturne avec BuildSysPro



Conclusions and perspectives

- Cities are warming faster than the average atmosphere (ground level)
- IR is important for UHI (Tmin) (and for energetics?)
- high T spatial variations within the neighborhood :
 - small in late night
 - much more pronounced during the day, depending on location
 - important effect of vegetation,
- IR anisotropy is very pronounced, above 20°C in some area & also strongly dependant on location.
- Pollution has a potentially important impact on urban solar and IR budgets
- Micro-scale, obstacle resolving meteorological models (=“atmospheric CFD”) can reproduce meteo fields and pollution at neighborhood scale
- Potential of coupling micro-meteorological with building models (at least for checking simpler models) and providing BCs for building models